Understanding adaptation and water market behaviour of irrigators and non-landholder stakeholders in the Murray-Darling Basin

Constantin Seidl

A thesis submitted for the degree of Doctor of Philosophy

The Centre for Global Food and Resources

The Faculty of the Professions

The University of Adelaide

April 2020

Table of Contents

List of Figures

List of Tables

Abbreviations

AAS	Australian Academy of Science
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABC	Australian Broadcasting Corporation
ABS	Australian Bureau of Statistics
ACCC	Australian Competition & Consumer Commission
ATO	Australian Taxation Office
AWBA	Australian Water Brokers Association
BOM	Bureau of Meteorology
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CICL	Coleambally Irrigation Cooperative Limited
CIT	Central Irrigation Trust
COAG	Council of Australian Governments
DA	Department of Agriculture
DAW	Department of Agriculture and Water
DAWR	Department of Agriculture and Water Resources
DELWP	Victorian Department of Environment, Land, Water and Planning
DEWNR	South Australian Department of Environment, Water and Natural Resources
DNRM	Queensland Department of Natural Resources and Mines (DNRME since December 2017)
DNRME	Queensland Department of Natural Resources, Mines and Energy
DSEWPAC	Department of Sustainability, Environment, Water Population and Communities
EWH	Environmental water holder
GL	gigalitre (one billion litres)
GMW	Goulburn–Murray Water
GPWA	General Purpose Water Accounting
GS	general security
GVIAP	Gross value of irrigated agricultural product

HS	High security
IIO	Irrigation infrastructure operator
IIGMDBWR	Interim Inspector-General of Murray-Darling Basin Water Resources
IO	Infrastructure operator
IR	Irrigation right
IVT	Inter-Valley Trade Restriction
KL	kilolitres
LMW	Lower Murray Water
LS	low security
LTAAY	Long-term average annual yield
MDB	Murray–Darling Basin
MDBA	Murray–Darling Basin Authority
MDBC	Murray-Darling Basin Commission
MDBBWF	Murray-Darling Basin Balanced Water Fund
MI	Murrumbidgee Irrigation Limited
MIL	Murray Irrigation Limited
MJA	Marsden Jacob Associates
ML	megalitre (one million litres)
NMDB	Northern Murray-Darling Basin
NRAR	Natural Resources Access Regulator
NRM	National resources management
NWC	National Water Commission
NWI	National Water Initiative
PC	Productivity Commission
PIIOP	Private Irrigation Infrastructure Operators Program (NSW)
RIT	Renmark Irrigation Trust
RMO	River Murray Operations
RTB	Restoring the Balance program in the Murray-Darling Basin
SDL	Sustainable diversion limit
SMDB	Southern Murray-Darling Basin

SRWUIP	Sustainable Rural Water Use and Infrastructure Program
VEWH	Victorian Environmental Water Holder
VWAP	Volume weighted average prices
WFF	Water for the Future program
WRP	Water Resource Plan
WSP	Water Sharing Plan

Glossary

Adaptation	The response to major changes in the environment (e.g. global warming) and/or political and economic shocks. Adaptation is often imposed on individuals and societies by external undesirable changes.
Adoption (in agriculture)	A change in practice or technology.
Annual crops	Crops that go through their entire lifecycle in one growing season (e.g. cotton, rice, cereal).
Basin Plan	A high level framework that sets standards (see sustainable diversion limits) for the management of the Murray-Darling Basin‘s water resources balancing social, environmental and economic outcomes.
Broadacre	Broadacre cropping (a term used mainly in Australia) describes large-scale agricultural production of grains, oilseeds and other crops (e.g. wheat, barley, sorghum).
Carry-over	Arrangements which allow water entitlement holders to hold water in storages (water allocations not taken in a water accounting period) so that it is available in subsequent years.
Catchment (river valley)	An area determined by topographic features, within which rainfall contributes to run-off at a particular point.
Commonwealth Environmental Water Holder (CEWH)	An independent statutory office established by the *Water Act 2007* and responsible for making decisions relating to the management of the Commonwealth environmental water aiming to maximise environmental outcomes across the Murray-Darling Basin.
Consumptive water use	The use of water for private benefit (e.g. irrigation, industry, urban, and stock and domestic uses).
Council of Australian Governments (COAG)	Is the peak intergovernmental forum driving and implementing reforms in Australia (members are the Prime Minister, State and Territory Premiers and Chief Ministers and the President of the Australian Local Government Association).
Environmental asset	According to the Basin Plan, include water-dependent ecosystems, ecosystem services and sites with ecological significance.
Environmental water	According to the Basin Plan, comprises water provided to wetlands, floodplains or rivers, to achieve a desired outcome, including benefits to ecosystem functions, biodiversity, water quality and water resource health.
Farming water season	Describes a 12-month period from July 1 to 30 June (similar to the financial year in Australia).

Groundwater	The supply of freshwater found beneath the earth's surface (typically in aquifers).
High security water entitlement	Provide a highly reliable water supply (usually full allocation 90-95 years out of 100) with not much variation between the years (except during extreme drought).
Irrigation Infrastructure Operators (IIO)	An entity that operates water service infrastructure to deliver water for the primary purpose of irrigation.
Long term average annual yield factor (LTAAY)	Expected long-term average annual yield from a water entitlement over a 100 year period.
Low/general security water entitlement	Provide a variable/uncertain water supply. General security provides LTAAY between 42-81%, and low security provides LTAAY between 24-35% in the Murray-Darling Basin.
National Water Initiative (NWI)	The national blueprint for water reform, agreed in 2004 by the Council of Australian Governments (COAG), to increase the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities and for the environment.
Over-allocation	The total volume of water able to be extracted by the holders of water (access) entitlements at a given time exceeds the environmentally sustainable level of take for a water resource.
Regulated river system	Rivers regulated by major water infrastructure, such as dams, to supply water for varies uses.
Reliability	The frequency with which water allocated under a water (access) entitlement is able to be supplied in full.
Permanent crops	Trees or shrubs, not grown in rotation, but occupying the soil and yielding harvests for several (usually more than five) consecutive years. Permanent crops mainly consist of fruit and berry trees, bushes, vines and olive trees and generally yield a higher added value per hectare than annual crops.
Surface water	Water that flows over land and in watercourses or artificial channels.
Sustainable diversion limit (SDL)	Maximum amount of water that can be taken for consumptive use reflecting an environmentally sustainable level of take (i.e. extractions must not compromise key environmental assets, ecosystem functions or productive base).
Transboundary water	A body of water that is shared by or forms the boundary between two or more political jurisdictions.

Unbundling	The legal separation of rights to land and rights to access water, have water delivered, use water on land or operate water infrastructure, all of which can be traded separately.
Unregulated river system	Rivers without major storages or rivers where the storages do not release water downstream.
Water Act 2007	An Act to make provision for the management of the water resources of the Murray-Darling Basin, and to make provision for other matters of national interest in relation to water and water information, and for related purposes.
Water allocation	A specific volume of water allocated to water (access) entitlements in a given season, according to the relevant water plan and the water availability in the water resource in that season (also known as temporary water).
Water buyback program	Principal government market-based instrument in Australia to produce environmental benefits in deteriorated sites across the Murray-Darling Basin by purchasing water entitlements from willing irrigators. In other words, water, previously allocated for consumptive uses, is reallocated back to the environment.
Water entitlement	A perpetual or ongoing entitlement to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan (also known as permanent water).
Water for the Future	A 10-year program of the Australian government to better balance the water needs of communities, farmers and the environment and to prepare Australia for a future with less water. This includes funding for water buybacks and irrigation infrastructure upgrades.
Water recovery	Recovering water for the environment through investing in infrastructure to achieve greater efficiency and through the purchase of water entitlements.
Willingness to pay/accept	The acceptable bid amount that an individual is prepared to pay/receive for acquiring/giving up the good in question.

Abstract

The impacts of water scarcity and climate change, such as a drier future with increased frequency of extreme events, have resulted in increasing pressure on already over-allocated Murray-Darling Basin (MDB) water resources. Therefore, understanding how irrigators adapt to future uncertainty is important for both economic, social and environmental reasons in the MDB. This thesis examines the key drivers for different types of MDB irrigators' planned future adaptation. One key mechanism that irrigators have used for adapting and mitigating water shortage includes participating in water markets. The evolution of water markets in the MDB, and the implementation of unbundling from the 2000s onwards, has seen both a) the emergence of new water products, and b) increasing involvement of environmental and non-landholder stakeholders. However, little is known about non-landholder behaviour and involvement in water markets. This thesis extends the current literature by exploring water ownership and trading strategies of all major MDB water market stakeholder groups, including environmental and non-landholder actors, and gives special focus to "derivative-type" temporary trading products.

The first analytical chapter used a quantitative data set of 1,000 sMDB irrigators to investigate irrigators' planned adaptation strategies and their drivers. Seemingly unrelated regressions, recursive biprobit, and multivariate probit modelling found that while all types of capital (e.g. farm, physical, etc.) are significant drivers of planned future adaptation, financial capital (e.g. debt, net farm income) is one of the most important. Other drivers vary in importance across types of adaptation and industry.

The second analytical chapter explores MDB stakeholders' water ownership and trading strategies, with special attention given to agri-corporate and non-landholder stakeholders, and new water products such as water futures and leases. Three different data sets are drawn upon: 1) the quantitative sMDB irrigator survey; 2) quantitative water forward and parking trade data provided by a private broker; and 3) qualitative in-depth interview data from 63 experts representing a variety of stakeholders. It was found that agri-corporates and non-landholders hold more diverse water portfolios, and engage more in derivative-type water product trading. Three areas of water policy reform are identified: data, rules and regulations, and new institutional development.

The third analytical chapter explored valuation and accounting methods used to estimate the financial asset value of MDB water entitlements. Drawing mainly upon the qualitative interview dataset, a wide divergence in methods was found with comparative valuation the most common valuation method used. Most MDB stakeholders account for water entitlement value at historic cost, while financial investors use fair market accounting to represent current market values. Historical cost accounting undervalues entitlements compared to fair value accounting. The case study of the environmental strategic purchase of Kia Ora overland-flow entitlements in southern Queensland illustrates the impact of valuation discretion on water entitlement values, leading to value differences for the same entitlement, of up to 97%.

As the need to adapt to climate change and future uncertainty increases, it is important to utilise all tools available to incentivise more irrigator adaptive behaviour. Water markets will remain an important adaptation tool, but along with their increased adoption there must be a similar evolution in the design of water markets for their efficient and equitable functionality for all stakeholders.

Thesis Declaration Statement

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

I acknowledge that copyright of published works contained within this thesis resides with the copyright holder(s) of those works. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library Search and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

I acknowledge the support I have received for my research through the provision of a University of Adelaide International Wildcard Scholarship, and ARC Discovery project DP140103946.

Constantin Seidl

April, 2020

Acknowledgments

“*Let me tell you the secret that has led me to my goal: my strength lies solely in my tenacity.*”
― Louis Pasteur

I never intended to endeavour doing a PhD, I was not even sure if I would do a Master’s degree. As a result of lucky coincidences, and tackling every challenge a day at a time, I ended up doing both.

However, this thesis would not have been possible without the academic, financial and emotional support given generously by many people.

I am forever grateful to my principal supervisor Professor Sarah Ann Wheeler for the support she offered me in a myriad of different ways. For one, if Sarah had not suggested that she would be my supervisor if I ever wanted to pursue a PhD, I would have never even thought about it. When I approached her two years later, after graduating from my Masters in 2016, she stayed true to her word and I was able to start my PhD at the University of Adelaide in the same year. Through this past three and a half years, Sarah has always supported and looked out for me, not always in a way I necessarily liked, but always in a way that was good for me. She always had an open door for me, respected and valued my ideas, and gave me inspiration, guidance, trust and patience, and last but not least financial support for conferences and seminars throughout the candidature. She is a role model, I will always be in her debt; I am humbled by her kindness and inspired by her work.

I extend my gratitude to my co-supervisor Associate Professor Alec Zuo who many-a-times generously endured me barging into his office seeking help with a particularly vexed econometrical or statistical problem. I have gained immensely from his econometric and data analysis advice, his continuous support throughout the thesis, and his stoic composure when tackling modelling issues when I already had succumbed to frustration and defeatism.

I thank both for the many hours spend on proof-reading, reviewing modelling results, discussing alternative avenues and giving insights on the interpretation of results. I would also like to thank my co-supervisor Dr Adam Loch who greatly supported the formation of the thesis topic, fostered my understanding of Australian farming systems and was always available to bounce off ideas and concepts. I have learned a lot from Adam, be it the importance and appreciation of strong theoretical foundations, strong communication skills, and how to write well-structured, clearly and concise. For that, I am very grateful.

I want to thank everyone who has generously offered me their time, insights and support over the course of my candidature. In particular I am grateful to Dr Claire Settre, Dr Julianne Haensch, Professor Jeff Connor, Dr Sahar Daghagh Yazd, Professor Mike Young and Dr Deborah Peterson. I want to also thank Dr Jane Edwards for her professional language editing support for this thesis manuscript.

I would like to gratefully acknowledge the financial support provided by the Centre for Global Food and Resources at the University of Adelaide, the Australian Research Council and the University of Adelaide for funding my research through the University of Adelaide International Wildcard Scholarship.

I want to thank all colleagues, fellow PhD students and staff, at the Centre for Global Food and Resources, for providing such a friendly environment and for being my substitute family in Australia. The emotional support and the assurance that you are accompanied by fellow students throughout this journey was invaluable. I particularly want to thank Dr Natasha Caulfield and Julia Avdeeva for always offering impeccable administrative and kind-hearted emotional support. My candidature would have not run as smoothly without them.

Finally, I would like to thank my parents and siblings for their emotional support and for giving me the opportunity to pursue my dreams in a far away country. I am eternally grateful to Devan Goodfellow, for his love, his inexhaustible emotional support and encouragement, and for being there for me when I needed a place to write up my thesis amidst the COVID-19 pandemic.

Publications and Presentations from this Thesis

Academic Journal Articles (peer-reviewed)

Seidl, C., Wheeler, S.A., Zuo, A. (2020) Treating water markets like stock markets: key water market reform lessons in the Murray-Darling Basin, *Journal of Hydrology*, 581, p. 124399.

Seidl, C., Wheeler, S.A., Zuo, A. (2020) High turbidity: water valuation and accounting in the Murray-Darling Basin, *Agricultural Water Management*, 230, p. 105929.

Conference Papers (peer-reviewed)

Seidl, C., Wheeler, S.A., Zuo, A., Loch, A. (2019) Traditional, corporate or environmental: the influence of attitudes on Murray-Darling Basin farmers' future adaptation strategies, *Proceedings of the 29th ÖGA Tagung (Annual Conference of the Austrian Society of Agricultural Economics)*, p. 39-40.

Current Working Papers

Seidl, C., Wheeler, S.A., Zuo, A. (2020) Accommodating, contractive or expansive: Murray-Darling Basin irrigators' planned adaptation preferences and drivers.

Conference Papers and Seminars

Seidl, C., Wheeler, S.A, Zuo, A. (2020) Treating water markets like stock markets: key water market reform lessons in the Murray-Darling Basin, *64th Australasian Agricultural and Resource Economics Society Conference*, 10th – 14th February, Perth, Australia.

Seidl, C., Wheeler, S.A., Zuo, A., Loch, A. (2019) Traditional, corporate or environmental: the influence of attitudes on Murray-Darling Basin farmers' future adaptation strategies, *Colloquium in Resource Economics Thaer-Institute Humboldt University*, 10th September, Berlin, Germany.

Seidl, C. (2019) How do we value water? *National Water Forum*, 28th March, Adelaide, Australia.

Seidl, C., Wheeler, S.A., Zuo, A., Loch, A. (2019) Not just money: drivers of future farm adaptation by southern Murray-Darling Basin irrigators, *63rd Australasian Agricultural and Resource Economics Society Conference*, 12th – 15th February, Melbourne, Australia

Seidl, C. (2019) Water ownership, investment and trading strategies: preliminary findings from qualitative interviews, *Seminar at the Australian Competition and Consumer Commission*, 12th February, Melbourne, Australia

Seidl, C., Wheeler, S.A., Loch, A., Zuo, A. (2018) Understanding the influences on future on-farm adaptation of southern Murray-Darling Basin Irrigators, *62nd Australasian Agricultural and Resource Economics Society Conference*, 6th – 9th February, Adelaide, Australia

Chapter 1 Introduction

Chapter 1 summarises the literature reviews of the individual thesis chapters, introduces the objectives and research questions, the research design and methodology, and provides a road-map of the thesis structure.

1.1 Water and irrigation in the world

Water scarcity and the failure to adapt to climate change have often been named as two of the biggest global risks (WEF 2019). These factors, combined with changing economic circumstances and variable markets, are major sources of uncertainty for farmers, especially irrigators, as many agricultural regions will have to deal with drier and more volatile climates in the future (IPCC 2019). This requires continuous adaptation well into the future, needing the employment of a wide range of diverse established and emerging strategies. A traditional approach that has been employed by irrigation farmers historically includes utilising economies of scale and irrigation technology to make farms more productive and to deal with uncertain economic circumstances and drier climates (de Roest et al. 2018; Turral et al. 2010). Although the drive to increase farm productivity through economies of scale will likely need to continue to satisfy the increasing demand for food associated with global population growth, continued increases in water extraction and decline in the quality and quantity of water resources requires the production of more crops with less water (Perry et al., 2017) without compromising ecosystems. Irrigators' plans for future adaptation include a choice of strategies which expand, but also those which contract the irrigation component of the farm, or those that accommodate changes to production systems without significantly altering the size of irrigated production. Increasingly, water markets are considered a key demand management strategy to address water scarcity (Rey et al. 2019; Wheeler et al. 2013a).

Australia plays a leading role in this space, with the most advanced water market system in the world; the Murray-Darling Basin (MDB) (Grafton et al., 2011).

