Berbel, J., & Esteban, E. (2019). Droughts as a catalyst for water policy change. Analysis of Spain, Australia (MDB), and California. *Global Environmental Change*, *58*, 101969.

Droughts as a catalyst for water policy change. Analysis of Spain, Australia (MDB), and California

Julio Berbel[1] and Encarna Esteban[2]

[1] Department of Agricultural Economics, University of Córdoba, Spain.
Research group WEARE.
Campus de Rabanales, Edificio C5
14014 Córdoba (Spain)
Phone: +34 957218457
Email: berbel@uco.es

[2] Department of Economic Analysis, School of Social Sciences and Humanities & IA2 (Instituto Agroalimentario de Aragón), University of Zaragoza, Spain.
Calle Atarazanas nº 4, 44003 Teruel (Spain)
Phone: +34 978 645 394
Email: encarnae@unizar.es

Acknowledgement: We would like to thank Professor Ariel Dinar for his valuable comments and suggestions on a previous version of the manuscript. The authors would like to also thank two anonymous reviewers for their critical review and help in improving the quality of the paper. The authors, however, bear full responsibility for the content of the paper. The authors have received financial support from MINECO-Grant: AGL-2014-53417-R.

Abstract: Droughts are natural hazards characterized by a prolonged period of below-average precipitation. Water scarcity is defined as insufficient water to meet demands in a region. This paper examines three regions (Spain, California, and the Murray-Darling Basin in Australia) which share similar social and climatic characteristics and face severe water-scarcity problems. The frequency and persistence of droughts in these regions over the last few decades have triggered changes in water laws as well as in the behaviour of water users and managers. This paper compares the major water policy reforms in these regions and the achievements and failures of the various approaches implemented. This comparison shows how despite the differences in institutions, governance systems and water allocation rules in the three regions, the recent droughts have catalysed the creation of new institutions and the implementation of sophisticated long-term measures to mitigate the impact of droughts. A deeper understanding of the effectiveness of mechanisms and regulations is necessary to better manage droughts worldwide. The uncertain impacts of climate change will probably require more effective responses to extreme climate events, and we hope the examples quoted here could profit other regions.

Keywords: drought, water policy, Spain, Murray-Darling Basin (MDB), California.

JEL Classification: Q54, Q58

Highlights:

- Recent drought events in Spain, MDB, and California have created severe social, economic and environmental impacts.
- Intense droughts in Spain, MDB, and California have acted as catalysts of policy change.
- Recent droughts forced the change from supply-side to more sophisticated governance systems and water conservations measures.
- Spain, MDB, and California have incorporated droughts as structural elements in their water planning and management.

1. Introduction

The essence of the quote "Never let a good crisis go to waste", attributed to Winston Churchill, can be applied to the incidence of drought as a catalyst for change in water policy. Droughts can have severe impacts on natural resources and on economic and social activities, damage biodiversity, and threaten human health (Sheffield et al., 2012). The analysis of the various experiences regarding how best to deal with droughts for regions facing severe water shortages can be instructive for policy-makers.

Water problem concerns have increased notably in recent decades (Mishra and Singh, 2010). There is a major difference, however, between water scarcity and drought (van Loon and van Lanen, 2013). A drought is a temporary climatic effect or natural disaster that can occur anywhere and can be short or prolonged. Water scarcity involves a lack of supply relative to demand, especially regarding the requirements of societies and ecosystems. Users in water-stressed regions have generally adapted to dealing with water shortages; however, droughts can greatly increase problems since they are random and uncertain events; the historical uncertainty of droughts and floods is increasing with climate change (Kiem et al., 2016). Droughts create periods of extreme water scarcity that can affect all sectors of water demand (urban, industrial, and agricultural) and disturb environmental flows (van Loon et al., 2016).

Supply-side mechanisms have traditionally been used to prepare for drought (Gleick, 2003). Water availability is increased usually through the use of stored water (dams and aquifers) and by finding new water sources, particularly groundwater, and far less frequently from desalinized, brackish, or reclaimed wastewater. However, supply-side measures alone are frequently insufficient for mature water economies and drought prone regions (Molle et al., 2010; Randall, 1981) where supply augmentation opportunities are often scarce and costly and water policy therefore often explores the application of demand-side instruments.

This paper examines how droughts have influenced water management policies in three developed economies. The research examines how drought episodes act to catalyze for water policy change. For this purpose, we select three regions (Spain, the Murray-Darling Basin (MDB) in Australia, and California) with similar socioeconomic characteristics and Mediterranean climates that have recently suffered prolonged droughts (Dai, 2011; Mishra and Singh, 2010). The main objective is to analyse how droughts have brought changes in water policies and stakeholder behaviour and reviews the success or failure of implemented instruments.

All three regions have highly developed economies, political stability, and democratic governments, with well-established public participation. However, the regions differ in their natural conditions and actions taken when facing water scarcity. Differences between regions can be found in the water scarcity policies, the establishment of water rights and obligations, and in water governance. These differences and similarities create a field for comparative discussion.

The paper is structured as follows: Section 2 briefly reviews the natural conditions and main characteristics of the three regions under analysis. Section 3 analyses the principal actions implemented in the three regions to manage drought. Section 4 summarizes how the latest droughts have prompted a shift in management and regulations in the three regions. Section 5 presents concluding remarks.

2. Water resources in Spain, Australia-MDB, and California

The comparison of the three regions shows unexpected similarities (Table 1). These parallels are especially notable between Spain and California (CA), which are comparable in almost all variables analysed (population, total area, irrigated capacity, resource availability, and storage volume). However, the Murray-Darling Basin (MDB) in Australia, differs from the other two in that a large part of the basin is a flat plateau with low precipitation and smaller population resides in the basin. In all three regions, irrigated agriculture is the principal water user. All three regions suffer also from a significant water scarcity (see Table 1). High-water demand together with low rainfall rates make water management and efficient resource allocation key issues in these areas.

TABLE 1 AROUND HERE

The three regions have a history of managing water scarcity, with similarities and differences in approach. Australia (MDB), CA, and Spain have traditionally suffered from water scarcity because of their Mediterranean climate and crop growth concentrated in the spring-summer season. The response to these climate characteristics, especially with respect to irrigation, has focused on water storage and transfers (groundwater, reservoirs, and canals) since low natural flows during summer cannot supply extensive irrigation. While natural conditions in the three regions are similar, their agriculture, water use, water institutions, and policies have evolved differently (Lund et al., 2018; Kahil et al., 2016; Kiem et al., 2016).

Spain has an average precipitation of approximately 660 mm/year, varying from 2,200 mm in northern areas to 120 mm in south-eastern basins. The large spatial variability in rainfall makes water use and restrictions in Spain differ substantially between northern basins influenced by the Atlantic climate and the rest of the country, which suffers from water scarcity. Agriculture is the main water user (72% of total abstractions), especially irrigated agriculture, which is 18% of the total cultivated area and over 60% of agricultural production. Exposito et al. (2017) provide an in-depth analysis of the evolution of Spanish irrigated agriculture and water use. In Spain, urban water supply is guaranteed and is of good quality. Moreover, southern Spain has water scarcity and prolonged droughts, leading to the growing use of seawater desalination and a lack of resources to cover water demands.

Australia has extremely varied water resources; it has both tropical humid areas and one of the driest populated areas on the planet (Richter, 2016; Crase, 2009). However, the biggest problem in Australia is the great variability and uncertainty of its rainfall (King et al., 2014; Nicholls et al., 1997). The MDB is one of the largest basins in Australia and one of the great river systems in the world (Dreverman, 2013), with an area larger than Spain and France together. The basin has around 2.6 million inhabitants, several industrial activities, and 70% of the country's agricultural value, representing around 40% of the gross national agricultural production[1] (Kirby et al., 2014). Water extractions from the MDB are 89% of national water use, with agriculture being around 95% of basin extractions (Australian Bureau of Statistics, 2016)[2].

California is in the driest part of the United States (southwest) with the largest geographic and climatic rainfall variability

[1] Value estimated for the period 2005-2006.

[2] Water consumption values are estimated for the period 2014-1015.

Table 1. Key hydrological data in the three regions

Average year data	Spain	California	Australia (MDB)
Area (km^2)	504,645[1]	403,517[6]	1,042,730[11]
Population (million)	47.3[1]	38.3[6]	2.1[11]
Average precipitation (mm)	662[3]	545[7]	457[11]
Renew. Water resources (GL/yr.)	111,000[2]	52,546[9]	32,800[11]
% Water resources/Rainfall	*33%*	*37%*	*6%*
Volume storage -reservoirs-(GL)	56,000[4]	63,039[8]	22,663[11]
Total water abstraction (GL/yr.)	33,000[1]	51,400[8]	7,150[12]
Irrigated area (thousand ha)	3,734[4]	3,561[8]	1,500[12]
% Irrigated./Cultivated area	*18%*	*20%*	*34%*
Water for irrigation (GL/yr.)	14,998[2]	40,704[8]	6,800[13]
Applied water per area (ML/ha/yr.)	*4.1*	*11.0*	*4.5*
Inter-basin Transfer (GL)	600[5]	17,515[10]	--
Groundwater use #	20%[1]	40%[8]	10%
% Irrigation use/total abstraction	*72%*	*80%*	*95%*

NOTE: Water use refers only to economic uses; MDB = Murray Darling Basin.

[1]Statistical Office (www.ine.es); **[2]**(Ministerio de medioambiente, 2000); **[3]**Hispagua Sistema EspañolInformación sobre el Agua. Precipitaciones. http://hispagua.cedex.es/datos/climatologia#precipitaciones; **[4]**Ministerio de Agriculturahttps://www.mapa.gob.es/es/estadistica/temas/estadisticas-agrarias/agricultura/esyrce/; **[5]**www.embalses.net; **[6]**= US Census Bureau (2017) (www.census.gov); **[7]** Average precipitation (July-June) totals for the entire state of California 1895-2016, NOAA National Center for Environmental information, “Climate at a Glance: Statewide Time Series”, retrieved on June 24, 2019 from https://www.ncdc.noaa.gov/cag/; **[8]***California Water Today*-Chapter_2/PPIC WATER POLICY CENTER (www.ppic.org); **[9]** Carle, David (2004). Introduction to Water in California. Berkeley: University of California Press**; [10**]“California's Water Systems” https://mavensnotebook.com/; **[11]** MDBA “Proposed Murray Darling Basin Plan” Murray-Darling Basin Authority. August 2012 Chapter 2 page 10; **[12]** MDBA “Proposed Murray Darling Basin Plan” Murray-Darling Basin Authority. August 2012 Chapter 2 page 21; **[13]**Australian Bureau of Statistics [4618.0] Water Use on Australian Farms, 201718 Released_30/04/2019; https://www.abs.gov.au/ausstats/abs@.nsf/mf/4618.0

Table 2. Main elements of drought management in the three regions

Item	***Spain***	***California***	***Australia (MDB)***
Conjunctive use of surface/groundwater	Included in the River Basin Management Plans	Water rights to surface water and groundwater separated	Water rights to surface water and underground sources are separate
Individual access to groundwater	Subject to license. No free access.	Land ownership implicitly carries the right to extensive groundwater pumping.	Not allowed (illegal)
Inter-basin transfers	2% Water resources	30% Water resources	Not applicable
Inter-basin transfers in droughts	Stop / market solution	Operative / State scale	Not applicable
Water rights	1985 Water Act - all water is public (minor exceptions)	Water rights are divided in multiple ways. Federal/State/Riparian/Appropriation/ Pueblo	Water rights allocated (CAP)
Legal water rights	Hierarchy of uses (urban&industry>agriculture)	Priority/seniority rights	Three levels of guarantee
Water-rights markets	Regulated since 2005	Regionally	Introduced in 1980s. Fully operational in 1997
Water-rights markets during droughts	Increase (mainly inter-basin)	Increase	Increase
Basin management	Basin authority	State management	MDB/State regulation
Aquifer Management	'Overdraft declaration'	New Assembly Bill No. 1739 (Sept/2014)	CAP and trade
Aquifer Management during droughts	Regulated by DMP	Sustainable Groundwater Management Act 2014	Not specific but allocation plan is adaptive and variable.
Drought Management Plans (DMP)	Compulsory basin scale Indicators/ Protocol	‘ad hoc’ committee	Not specific but allocation plan is adaptive and variable.
Indicators	Four levels (integrated resources index)	Drought conditions (SPI based)	Three levels (integrated resources index)
Automatic water-saving measures	Yes	Not planned	Yes
Governance protocol	River Basin Authority reinforced	‘Ad hoc’ committee	Not applicable

DMP = Drought Management Plan

in the country (Hanak et al., 2011, Chapter 1). Northern California is humid compared to the dryness of the southwest. While northern California receives around 75% of the state's total rainfall, 75% of the state water use is for cities and agriculture in the south (Hanak et al., 2011 pp. 3). California has around 40 million inhabitants, with 23 million living in the south (Los Angeles and nearby areas). Around one-sixth of all irrigated land in the United States and 8% of the value of national agricultural production is in California's Central Valley (Reilly et al., 2008). Total water consumption in 2015 was approximately 51,400 Mm^3, of which 80% was for agriculture and 15% for cities (Mount and Hanak, 2016).

Spain, Australia-MDB, and CA have suffered frequent and intense droughts that have created economic, social, and environmental problems (Jenkins, 2013; van Dijk et al., 2013; Harou et al., 2010). The 'Millennium Drought' (1995-2010) in Australia (Kiem and Austen, 2013) had an estimated economic impact of AUD \$3.5 10^9 and caused a devastating drop in agricultural production (Mishra and Singh, 2010). In Spain, the recurrent droughts over the past 60 years have reduced river flows by 30%, and by as much as 70% in some south-eastern basins (Schwabe et al., 2013, pp. 15). In CA, the annual impact of the recent drought on agriculture has been estimated at approximately USD \$2.7 10^9 (Howit et al., 2015; Lund et al., 2018). Furthermore, droughts have damaged hydrological systems, and numerous ecosystems are suffering from deterioration due to overexploitation and degradation of the water bodies in the three regions. Most impacts on natural resources have not been valued. The recurrence of droughts in these three regions has motivated changes in water regulations and prompted institutions to improve water management.