1.2 Water in the MDB

Chapter Two provides a detailed analysis of water issues in the MDB. The MDB is Australia's largest and most important river system, spanning 1,055,600 km^2. It contains parts of the states of New South Wales (NSW), Queensland (QLD), South Australia (SA), Victoria (VIC) and the entire Australian Capital Territory (ACT). The MDB contains two regions: 1) the southern Basin (sMDB), and 2) the northern Basin (nMDB). The nMDB is characterised by high rainfall and runoff variability, low storages and mainly unregulated and ephemeral rivers on extensive floodplains (BOM 2020e). In contrast, the sMDB is highly regulated, contains the majority of MDB irrigators (ABS 2019c), and contains a large number of nationally and internationally significant wetland and environmental assets (BOM 2020e). The sMDB is hydrologically connected, allowing for water trading between different stakeholders across different states, including irrigators and the environment and has one of the longest and most adopted water markets in the world (Wheeler et al. 2014a). Due to these factors and data availability, the sMDB is the focus of this thesis.

Rainfall is highly variable in the MDB, with annual average rainfall as much as 2,100 mm in the south-east to only around 300 mm in the semi-arid areas of the west. The northern parts of the nMDB have a subtropical climate, leading to higher stream flows in January-March, following the summer rainfall period, whereas the sMDB has a more temperate climate with higher flows in August-October, following winter rainfall (BOM 2020f). With the majority of rainfall evapotranspiring, only about 6% of rainfall is available for consumptive use (MDBA 2018).

The MDB has historically been subject to high runoff variability, including extreme flooding and drought. Apart from the current drought in south-eastern Australia (BOM 2020c), the most recent was the Millennium Drought (2001/02-2009/10), which resulted in 20% less rainfall, corresponding to a reduction in inflows of about 50% of the long-term annual inflows in parts of the basin (Prosser 2011). Unparalleled in its severity and longevity, the Millennium Drought proved to be a catalyst for major water policy reform, ultimately leading to the most extensive reform process in Australian water policy history through the *Water Act* 2007 and the *Basin Plan* 2012.

Climate change is expected to materially impact MDB water resources. Surface-water availability is expected to decrease by a median amount of 11% by 2030, under a median climate change scenario (CSIRO 2008, 2012), and rainfall may decline up to 13-48% by 2090 under a high global emission (RPC 8.5) scenario (Timbal et al. 2015). The sMDB is projected to experience greater reductions in annual runoff, with up to 15% possible in the southern most catchments. Additionally, future droughts are predicted to be more frequent and severe (Chiew et al. 2011), arguably making the Millennium Drought an example of future climate change in the MDB (Grafton et al. 2014a). Reduced surface-water availability also has other implications, such as increased salinity (Beare and Heaney 2002), water quality deterioration (e.g. algae blooms) (MDBA 2020b), and increased variability of supply (Connor et al. 2012). Future water scarcity and variability highlight the need for irrigators' ongoing adaptation and for continuous policy reform, to enable flexible arrangements to support irrigators' livelihoods while also supporting healthy MDB environments and ecosystems.

1.2.1 Irrigated agriculture and MDB water Resources

Chapter Two provides a detailed analysis of irrigation issues in the MDB. Irrigated agriculture only covers about 3% of the MDB's area (BOM 2020e) but uses the majority of available water - 69% of all water diversions in 2017/18 (ABS 2019c). Cotton, irrigated pasture, and rice consumed the largest share of MDB water in 2017/18, with cotton dominant in the nMDB and pasture dominant in the sMDB (Wheeler and Garrick 2020). MDB water consumption contracted during the Millennium Drought, but subsequently increased until 2013/14 with higher rainfalls and the end of the drought, followed by drier conditions and falling consumption thereafter (ABS 2019a).

First established mainly along the MDB rivers, during European colonisation of Australia in the 19th and 20th centuries (Connell 2007; Guest 2016), irrigated agriculture is now of major importance in the MDB, with the region contributing 40% of Australia's gross value irrigated production in 2017/18 (ABS 2019c). Since its inception, MDB irrigated agriculture has adapted to changing circumstances and various extreme events, such as over-allocation of water resources, droughts, economic depressions, increasing water prices and rising water tables and salinity levels (Hallows and Thompson 1995). As such, MDB irrigators have proven extremely resourceful and adaptive; qualities needed more than ever for facing a drier and more variable climate.

Water trading and water markets, informally operating since the 1960s (Connell 2007), have been one of irrigators' most effective adaptation tools. For example, real adjusted gross value of irrigated production only decreased by 10% during the Millennium Drought, despite a 70% decline in irrigated water use (Kirby et al. 2014a, pp. 157, table 1). This was possible through water markets facilitating the reallocation of scarce water resources to higher value crops, while lower value industries generated income through water sales, enabling continued business survival and substituting fodder for pasture in the livestock sector (Kirby et al. 2014a). Water entitlement sales to the government further enabled irrigators to keep farming, reduce farm debt, and restructure their farm enterprises (Haensch et al. 2019; Wheeler and Cheesman 2013; Wheeler et al. 2012b). Water trading continues to provide irrigators with efficiency benefits for adaptation in response to a range of challenges, such as variable water supply or water shortage, financial issues and farm debt, and business restructure. It will remain at least as important, if not more, under future climate change: Kirby et al. (2014b) estimated that a climate change induced 25% reduction in future annual average water availability, translates to only a 10% contraction of GVIP, mainly because of adaptation through water trading between different irrigation activities.

1.2.2 Water Policy reform history and the Basin Plan

Chapter Two provides a detailed analysis of water policy reform issues in the MDB. Since Australian Federation, water policy in the MDB has undergone numerous and significant reforms, both at the state and the national level. While equity of water sharing arrangements were the main concerns in the early days of MDB water reform, addressing over-allocation, environmental damage and the balance between consumptive and environmental water use were the main focus from 1994 onwards (Guest 2016).

Beginning with the Council of Australian Governments (COAG) reforms in 1994, water policy led to ever increasing water market and trade liberalisation, strong commitments to interstate trading and reducing monopolistic behaviour of irrigation infrastructure operators (IIOs). The *National Water Initiative* (2004) and the *Water Act* (2007) are arguably the most important reforms in regards to enabling MDB water markets: unbundling water and land ownership and creating a federal framework for water trading, trading rules and harmonising water market products (Wheeler et al. 2014a). The *Water Act* saw the creation of the Murray-Darling Basin Authority (MDBA), which is charged with developing the *Basin Plan* to readjust the balance between consumptive water use and the environment, the creation of the Commonwealth Environmental Water Holder (CEWH), and the Commonwealth Environmental Water Office (CEWO). Tasked with acquiring and managing environmental water recovered from irrigation to achieve positive ecological outcomes utilising the MDB water market trading system, the CEWH formally enshrines the environment as a water market participant in its own right (Loch et al. 2011).

Passed into law in 2012 after multiple attempts to disallow it (Loch et al. 2014b), the *Basin Plan* has since been the framework determining the relationship between consumptive and environmental use of MDB water resources. The Plan is to "*promote the use and management of the Basin water resources in a way that optimises economic, social and environmental outcomes*" (*Water Act 2007*, Part 2, Subdivision B, 20(2)) by specifying basin-wide long-term levels of sustainable water use— the sustainable diversion limits (SDLs). After a lengthy process and much controversy about around the *Guide to the Proposed Basin Plan* 2010, the *Basin Plan* in 2012 stipulated the recovery of 3,200GL of consumptive water for environmental purposes, comprised of 2,750GL to be recovered directly from willing water user sellers (irrigators and Irrigation Infrastructure Operators (IIOs)). A further 450 GL from improving water infrastructure efficiency by so-called efficiency and supply measures was also struck as an agreement (Grafton and Wheeler 2018; Parliament of Australia 2012). In 2018, legislative amendments under the Northern Basin Review reduced entitlement recovery to 2,680GL; this figure was revised down by a further 605GL (subject to the implementation of 36 'supply measure' projects that are meant to offset water in exchange for 'equivalent environmental outcomes'), bringing the total amount to 2,075GL (Grafton 2019; Productivity Commission 2018). The acquired water is held in trust by the CEWO and managed by the CEWH, who is able to trade water to undertake environmental watering (CEWO 2014) in order to achieve the environmental outcomes defined under the *Basin Plan* (MDBA 2014a). As of 31st December 2019, a total of 2,103.8GL of long-term average annual yield (LTAAY) of water entitlements has been recovered by the Commonwealth, which is about 77% of the original 2750GL water recovery target under the *Basin Plan* (DAWE 2020b).

Water recovery under the *Basin Plan* utilised three main mechanisms: 1) a market-based approach called *Restoring the Balance (RtB)*, which buys water entitlements from willing sellers through competitive tenders (Wheeler and Cheesman 2013); 2) subsidising irrigation infrastructure efficiency upgrades in exchange for 50% of achieved water savings— the Sustainable Rural Water Use Infrastructure Program (SRWUIP) (Grafton and Wheeler 2018); and 3) the strategic purchases of water entitlements through direct negotiation with the seller (DAWR 2018).

All three mechanisms are highly contentious, albeit for different reasons. Irrigators and rural communities routinely blamed the buyback of water entitlements under *RtB* for increased water prices, farm exit and decline in communities, although these factors are mainly caused by drought and low agricultural output prices (Wheeler et al. 2020b; Wittwer 2011). Indeed, a rare scientific consensus considers water buybacks the most effective, low-cost way to recover environmental water, which has the least third-party impacts (Dixon et al. 2011; Grafton and Wheeler 2018; Productivity Commission 2010; Wheeler and Cheesman 2013; Wheeler et al. 2013a; Wheeler et al. 2014c; Wheeler et al. 2012b). Despite this, buyback was capped at a maximum volume of 1,500GL in 2015, due to political and social pressure from irrigators and interest groups (Parliament of Australia 2015), and strategic purchases involve the only buyback of entitlements currently happening.

Irrigators' preferred option for water recovery and, since 2015, the focus of recovery efforts, is irrigation and water infrastructure efficiency upgrades under the SRWUIP program. Efficiency upgrades have drawn extensive criticism from the scientific literature for, boiling down to nine main arguments (Wheeler et al. 2020a): 1) cost-effectiveness (Grafton and Wheeler 2018); 2) governance and transparency (Victorian Ombudsman 2011); 3) impacts on return flows (Williams and Grafton 2019); 4) rebound effects increase irrigated planting area (Adamson and Loch 2018); 5) increased utilisation of water entitlements (Wheeler et al. 2014c); 6) groundwater substitution (Wheeler et al. 2014c); 7) equity (Wheeler et al. 2020a); 8) flood-plain harvesting (Four Corners 2019; Slattery et al. 2019); and 9) reduced resilience through substitution to permanent crops (Adamson and Loch 2018; Adamson et al. 2017).

Strategic purchases recover water through direct negotiations with potential sellers and are argued to be superior to competitive tenders in thin water market conditions (Reeson and Whitten 2015). In practice, strategic purchases have proven a lack of transparency about prices paid and water volumes recovered, casting serious doubts about their "value for money" (Slattery and Campbell 2018a, 2019). There have also been allegations of collusion and rent seeking by vested interests in regard to strategic purchases (Grafton and Williams 2019; Slattery and Campbell 2018b, 2020).

As of 31st December 2019, the Commonwealth has recovered around 1,231GL of long-term average annual yield (LTAAY) water through buyback, around 694GL through infrastructure upgrades (DAWE 2020b)[1], and spent roughly AUD$148,280,000 on 10 strategic purchases between May 2016-August 2017 to recover an undisclosed amount of water (DAWE 2019a). However, due to NSW not completing their water resource plans on time, and therefore not specifying their catchment level SDLs, *Basin Plan* implementation and water recovery was extended from 2019 to 2024 (Grafton et al. 2020b).

The *Basin Plan* also included a further suite of water market liberalisation trading rules measures. They require mandatory price reporting for all allocation and entitlement trades, transparent trading rules and delivery rights conditions for Irrigation Infrastructure Operators (IIOs), mandate reduced barriers to surface-water and delivery rights trading, and make all water trade subject to water trading rules, including tagged allocation trades, provided the tag was established on or after 10th October 2010 (MDBA 2019f). Due to implementation issues, mandatory price reporting and subjecting tagged trades to trading rules and restrictions has not been fully implemented at time of writing (DELWP 2020a; MDBA 2019m).

1.2.3 Current issues and policy initiatives

Chapter Two provides a detailed analysis of current water issues and policy initiatives in the MDB. Although legislative water policy reform has been undertaken since the *Basin Plan*, some current issues have emerged. In July 2017, the Australian Broadcasting Corporation's Four Corners aired a report alleging water theft and non-compliance with the *Basin Plan* in the Barwon-Darling region of northern NSW (Four Corners 2017). The program alleged unlawful water extraction, meter tampering, and collusion between the NSW water regulating authority and irrigation interests. In response, the NSW government commissioned a review, which substantiated the allegations (Matthews 2017). NSW subsequently established the Natural Resource Access Regulator (NRAR) to review and enforce compliance with water management rules (Parliament of NSW 2017), while there were also three additional compliance reports tabled by the NSW Ombudsman between 2017 and 2018 (Carmody 2018). Furthermore, the courts found the irrigators incriminated by Four Corners guilty of unlawful water take and issued substantial fines (*Water NSW v Barlow* 2019; *Water NSW v Harris (No 3)* 2020). The programme also prompted the instigation of the Commonwealth's 'Murray-Darling Basin Compliance Review' (MDBA 2017b), and the creation of the South Australian Murray-Darling Basin Royal Commission.

The South Australian Murray-Darling Basin Royal Commission under Commissioner Bret Walker SC found, among other issues, that the process chosen by the MDBA to set the SDL, under the *Basin Plan*, was not in compliance with the *Water Act* and is unlawful. It rejected the MDBA's approach of how to incorporate climate change in the *Basin Plan*, and the authority's infamous "triple bottom line" approach of balancing economic, social and environmental targets for recovering environmental water, instead mandating a higher environmental recovery target. However, the Royal Commission has seemingly had little policy impact, arguably due to political cooperation between the Liberal SA and Commonwealth governments.

A series of mass fish kill events in the Lower Darling (NSW) in late 2018 and early 2019 has prompted two competing scientific reviews exploring the causes of the events; one by the Australian Academy of Sciences (AAS 2019) and one by a team led by Professor Rob

[1] With a further 15GL gifted by the Queensland government, and 163.4GL recovered by state governments

Vertessy (Vertessy et al. 2019). While both reports agree on the main causes— stratification and subsequent mixing of oxygen-depleted water layers— they differ in their judgement about water management impacts. The AAS (2019) identified changes to the Barwon-Darling water sharing plan, over-extraction and the operation of the Menindee Lakes storage system under the Menindee Lakes Water Saving Project (DPIE 2020) as contributing factors, while the Vertessy report makes no such attribution (Vertessy et al. 2019). Together with the controversy around the Broken Hill pipeline business case (DPI 2016), which shows the main project beneficiaries are irrigators upstream of the Menindee Lakes System, this has contributed to the impression in some local communities that town water supply, indigenous and environmental considerations take second place to powerful and vested-irrigation interests (Hannam 2019), with claims the MDBA and state regulatory authorities having been institutionally captured (Grafton and Williams 2019).

Fuelled by the current drought and irrigators' vocal protests, the Commonwealth has undertaken a number of initiatives. For example, On 1st October 2019, the role of Interim Inspector-General of Murray-Darling Basin Water Resources was created, appointing Mick Keelty, a former Australian Federal Police commissioner (IIGMDBWR 2020). The Inspector-General is to support the implementation of the *Basin Plan* by undertaking an inquiry into the management of Murray–Darling Basin water resources, including the *Murray-Darling Basin Agreement* (1992) which governs the sharing of MDB water resources between the states. As the role has no enforcement or legislative powers and given the states' lack of interest in changing water sharing arrangements (excluding NSW), policy impacts resulting from the Inspector-General's inquiry are unlikely at this stage.

The "Independent Panel for the Assessment of Social and Economic Conditions in the Murray–Darling Basin", chaired by Robbie Sefton, was established in June 2019. Its terms of reference include: 1) review economic conditions in rural and regional communities across the MDB; 2) assess (positive and negative) impacts of water reforms on the vulnerability, resilience and adaptive capacity of MDB, including the impacts of environmental water reforms; 3) investigate structural changes in the MDB, separating the effects of drought and structural changes from the effects of water reform; 4) support longer-term efforts to monitor and understand social-economic conditions and the impacts of water reform; and 5) explore a range of options that stimulate, support and promote healthy and sustainable rural and regional communities in the MDB (MDB Socio-economic Panel 2020). The Panel submitted a draft report on 16th March 2020 and is expected to deliver its final report by 30th April 2020. The draft report made 20 draft recommendations, grouped in five broad areas: 1) better community involvement and consultation; 2) meeting the needs of First Nations; 3) implementing water reforms with greater care to minimise potential negative externalities; 4) supporting communities' adaptive capacity to change; and 5) addressing critical gaps in community wellbeing, infrastructure and services (MDB Socio-economic Panel 2020).

The Commonwealth implemented the *Water for Fodder* program in 2019/2020. This was an agreement to use the Adelaide desalination plant to produce an extra 100GL of water for SA water consumption in exchange for Commonwealth funds (DAWE 2020a). In turn, 100GL of Murray water (40GL in 2019/20 and 60GL in 2020/21) from the SA state entitlement will be made available to irrigators, in blocks of 50ML for $5000 per water allocation account, to produce fodder at a discounted price of AUD$100/ML (DAWE 2019d). At the time of writing, of the 40,000ML available in round one, 14,250ML were delivered to irrigators in NSW, 25,100ML to irrigators in VIC, and 650ML to irrigators in SA (DAWE 2020c).

Another initiative was the Australian Competition & Consumer Commission was tasked to review of water market functionality and unethical behaviour of water market intermediaries

(ACCC 2019a; Frydenberg 2019). The recent increase in water market prices and non-landholder investor market participation has galvanised irrigators' concerns about water market functionality, resulting in political action. The ACCC is expected to present its final report on 20th November 2020.