3. Drought prevention and management in action

The severe droughts, especially during the past few decades (the 'Millennium Drought' in Australia, the 2007-2016 drought in CA, and the 1990-1995 'Megadrought' in Spain) triggered changes from traditional ways of managing drought and water scarcity. While similar actions have been implemented in all three regions (hardware), there are notable differences in the use, management, and operation of these actions. Differences in institutions and governance regarding the allocation and management of water rights and local culture and history have led to different solutions. The review by OECD (2015) of country allocation regimes concludes that definition of water right entitlement characteristics is critical for water management under scarcity and drought conditions. Table 2 illustrates the major elements of drought management during the last few decades in Spain, Australia-MDB, and CA. This section focuses on the main reforms in the three regions.

3.1. Institutional management: Basin Management Plans and Drought Plans

The management of any basin/aquifer requires planning and resource allocation to match water supply with demand during droughts and other temporary water scarcity periods. Drought should be incorporated in river basin management plans (RBMPs) and, in arid and semi-arid areas, in specific Drought Management Plans (DMPs).

3.1.1 Spanish RBMPs and DMPs

Spain has a long history of State intervention in water management. The 1879 Water Law regulated the private use of water both individually and through "water users' associations" (WUAs), which have a key role in

Spain´s water policy. This law established administrative licences for water rights and declared water resources to be public property under the control of the State. Additionally, water agencies (River Basin Authorities - RBAs) were created in the 1920s to execute water policy, mainly through supply-side actions (Blomquist et al., 2005). Amendments to the 1879 Water Law, resulting in the 1985 Water Law, reinforced the public nature of water resources and raised the priority of water quality protection and ecosystem health. Additionally, this law led to the first cycle of River Basin Management Plans (RBMPs) which strove to implement water rights defined with supply guarantees (with a failure threshold below 10% for irrigation and 0.2% for urban sectors). Thus, RBMPs have already included a type of drought management plan in the form of supply guarantees.

The 1978-1984 drought probably heavily influenced the 1985 Water Law. However, the 1990-1995 'Megadrought' affected all of Spain during the first cycle of RBMPs and had a marked impact on the regulation and allocations of water under extreme conditions. As a reaction to this drought, the 2001 National Hydrological Plan Act incorporated the concept of drought management plans (DMPs) to be drawn up by the RBAs. These plans include a) drought diagnosis (definition of indicators and monitoring); b) program of measures; c) management options; and d) a follow-up system. Once a drought has been identified, the DMPs should identify the most appropriate mitigation measures, adapted to the different established drought thresholds and phases. The environmental effects of droughts on ecosystems were not initially included in the RBMPs (1992) and were incorporated into Spanish legislation through the 2001 Water Law and were also included in the 2009 and 2015 RBMPs. The purpose of the 2001 Water Law was to include the European Water Framework Directive (WFD) in Spanish law, which aimed to achieve a 'good environmental status' of all European water bodies and encourage efficient water management.

3.1.2 Murray-Darling Basin RBMPs and DMPs

With the establishment of the Commonwealth of Australia in the early 1900s, the federal government assumed the management of its water resources. Traditional riparian water rights were eliminated and replaced by water licences controlled by each federal state. Water resources were declared public property under the control of public organizations. The management of water resources was assigned to the different territories, with economic support from the Commonwealth Government (Connell, 2015).

The 'Millennium Drought' in Australia led to the creation of the Murray-Darling Basin Authority (MDBA) in 2007 for water management in the MDB under the 2007 Water Act. The MDBA developed and implemented a Basin Plan (first implemented in 2012). The main objective of the Basin Plan is integration of economic, social, and environmental goals to manage scarce water resources in the Basin (Kneebone and Wilson, 2017). The severe depletion of water resources in the MDB has damaged several of its ecosystems. The Basin Plan establishes 'sustainable diversion limits' (annual limits on water extractions) to control excessive withdrawals (Kneebone and Wilson, 2017). The 'Millennium drought' triggered advances in water reforms in the MDB (Kiem, 2013). However, major challenges facing the MDBA and the 2012 Basin Plan involve the integration with water stakeholders in the preparation and application of various water actions (Connell, 2017) and the maintenance of environmental flows (Kiem, 2013).

3.1.3 Californian RBMPs and DMPs

Water in California is managed by a decentralized system with many local, municipal, and regional water agencies and organizations (Hanak et al., 2011, pp.7). Additionally, both federal and state governments participate in and regulate water management, including the extensive hydraulic infrastructure throughout the State (the Central Valley Project in the 1950s and the State Water Project in the 1960s). California differs in its water management by not having traditionally defined water as common property, but instead having a large and diverse group of water rights. Surface water in CA is allocated based on three types of water rights (Gray et al., 2015). The California State Water Resources Control Board supervises surface water rights but sometimes lacks information and enforcement capacity to curtail water use.

A major problem in CA has been the traditional non-management of groundwater, which has led to serious groundwater depletion and related impacts. Groundwater depletion during the last drought (2007-2016) triggered passage of the Sustainable Groundwater Management Act (2014) to protect groundwater. This reform has led to the creation of local Groundwater Sustainability Agencies (GSAs) to monitor and control groundwater extractions in most basins and sub-basins throughout the state. These agencies are to develop groundwater management plans to meet sustainable objectives (Moran and Wendell, 2014). The main challenges involve the creation of these new local institutions and the adaption of the existing institutions to the new functions (Blomquist, 2016).

3.1.4 The RBMPs and DMPs in the three regions

In all three regions, the implementation of integrated and coordinated water management plans is a response to recent droughts (Spain, 1990-1995; MDB, 1995-2010; and CA, 2007-2016). Additionally, authorities in the three regions have striven to include cooperation among stakeholders and institutions in water planning; however, marked differences can be observed in levels of coordination and achievement.

Associated with the RBMPs, DMPs are integrated into the planning process. This is the case in Spain, where DMPs are based on indicators. Australia takes an adaptive approach, with water allocations defined as a percentage of available resources annually. Finally, CA has an 'ad hoc' approach to drought, although the recent Sustainable Groundwater Management Act (2014) will improve and standardize drought responses with better integration of surface and underground water. Despite recent efforts to better integrate management of water resources in CA, the '*water allocation system remains hampered by inconsistencies, unclear regulatory authorities, and lack of transparency and information*' (Gray et al., 2015). However, recent droughts have catalysed the creation of institutions and regulations to reduce pressure on water resources, especially in periods of drought, and to reduce water use.

3.2. Economic Instruments: water trading

Water markets are a major economic instrument to deal with drought in the three regions. However, there are major differences between the three areas in terms of the volume of water traded and the institutions used to manage water markets.

3.2.1 Australia's water markets

Water markets in Australia are well-known economic instruments to economically enhance water-resource allocation and adapt to climate change (Kiem, 2013). Market exchanges of water rights are supported and managed by public organizations (Commonwealth Government and State Governments). Water trades are exchanges of water entitlements allocated to irrigators. Permanent water entitlements, or rights, are assigned based on the year's river flow, which allows water allocations to vary with water availability each year. Additionally, some 'seasonal allocations' are also assigned based on the amount of water available in storage facilities. Irrigators can trade these water allocations. While water markets in the MDB started in 1989, the traded volume increased significantly during the 1991-1996 drought to support high-value production, especially in agriculture (Crase et al., 2004). However, the largest boost in water trading occurred during the 'Millennium Drought' (Wildman and Forde, 2012).