1.2.4 Water markets

Chapter Three provides a detailed analysis of water market issues in the MDB. Water markets effectively allocate scarce resources by enabling water to move from low to high value uses through trade (Grafton et al. 2016; Howe et al. 1986; Wheeler et al. 2014a). Water markets exist in a number of different countries (O'Donnell and Garrick 2019) and with different degrees of formality (Bjornlund 2004). However, implementation of robust water markets is limited (Wheeler et al. 2017b) and water market impacts and functions are frequently misunderstood (Grafton et al. 2016). Water policy reform in the MDB has continuously advanced water market development over the last 30 years. It is therefore no surprise that MDB water markets are globally recognised as the most advanced (Grafton et al. 2011), having significant value in fostering understanding of water markets.

There are two main water markets in the MDB, a market for water entitlements (permanent water) and a market for water allocations (temporary water). The COAG reforms define water allocations and entitlements as (COAG 2004a, p. 30):

Water (access) entitlement: *a perpetual or ongoing right to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan.*

Water allocation: *the specific volume of water allocated to the water entitlement in a given season, defined according to rules established in the relevant water plan.*

Water markets have been an integral part of water policy initiatives since the 1994 COAG reforms and are an established water management tool (Bjornlund 2006). Although operating locally within IIOs in the 1980s (Wheeler et al. 2014a), water trading became more common only after unbundling of water and land ownership in the early 2000s (Crase et al. 2014). Water markets were also a major tool for environmental water recovery under the *Water Act* and *Basin Plan* (Wheeler and Cheesman 2013). MDB water markets have had a range of positive externalities and efficiency benefits, such as delivering environmental benefits through water recovery and environmental watering, enabling irrigator's climate change and drought adaptation and increasing the gross value added to farming activities (Grafton et al. 2016). On the other hand, there have been recorded negative externalities and impacts from imperfect competition and information (Wheeler and Garrick 2020).

Although water markets exist both in the nMDB and sMDB, trading has predominantly occurred in the sMDB, due to stronger institutions, more diverse stakeholders, highly regulated systems and the presence of major water storages (Wheeler and Garrick 2020). MDB water markets are worth around AUD$2 billion annually (MDBA 2019l), with commercial allocation and entitlement trade values for 2018-19 estimated at AUD$566 million for allocations and AUD$699 million for entitlements (Wakerman Powell et al. 2019). Water trading activity in the sMDB represented over 80% of total Australian water trades and sMDB irrigators were 4.8 times more likely to have conducted an allocation, and 7.9 times more likely to have conducted an entitlement trade, based on the average transaction per irrigation business from 2008/09-2017/18 using ABS data (Wheeler and Garrick 2020).

Although it was estimated that the majority of irrigators in the sMDB had participated at least once in allocation and entitlement markets by 2015/16, allocation trade is the most common form of trading (Wheeler and Garrick 2020), due to its simplicity. Entitlement trading, by contrast, particularly inter-state trading, remains more complex. While allocation trade is often used as a risk management tool by irrigators (Zuo et al. 2015a), entitlement trading is more strategic, often facilitating farm restructure, relocation, or reduction of farm debt (Haensch et al. 2016b; Wheeler et al. 2012b). Entitlement trade increased with environmental water recovery during the Millennium Drought, and has since not subsided to pre-drought levels, despite the cap on buybacks in 2015 (ABARES 2018).

Finally, although theorised in the academic literature for some time (Bayer and Loch 2017; Brennan 2008; Wheeler et al. 2013a), new temporary water market products, such as water leases, water forwards and parking contracts, have only recently emerged. Trading volume and prices for these products are practically unknown, because they employ standard entitlement and allocation trade mechanisms and are therefore masked in the water register data (ABARES 2018; Seidl et al. 2020b). Since 2009, non-landholder water market participants, such as financial investors and superannuation companies, have also emerged. Their water trading behaviour and entitlement ownership is largely unknown, given the lack of publicly available water entitlement ownership register specifying stakeholder types. The closest approximation of ownership is 12% of high reliability water entitlements in northern Victoria in 2017/18 held by the “non-user” group (DELWP 2019a). However, as the non-user group also includes irrigators’ self-managed superannuation funds, the volume owned by “true” investors is likely smaller. Chapter 6 provides more analysis and detail on this.

1.3 Literature Review

The following section provides a brief overview of key literature concerned with irrigators’ adaptation behaviour and MDB water market stakeholders’ water ownership and trading strategies, in order to highlight current gaps in the literature and to contextualise the research questions addressed by this thesis.

1.3.1 Irrigator adaptation and adoption behaviour

Chapter Two, Three and Five provide a detailed analysis of irrigation issues in the MDB. The literature on farmers’ adoption behaviour is vast, starting with the famous study on hybrid corn diffusion by Ryan and Gross (1943). Adoption research has endeavoured to understand the drivers and personal characteristics impacting farmers’ decisions to adopt new technology, and the adoption literature in agricultural economics is vast. Adaptation is a sub-area of the wider concept of adoption: adaptations are changes in public and private decision making and resource allocation in expecting, or responding to, the prospect, or reality, of large-scale and long-lasting changes (Zilberman et al. 2012).

Contributing to the size of the adoption literature is the number of different research disciplines involved, the large diversity of research questions and heterogeneous contexts of farming systems (Pannell and Zilberman 2020). While earlier adoption studies focused on socio-economic characteristics of utility-maximising, perfectly rational farmer decision-makers, more recent work gives more weight to uncertainty and risk preferences, investigates social aspects (i.e. social group membership) and bounded rationality concepts (Chavas and Nauges 2020). However, the majority of studies have focused on explaining ex-post adoption, rather than endeavouring to understand future adoption plans (Llewellyn and Brown 2020).

In contrast, adaptation is adoption in response to an external force or stressor. The most important external stressor is arguably climate change, leading to an extensive literature on farmers' climate change adaptations. As such, adaptation is the focus of this thesis. Given the multi-dimensionality of adaptation and adoption, Smit and Skinner (2002) suggest grouping adaptation strategies around shared characteristics or research interests to reduce complexity. For example, adaptation strategies can be planned or autonomous (Adger et al. 2005), incremental or transformative (Park et al. 2012), anticipatory or reactive (Fankhauser et al. 1999), hard or soft (Wheeler et al. 2017c), and short- or long-term (Smit and Skinner 2002).

Considerable work has been done on the adoption of individual adaptation strategies (Bradshaw et al. 2004; D'Emden et al. 2006; de Sousa et al. 2017; Deressa et al. 2009; Moniruzzaman 2015; Pannell et al. 2006; Wang et al. 2015b), whereas a smaller number of studies explore multiple different adaptation strategies simultaneously (Below et al. 2012; Dinh et al. 2017; Nicholas and Durham 2012; Wheeler et al. 2013b).

Potential drivers for adaptation are numerous, but certainly include socio-economic factors, as well as climatic and environmental characteristics. To simplify these influences, Ellis (2000) suggests grouping them in relation to five different types of capital: financial, human, natural, physical, and social capital. Financial capital includes, for example, farm income and wealth, human capital encompasses farmer education and age, natural capital considers rainfall and temperature, physical capital includes farm technology and machinery, and social capital entails factors such as membership in social groups. Chapter 5 provides more analysis and detail.

1.3.2 Adaptation gap

Although there has been extensive research on general farmer adaptation and adoption behaviour, empirical quantitative analysis of farmers' planned adaptation decisions, addressing complex, forward-looking and site-specific characteristics of adaptation processes (Below et al. 2012; Wheeler et al. 2013b) has been less common. In particular the role of social influences and farmers' beliefs for future adaptation is under-explored (Pannell and Zilberman 2020).

MDB irrigators have historically employed a range of adaptation tools, with water trading as an integral part (Dinh et al. 2017; Kirby et al. 2014a), but their future adaptation behaviour in the face of increasing uncertainty, due to climate change and other factors such as industry restructure, is largely unexplored. To our knowledge, Wheeler et al. (2013b) is the only study exploring MDB irrigators' planned behaviour in relation to their beliefs using 2010 data, albeit with a narrow focus on only eight potential adaptations in total.

There is a clear gap in understanding MDB irrigators' planned adaptation of a wide range of strategies, and the impact of attitudes and beliefs, other than climate change belief, on drivers of planned adaptation. Addressing this gap is of particular importance as uncertainty about climate change impacts increases and policy incentivising adaptation will increasingly need to tackle the risk of insufficient adaptation to climate change (WEF 2019). This is further explored in Chapter 5.

1.3.3 Water market trading behaviour and stakeholders

Chapter Three provides a detailed analysis of stakeholders' water market trading behaviour. Given that water trading is an essential tool for MDB irrigators, a number of studies have analysed the determinants of MDB irrigators' water trading decisions. However, there are important differences between water allocation and water entitlement trading behaviour. Water allocation trading is more associated with short-term risk management; for example in response to seasonal fluctuations of water prices or availability (Bjornlund 2002, 2006; Loch et al. 2012; Nauges et al. 2016; Zuo et al. 2015a). There are also institutional drivers for allocation trade, such as the needs to balance water allocation accounts at the end of the water year (Wheeler et al. 2008b), or to manage carry-over (Brennan 2008).

Irrigators' entitlement trading is more strategic and based on long-term considerations, such as farm finances, restructure or farm exit, but also social factors such as community acceptance (Haensch et al. 2019; Haensch et al. 2016b; Wheeler and Cheesman 2013; Zuo et al. 2015b).

Since the *Water Act*, the environment is an active water market participant through environmental water holders (EWHs) such as the CEWH. EWH trading behaviour is markedly different from irrigator trading behaviour. When allocations are traded by EWHs, they are mainly a transfer of a volume of water to be used for environmental watering events and are therefore non-commercial (MDBA 2014a). Most EWHs follow the trading strategy set out by the CEWH (CEWO 2014), only allowing commercial water trading under very specific conditions. At the time of writing, the CEWH and other EWHs have mostly acted as allocation sellers (VEWH 2018b), and even that in a limited capacity because unused water allocations generally are carried over. However, as at March 2020, the CEWH was considering purchasing water allocations (AUD$2 million worth) in the nMDB from Queensland agribusiness Eastern Australia Agriculture (Davies 2020). To the author's knowledge, this is the first time the CEWH has bought water allocations.

With further environmental water recovery through buyback capped since 2015 (Parliament of Australia 2015), EWH entitlement trades are mainly in order to rebalance existing water holdings.

It has to be noted that there is limited activity of private EWHs in the MDB. As private non-governmental entities, they are not directly bound by political and policy considerations. They are able to act more akin to irrigators in the market and undertake commercial water trading for profit. The most prominent example of these EWHs is the Murray-Darling Basin Balanced Water Fund, which employs a trading strategy of selling water allocations at high prices (in drought) and buying at low prices (in wet periods) to both maximise environmental outcomes and shareholder financial returns (Carr et al. 2016). This is explored in more detail in Chapter 3.

1.3.4 Water market gaps

Hence, to date, no study has explored how irrigators and EWHs make use of emerging derivative-type[2] temporary water products, such as leases, forwards and parking contracts.

[2] Pirrong (2011, p. 6) defines derivatives contracts as "promises to pay amounts that depend on some market price or event", with the risk that the party obligated to make a payment under the contract will be unable to pay. Applied to the water market, "payment" can also mean the delivery of a volume of water instead of money. This

Although some studies discuss the theoretical foundations (Bayer and Loch 2017; Brennan 2008; Wheeler et al. 2013a), the practical application and trading behaviour of these water market products across MDB stakeholders is unexplored, despite anecdotal and evidence from the grey literature suggesting their increasing popularity.

Unbundling and subsequent water policy reform have led to sufficient trust in water entitlements' legal security that they have become a mortgageable asset (Waterfind 2019a), significantly contributing to irrigators' asset bases. Whether that has instigated a paradigm shift towards water entitlements being perceived as an investment asset, rather than a production input, and how financial institutions value entitlements for mortgage purposes, is currently unknown.

Finally, there has been an increase in non-landholder and financial investor water market activity and ownership since 2009. Although a small number of studies suggest investors may seek diversification benefits (Roca et al. 2015) and competitive returns from investing in water entitlements (Wheeler et al. 2016a), financial investors' motivations to enter the water markets are ultimately unexplored in practice. Similarly, as publicly available data neither tracks water ownership nor water trading behaviour by stakeholder type (e.g. EWH, Irrigator, IIO), non-landholders' water ownership and trading strategies are also unknown.

Addressing these gaps is important and timely, with non-landholder investment and trading in new water market products increasing, and irrigators' concerns about these developments galvanised by the current drought and its distributional impacts on water availability and water prices. Chapters 6 and 7 provide more analysis and detail.

1.4 Objectives and research questions

The aim of this thesis is to explore how irrigators adapt to future uncertainty and risk, using the water market as a key strategy. Given the evolution of water markets in terms of new temporary products and non-landholder stakeholders, as well as water entitlements being a mortgageable and financial asset, this thesis also explores how these changes manifest in water ownership and trading strategies for different stakeholder groups, whether water is seen as a financial asset and how it is valued as such, and, finally, how current water market institutions and policy need to change in order to adapt to these new water market developments. To achieve these objectives and to fill the gaps previously identified, a number of research questions are formulated. The questions ask *how* irrigators plan to adapt to future uncertainty, *what* are the influential factors in this decision and *how* they are impacted by different world views? Research questions relating to new and recent developments in MDB water markets ask *what* new temporary water market products, ownership and trading strategies are used and by *whom*; *is* water seen as a financial asset and *how* is it valued? Specific questions include:

thesis refers to derivatives on water as "derivative-type" temporary water products to acknowledge that they are not derivatives in the true financial sense.

1) What type of strategies do MDB irrigators plan to use to adapt in the future?
   a. What strategies are favoured by different irrigator groups?
2) What influences are associated with irrigators' planned adaptation?
   a. Do influences on adaptation strategies vary by irrigator group?
3) What different water entitlement ownership and water trading strategies are used by MDB irrigators?
   a. In particular, what are the entitlement and water trading strategies of agri-corporates, EWHs and non-landholder financial investors in the MDB?
4) How are water leases, forwards and parking, used by various MDB water market stakeholders?
5) What are the views of MDB stakeholders towards whether water entitlements are seen as a financial investment asset?
   a. How are water entitlements valued by banks for financial purposes, such as mortgaging?
   b. Are there significant differences by stakeholders in water asset valuation in the MDB and does this materially affect water entitlement financial values?

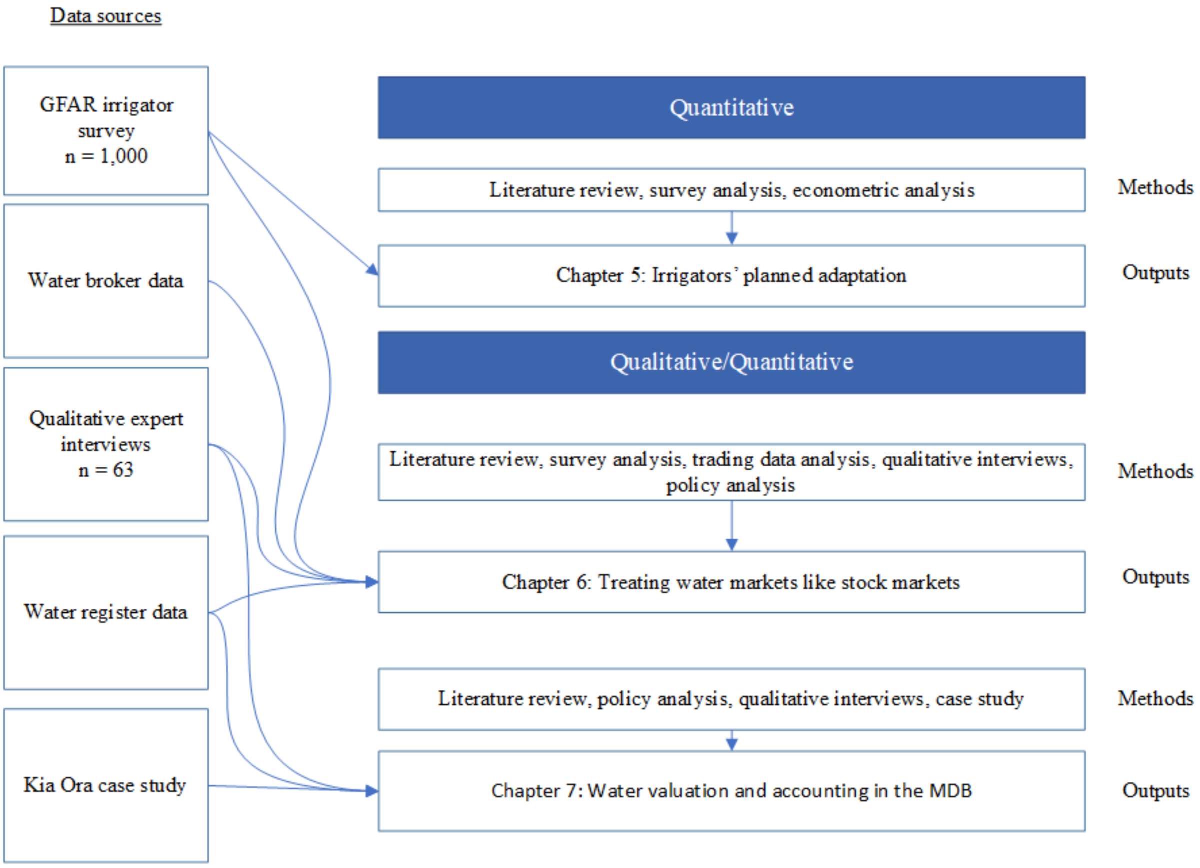
Using insights derived from the findings of the above investigations, the thesis also seeks to make suggestions about how water market institutions and water policy can be improved.

1.5 Research design and methodology

To answer these research questions and address the gaps in the literature, this thesis uses mixed-methods research. Mixed-methods involves mixing qualitative and quantitative approaches, concepts and techniques in one research study (Creswell 1998, 2003). The use of mixed method approaches is motivated by combining the insights gained by qualitative and quantitative approaches to address interacting or complex research topics (Creswell 2003; Palinkas et al. 2011; Tashakkori et al. 2015). This approach is particularly appropriate for water resource research due to the different, but legitimate, perspectives on water-use, water management, and water trading both as adaptation and as risk management, as well as the complex nature of water as an economic commodity and common pool resource.

This thesis combines two main methodologies, quantitative and qualitative: 1) an econometric analysis of a survey of 1,000 sMDB irrigators, supported by water broker individual forward and parking trade data (quantitative), and 2) a large number of semi-structured interviews with experts from agri-corporates, banks and EWHs (n=63), or who are financial investors, property and water evaluators, and water brokers (qualitative). These methodologies are supported by a range of case studies, private water market broker, water register data, policy analyses and literature reviews. The overall research design is depicted in Figure 1.1.

Figure 1.1 Research design



1.6 Thesis structure

This thesis is organised into eight chapters and combines published and unpublished work. Following this introduction, Chapter 2 introduces the study area (the sMDB) and provides an overview of physical and climatic conditions, and water policy and reform history in the MDB from Australian Federation to the present day.

Chapter 3 provides a detailed discussion of MDB water markets, trading volumes and restrictions, as well as irrigators' and EWHs' allocation and entitlement trading behaviour and motivations. This chapter concludes by introducing the gaps in the water market related literature.

Chapter 4 gives some extra justification on the mixed methods approach chosen and more details on each of the data sources used in this thesis. It gives special attention to the sampling, recruitment and interview processes applied to collect data from the qualitative expert interviews.

The following three analytical chapters provide the analyses and results answering this thesis' research questions. These chapters are summarised in Table 1.1.

Table 1.1 Summary of analytical chapters

Chapter	Topic	Data sources	Time period	Methods
5	Irrigators' planned adaptation behaviour	GFAR irrigator survey	2015/16	Partitioning clustering, recursive bi-probit models, multivariate probit models, seemingly unrelated regression models
6	Water ownership and trading strategies, policy improvements	GFAR irrigator survey, qualitative expert interviews, water register and water broker data	2015/16 - 2018/19	Survey analysis, mean and frequency analysis, thematic and qualitative analysis
7	Water entitlement valuation and accounting	Expert interviews, water register data	2018/19	Thematic and qualitative analysis, case study

Chapter 5 provides a literature review of irrigators' planned adaptation strategies and their drivers, as well as an econometric analysis of an irrigator survey (n=1,000 in the sMDB in 2015/16) to determine irrigators' planned adaptation behaviour and its drivers. This chapter is written in manuscript style but has not yet been submitted to a journal. Note that some repetition (i.e. study area) will be encountered due to the format of this chapter.

Chapter 6 presents a published journal article:

> Seidl et al. (2020b), 'Treating water markets like stock markets: Key water market reform lessons in the MDB', *Journal of Hydrology*, vol. 581, p. 124399.

This chapter comprises a literature review on water investment and non-landholder engagement in MDB water markets. It employs qualitative and quantitative data to explore water ownership and trading strategies by different MDB stakeholders, their views on water entitlements as an investment asset and suggested water market policy improvements and reforms. Again, some repetition (i.e. study area and water market gaps) will be encountered due to the format (i.e. publication) of this chapter.

Chapter 7 presents a published journal article:

> Seidl et al. (2020a), 'High turbidity: water valuation and accounting in the Murray-Darling Basin', *Agricultural Water Management*, vol. 230, p. 105929.

This chapter includes a review of relevant water entitlement valuation and accounting frameworks. It employs qualitative data and a case study to explore the predominant water accounting and valuation approaches used for MDB water entitlements. It also illustrates the impact of different valuation methods on water entitlement financial values. Again, some repetition (i.e. study area) will be encountered due to the format (i.e. publication) of this chapter.

Chapter 8 summarises the thesis' findings, discusses limitations of the thesis and its policy implications, while also making recommendations for further research.

The Appendices provide additional information which is not covered in various chapters.

Chapter 2 The Murray-Darling Basin: Physical setting and water policy history

This chapter introduces the study area—the Australian Murray-Darling Basin (MDB)—describes its physical and climatic characteristics and outlines some important socio-economic characteristics. It provides an overview of water policy development from the 1990s to today and concludes by sketching some current policy issues. Each phase of water policy reform has led to a maturing of the water market, increased irrigator participation, has enabled non-irrigator stakeholders to own and trade water, and led to the trading of new water trading products (discussed in Chapter 3).

2.1 The study area

2.1.1 The Murray-Darling Basin

The Murray-Darling Basin is Australia's largest agricultural region, an area of great environmental, economic, cultural, social and touristic significance. Agricultural production in the basin is diverse, ranging from primarily broadacre farming and grazing livestock in the north, to dairy and horticulture in the south. Routinely referred to as Australia's 'food bowl', it generated 40% of Australia's AUD$58.9 billion gross value agricultural production (GVAP)[3] in 2017/18 (ABS 2019b). The Basin encompassed 64% of Australia's irrigated area in 2017/18 and is home to about around 42% of all irrigating businesses (ABS 2019c). Overall, the region contributed AUD$8.6 billion of the gross value of irrigated agricultural production (GVIAP)[4] in 2017/18, constituting more than 48% of Australia's GVIAP that year. Irrigation activities used 6.8 million megalitres[5] (ML) of irrigation water on 1.5 million hectares of land, with irrigated pasture and cotton accounting for more than half of the water used (ABS 2019b, 2019c). Despite lower water extractions and a smaller area under plantation, the GVIAP of horticultural crops has increased over time, from AUD$2.05 billion in 2013/14 to AUD$2.85 billion in 2017/18, driven by high demand and attractive prices for almonds, citrus and grapes.

The following features highlight the MDB's importance as a region, demonstrating that it:

- Spans 1.06 million square kilometres (14% of Australia's landmass)
- Is home to more than 2.6 million Australians
- Provides drinking water for over 3 million people
- Encompasses 41% (more than 35,000) of all Australian farms
- Is home to almost 9,500 irrigators
- Creates tourism revenue of AUD$8 billion annually
- Is home to forty Aboriginal nations
- Provides critical habitat for more than one hundred and twenty water bird and forty-six native fish species

[3] GVAP is calculated by multiplying the wholesale price and quantity of agricultural commodities produced (ABS 2019b)
[4] GVIAP is calculated by multiplying the wholesale price and quantity of agricultural commodities produced by irrigation (ABS 2019b).
[5] 1 ML = 1 million litres

- Has 77,000 km of rivers and 30,000 wetlands, sixteen of which are internationally recognized (ABS 2019c; MDBA 2019k).

Figure 2.1 shows the boundaries of the nMDB and sMDB in south-eastern Australia, spanning parts of Queensland (QLD), New South Wales (NSW), Victoria (VIC), South Australia (SA) and the Australian Capital Territory (ACT).

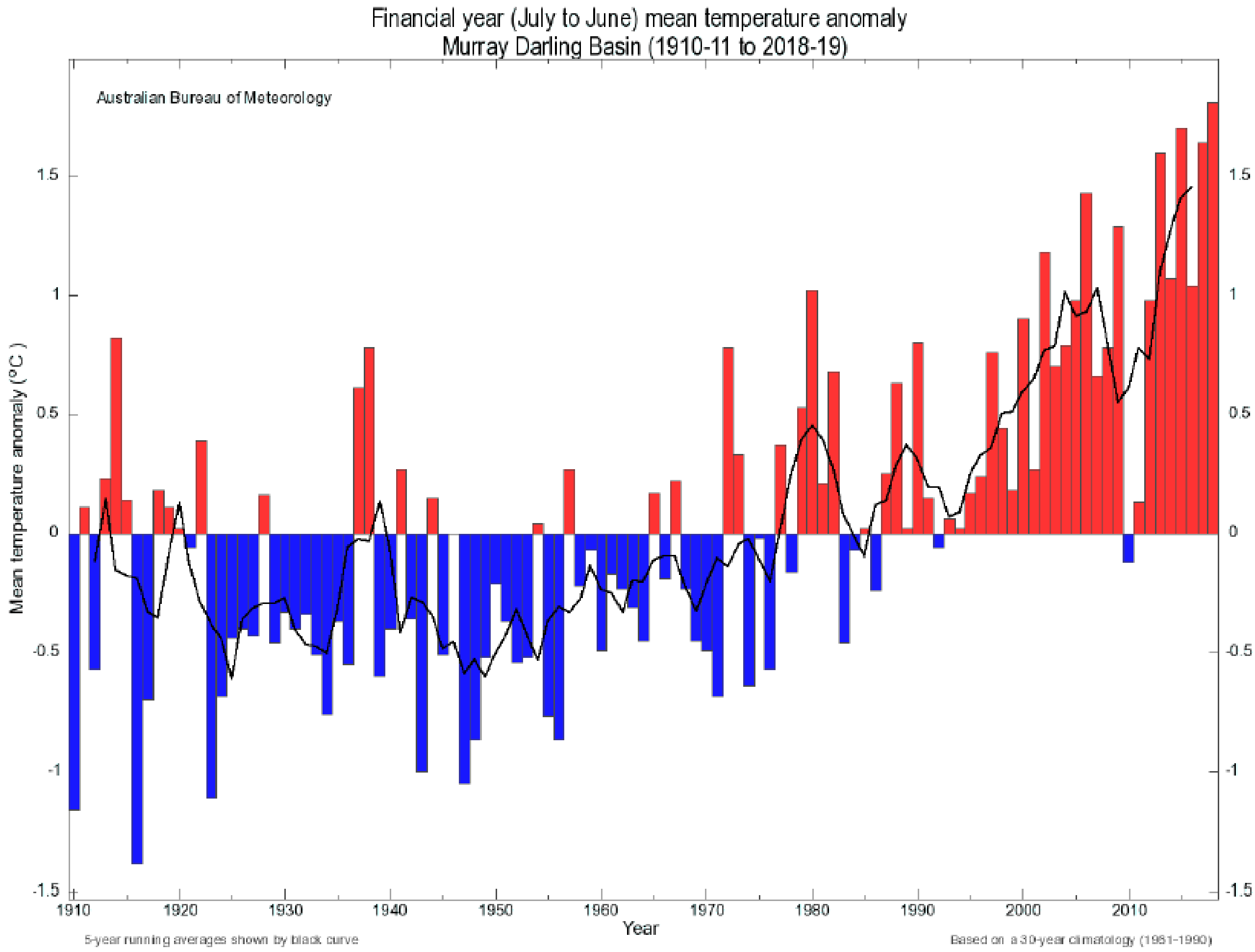
Figure 2.1 Map of the Murray-Darling Basin

Source: MDBA (2016a)

The MDB is comprised of twenty-two catchments and river valleys; nine in the northern part of the basin and thirteen in the southern part. The MDB is Australia's largest and most complex river system, with the River Murray the most important water source for the southern, and the Darling River for the northern part of the Basin. The Basin's northern section is subtropical, but the southern reaches are mainly temperate, with marked variability in temperature, climate and rainfall. Figure 2.2 and Figure 2.3 shows the mean temperature anomaly[6] and the rainfall anomaly for the financial years (water years) 1900/01-2018/19 in the Basin.

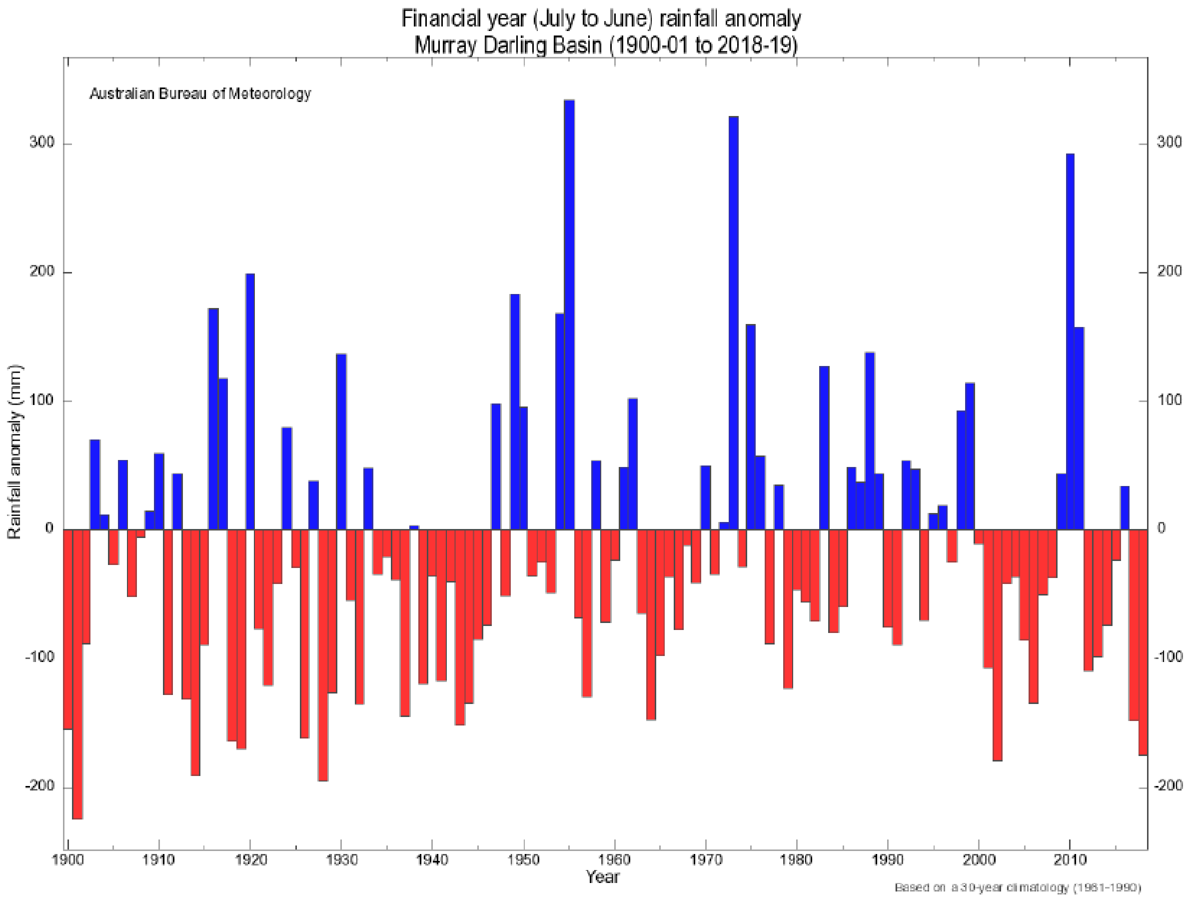
[6] A mean anomaly shows the difference of a yearly mean (temperature or rainfall) and the long-term mean of the whole data period.

Figure 2.2 MDB historic mean temperature anomaly and five year moving average from 1900/01-2018/19



Source: Adapted from BOM (2020b)

Figure 2.3 MDB historic mean rainfall anomaly from 1900/01-2018/19



Source: Adapted from BOM (2020b)

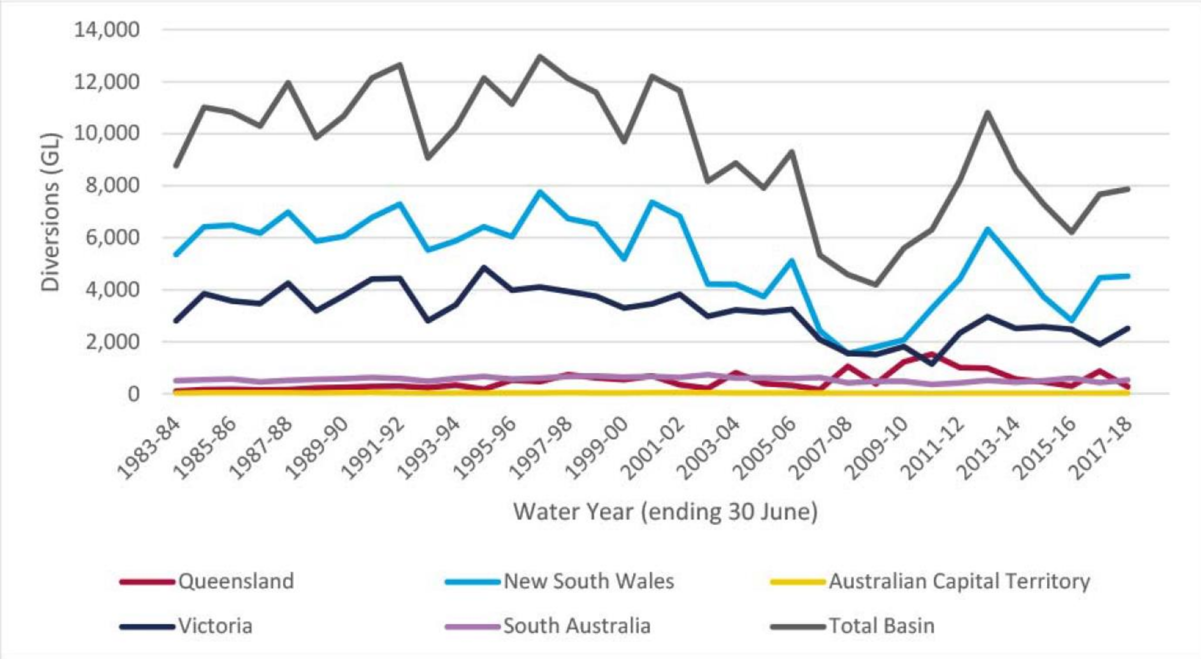
Rainfall in the eastern part of the MDB can be as high as 2,100 mm, whereas the western side is hotter and drier, only receiving mean annual rainfall of less than 300 mm (BOM 2019b). With an annual average rainfall of 470 mm throughout the whole basin and 94% of rainfall being evapotranspired by plants, 86% of the basin contributes no water to river runoff, except in times of flood (MDBA 2018).

Large-scale climatic drivers, including the El Nino – La Nina Southern Oscillation, the Indian Ocean Dipole and the Southern Annular Mode (Neave et al. 2015) contribute to and exacerbate rainfall variability. These climatic phenomena drive large annual and decadal changes in the MDB's climate, with droughts and bushfires in south-eastern Australia largely a result of the El Nino- La Nina Southern Oscillation (Baines 1998). To deal with this variability, an extensive network of irrigation infrastructure and water storages have been established; able to store a maximum of 22,746 gigalitres[7] (GL). Storage capacity in the nMDB is only around 32% of the sMDB's capacity, which has a storage capacity of 16,296GL. The most important storages in the sMDB are the upstream storages of Hume and Dartmouth dam in the east, with capacities of 3,005GL and 3,856GL respectively. Although smaller, Lake Victoria (677 GL) and the Menindee Lakes system (1,731GL) in the west are important for managing water supply to SA (MDBA 2020a).