3.2.2 Spain's water markets

While water markets had been traditionally used in Spain, especially in the arid southeast, they were abolished under the 1985 Water Law. However, the 2005-2008 drought forced reestablishment of water markets to support high-value crops by trading between different users. A precedent to the 2005 market regulation was the 1990-1995 'Megadrought' that compelled the city of Seville and a nearby irrigation community to participate in an 'ad hoc' water trade (Gómez-Ramos and Garrido, 2004). Finally, the 2005-2008 drought triggered legislative changes, leading to new regulation of water markets in 2005, with a higher volume during drought years (Giannoccaro et al., 2016). However, water markets and the volume of water traded in Spain remain small and are concentrated in a few regions. Additionally, water trading occurred almost exclusively during droughts, and even under these extreme scarcity situations, trading accounted for less than 5% of total water use (Palomo-Hierro et al., 2015).

3.2.3 California's water markets

Water markets in CA are still small in their operation and volume (a situation similar to that in Spain), with approximately just 3% of total water use (Hanak and Jezdimirovic, 2016). Water markets in CA were implemented in the early 1980s to support water reallocations, especially in droughts and between areas and sectors with different water scarcities. Most transactions were from irrigators to urban users, because urban areas were more willing to pay. Significantly expanded water trades occurred during the 1987-1992 drought (Hanak and Jezdimirovic, 2016). In the 1990s, Emergency Water Banks were activated to enable water transfers (Aghakouchak et al., 2015). In 1991, California Water Banks started operating after a 5-year drought (Brown, 2006). These Water Banks, operated by a central banker to provide water for critical industrial, urban, and agricultural regions, while preserving ecosystems (Lund et al., 1992).

In CA, water markets are based on short-term, long-term, and permanent water transfers, to reallocate water to higher-value water uses. Traditionally, most of the water transactions were short-term water leases, with most sales from agriculture to urban users and to more profitable farming (mainly in the San Joaquin Valley). Long-term water leases have increased notably since 2005. Since 2006, the trade in long-term water leases together with permanent transfers have exceeded the trade in short-term transfers. Furthermore, since 2000, the major water buyers have been cities and resources for environment uses and not farmers (Hanak and Jezdimirovic, 2016). Inflexibilities due to the high investment costs of both short-term and long-term water leases seems to impede the participation of small districts in water markets, thereby reducing the trade in water for alleviating drought water scarcity (Regnacq et al., 2016).

3.2.4 Water markets and water banks in the regions

While water trade appears to be efficient and flexible in allocating water resources, especially with droughts, this system can have flaws for external parties (Regnacq et al., 2016; Hanak, 2005). Droughts have acted as a catalyst for water markets and water banks. Despite major differences between these regions in implementation, droughts clearly triggered water marketing.

‘Water markets’ refers to a wide range of forms of voluntary exchanges of water between users. Within those different types, a water bank is a market mechanism through an administrative agency (public or private) which acts as an intermediary in the trading of rights (Montilla-López et al., 2016). In Spain, the implementation of specific legislation (water markets) and the creation of public water banks were sparked by the 2005-2008 drought. Similarly, while water trade is legal in California, it adds flexibility under drought conditions and ‘public water banks’ have been implemented to manage water scarcity in times of drought. Further motivated by the Sustainable Groundwater Management Act (SGMA), several water districts are purchasing water to replenish aquifers, especially those drawn down in California’s 2007-2016 drought. Water trading was primarily allowed in the MDB during the 1982-1983 drought. However, it was not until 2007, the worst year of the ‘Millennium Drought’, when deep changes of institutional and trading rules were implemented to allow the allocation and re-allocation of water across competing uses and users (Grafton and Horne, 2014).

3.3. Water-saving investment

The three regions have implemented policy support to induce adoption of water conservation equipment and the lining and improvement of distribution networks to reduce water abstractions. Other activities in the three regions include the use of desalinated seawater, brackish water, or water reuse. The possibility of a rebound in water saving investment is the focus of academic and policy debate on how improvement in irrigation efficiency may (and frequently does) lead to increased consumptive water use as farmers use the "saved water” to expand or intensify production. The implementation of this policy and the economic and environmental analyses available in the countries are described below. Perry et al. (2017) published a review of the impact of subsidies to water saving around the world. The general conclusion of the report is that “*The benefit at the local “on-farm” scale may appear dramatic, but when properly accounted at basin scale, total water consumption by irrigation tends to increase instead of decreasing*”, this section will analyse this policy in the three regions.

3.3.1 Water savings in Australia

Although the most relevant impact of the ‘Millennium Drought’ on water regulations and policies in the MDB was the implementation of water markets, this drought also motivated far-reaching changes and an extensive adaptation of irrigation agriculture (Connor and Kazcan, 2013). The drought drove improvements in water allocation and management. In the early 2000s, approximately two-thirds of irrigators in the MDB moved to pressurized irrigation systems, which enable a more efficient use of water resources by reducing return flows to bodies of saline groundwater (Maraseni et al., 2012). Additionally, public investments were made in Australia to reduce the water losses to saline groundwater from canals and hydraulic infrastructure. In 2007, the Australian Government committed to invest more than AUS$12 10^9 billion on water problems (Grafton, 2017). This large investment allocates funding to infrastructure improvements (off-farm and on-farm) and to the acquisition of water rights (Connell and Grafton, 2011; Grafton, 2017).

Although the primary use of water is in agriculture, the ‘Millennium Drought’ also involved a change in perceptions of urban water use. Desalinization plants and water recycling plants were built to relieve the pressure on the MDB, leading to a nearly 50% reduction in the per capita municipal use in some regions (Aghakouchak et al., 2014). Regarding the cost effectiveness of water-saving policies, Grafton and Wheeler (2018) argue that the ‘*cost of water recovery from infrastructure (subsidies) is at* *least 2.5 times more expensive than purchasing water entitlements from willing sellers*'.

3.3.2 Water savings in Spain

The Spanish national program for irrigation modernization began in 2002 (MAPA, 2002) in response to the 1990-1995 drought. The national policy of subsidizing water saving and conservation technologies was considered as the core of the national plan for "drought emergency measures". The Spanish government developed the National Irrigation Program to convert the old open-channel distribution infrastructure into pressurized pipe networks to achieve annual water savings of 3,000 GL (Berbel et al., 2019). Water-saving techniques are the main irrigation management initiatives in the implementation of the WFD and the RBMPs in southern Spain (Berbel et al., 2019). National investments of EUR $4{,}0 \cdot 10^9$ have been made in water conservation technologies, which have affected 1.5 Million ha with an estimated water abstraction reduction of 1,925 Mm^3 (Berbel et al., 2019).

Regarding urban water, levels of consumption (137 l/day/inh.) leave a margin for water savings. In certain RBMPs, quantitative goals have been set for urban supply and maximum admissible leakage. However, in coastal and water-scarce areas, water reuse is already well established. Additionally, reclaimed wastewater and desalination plants were included as a measure to fight water scarcity (either short or long term). Their adoption accelerated during the 2005-2008 drought and reached approximately 500 GL of desalinated water produced, mainly for urban use, with 200 GL used by agriculture.