[7] 1 GL = 1 billion litres

The MDB's water resources are diverted for a variety of uses, such as irrigation, industrial, municipal and potable water supply, but irrigated agriculture accounts for the lion's share of water extraction— 69% of total MDB diversions in 2017-18[8] (ABS 2019c; BOM 2019b). The MDB also has substantial groundwater resources, with groundwater extraction of 1,412 GL/y on average from 2002/03 to 2017/18 (MDBA 2019j). Water extraction in the MDB is governed by a system of proportional water extraction rights called water entitlements (see Chapter 3), and therefore corresponds to the variability of overall water availability, as illustrated in Figure 2.4. The period of the Millennium Drought (2001/02-2009/10) and the current drought since 2013/14 are clearly visible in the declining volume of water diversions.

Figure 2.4 MDB diversions from 1983/84 - 2017/18



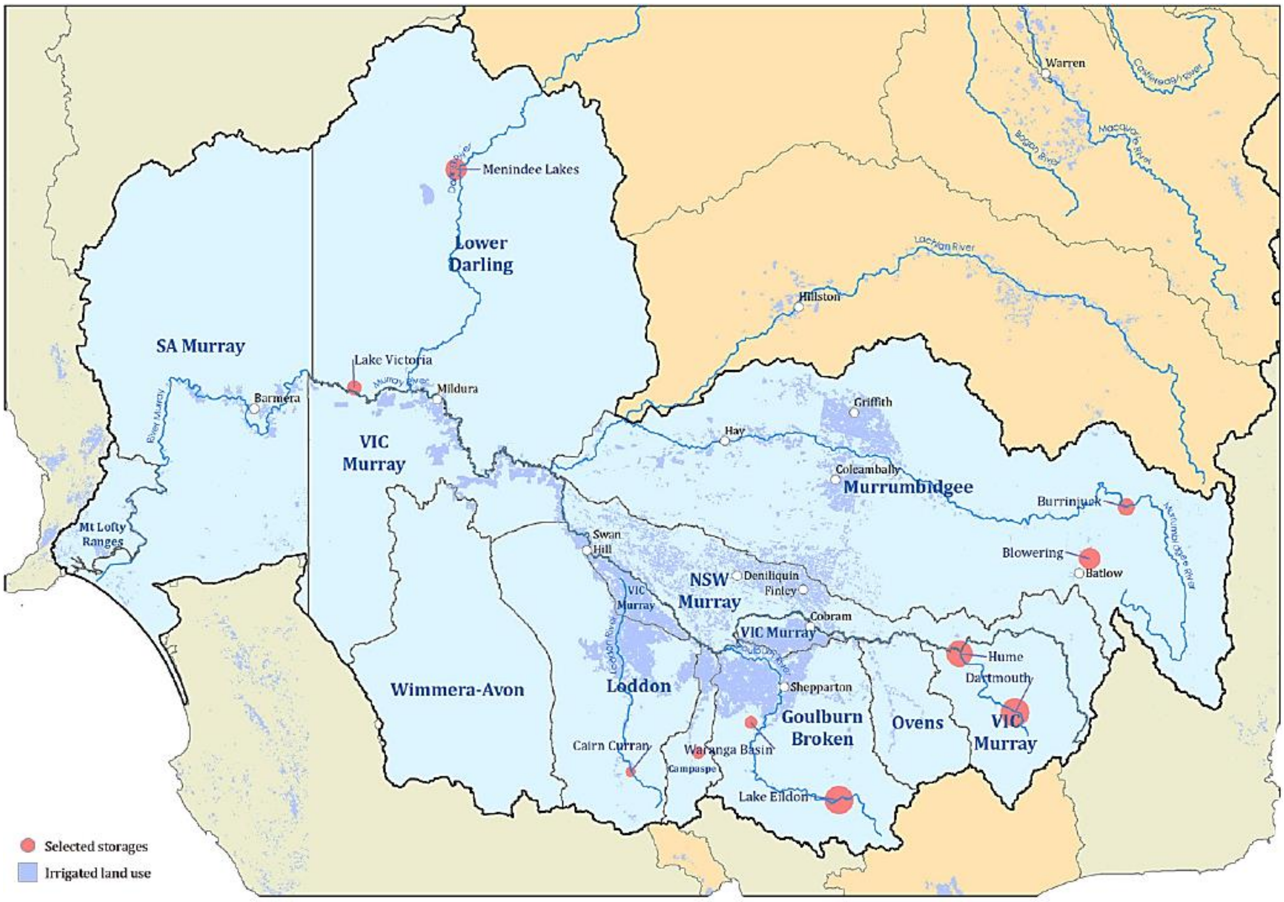
Source: MDBA (2019j, p. 97)

2.1.2 The southern Murray-Darling Basin (sMDB)

The sMDB covers parts of SA, VIC and NSW, and the whole of the ACT. Figure 2.5 shows the sMDB and its catchments, including its significant water storages. The sMDB is a highly regulated and interconnected river system, comprising the majority of the MDB's irrigated farms and a number of its significant irrigation districts (ABARES 2014).

[8] Calculated by dividing 7,065,319 ML irrigation water use (ABS 2019c) by the sum of all diversions, 10,305,260 ML, in the MDB in 2017/18 (BOM 2019b).

Figure 2.5 The sMDB and its significant storages



<u>Source:</u> ABARES (2018, p. 16)

Due to its long history of irrigation, beginning in 1887 with Australia's oldest irrigation trust, established by the Chaffey brothers, and subsequent extensive water resource development, the sMDB has long suffered from water overallocation and environmental degradation (Connell 2007; Kingsford 2000; Quiggin 2001). Together with a series of droughts, these factors have made the region the focal point of water policy reform and government regulation (Grafton and Jiang 2009; Quiggin 2012; Thampapillai 2009).

The sMDB has a temperate climate, with most rainfall occurring in the south-eastern part, and becoming progressively drier and hotter in the west, particularly in SA. Irrigation supports a wide range of crops in the sMDB, ranging from cotton and rice, vegetables and irrigated pasture, dairying, citrus, grapes, stone fruit and nuts. The highly variable climate, combined with water storage capacity, the diversity of agricultural production and corresponding GVIAP per crop, provides the basic foundation making water trading possible, leading to the development of a highly dynamic water market in the sMDB (ABARES 2017). However, the sMDB and the MDB at large is expected to experience the adverse effects of climate change.

2.1.3 The MDB and climate change

The localised impacts of climate change are highly uncertain and heterogeneous, making predictions about temperature or rainfall patterns challenging. Yet, many agricultural regions are expected to be adversely affected, both through higher temperatures and less rainfall, but also by an increased incidence of extreme events, such as floods and droughts (IPCC 2019).

Climate change is likely to manifest in decreased water quality and quantity in the MDB (Pittock and Finlayson 2011; Quiggin et al. 2010). Despite mounting global evidence of climate change (IPCC 2014, 2019), available predictions and forecasts for the MDB are now somewhat dated, following the withdrawal of research funding by the Australian government in 2017 (Karp 2020). Surface water availability is expected to decrease by a median amount of 11% by 2030, under a median climate change scenario (CSIRO 2012). This will likely lead to increased salinity (Nielsen and Brock 2009), deterioration of water quality (e.g. algae blooms) (Davis and Koop 2006), and more variable supply (Connor et al. 2012). Although the highest mean reductions of water availability are expected in the sMDB (CSIRO 2012), irrigated agriculture might be able to tolerate a median climate change scenario as agricultural profits would only decrease by a small amount (Jiang and Grafton 2012). However, an extremely dry climate in the future would substantially reduce profits.

Projections also suggest droughts will become more frequent and extreme (Chiew et al. 2011), with the Millennium Drought (2001/2-2009/10) providing an example of potential future drought conditions and necessary adaptations (Grafton et al. 2014a). Table 2.1 shows the CSIRO's (2008) projected rainfall and runoff changes for future climate change scenarios.

Table 2.1 Annual rainfall and runoff averaged across historic, recent and future MDB climate scenarios

Climate Scenario	**Rainfall (mm)**	**Rainfall change (% of historic)**	**Runoff (mm)**	**Runoff change (% of historic)**
Historic (1895-2006)	457	0	27.3	0
Recent (1997 -2006)	440	-4	21.7	-21
Future – median (2030)	444	-3	24.7	-9
Future – extreme dry (2030)	396	-13	18.3	-33
Future – extreme wet (2030)	495	8	31.7	16

Source: CSIRO (2008, p. 21)

More recent climate change projections for the Murray Valley demonstrate that the sMDB will become warmer and drier by 2030 (Table 2.2), while also experiencing more frequent and prolonged droughts, under all models of standard greenhouse gas emission pathways (Timbal et al. 2015).

Table 2.2 Projected mean annual maximum temperature and mean annual rainfall in the Murray catchment by 2030

Greenhouse gas emission concentration pathway*	Mean annual maximum temperature in 2030 (°C)	Change to baseline (%)	Mean annual rainfall in 2030 (mm)	Change to baseline (%)
Baseline concentration (1995)	21.3	0	549	0
Medium concentration pathway (RCP 4.5)	22.6	+6	472	-14%
High concentration pathway (RCP 8.5)	22.5	+6	488	-11%

* For definitions of greenhouse gas emission pathways see (IPCC 2014)
Source: Timbal et al. (2015, p. 34)

These reductions in water availability will not homogeneously affect irrigation and environmental water users; their impact rather depends on the location and the relative reliability of the stakeholders' water entitlements. However, the adverse impacts on the environment will likely increase with a drier future, given that it is already disproportionately disadvantaged in drought periods, due to the nature of its water entitlements and the presence of environmental and ecosystem thresholds and tipping points (Pittock 2013).

Although current water regulation in form of the *Basin Plan 2012* (see section 2.2.5) offers the potential to include climate change analysis and associated water resources impacts into allocative decision-making frameworks, this is not fully realised (Cosier et al. 2017; Pittock et al. 2015). Climate change in the *Basin Plan* ought to be addressed on a catchment by catchment basis through the states' water resource plans, determining the relative allocation of water to environmental and consumptive uses, and their periodic 10-year reviews (MDBA 2019g). This 10-year review approach is widely seen as inadequate: 1) to address ecosystem thresholds and tipping points; 2) to incorporate new climate science in a timely manner; and 3) is criticised for condensing an environmentally sustainable level of water extraction under changing climatic conditions for every catchment into one static number: the sustainable diversion limit (Grafton 2019; Hart 2016; Pittock et al. 2015; Walker 2019). Failure to adequately incorporate climate change presents material risks to environmental water recovery and associated outcomes, as required by the *Basin Plan* (Kirby et al. 2014b). Maintaining and restoring the health of the Lower Lakes and Murray mouth, important RAMSAR listed wetlands assets, will be particularly challenging (Pittock and Finlayson 2013; Settre and Wheeler 2017).

Climate change also poses risks for consumptive water users. With rural communities running out of drinking water in the current drought (Vincent 2018), and a series of mass fish kill events in 2018/19, the consequences of the interplay of climate change and water sharing arrangements skewed towards irrigated water extraction in the MDB are being dramatically displayed (AAS 2019; Natural Resources Commission 2019).

2.2 Water policy and reform history in the MDB

Given the MDB's variable climate and the fact it is a river system crossing state boundaries, there is a long history of water policy and water sharing agreements for the Basin. This section outlines the historic water reform process in the MDB, beginning with Australian Federation, but its main focus is on policies from the 1990s onwards.

2.2.1 From Federation to the 'Cap'

With the colonisation of Australia, including the MDB, water sharing and management in the Basin followed the riparian rights system, called the riparian doctrine, based on British common law (Guest 2016). The legal decision to regard Australia as *terra nullius* (land belonging to no one) meant that Aboriginal water rights and management practices were not recognised, despite Aboriginal peoples having used the Basin's water resources for thousands of years. Despite the Mabo ruling on Native Title, providing a pathway for Aboriginal ownership of customary waters, the question of Native Title over MDB water resources has not yet been settled (Jackson 2011; Marshall 2016; O'Bryan 2016).

The riparian doctrine allows landholders owning land adjacent to a stream to extract water, given this does not interfere with the rights of other riparian rights holders. While working well in the British context of abundant and fairly reliable rainfall, this system did not translate well to variable and drought-prone Australia, where rights holders had incentives to maximise water use when water was available, often to the detriment of downstream users (Guest 2016). With litigation as the only pathway to rectify this, there was real danger of the court system being overwhelmed with cases about water sharing and extraction. To mitigate this problem, the *Irrigation Act* was enacted in 1886, placing water firmly within state control, managed by state irrigation trusts, rather than the courts (Crase and Cooper 2015).

Water sharing in the River Murray was a major obstacle to Federation in 1901 and the forming of an Australian constitution. South Australia emphasized a need to vest water in federal control to protect the interests of downstream water users, and to guarantee a minimum flow at all times to allow for river navigation (Wheeler 2014). New South Wales (NSW) and Victoria were not willing to accept such a provision, preferring state-based control, with NSW disagreeing in principle over reducing states' powers, and Victoria aiming to maintain sovereignty over issuing generous extraction rights to support its important irrigation sectors. Ultimately, NSW and Victoria prevailed, with the Australian Constitution under section 100 prohibiting the Commonwealth's right to interfere with states' water management (Guest 2016).

Extensive irrigation development in Victoria and drought in the 1910s galvanised the need for a water sharing framework between the states. With negotiations starting in 1902, the states ultimately signed the *River Murray Waters Agreement* in 1914, with South Australia receiving a guaranteed water entitlement of 1,547 GL a year, equally provided for by NSW and Victoria, in exchange for South Australia and the Commonwealth contributing funds to the construction of locks, weirs and upstream storages (Guest 2016; Quiggin 2001; Wheeler 2014).

The *River Murray Waters Agreement* started a prolonged period of extensive water and irrigation infrastructure development lasting well into the 1970s, ultimately leading to the present storage and irrigation district configuration. The period from 1914-1970s saw the construction of a number of weirs and locks along the Murray (1922-1939), the Hume Dam (1934), the barrages at Goolwa (1940), the Dartmouth Dam (1979) and the Snowy Mountains Scheme (1974). The South Australian entitlement was increased to 1,850 GL in 1970, in order to convince South Australia (SA) to defer building a dam in Chowilla and agree instead to the construction of the Dartmouth Dam (Guest 2016).

One result of these activities were water quality problems in the river, particularly salinity, prompting the Commonwealth and the states to revisit the 1914 *River Murray Waters Agreement*. This led to the *Murray-Darling Basin Agreement* 1987, which widened the scope of the 1914 agreement to include the whole MDB, making provision for Queensland to join. The agreement established a new organisation—the Murray-Darling Basin Commission—tasked with improving water quality, salinity management, responding to land degradation, and equitable management of water resources between the states (Guest 2016; Quiggin 2001).

MDB water extraction more than tripled between 1944 to 1994, mainly driven by irrigation development in NSW, leading to the largest ever recorded blue-green algae bloom in the Darling River in 1992. This expanded the focus from salinity management to environmental health and the proper balance between irrigation and the environment. Ultimately, a cap on extractions (the 'Cap') at 1993-94 levels of extraction (except Queensland, set at 1999-2000 levels and South Australia where the Cap was set at an average use of 90% of entitlements) was established in 1995 (AAS 2019). The *Murray-Darling Basin Agreement* replaced the *River Murray Waters Agreement* as the document governing water sharing between the states in 1992, with Queensland and the Australian Capital Territory officially joining in 1992 and 1998, respectively (Guest 2016; Quiggin 2001).

2.2.2 The Council of Australian Governments reforms and the 'Cap' on extraction

Established in 1993, the Council of Australian Governments (COAG) has played a major role in MDB water reform. A product of the time of liberalisation and market based instruments, the COAG agreed to a water policy framework facilitating the separation of water and land ownership (COAG 1994). With water entitlements recognized as tradeable property rights, the objective was to achieve an efficient allocation of the common-pool resource water via a private market, in the spirit of Coase (1960). This included formally recognising the environment as a water user (Loch et al. 2011).

Environmental degradation and over-allocation of the MDB was apparent in the early 1990s, leading to ongoing concern about the balance of water use between irrigation and the environment. The COAG reforms included an audit of MDB water resources by the Murray-Darling Basin Commission, which found that extractions had increased significantly since 1988 and would continue to increase unsustainably (MDBMC 1995). This led to a cap of water extraction at 1993/94 levels; first introduced temporarily in 1995, but then made permanent in 1997 (Connell 2007). The Cap's primary objectives were to: 1) maintain and improve existing MDB flow regimes to protect and enhance the environment; and 2) achieve sustainable consumptive use by managing and developing water resources to meet ecological, economic and social needs (Guest 2016).

However, the Cap still prioritised existing consumptive extraction over environmental uses (Loch et al. 2011) and even led to a short-term increase in water extractions as irrigators increased their use of groundwater, which was not covered by the Cap, and activated previously under- and unused entitlements, called dozer and sleeper licences (Bjornlund 2007). Additionally, cap monitoring in unregulated systems was challenging due to a lack of gauges (Lee and Ancev 2009), and irrigators made increased use of farm dams to intercept run-off, which further reduced water availability in the MDB (Kendall 2013).

Cap implementation remained slow and challenging for both technical and political reasons. The COAG reforms required implementation by the states and the ACT, but they were given complete autonomy on how to do this. This resulted in a varying level of water extractions and management impacts across the states (Bjornlund and McKay 2002). The Cap also faced strong political opposition, particularly from the National Party and irrigation groups. While SA's diversions were within the Cap, NSW and Victoria exceeded it in some catchments, with the then status quo of Cap non-compliance in some catchments very resistant to change, particularly in NSW. Queensland, while supporting the Cap in principle, argued that, given its late participation in the *Murray-Darling Basin Agreement*, low levels of MDB water resource development and extraction, and no statutory mechanisms to restrict overland flow diversions, it could not fully implement the Cap. Consequently, at the time of the five year review of Cap compliance, NSW was still not compliant in three catchments, while Queensland and the ACT had yet to establish their Cap levels (MDBC 2000). Ultimately, Queensland only fully adopted the Cap in 2010 (Guest 2016).

Despite its initial negative effect on water extractions and return flows[9], and its implementation challenges, the Cap did attempt to commit all states to ending unfettered irrigation development and also established environmental concerns as a core consideration for water management in the MDB (Wheeler 2014). Setting the Cap at historic extraction levels might not have been the best way to achieve substantial environmental outcomes, but it was necessary to overcome political opposition and to establish collaboration between the states (Guest 2016). Finally, although the Cap did not immediately provide sustainable use of water resources in the MDB, environmental degradation would have been much worse without this crucial first step (MDBC 2000).

2.2.3 The National Water Initiative 2004

Given the shortcomings of the Cap, increasing water scarcity and water quality challenges, the *National Water Initiative* (NWI), was legislated to be the instigator of a second wave of water reforms (COAG 2004a). This included a commitment to rebalance water extractions towards environmental objectives in the form of the *Intergovernmental Agreement on Addressing Water over-allocation and Achieving Environmental Objectives in the Murray-Darling Basin* (COAG 2004b).

The NWI introduced a system of water resource management based on bipartisan agreements between the Commonwealth and the states, spelling out federal objectives and state responsibilities and commitments (Foerster 2011). This management system was based on water sharing plans, defining environmental flow requirements and then determining a fixed share of available water for consumptive use, with no initial compensation for reduced water entitlements (Loch et al. 2011).

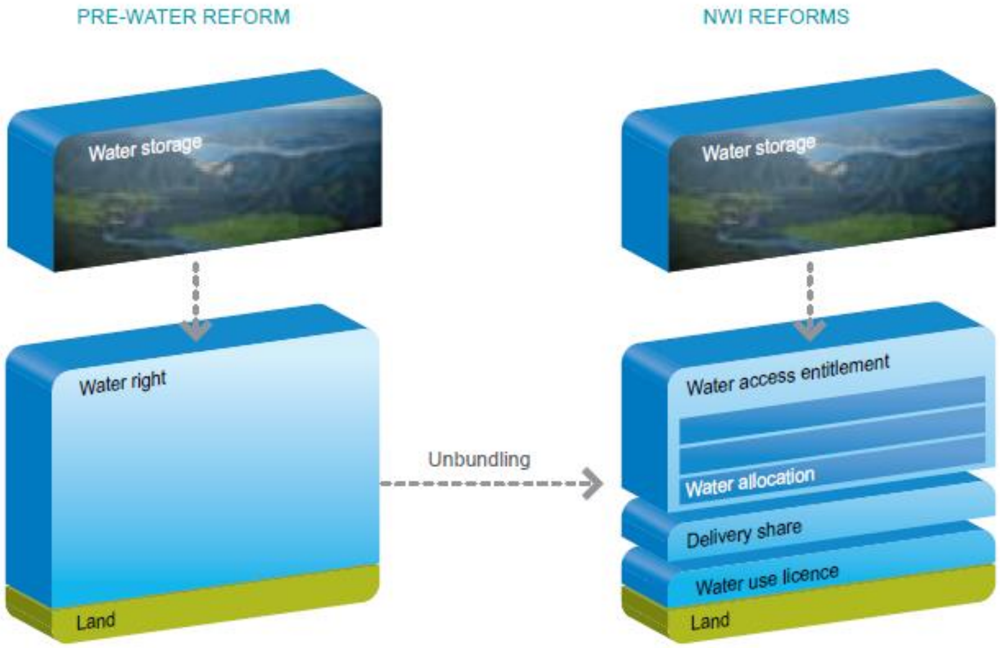
Another important reform under the NWI was the establishment of a common water accounting framework for all Australian water resources, in order to facilitate planning, monitoring, trading, and environmental and farm management (COAG 2004a). This ultimately led to 'General Purpose Water Accounting', which is based on accrual financial accounting methods, consisting of accounts for water assets and water liabilities (Water Accounting Standards Board 2012a). These water accounts are published annually by the Bureau of Meteorology (BOM 2020d).

[9] Return flows are the proportion of water extracted for irrigation which is not consumed and returns through either seepage to groundwater and/or surface runoff to streams. Return flows that are later recovered and reused and become available for stream and river flows are called 'recoverable return flows' (Williams and Grafton 2019).

2.2.3.1 Unbundling

The NWI aimed to remove barriers to water trade by changing the definition of water entitlements; from a volumetric right to a share of a common pool resource. Removal of further trade barriers, such as the unbundling of land and water ownership, were also a key objective, enabling them to be sold separately (Crase et al. 2014). Additionally, other aspects of water ownership were also unbundled into four different rights: 1) a water entitlement, granting the right to extract a share of available water into perpetuity; 2) a water use licence, allowing irrigators to use the water on their land; 3) a water allocation account, tracking water extracted against allocation volume available under an entitlement; and 4) a delivery share, which is an irrigator's right to have water delivered to their property using the infrastructure of their irrigation district (Wheeler 2014). Figure 2.6 gives a graphic representation of unbundling by the NWI.

Figure 2.6 Unbundling of water rights under the NWI



Source: NWC (2011b, p. 83)

Unbundling of water from land was an emotionally and politically charged issue; many irrigators and rural communities feared it would lead to an exodus of water rights from upstream to downstream catchments, particularly in Victoria. Another public concern was the emergence of so-called water barons, investors without landholdings or agricultural production, who would, it was feared, withhold water from irrigators in order to drive up prices (Bjornlund et al. 2011; Loch et al. 2013). As a response, Victoria implemented a suite of trading restrictions, aiming to circumvent the dangers and impacts of these issues. The '4% rule' limited annual water entitlement trading out of an area to 4% of the total entitlements on issue in a given catchment. A '10% rule' was also established, limiting water entitlement ownership by the non-water user group[10] to 10% of entitlements on issue (DELWP 2020b). Although these concerns were ultimately unfounded, and the corresponding trading

[10] The non-user group are water allocation accounts without a water use licence attached (DELWP 2019a).

restrictions removed (see section 2.2.5.3), distrust and suspicion towards non-landholder water ownership has never fully dissipated in rural and irrigation communities.

Additional concerns surrounded potentially negative impacts of water markets on the environment, by changing the location and timing of natural flows (Wheeler et al. 2014a). However, evidence suggests that compared to drought and river regulation (i.e. weirs and locks), the impact of water trading is small, while also not affecting key ecological assets (NWC 2012).

2.2.3.2 The Living Murray

To improve river and environmental health, the NWI sought to address over-allocation of MDB water resources by an initiative to reallocate water to the environment - *The Living Murray*. The program aimed to recover consumptive water from irrigation using two approaches: 1) buying water from irrigators through the market; and 2) by increasing water use efficiency through infrastructure. A budget of AUD$500 million was allocated to buy water entitlements from irrigators to contribute to additional environmental flows (around 500 GL per year) for six environmental 'icon sites' on the Murray until 2009. An additional AUD$150 million was earmarked to construct the extra water delivery infrastructure to access the environmental assets. Funding to *The Living Murray* was increased in 2009 to AUD$700 million for entitlement purchases and AUD$270 million for infrastructure expenditure (Lee and Ancev 2009; MDBA 2011b).

The states were tasked with both the details of implementing the NWI reforms, and defining and recovering an adequate water volume to provide environmental flows. However, due to a lack of coordination and tensions between the states (Connell and Grafton 2011), it became evident that individual states were not able to manage and improve the material and ongoing environmental issues plaguing the MDB. At the time a multi-year deep drought (later to be known as the Millennium Drought 2001/2-2009/10), and record low inflows in 2006, pushed the NWI objectives to the brink of collapse and the Commonwealth decided to step in, in coordination with the states, to progress what had been incompletely realized objectives through a new policy; the *Water Act* 2007 (Loch et al. 2011).

2.2.4 The Water Act 2007

The *Water Act* aimed to achieve extensive legislative, regulatory, and stakeholder reform through coordinated efforts between the Commonwealth and the states and was passed into law in 2007. As many-a-time previously, drought proved to be a catalyst for political will and enabled the implementation of new water policy tools, amongst them buying water for the environment from willing sellers, and creating the Murray-Darling Basin Authority (MDBA), a new administrative entity replacing the Murray-Darling Basin Commission (Wheeler 2014). Water recovered for the environment was to be managed by the Commonwealth Environmental Water Holder (CEWH), supported by a new statutory body, the Commonwealth Environmental Water Office (CEWO). Furthermore, the *Water Act* allows the Commonwealth water minister to make water market rules, on advice from the Australian Competition & Consumer Commission (ACCC), which is tasked with monitoring market behaviour and water charges (ACCC 2011). Furthermore, the Bureau of Meteorology was made the custodian and collector of water resource information (Parliament of Australia

2007). Carry-over was also introduced, a mechanism by which irrigators are able to store unused water allocations in system storages for the next year (Grafton and Wheeler 2018).

The MDBA was charged to develop a strategic plan facilitating sustainable water management and to overcome legal barriers to integrated management of the MDB's water resources by the states. Sustainable water management was to be achieved by the MDBA producing a 10-year *Basin Plan*, specifying a "sustainable limit of take" from the basin, in the form of one number— the sustainable diversion limit (SDL) (Kendall 2013).

The *Water Act* is a complicated legal balancing act; the Commonwealth is forbidden from interfering with states' water management under the Constitution (see section 2.2.1), yet the *Water Act* does just that. The Commonwealth justifies its legal standing by its jurisdiction and commitments in matters of foreign policy (the external affairs power), by arguing that it is a signatory to the RAMSAR convention, and the MDB contains a number of RAMSAR-listed wetlands. However, conferral of power by the states was still necessary (Walker 2019). Public opinion strongly supported action on water reform, galvanised by the drought and related extensive environmental degradation. The Commonwealth also promised substantial financial resources to support water efficiency improvements and environmental water recovery; initially AUD$10 billion over 10 years (Grafton and Wheeler 2018; Guest 2016). This ultimately brought the states to the table.

2.2.4.1 Water for the Future

The AUD$10 billion over 10 years promised to the states under the *Water Act* became part of the *Water for the Future* (WFF) program, which was expanded to AUD$12.9 billion in 2008 (Parliament of Australia 2010). The WFF employed market-based instruments such as entitlement buybacks, and infrastructure upgrades, to achieve environmental watering goals and made explicit mention of climate change impacts and adaptation strategies. Irrigators received large subsidies to modernise their irrigation infrastructure, with AUD$5.8 billion provided for projects increasing on-farm water use efficiency (DEWHA 2010). An additional AUD$3.1 billion was used to buy water entitlements from willing sellers via the water market (Grafton and Wheeler 2018).

The buyback part of the WFF was labelled *Restoring the Balance* in the MDB (*RtB*). It aimed to recover entitlements from willing sellers, mostly through a series of competitive tenders from 2008 onwards (Wheeler and Cheesman 2013). Water allocations received from the purchased entitlements are used to water key environmental assets like significant wetlands and floodplains to improve the MDB's environmental health. Under the *Basin Plan*, the *RtB* became one of the mechanisms to recover water for the environment (see section 2.2.5).

Buybacks were successful in recovering water for relatively low costs (compared to infrastructure programs), not least due to the competitive auction mechanism employed (Tisdell 2011). While water was only purchased through completely voluntary transactions from willing sellers, buyback was met with hostility in rural communities, by parts of the media and some politicians, many of whom claimed that, rather than being willing sellers, financial difficulties faced by irrigators during and after the drought 'forced' them to sell entitlements. Buybacks were routinely blamed for loss of employment and farm enterprises resulting from the impact of drought (Bjornlund et al. 2011; Wittwer 2011). Despite negative perceptions, buybacks enabled desperate and highly indebted sellers to receive good income from high entitlement prices at a time when production income was often low, and they allowed for a rebalancing of farm finances or personal retirement (Wheeler et al. 2014b, 2014c). Wheeler and Cheesman (2013) found that the majority of irrigators participating in buybacks did so to reduce debt, restructure the farm or retire from agriculture. Many sold only a portion of their water holdings, or sold surplus water entitlements, and remained in production. Despite a wealth of scientific economic evidence, grievances and hostility towards buyback remains strong in many rural communities and irrigation industries.

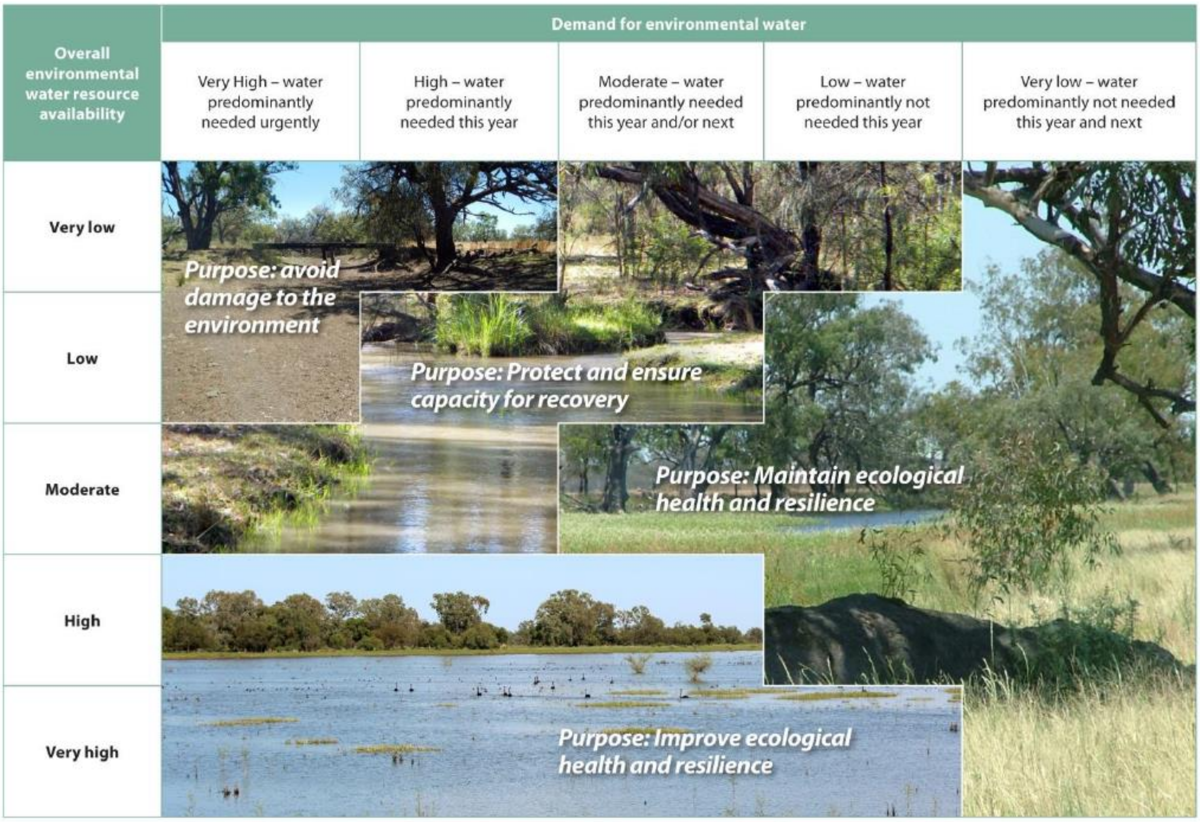
2.2.4.2 The Commonwealth Environmental Water Holder

The *Water Act* legislated the Commonwealth Environmental Water Holder (CEWH) to be the custodian of water recovered under the WFF program. The CEWH, Jody Swirepik at the time of writing, has complete water trading and management decision powers (CEWH 2018). She is supported by a statutory authority, the Commonwealth Environmental Water Office (CEWO), which legally holds the water portfolio, executes water trading decisions and administers environmental watering. Unlike water recovered under *The Living Murray*, which is held jointly by the MDBA and the states, water stemming from recovery under the WFF is managed by an organisation solely dedicated to maximising environmental outcomes and which is designed to be an independent and active participant in the water market. The formation of the CEWH thus represents the advent of a completely new type of water market actor; Environmental Water Holders (EWH).[11] The CEWH/CEWO fund their management activities, but not staff, through the 'Environmental Water Holdings Special Account' (Parliament of Australia 2018). The special account ensures that the CEWH does not need to sell environmental water to fund CEWO's and their own expenses, and it covers statutory fees to state water authorities, the management of credits/debits resulting from the sale/purchase of environmental water, and the costs of monitoring and evaluating environmental watering outcomes.

Environmental watering activities are governed by the *Framework for Determining Commonwealth Environmental Water Use* (CEWO 2013), the *Basin-wide environmental watering strategy* (MDBA 2014a) and annual environmental watering priorities (MDBA 2019d). Figure 2.7 illustrates Commonwealth environmental watering objectives in relation to water availability. Environmental watering is not done by the CEWO directly, but rather delegated to third parties, such as state governments or environmental NGOs, who will receive a transfer of necessary allocation water and sometimes funds from the CEWH to cover operations (Parliament of Australia 2018).

[11] Environmental water holders can be public or private. Victoria is the only other state which has a dedicated statutory body to manage its environmental water, the Victorian Environmental Water Holder founded in 2010 (O'Donnell 2012). The other states manage their water as part of other departments: South Australia's Department of Environment and Water, Queensland's Department of Natural Resources, Mines and Energy, and New South Wales' Department of Planning, Industry and Environment. An example of a private environmental water holder is the Murray-Darling Basin Balanced Water Fund (Carr et al. 2016).

Figure 2.7 Purpose of Commonwealth environmental water management



Source: CEWO (2019, p. 10)

The CEWH is independent insofar as they are not subject to direction from Commonwealth ministers or departmental secretaries. The CEWO has no decision-making powers. However, ministers can still direct the CEWH to make Commonwealth environmental water available, or make legally binding operating rules in relation to how the CEWH deals with water allocations and entitlements (Parliament of Australia 2018). This arguably makes the CEWH less independent than other public environmental water holders which have better safeguards from political interference (O'Donnell 2013).