3.3.3 Water savings in California

In CA, farmers also adopted strategies to deal with the reduction in water availability, and opted for an increase in irrigation efficiency, water storage, and a shift in crop-patterns towards highly profitable production. Irrigation district modernization programs, with increasing efficiency of water delivery from canals, have been implemented in recent decades. Modernization in irrigation districts in CA has been implemented with the support of the State and federal agencies and carried out by individual districts and program managers (Burt, 2013). The improvements in the water-use efficiency in Californian irrigation agriculture enabled the economic productivity of water to be increased from an average of 420 USD/acre in the 1960s to more than 800 USD/acre in 2010 (Cooley et al., 2014b). This notable increase in the economic productivity of water arises from shifts towards high-value crops and the adoption of more efficient irrigation technology, especially when replacing flood technology with micro-sprinkler and drip (Tindula et al., 2013). Additionally, changes in irrigation management practices, such as the reduction in pre-plant irrigation quantities for many annual crops, have also led to gains in water efficiency (Hutmacher, 2013). However, improvements in irrigation technology also can have several negative impacts from reducing returns flows to streams and/or aquifers (Grafton et al., 2018). While improvements in irrigation efficiency should involve water savings, the saved water is frequently used to expand irrigation and to reduce returns, which reduces aquifer recharge (Scanlon et al., 2012).

Additionally, regulations in CA from the last drought expanded urban water conservation and savings. Recent regulations require districts to regularly report their water use (as often as monthly). Aggressive urban conservation programs (Urban Water Management Plans) have been implemented (Aghakouchak et al., 2015). Regulations such as the Urban

Water Management Planning Act (UWMP) and the Urban Water Management Plans (the latest, in 2015) aim to clearly describe water conservation measures to increase efficiency and conserve water (Berghoff, 2015). For example, while water reuse had already been implemented in CA, it became more widespread following the drought, especially in southern CA (Cooley et al., 2014a). Water-recycling programs, such as the 'toilet to tap' initiative, were promoted in some districts that were suffering from severe water shortages due to drought.

3.3.4 Comments on water-saving policies and alternative water sources

Clearly, the recent droughts in the three regions have catalysed additional water-saving and conservation measures and regulations. Regarding agriculture, water-saving investments have been promoted in the three regions and the implementation induces management changes in the farm water management decisions (Berbel, et al., 2018). Improvements in irrigation technology and advanced farm management practices have reduced water use (Cooley et al., 2009). While this statement remains true, irrigation modernization is still subject to scientific and policy debate. The improvement in irrigation technologies, involving the use of less water resources, can lead to unexpected results such as the 'rebound effect' whereby water consumption is higher after the implementation of the measure. The use of more efficient irrigation technologies, which in theory should lead to water conservation, frequently results in higher water consumption (Perry et al., 2017, Grafton et al., 2018). In general, irrigation technology improvements have boosted increases in irrigated land and/or switching to high-value crops with larger water requirements (Hanak et al., 2010). An additional problem is the decline in the recharge of aquifers from reduced returns flows from agriculture irrigation efficiency increases (Grafton et al., 2018; Pfeiffer and Lin, 2014). These pervasive effects can be prevented when modernization is complemented with appropriate water governance measures and command and control instruments (Berbel and Mateos, 2014).

The recent droughts in the three regions also altered perceptions of water use, especially in urban areas. In all three regions, several policies have been implemented to reduce water use. The construction of desalination and water-recycling plants supplied certain municipal water use. Similarly, regulations were implemented to reduce water consumption and to incentivize urban water conservation.

In CA, recycled wastewater, urban stormwater, and desalinated seawater and brackish water in year 2015 provide around 2.5% of the state's urban and farm water supply, (Mount and Hanak, 2016). In Spain, desalinated sea water and reclaimed wastewater supply around 2% of total demand, plus the reclaimed brackish water that is not quantified (Morote et al., 2019).

4. Discussion: Droughts as a *catalyst* for water policy reforms

Policy domains tend to be stabilized by the actions of interest groups who share an interest in maintaining the status quo of water policies and programs (Marsh and Rhodes, 1992). Fernandez and Rodrik (1991) argued that governmental resistance to adopting policies which economists consider to be efficiency-enhancing can be explained by uncertainties regarding the distribution of gains and losses from reform. Therefore, radical changes in water policy may occur following major political events (e.g., the water market in Chile after the Pinochet coup) or natural disasters (e.g., the repeated drought episodes in CA, Australia-MDB, and Spain). In the Colorado Basin, drought has triggered fundamental changes to water resource management (Cody et al., 2015).

Normally, water policy is stable, and changes occur incrementally. Changing climatic conditions, whether experienced or anticipated, can be regarded as just one signal among many to which organizations may respond (Berkhout et al., 2006). Since droughts influence rural and national economies, stakeholders and policy-makers may move away from viewing drought events as a ‘crisis’, and start to acknowledge that multi-year droughts could become more frequent (Kiem and Austin, 2013). Recent droughts have forced a shift in water regulations away from crisis response towards a more proactive risk-based approach. The formulation of a drought policy has involved extensive changes to water rights and water management policy (Wilhite, 2011). Studies, such as that by Wei et al., (2017), highlight how the ‘Millennium Drought’ triggered a package of policy initiatives and management practices to ensure sustainable water use. Similarly, Ching and Mukherjee (2015) investigated the hypothesis that water management policy is path dependent by looking at the formation of collective choice rules in integrated water-resource management reforms in the River Basins of the Yellow river and of the Ganges.

The main impact of recent droughts in Spain, Australia-MDB, and CA has been the shift in water regulation and water management from traditional supply-side measures to more sophisticated water conservation systems. The idea behind these new approaches is based on long-term measures to mitigate the impact of droughts instead of traditional on/off reactions to droughts. As analysed above, the transition from an ‘old’ water management to a ‘new approach’ has been triggered by the recent extraordinary droughts: the 'Millennium drought' in Australia (1995-2010), the 1987-1992 and the 2007-2016 droughts in California, and the 'Megadrought' (1990-1995) in Spain. Following these events, the three regions moved to further incorporate droughts as structural elements in their water planning and management instead of managing them as on/off ‘emergency situations’.

During the 1978-84 and 1991-95 droughts in Spain, water management was typically reactive with classic supply-side policies: increase in irrigated areas, water supply (storage), and water transfers (since the 70s). In response to a drought, the government tended to declare an 'Emergency Situation' and support irrigators with subsidies. To avoid this short-term policy, an ambitious rain-fed insurance policy was established based on a public-private partnership and re-insurance systems. Currently, 2.4 million hectares are insured against drought. The confluence of various factors forced a major shift towards the present situation. Those factors include: (1) the low effectiveness of new dams (Spain is the country with the highest ratio of large dams per capita); (2) public opposition to increasing dam capacity due social and environmental impact; and (3) the adoption of the WFD in year 2000. Three main measures made a marked difference: a) preventative Drought Management Plans (DMPs), first approved in 2007 and revised in 2017; b) water markets (regulated in 2005); and c) emphasis on water-saving (such as irrigation modernization, which started in the 2000s).

In Australia, the change in water-management occurred in 1989 (Courtenay-Boterill, 2003). Traditionally, droughts were considered natural disasters and were not properly managed apart from some subsidies for large economic impacts, especially to irrigators and farmers. The Commonwealth Government managed these subsidies or grants for disasters. By 1992, drought policy in Australia acknowledged the fact that droughts were part of the country’s climatic conditions, and simply differentiated between ‘normal’ and ‘extreme’ droughts (Courtenay-Boterill, 2003). Considering droughts as part of the climate in the MDB involved implementing measures to mitigate and adapt to drought events. However, the severity of the last drought in Australia highlighted the need for new measures to guarantee water supplies. The most widely reported action in Australia to deal with water scarcity and droughts has been the development of water markets, but other measures, such as the creation of the RBA, the approval of RBMP, and subsidies for WSCT equipment, also have been implemented. Australia stands out for two of its major mechanisms: a) extensive implementation of water markets and water trade between regions; b) development of the MDB Plan, specifically including Drought Management Plans.