At 31st December 2019, the CEWH holds 2,103.8GL of long-term annual average yield (LTAAY)[12] of entitlements (DAWE 2020b), recovered mainly through *RtB* and initiatives under the *Basin Plan* (see section 2.2.5).

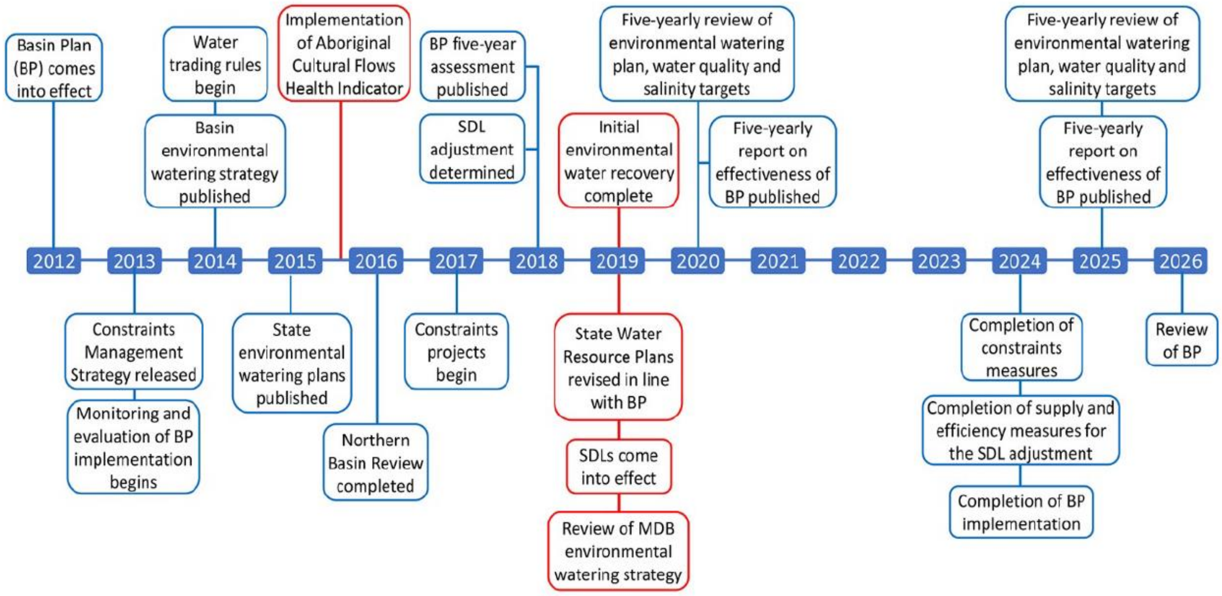
2.2.5 The Basin Plan 2012

As mandated by the *Water Act*, the MDBA engaged in a process of creating the *Basin Plan* which would determine the balance between environmental water use and sustainable human consumption via the 'sustainable diversion limit' (SDL), which is defined as the maximum amount of consumptive water extraction. This was to be determined by "the best available science" (*Water Act*, para 21(4)(b)). Every state is supposed to provide a water resource plan for every catchment by 2019, determining a local SDL and therefore the balance between water consumption and the environment. These water resource plans need to be approved by

[12] The long-term annual average volume of water permitted to be taken for consumptive use under a water access entitlement. Currently all LTAAY figures are calculated using the long-term diversion limit equivalent factors, with these factors to be accredited in finalised state water resource plans (Cheesman and Wheeler 2012).

the MDBA. With all water resource plans approved, these new SDLs would ultimately replace the 1993/94 Cap (Kendall 2013). Figure 2.8 shows a timeline of Basin Plan implementation.

Figure 2.8 Basin Plan implementation timeline; red lines indicate delayed or partly implemented activities



Source: Grafton et al. (2020b, p. 5)

However, the development and implementation phase of the Basin Plan was highly contentious almost from the outset. The MDBA gave strong weighting to the requirement of “best available science”, and quietly compiled models and simulations to inform a first draft of the plan. This was done largely in-house and in collaboration with experts, but without substantial engagement with, or information for, the community (Walker 2019). In 2010, the MDBA released the *Guide to the proposed Basin Plan* (MDBA 2011a), which stated that 3,000-7,600GL of water would need to be recovered from consumptive use to achieve a sustainable balance with the environment. The document was viewed by irrigation communities with such a degree of hostility that copies of the *Guide* were publicly burned by farmers (Bowmer 2014; Quiggin 2012). Recovering these amounts of water was perceived as unattainable without major negative impacts for communities and the irrigation sector; and the *Guide* was seen as failing to balance social and environmental needs (Loch et al. 2014a). Another aspect of contention was the lack of community consultation while the *Guide* was being developed (Crase 2011).

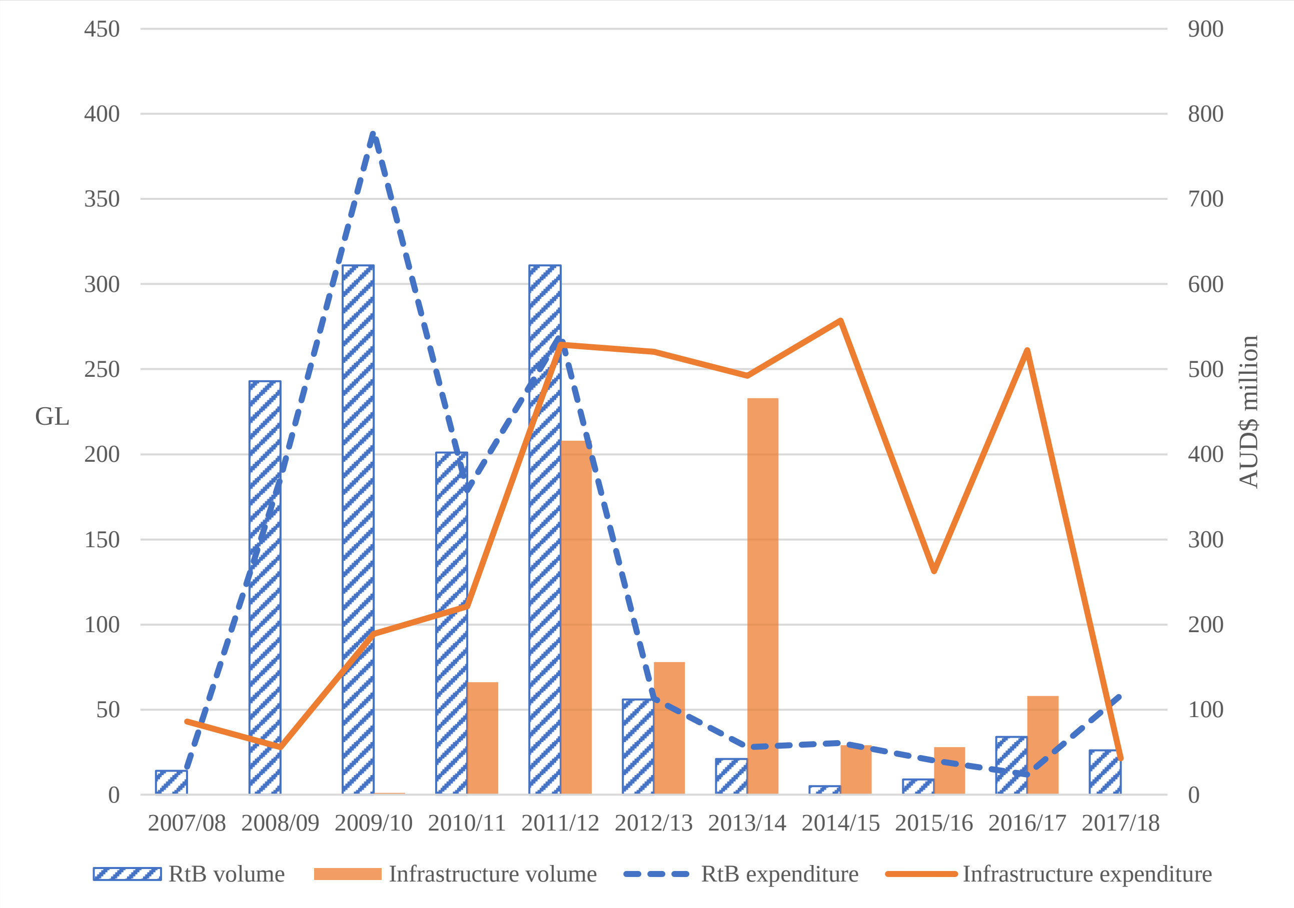
The public burning of the *Guide* and its hostile reception by stakeholders was described as a traumatic experience for the staff of the MDBA. It subsequently adopted the notion of a ‘triple bottom line’, maximising environmental outcomes so long as they did not adversely impact economic and social outcomes. Many have described this as an essential paradigm shift within the MDBA, away from an ‘environment first’ to an in practice ‘irrigation first’ approach in setting the SDL (Walker 2019). The *Basin Plan* was ultimately passed into law in 2012, mandating an SDL of 10,873GL/y, and requiring 3,200GL/y to be recovered for the environment by 1st July 2019. These 3,200GL/y consisted of an initial recovery target of 2,750GL/y, with an additional 450GL/y to be achieved via supply infrastructure efficiency upgrades (Parliament of Australia 2012).

However, this recovery amount has not been achieved so far for a number of reasons. At the time of writing: 1) not all water resource plans have been completed and approved by the MDBA (MDBA 2019e), with NSW refusing to finalise the task in the on-going drought (Davies 2019a); 2) river flows may have decreased by 700GL/y (Williams and Grafton 2019) because return flows may have reduced, and previously underutilised existing water entitlements are fully used (Wheeler et al. 2014c); 3) groundwater extractions have increased, by around 400GL/y between 2012/13-2017/18 (MDBA 2019a); 4) increased interception and capture of flood or overland flow water with farm dams and levees in the nMDB (AAS 2019; Slattery et al. 2019); 5) incomplete or inadequate monitoring, compliance and water metering enabling unlawful extraction of water (Matthews 2017); 6) in the wake of the 'Northern Basin Review', environmental water to be recovered in the nMBD was reduced by 70GL/y (MDBA 2016b); and, finally, 7) the SDL adjustment mechanism, allowing states to reduce environmental water by 605GL/y if equivalent outcomes can be achieved through infrastructure (Grafton et al. 2020b). This ultimately reduced the overall amount of environmental water recovery to 2,075GL/y (Grafton 2019).

2.2.5.1 Restoring the Balance in the MDB

The initial volume of 3,200GL/y of environmental water recovery was also to be achieved by a mix of water entitlement buyback and infrastructure efficiency upgrades. Water bought back under the *RtB* was repurposed towards achieving the *Basin Plan* recovery targets. Although buybacks are more effective in recovering water and the preferred option by the vast majority of Australia's water economists (Adamson and Loch 2018; Connor et al. 2013; Crase and O'Keefe 2009; Grafton 2010; Grafton and Wheeler 2018; Iftekhar et al. 2013; Lee and Ancev 2009; Loch et al. 2014b; Productivity Commission 2010; Quiggin 2012; Wittwer and Dixon 2013), emphasis increasingly shifted towards water recovery through infrastructure under the *Basin Plan,* in response to community pressure and preferences (Loch et al. 2014a). Figure 2.9 illustrates the shift in environmental water recovered by infrastructure or buyback over time.

Figure 2.9 Commonwealth environmental water recovery and expenditure 2007/8 - 2017/18



Source: Own Figure, adapted from Grafton and Wheeler (2018)

The Commonwealth spent about AUD$6 billion of the initial funding to recover 1,931GL of LTAAY environmental water by 30th September 2017. Of this, AUD$0.72 was spent on *RtB* for every AUD$1 spent on infrastructure. *RtB* water cost an average of $2,026/ML, whereas infrastructure recovery was at least 2.5 times more expensive, at an average cost of $4,970/ML (Grafton and Wheeler 2018), and this relative difference is increasing.

In the early days of the *Guide* and the *Basin Plan*, an additional argument was used against buybacks: stranded assets. A stranded asset is any component of the water delivery system (e.g. meter, off-take wheel, channel diversion box etc.) that reduces in value on the market as compared to its value on a balance sheet because it has become obsolete (or unused) before being fully depreciated by an IIO. The argument was as follows: if an irrigator in an irrigation trust sells all their water to buyback and then quits farming, the irrigation infrastructure connecting their farm is unused, because without water the paddock will not be used. When there is a permanent decrease in the demand for water delivery services the assets of IIO can become unused or underused (or stranded). Other irrigators in the trust subsequently have to shoulder a larger share of operation and maintenance costs as there are fewer people in the network. This is sometimes also called the 'swiss cheese effect' (Loch et al. 2014a). The conviction was that this stranded asset effect would not happen with irrigation infrastructure upgrades because they keep irrigators on the land, rather than them exiting the industry (Productivity Commission 2010).

However, Wheeler and Cheesman (2013) found that 94% of partial entitlement sellers in an irrigation district kept their water delivery rights, while 83% of irrigators who sold all their entitlements still kept their delivery rights. Stranded assets did not seem to be an issue early on because irrigators who chose not to terminate delivery rights did so because they expected to continue farming by buying either allocations or buying entitlements in the future. Another reason was the wish to ensure that their farm could be resold as an irrigation property.

IIO areas now impose termination or exit fees to cover the ongoing costs associated with maintaining the delivery infrastructure and stranded assets. These are a charge imposed on entitlement trade and subsequent loss of a water access entitlement out of an irrigation district or area, typically ten times the annual total network access fees (ACCC 2016).

Given its unpopularity, buyback was capped at a total volume of 1,500GL in 2015 (Parliament of Australia 2015), with recovery efforts thereafter focussing strongly on infrastructure programs from 2013 onwards, and only 'strategic' closed tender purchases followed thereafter. Despite this, fifty-nine percent[13] of the 2103.8GL of LTAAY of water entitlements recovered as of 31st December 2019 has been recovered through the *RtB* program, with the remainder through infrastructure upgrades (DAWE 2020b; Grafton and Wheeler 2018).

2.2.5.2 The Sustainable Rural Water Use and Infrastructure Program, the sustainable diversion limit adjustment mechanism, and strategic purchases

The infrastructure component of environmental water recovery under the *Basin Plan*— the Sustainable Rural Water Use Infrastructure Program (SRWUIP)— investing AUD$5.8 billion, aims to recover water by increasing on-farm irrigation efficiency and the efficiency of off-farm infrastructure (Crase and O'Keefe 2009). This follows the view that leakage and seepage causes water loss, with this loss able to be recovered through more efficient infrastructure (Quiggin 2010). The government subsidises upgrades to on-farm irrigation infrastructure (e.g. furrow to drip irrigation) in return for 50% of the achieved water 'savings' (Grafton and Wheeler 2018). Part of SRWUIP is the 'Environmental Work and Measures Feasibility program', which aims to reduce the amount of water needing to be recovered by increasing the efficiency of environmental watering through additional infrastructure[14] (DAWE 2019b). As per 31st December 2019, 694.2GL have been recovered by the Commonwealth through infrastructure upgrades (DAWE 2020b; Grafton and Wheeler 2018).

Water recovery through infrastructure upgrades faces a range of criticisms in the academic literature, boiling down to nine main arguments: 1) cost-effectiveness; 2) governance and transparency; 3) impacts on return flows; 4) rebound effects trough increased planting area; 5) increased utilisation of water entitlements; 6) groundwater substitution; 7) equity; 8) flood plain harvesting; and 9) reduced resilience through substitution to permanent crops (Wheeler et al. 2020a).

Many studies have demonstrated that water recovery through infrastructure is more expensive than buyback (Adamson and Loch 2018; Productivity Commission 2010; Wittwer and Dixon 2013). One feature of this is the diminishing marginal return of water recovered through more efficiency when irrigation infrastructure is already quite efficient (Adamson and Loch 2018;

[13] 1231 GL of LTAAY recovered by *RtB*, divided by 2103.8GL LTAAY of entitlement holdings at 31st December 2019.
[14] For example, flow regulators, weirs and channels for environmental watering, and low-flow bypasses

Loch et al. 2014b). Transparency of programs has also been problematic, with some projects subject to corruption charges (Victorian Ombudsman 2011).

The third argument centres around the fact that increased irrigation efficiency reduces return flows, as a higher percentage of the water applied on the field is used by crops (Grafton and Wheeler 2018; Perry et al. 2017). These return flows were previously available to the system in form of increased base flows, which are at their core free environmental flows (Williams and Grafton 2019). On a basin scale, water efficiency upgrades can in fact lead to increased water consumption through reduced return flows, changed crop mix and an increased area of agricultural plantings (Adamson and Loch 2018; Grafton et al. 2018; Loch and Adamson 2015). The increase of planted area as a result of irrigation infrastructure subsidies is often referred to as the 'rebound effect' (Loch and Adamson 2015; Wheeler et al. 2020a).

Wheeler et al. (2014c) found that irrigation infrastructure subsidies increase the utilisation of previous un- or underutilised water entitlements and contribute to a substitution of surface and groundwater. This is problematic given that surface and groundwater in the MDB is often interconnected (Quiggin 2010), but regulated and accounted for separately. Criticism also surrounds equity implications of irrigation infrastructure subsidies, as benefits are not evenly spread, but rather large corporate entities have a much higher probability of receiving irrigation subsidies than family farms (Wheeler et al. 2020a). Subsidising infrastructure in the nMDB often means new farm dams to increase flood plain harvesting, in effect diverting water which would have benefitted streams and rivers (Four Corners 2019; Slattery et al. 2019).

More efficient irrigation infrastructure typically requires the use of pumps, increasing electricity costs (Mushtaq et al. 2015), a key contributor to farmers' psychological stress (Wheeler et al. 2018). Infrastructure subsidies also incentivise irrigators to switch to perennial production, which reduces flexibility to adapt to climate change or drought, as plant assets need to be kept alive to stave off catastrophic capital loss (Adamson and Loch 2018; Adamson et al. 2017). This will also lead to a hardening of water market demand, driving up allocation prices during drought (Adamson and Loch 2014; Loch and Adamson 2015).