As in Spain, water provision in CA was assured through the extensive hydraulic infrastructures throughout the State. Despite the large increase in water supply in CA (Central Valley Project, State Water Project, Colorado Transfers), the growing demand for resources triggered several regulations. Most water laws and regulations date back to the late 60s and 70s, when a set of policies were established to protect water bodies and the environment (National Environmental Policy Act, Clean Water Act, California Environmental Act, and Endangered Species Act). Further changes in water regulations occurred during the 2007-2009 drought, when a 'water emergency' was officially declared for the first time in CA (Garone, 2015). The latest drought in CA (2012-2016), considered the worst drought in more than a century (Aghakouchak et al., 2015), prompted several policies to control the serious overexploitation of aquifers and to promote water conservation policies. In the case of CA, the three main policies promoted to tackle droughts were: a) a groundwater management plan (Sustainable Groundwater Management Act, 2014); b) water reuse, stakeholders' water restrictions, and public awareness programs; and c) water banks.

Despite efforts in the three regions to better adapt water management to droughts, unresolved problems remain. It is insightful to analyse unexpected results from drought management policies, such as the negative impacts of improving irrigation efficiency. While increases in irrigation efficiency could reduce water consumption, it is necessary to accompany this action with others to control water use (Pfeiffer and Lin, 2014). Additionally, improvements in irrigation technology involve lower returns and exert a direct negative effect on the recharge of aquifers.

A key issue in all three regions is the protection of aquatic ecosystems, yet most measures implemented for droughts have hardly accounted for serious damage caused to ecosystems. The protection of aquatic ecosystems and their ecological functions have been incorporated in water regulations and water policy for the three regions. However, the large trade-offs between human water use and ecosystem requirements have yet to be properly resolved and damage to ecosystems remains a central issue (van Dijk et al., 2013).

Other relevant problems are related with water contamination and effective control of the intense depletion of groundwater (Giordano, 2009). Furthermore, several water pollution problems arise with reductions in water flows (e.g. salinization) in both surface and underground bodies of water (Jones and van Vliet, 2018; Mosley, 2015). The control of the depletion and quality of groundwater remains a challenge in the three regions, and the important role of these resources during droughts must be considered. Finally, the instruments and actions implemented failed to adequately address issues of rural development and impacts on non-agricultural sectors. The implementation of water markets is subject to private transaction costs of water trading that can limit the efficient allocation of water resources and could impede water transactions between some irrigators and small communities (Loch et al., 2018; Regnacq et al., 2016). This has been addressed by Australian institutions where water markets can be considered the most highly developed in the world due to their low transaction cost and transparent and rigorous entitlement definition and management system.

Corresponding trading systems in Spain and CA are less developed. Most of these issues have yet to be resolved in the three areas under analysis and they represent a major challenge for drought plans and water policies.

5. Concluding remarks

This paper compares some of the main drought management instruments in three similar developed economies with Mediterranean climates: namely, Spain, Australia-MDB, and California. The water scarcity conditions in all three regions together with the high incidence of droughts have led to the introduction of regulations for more efficient water management and resource allocation. The similarities and differences in their solutions illustrate the successes and failures of contrasting and/or complementary mechanisms.

The recent droughts in these three regions (Spain, MDB, and CA) catalysed changes in water policy. Traditionally, responses to droughts in these regions mostly focused on supply-side and short-term measures instead of demand-side and long-term regulations aimed at protecting against and mitigating the severe impacts of these events. The previous analysis highlights how droughts have been the driving force for major institutional and social reforms in Spain, MDB-Australia, and CA. While the improvements are intense, several issues remain pending. For long-term efficiency, drought management strategies should include hydrological and environmental goals, although one major challenge involves the existing uncertainty regarding droughts. We have large uncertainties regarding when a drought will occur, its extent, intensity, and spatial scale (Kiem et al., 2016; Cook et al., 2014). Furthermore, there is also a lack of scientific knowledge regarding the potential socio-economic impacts of droughts (Liu et al., 2018). What we do certainly know is that the next drought is coming.

References

Aghakouchak, A., Feldman, D., Hoerling, M., Huxman, T., and Lund, J. (2015). Recognize anthropogenic drought. Nature, 524, 409-411.

Aghakouchak, A., Feldman, D., Stewardson, M.J., Saphores, JD., Grant, S., and Sanders, B. (2014). Australia’s drought: lessons for California. Science, 343, 1430.

Australia Bureau of Statistics. (2016). Water Accounts, Australia 2014-15. http://www.abs.gov.au/ausstats/abs@.nsf/mf/4610.0. (03/03/2017)

Berbel, J., Expósito, A. and Gutiérrez-Martín, C. (2019). Effects of the Irrigation Modernization in Spain 2002–2015. Water Resources Management (2019) 33: 1835–1849.

Berbel, J., Gutierrez-Marín, C. and Expósito, A. (2018). Impacts of irrigation efficiency improvement on water use, water consumption and response to water price at field level. Agricultural Water Management, 203, 423-429.

Berbel, J., and Mateos, L. (2014). Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. Agricultural Systems 128, 25-34.

Berghoff, R. (2015). A technology-based approach to water conservation in California. UCLA Journal of Environmental Law & Policy, 33(2), 405-443.

Berkhout, F., Hertin, J., and Gann, D. M. (2006). Learning to Adapt: Organisational Adaptation to Climate Change Impacts. Climatic Change 78, 135-156.

Blomquist, W. A. (2016). SGMA and the challenge of groundwater management sustainability. UC Davis Center for Watershed Sciences.

Blomquist, W. A., Giansante, C., Bhat, A., and Kemper, K. (2005). Institutional and policy analysis of river basin management: The

Guadalquivir River Basin, Spain. World Bank Policy Research Working Paper.

Brown, T. C. (2006). Trends in water market activity and price in the western United States. Water Resources Research 42, W09402.

Burt, C. M. (2013). The irrigation sector shifts from construction to modernization: What is required for success? Irrigation and Drainage 62, 247-254.

Ching, L., and Mukherjee, M. (2015). Managing the socio-ecology of very large rivers: Collective choice rules in IWRM narratives. Global Environmental Change 34, 172-184.

Cody, K. C., Smith, S. M., Cox, M., and Andersson, K. (2015). Emergence of Collective Action in a Groundwater Commons: Irrigators in the San Luis Valley of Colorado. Society & Natural Resources 28, 405-422.

Connell, D. (2017). Arguing the case to include a wider range of stakeholders in the Murray-Darling Basin policy process. Water Economics and Policy, 3(3), 1650040-1 - 1650040-20.

Connell, D. (2015). The Murray-Darling Basin. In "Federal Rivers: managing water in multi-layered political systems" (D. Garrick, G.R.M. Anderson, D. Connell, and J. Pittock, Eds). Edward Elgar, Cheltenham, UK.

Connell, D., and Grafton, R.Q. (2011). Water reform in the Murray-Darling Basin. Water Resources Research, 47(12).

Connor, J., and Kaczan, D. (2013). Principles for economically efficient and environmentally sustainable water markets: The Australian experience. In: Schwabe, K., Albiac, J., Connor, J., Hassan, R., Meza, L. (Eds.), Drought in Arid and Semi-Arid Environments: A Multi- disciplinary and Cross-country Perspective. Springer, Dordrecht, pp. 357–374.

Cook, B. I., Smerdon, J. E., Seager, R., and Coats, S. (2014). Global warming and the 21st century drying. Climate Dynamics 43(9-10), 2607-2667.

Cooley, H., Gleick, P., and Wilkinson, R. (2014a). Water reuse potential in California. Issue Brief, Pacific Institute. June, 2014.

Cooley, H., Gleick, P., and Wilkinson, R. (2014b). Agricultural Water Conservation and Efficiency Potential in California. Issue Brief, Pacific Institute. June, 2014.

Courtenay-Botterill, L. (2003). Uncertain climate: the recent history of drought policy in Australia. Australian Journal of Politics and History 49: 61-74.

Crase, L. (2009). Water policy in Australia: the impact of change and uncertainty. In "Policy and strategic behaviour in water resource management" (A. Dinar and J. Albiac, Eds). Earthscan, London, UK.

Crase, L., Pagan, Pl, and Dollery, B. (2004). Water markets as a vehicle for reforming water resource allocation in the Murray-Darling Basin of Australia. Water Resources Research 40.

Dai, A. (2011). Drought under global warming: a review. Climate Change 2(1), 45-64.

Dreverman, D. (2013). Responding to extreme drought in the Murray-Darling Basin, Australia. In "Drought in arid and semi-arid regions: a multi-disciplinary perspective" (K. Schwabe; J. Albiac; J.D. Connor; R.M. Hassan; and L.M. Gonzalez, Eds). Springer, Dordrecht.

Expósito, A., & Berbel, J. (2017). Agricultural irrigation water use in a closed basin and the impacts on water productivity: The case of the Guadalquivir river basin (Southern Spain). Water, 9(2), 136.

Fernandez, R., and Rodrik, D. (1991). Resistance to Reform: Status Quo Bias in the Presence of Individual- Specific Uncertainty. The American Economic Review 81, 1146-1155.

Garone, P. (2015). Drought in California: Entering a new water future. Solutions for a sustainable and desirable future 6 (5), 71-76.

Giannoccaro, G., Castillo, M., and Berbel, J. (2016). Factors influencing farmers' willingness to participate in water allocation trading. A case study in southern Spain. Spanish Journal of Agricultural Research 14, 0101.

Giordano, M. (2009). Global Groundwater? Issues and Solutions. The Annual Review of Environment and Resources 34, 153-178.

Gleick, P. H. (2013). Global Freshwater Resources: Soft-Path Solutions for the 21st Century. Science 302, 1524-1528.

Gómez-Ramos, A., and Garrido, A. (2004). La cesión de derechos de agua de la agricultura a los usos urbanos. Una aproximación a un contrato de cesión entre la z.r. del viar y la ciudad de Sevilla. Andalucía Geográfica, 55-61.

Gómez, C. M. G., and Blanco, C. D. P. (2012). Do drought management plans reduce drought risk? A risk assessment model for a Mediterranean river basin. Ecological Economics 76, 42-48.

Grafton, R. Q., Williams, J., Perry, C. J., Molle, F., Ringler, C., Steduto, P., Udall, B., Wheeler, S. A., Wang, Y., Garrick, D., Allen, R. G. (2018). The paradox of irrigation efficiency. Science 361(6404), 748-750

Grafton, R. Q. (2017). Water Reform and Planning in the Murray-Darling Basin, Australia. Water Economics and Policy, 3 (3), 1702001-1 - 1702001-18.

Grafton, R. Q., and Horne, J. (2014). Water markets in the Murray-Darling Basin. Agricultural Water Management 145, 61-71.

Gray, B., Hanak, E., Frank, R., Howitt, R., Lund, J., Szeptycki, L., and Thompson, B. (2015). Allocating California's water: Directions for reform. Public Policy Institute of California (PPIC). November 2015.

Hanak, E., and Jezdimirovic, J. (2016). California's water market. PPIC Water Policy Center, March 2016. San Francisco, CA.

Hanak, E., Lund, J., Dinar, A., Gray, B., Howitt, R., Mount, J., Moyle, P. and Thompson, B. (2011). "Managing California's Water: From Conflict to reconciliation". Public Policy Institute of California (PPIC). San Francisco, CA.

Hanak, E. (2005). Stopping the drain: third-party responses to California's water market. Contemporary Economic Policy 23(1), 59-77.

Harou, J. J., Medellín-Azuara, J., Zhu, T., Tanaka, S. K., Lund, J. R., Stine, S., Olivares, M. A., Jenkins, M. W. (2010). Economic consequences of optimized water management for a prolonged, severe drought in California. Water Resource Research 46(5), W05522, doi:10.1029/2008WR007681.

Howitt, R., MacEwan, D., Medellín-Azuara, J., Lund, J., and Sumner, D. (2015). Economic analysis of the 2015 drought for California Agriculture. UC Davis Center for Watershed Sciences. ERA Economics, UC Agricultural Issues Center. August 17, 2015.

Hutmacher, R. B. (2013). Crop choices with limiting water supplies: deficit irrigation and and sensitivity crop growth stages. In: Schwabe, K., Albiac, J., Connor, J., Hassan, R., Meza, L. (Eds.), Drought in Arid and Semi-Arid Environments: A Multi- disciplinary and Cross-country Perspective. Springer, Dordrecht. Chapter 7, pp. 123-142.

Jenkins, K. (2013). Indirect economic losses of drought under future projections of climatec change: a case study for Spain. Natural Hazards 69, 1967-1986.

Jones, E., and van Vliet M.T.H. (2018). Drought impacts on river salinity in the southern US: Implications for water scarcity. Science of the Total Environment 644(1), 844-853.

Kahil, T. H., Albiac, J., Dinar, A., Calvo, E., Esteban, E., Avella, L., and Garcia-Molla, M. (2016). Improving the Performance of Water Policies: Evidence from Drought in Spain. Water 8(2), 34, doi:10.3390/w8020034.

Kiem, A. S., Johnson, F., Westra, S., van Dijk, A., Evans, J. P., O'Donell, A., Rouillard, A., Barr, C., Tyler, M., Jakob, D., Woldemeskel, F., Sivakumar, B., and Mehortra, R. (2016). Natural hazards in Australia: Droughts. Climatic Change 139, 37-54.

Kiem, A. S. (2013). Drought and water policy in Australia: Challenges for the future illustrated by the issues associated with water trading and climate change adaptation in the Murray–Darling Basin. Global Environmental Change 23, 1615-1626.

Kiem, A. S., and Austin, E. K. (2013). Drought and the future of rural communities: Opportunities and challenges for climate change adaptation in regional Victoria, Australia. Global Environmental Change 23, 1307-1316.

King, A. D., Klingaman, N. P., Alexander, L. V., Donat, M. G., Jourdain, N. C., and Maher, P. (2014). Extreme rainfall variability in Australia: patterns, drivers, and predictability. Journal of Climate 27, 6035-6050.

Kirby, M., Bark, R., Connor, J., Qureshi, M. E., and Keyworth, S. (2014). Sustainable irrigation: How did irrigated agriculture in Australia's Murray-Darling Basin adapt in the Millennium Drought? Agricultural Water Management 145, 154-162.

Kneebone, J., and Wilson, B. (2017). Design and early implementation of the Murray-Darling Basin Plan. Water Economics and Policy, 3(3), 1650041-1 - 1650041-16.

Liu, W., Sun, F., Lim, W. H., Zhang, J., Wang, H., Shiogama, H., and Zhang, Y. (2018). Global drought and severe drought-affected population in 1.5 and 2 °C warmer worlds. Earth and System Dynamics 9, 267-283.

Loch, A., Wheeler, S. A., Settre, C. (2018). Private Transaction Costs of Water Trade in the Murray–Darling Basin. Ecological Economics 146, 560-573.

Lund, J. R., Medellín-Azuara, J., Durand, J., and Stone, K. (2018). Lessons from California's 2012-2016 drought. Journal of Water Resources Planning and Management 144(10), 04018067.

Lund, J. R., Israel, M., and Kanazawa, R. (1992). Recent California Water Transfers: Emerging Options in Water Management. Center for Environmental and Water Resources Engineering. Department of Civil and Environmental Engineering, UC Davis. November, 1992.

MAPA (2002). Real Decreto 329/2002, de 5 de abril, por el que se aprueba el Plan Nacional de Regadíos. Vol. Boletín Oficial del Estado No. 101 April 27, 2002, pp. 15558- 15566. Ministerio de Agricultura, Pesca y Alimentación, Madrid, Spain.

Maraseni, T. N., Mushtaw, S., and Reardon-Smith, K. (2012). Climate change, water security and the need for integrated policy development: the case of on-farm infrastructure investment in the Australian irrigation sector. Environmental Research Letters, 7.

Marsh, D., and Rhodes, R. A. W. (1992). "Policy networks in British government," Clarendon Press.

Mishra, A.K., and Singh, V.P. (2010). A review of drought concepts. Journal of Hydrology 391, 202-216.

Ministerio de medioambiente (2000). "Libro Blanco del Agua en España," Madrid.

Molle, F., Wester, P., and Hirsch, P. (2010). River basin closure: Processes, implications and reforms. Agricultural Water Management 97, 569-577.

Montilla-López, N., Gutiérrez-Martín, C., and Gómez-Limón, J. (2016). Water Banks: What Have We Learnt from the International Experience? Water 8, 466.

Moran, T., and Wendell, D. (2014). The sustainable Groundwater Management Act of 2014: Challenges and opportunities for implementation. Water in the West.

Morote, Á.-F., Olcina, J., and Hernández, M. (2019). The Use of Non-Conventional Water Resources as a Means of Adaptation to Drought and Climate Change in Semi-Arid Regions: South-Eastern Spain. Water 11, 93.

Mosley, L.M. (2015). Drought impacts on the water quality of freshwater systems; review and integration. Earth-Science Reviews 140, 203-214.

Mount, J. and Hanak, E. (2016). Water use in California. PPIC Water Policy Center. July 2016.

Nicholls, N., Drosdowsky, W., and Lavery, B. (1997). Australian rainfall variability and change. Weather 52, 66-71.

OECD (2015). Water Resources Allocation: Sharing Risks and Opportunities. OECD Studies on Water. Paris. OECD Publishing.

Palomo-Hierro, S., Gómez-Limón, J., and Riesgo, L. (2015). Water Markets in Spain: Performance and Challenges. Water 7, 652.

Perry C, Steduto P, Karajeh F (2017) Does improved irrigation technology save water? A review of the evidence. FAO. Cairo, Egypt. http://www.fao.org/3/b-i7090e.pdf.

Pfeiffer, L., Lin, C. C.-Y. (2014). Does efficient irrigation technology lead to reduced

Groundwater extraction? Empirical evidence. Journal of Environmental Economics and Management 67, 189-208.

Randall, A. (1981). Property entitlements and pricing policies for maturing water economy. The Australian Journal of Agricultural Economics 25 (3), 195-220

Regnacq, C., Dinar, A., and Hanak, E. (2016). The gravity of water: water trading frictions in California. American Journal of Agricultural Economics, 98(5), 1273-1294.

Reilly, T. E., Dennehy, K. F., Alley, W. M., and Cunningham, W. L. (2008). Ground-Water availability in the United States. U.S. Geological Survey Circular (USGS), Circular 1323.

Richter, B. (2016). A market-based strategy for sustainable water management. National Geographic. (http://voices.nationalgeographic.com/2016/08/23/a-market-based-strategy-for-sustainable-water-management/)

Scanlon, B. R., Faunt, C. C., Longuevergne, L., Reedy, R. C., Alley, W. A., McGuire, V. L., McMahon, P. B. (2012). Groundwater depletion and sustainability of irrigation in the US High Plains and Central Valley. Proceedings of National Academy of Science 109(24), 9320-9325.

Schwabe, K., Albiac, J., Connor, J. D., Hassan, R., and Meza González, L. (2013). Drought in Arid and Semi-Arid Regions. In: Schwabe, K., Albiac, J., Connor, J., Hassan, R., Meza, L. (Eds.), Drought in Arid and Semi-Arid Environments: A Multi- disciplinary and Cross-country Perspective. Springer, Dordrecht, pp. 15.

Sheffield, J., Wood, E. F., and Roderick, M. L. (2012). Little change in global drought over the past 60 years. Nature 491: 435-438.

Tindula, G. N., Morteza, N. O., and Snyder, R. L. (2013). Survey of irrigation methods in California in 2010. Journal of Irrigation and Drainage Engineering 139(3), 233-238.

van Dijk, I. J. M., Beck, H. E., Crosbie, R. S., de Jeu, R. A. M., Liu, Y. Y., Podger, G. M., Timbal, B., and Viney, N. R. (2013). The Millennium Drought in southeast Australia (2001–2009): Natural and human causes and implications for water resources, ecosystems, economy, and society. Water Resources Research 49(2), 1040-1057.

van Loon, A.F., Stahl, K., Baldassarre, G.D., Clark, J., Rangecroft, S., Wanders, N., Gleeson, T., van Dijk, I.J.M., Tallaksen, L.M., Hannafor, J., Uijlenbhoet, R., Teuling, A.J., Hannah, D.M., Sheffield, J., Svoboda, M., Verbeiren, B., Wagener, T., and van Lanen, H.A.J. (2016). Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches. Hydrology and Earth System Sciences 20, 3631-3650.

van Loon, A. F., and Van Lanen, H. A. J. (2013). Making the distinction between water scarcity and drought using an observation-modeling framework. Water Resources Research, 49, 1483-1502.

Wei, J., Wei, Y., and Western, A. (2017). Evolution of the societal value of water resources for economic development versus environmental sustainability in Australia from 1843 to 2011. Global Environmental Change 42, 82-92.

Wilhite, D. (2011). Breaking the hydro-illogical cycle: progress or status quo for drought management in the United States. European Water 34, 5-18.

Wildman, R. A. Jr., and Forde, N. A. (2012). Management of water shortage in the Colorado River Basin: evaluating current policy and the viability of interstate water trading. Journal of the American Water Resources Association 48 (3), 411-422.