Prioritising water infrastructure programs over buybacks for water recovery can be seen as a short-term strategy to address political risk and the preferences of vested interests (Grafton and Williams 2019), but may ultimately cause substantial, long-term negative effects, particularly in prolonged drought scenarios and a drier and more variable climatic future driven by climate change.

The 450GL of additional water in the *Basin Plan*, to be recovered by infrastructure efficiency, is part of the sustainable diversion limit adjustment mechanism laid out in the *Water Act* 2007. Relevant infrastructure includes a suite of efficiency, supply and constraint measures endorsed by the Murray-Darling Basin Ministerial Council in 2016, referred to as 'efficiency projects". These are funded to the tune of AUD$1.775 billion by the Commonwealth for 10 years beginning in 2014/15 (DAWE 2019c). However, the timeframe for project completion has been extended from 2019 to 2024 (Adamson and Loch 2014). In 2018, the *Basin Plan Amendment (SDL Adjustment) Instrument 2017* allowed for a further adjustment of 605GL through so-called 'supply measures', which reduce evaporation from storages or enable more effective environmental watering through infrastructure, with the Commonwealth contributing an extra AUD$1.3 billion of funding. Including the adjustments made through the Northern Basin Review (where water recovery was reduced by 70GL), efficiency, and supply projects reduce the amount of water needed to be recovered for the environment from 3,200GL to 2,075GL by 2024 (DAWE 2019c; MDBA 2017c).

The Commonwealth uses not only buybacks and infrastructure investment to recover water, but from 2013 onwards relied on strategic purchases of water. The difference between a buyback under *RtB* and a strategic purchase is that buyback employs a competitive tender process, whereas strategic purchases are directly negotiated between the Commonwealth and the seller. Strategic purchases are claimed to be superior to buyback if the market is thin (e.g. a limited number of sellers), as is the case in northern NSW and southern QLD, and if there is concentration of market power, allowing market participants to manipulate prices (Reeson and Whitten 2015; Tisdell 2011). The Commonwealth uses strategic purchases in cases where a substantial volume of water needs to be recovered in a thin market, but also generally prefers strategic purchases over buybacks as they are seen to have less socio-economic impact and face less community resistance (DAWR 2018). By 16th December 2019, AUD$148,279,090 had been spent on ten strategic purchases between May 2016 to August 2017 (DAWE 2019a), to recover an undisclosed amount of water. Strategic purchases are contentious for a number of reasons: they are seen to not demonstrate value for money, and to suffer from a lack of transparency, both about water volumes recovered and terms and conditions of the sale (Grafton 2019; Slattery and Campbell 2018a, 2018b, 2019, 2020).

2.2.5.3 Basin Plan water trading rules

As part of an ongoing effort to increase market efficiency and functionality, beginning with the NWI, the MDBA implemented new water market trading rules under the *Basin Plan* in 2014 (MDBA 2019f). Although a number of water trading restrictions have already been removed since the *Water Act*, such as the Victorian '10% rule' in 2009, others only fell with the introduction of the *Basin Plan* trading rules, for example the '4% rule' which was removed in 2014 (DELWP 2020b). The new rules require mandatory price reporting for all allocation and entitlement trades in all states. They also mandate no barriers to surface water trade, except when trade is physically constrained, catchments lack connectivity, or where the environment may be harmed (MDBA 2019f). Examples of restrictions attributed to these conditions are the Barmah Choke constraint, the Goulburn-Murray intervalley trade restriction (IVT), and the Murrumbidgee IVT (DPI 2018; MDBA 2010c, 2019c). Similarly, IIOs must not unreasonably restrict water delivery rights trading, and communicate their trading rules and delivery rights conditions transparently under the *Basin Plan* trading rules. Water allocation and carry-over announcements need to be made available to stakeholders in a timely manner, while trading on classified information is forbidden (i.e. based on allocation announcements not yet publicly available). There is quantitative evidence that insider trading reduced following the implementation of this rule (de Bonviller et al. 2019).

Exchange rates were commonly used in the early days of the water market to facilitate the conversion of entitlements between catchments and to calculate the corresponding impacts on the Cap (MDBA 2010a, 2010b). Over time, this practice was phased out and replaced by allocation trading or tagging. Irrigators can simply transfer allocations received on an entitlement between catchments, or 'tag' the extraction of an entitlement to a different catchment (MDBA 2010d). The *Basin Plan* trade rules restrict the use of exchange rates, while also making tagged allocation subject to all trading rules for normally traded allocation (i.e. IVTs), provided the tag was established on or after 10th October 2010 (MDBA 2019f).

Despite the new trading rules, implementation challenges remain, because it is the states' responsibility to implement and enforce the changes mandated by the *Basin Plan* trading rules. A recent review of price reporting by the MDBA found that mandatory price reporting is not enforced in all states, contributing to poor data quality and a large number of trades misreported as AUD$0 (Deloitte 2019; MDBA 2019m).

2.3 Recent developments

With a substantial number of water resource plans not yet complete, and the timeline for environmental water recovery and the *Basin Plan* review extended to 2024, no major Commonwealth-state policy development has taken place since 2012. However, given a large number of reviews on various topics of water management in the last two to three years, a number of current issues have emerged, which are discussed in this section.

2.3.1 ABC Four Corners, water theft and compliance

In July 2017, the Australian Broadcasting Corporation's flagship investigative journalism program, Four Corners, aired a report alleging water theft and non-compliance with the *Basin Plan* in the Barwon-Darling region of northern NSW (Four Corners 2017). The piece claimed water had been taken without a permit, in violation of a 'no-pump' embargo, meters had been tampered with, and that high-ranking officials of the NSW water regulating authority colluded with large irrigation interests, passing on confidential government information to them.

The program received extensive nation-wide attention and dominated news headlines for weeks. While immediately sacking the officials incriminated by Four Corners (Begley 2017), the NSW government also commissioned a review, substantiating the allegations of compliance shortcoming and conflict of interest within the responsible NSW regulator, on the one hand tasked with monitoring compliance and on the other hand having an entrenched pro-irrigator organisational culture (Matthews 2017). As a consequence, the new Natural Resource Access Regulator was established and tasked with reviewing and enforcing compliance with water management rules in NSW (Parliament of NSW 2017). In addition, there were three compliance reports into water management tabled by the NSW Ombudsman between 2017 and 2018 (Carmody 2018). The claims of water theft have also been substantiated, with one of the irrigators in question fined around AUD$190,000 in penalties plus court costs (*Water NSW v Barlow* 2019; *Water NSW v Harris (No 3)* 2020).

Outside NSW, the Four Corners episode led to the Commonwealth 'Murray-Darling Basin Compliance Review' (MDBA 2017b), which found significantly different levels of compliance monitoring and prosecution between the states. This finding was replicated by the South Australian Murray-Darling Basin Royal Commission (Walker 2019) described in the following section.

2.3.2 The South Australian Murray-Darling Basin Royal Commission

Established by the Weatherill government on 23rd January 2018, the South Australian Murray-Darling Basin Royal Commission under Commissioner Bret Walker SC examined, amongst other issues: 1) whether the water resource plans as defined by the *Water Act* and *Basin Plan* will be compliant and operative by 30th June 2019; 2) if the *Basin Plan* will be able to deliver the mandated 450GL of environmental water; 3) the impact of water theft and compliance on the 450GL; and 4) whether the *Basin Plan* takes climate change into account.

Hearing evidence from over 70 witnesses, including a number of Australia's most eminent MDB researchers, and with the final report reaching an impressive size of 756 pages, the South Australian Murray-Darling Basin Royal Commission arguably represents the most comprehensive and detailed review of the *Basin Plan* and related issues. Remarking that the *Basin Plan* is an exceptionally poorly drafted and executed legal document, Commissioner Walker (2019) found that the SDL in the *Basin Plan* is not based on 'the best available science', is not prioritising environmental health as required by the *Water Act*, but is rather dictated by economic and political pressures, partly as a result of the MDBA's experience with the burning of the Guide (see section 2.2.5). Witness evidence stated that the consensus of the MDBA staff at the time was that the '*SDL had to be a number beginning with 2*' (Walker 2019, p. 216), indicating that environmental water recovery had to be below 3,000GL. The Royal Commission completely rejects the MDBA's interpretation of the *Water Act* that lead to the infamous "triple bottom line": the *Water Act* mandates an SDL to be set in a way that gives priority to environmental outcomes, before balancing social and economic outcomes. As such, the *Basin Plan* is in violation of the *Water Act*.

Walker (2019) also found that the 450GL of environmental water recovery through efficiency measures will not eventuate, dramatically expressed in evidence given by a former CEWH who stated that '(I) *would put my house on it that there won't be 450 gigalitres*' (Walker 2019, p. 414).

While the Commission refrained from making comments on the impact of water theft because it was the subject of ongoing criminal investigation at the time, it found the *Basin Plan* does not incorporate climate change in a satisfactory manner. While the MDBA argues that climate change is incorporated through the 10-year review process of the *Basin Plan* (MDBA 2019i), the Royal Commission regards this process as inadequate, determining that a focus on 110 years of climate averages and a 10-year review process do not constitute adaptive management and 'best available science' (Walker 2019).

South Australia experienced a change in government while the Royal Commission was in progress. The MDBA forbade its staff answering Commission summonses, arguing that a state royal commission cannot summon federal bureaucrats, referring the matter to the High Court. The new SA Liberal Government did not grant Commissioner Walker a requested extension to settle this matter, leading to a public stoush between the SA government and Walker. Another extension request in order to explore a massive fish kill event in the Darling River System at 15th December 2018 was also not granted (MacLennan 2019). Despite its comprehensive assessment, the South Australian Murray-Darling Basin Royal Commission has instigated little policy change, arguably due to the new South Australian Liberal Government not wanting to alienate the Federal and New South Wales Liberal Governments.

2.3.3 Fish kills and the Menindee Lakes Water Saving Project controversy

A series of four major fish kills in the Darling-Menindee Lakes System (NSW) took place between 15th December 2018 and 4th February 2019, leading to millions of dead fish, including native species like the iconic Murray Cod and/or Golden Perch (AAS 2019). Two competing reviews were commissioned to explore their cause; one commissioned by the Labour party and conducted by the Australian Academy of Sciences, and the second commissioned by the Liberal Commonwealth Government and conducted by a team led by Professor Rob Vertessy.

Both reports agree on the immediate cause of the fish kills: stratification and then mixing of oxygen-depleted bottom water with the smaller oxygenated surface layer. At that time hot temperatures and low- and no-flows conditions favoured the growth of large blue-green algae blooms and the separation of water layers. When the blooms died, the organic matter fed bottom layer microorganisms, which used all available oxygen. A subsequent drop in temperature then triggered mixing of the surface and bottom layers, lowering the water's oxygen levels below the ability to support fish respiration (AAS 2019; Vertessy et al. 2019).

A notable difference between the reports is their stance on the contribution of MDB water management. While Vertessy et al. (2019) attribute the events purely to the ongoing drought and weather conditions, the AAS (2019) directly links changes in the 2012 Barwon-Darling water sharing plan, allowing irrigators to extract more water at lower river flow levels, and the changed operation of the Menindee Lakes system as important factors contributing to the fish kills. The Lakes were drained in 2016-17 to trigger widespread Murray Cod and Golden Perch spawning, while there were no inflows from the Darling river. In 2017, the MDBA released large volumes of water from the Menindee Lakes to supply South Australia's water requirement under the *Murray-Darling Basin Agreement*, further lowering lake levels. With ongoing drought severing river connectivity and lowering lake levels, large numbers of fish congregated in the remaining available water bodies. These water bodies were the sites of the fish kills (AAS 2019), and the high concentration of fish significantly contributed to the magnitude of the fish kill events.

The Menindee Lakes Water Saving Project, part of NSW's contribution to the SDL adjustment mechanism, aims to operate the lakes at lower storage levels to reduce surface evaporation, given the flat topography of the region (DPIE 2020). The local community believes implementation of the Menindee Lakes Water Saving Project will enable the lakes to be drained in two months rather than nine, leaving Menindee with only 80GL, jeopardising town water supply and enabling conditions (like the present ones) for fish kills to occur more often (AAS 2019). Significant contention also surrounds the Broken Hill Pipeline[15] business case, which openly admitted the main benefactors of the pipeline were irrigators upstream of the Menindee Lakes (DPI 2016). While in the grip of the drought, communities consider that town drinking water supply, Indigenous, and environmental considerations take second place to powerful irrigation interests (Grafton 2020; Hannam 2019), supporting claims of widespread institutional capture of governments, the MDBA, and regulatory authorities by vested interests (Grafton and Williams 2019).

2.3.4 The Independent Socio-economic Panel and the Water for Fodder Program

To address contention about the economic impacts of water recovery, the "Independent Panel for the Assessment of Social and Economic Conditions in the Murray–Darling Basin", chaired by Robbie Sefton, was established in June 2019. Its terms of reference include: 1) reviewal of economic conditions in rural and regional communities across the MDB; 2) assessing (positive and negative) impacts of water reforms on the vulnerability, resilience and adaptive capacity of MDB, including the impacts of environmental water reforms; 3) investigating structural changes in the MDB, separating the effects of drought and structural changes from the effects of water reform; 4) supporting longer-term efforts to monitor and

[15] The Broken Hill pipeline supplies the town with water from the 270 km away Murray River at Wentworth, instead of from the 100 km away Menindee Lakes (DPI 2016). This is essential for the Menindee Lakes Water Saving Project to be viable, as the needs to provide reliable water supply to Broken Hill would make operation of the lakes below a certain level impossible.

understand social-economic conditions and the impacts of water reform; and 5) exploring a range of options that stimulate, support and promote healthy and sustainable rural and regional communities in the MDB (MDB Socio-economic Panel 2020). The Panel submitted a draft report on 16th March 2020 and is expected to deliver its final report by 30th April 2020. The draft report made 20 draft recommendations (see Table 2.3), grouped in five broad areas: 1) better community involvement and consultation; 2) meeting the needs of First Nations; 3) implementing water reforms with greater care to minimise potential negative externalities; 4) supporting communities' adaptive capacity to change; and 5) addressing critical gaps in community wellbeing, infrastructure and services (MDB Socio-economic Panel 2020).

Table 2.3 MDB Socio-economic Panel draft recommendations

Categories	Recommendations
Community involvement	• Find better and more effective ways to engage with rural and regional communities, empowering communities, keeping government accountable, and making the case for reform (Draft recommendation 1). • Provide greater clarity and certainty around long term policy, drive greater accountability and improved delivery of outcomes, building trust and ensure more people share the benefits of water reforms (Draft recommendation 1) • Ensure local leadership capacity and government are part of the solution, tailoring policies to community needs (Draft recommendation 1) • Governments should invest in the ongoing development of effective water markets and improving the water literacy of market participants. (Draft recommendation 1) • Extend the MDB Economic Development Program beyond 2023 until 2030, and increase its scale. This extension will empower communities to make longer term investments in their future (Draft recommendation 3) • Recognise that the benefits of water reforms have been uneven, and ensure future dividends are shared more evenly. The future investment in the MDB Economic Development Program should be refocused into vulnerable and disadvantaged communities most negatively impacted by Basin water reforms (Draft recommendation 4) • Allow flexibility for the socioeconomic neutrality test to be supplemented, empowering communities to move to a less water dependent future. (Draft recommendation 5)
First Nations	• Increase First Nations communities' access to water for cultural and economic purposes (Draft recommendation 9). • Fund First Nations groups to work with experts in valuing ecosystem services at culturally significant sites (Draft recommendation 10). • Better embed and mainstream First Nations participation in water policy and planning (Draft recommendation 11).
Water reform implementation	• Time further water recovery to match the capacity to deliver water to where it is needed. This approach means slowing further recovery in the Basin, and accelerating delivery constraints relaxation (Draft recommendation 2). • Address deliverability constraints as a priority, reflecting community concerns (Draft recommendation 6). • Fund efforts to monitor and evaluate environmental benefits, and research to improve the efficiency and effectiveness of environmental watering (Draft recommendation 14). • Increase research and innovation funding, focusing on farm system diversification and translating into on-ground application (Draft recommendation 15). • Make transparent the future obligations of government, water users and utilities to provide and maintain water infrastructure (Draft recommendation 18).
Adaptive capacity	• Improve water security planning and investment for towns and cities (Draft recommendation 7). • Develop regional pilot programs for alternative urban water supply sources (Draft recommendation 8) • Agree on a framework to develop better indicators of community wellbeing (Draft recommendation 12). • Fund a program for First Nations groups to build a baseline, tracking social and economic conditions and outcomes of water reform (Draft recommendation 13). • Create a baseline to track environmental and community socio-economic outcomes from water reform (Draft recommendation 14). • Consider developing a Basin-specific infrastructure fund, focusing on digital connectivity (Draft recommendation 17).
Wellbeing, infrastructure and services	• Address gaps in service and infrastructure provision for outer regional and remote MDB (Draft recommendation 16). • Attract and retain frontline service providers, specialising in household distress, mental health issues, and financial hardship (Draft recommendation 19). • Work with communities with acute social and economic issues, developing action and outcome plans that address these issues. Plans should build on any existing plans and be driven by local communities (Draft recommendation 20)

Source: Adapted from MDB Socio-economic Panel (2020)

To aid livestock irrigators, the Commonwealth also implemented the *Water for Fodder* program in 2019/2020: an agreement to use the Adelaide desalination plant to produce an extra 100GL of water for SA water consumption in exchange for Commonwealth funds (DAWE 2020a). In turn, 100GL of Murray water (40GL in 2019/20 and 60GL in 2020/21) from the SA state entitlement will be made available to irrigators, in blocks of 50ML for AUD$5,000 per water allocation account, to produce fodder at a discounted price of AUD$100/ML (DAWE 2019d). At the time of writing, of the 40,000 ML available in round 1, 14,250 ML were delivered to irrigators in NSW, 25,100 ML to irrigators in VIC, and 650 ML to irrigators in SA (DAWE 2020c). This program has been widely criticised, including its third-party impacts and high cost of AUD$82.6-100 million, and indeed, the current announcement of carryover allowed within the program (Miller 2020) has potentially signalled its lack of usefulness and waste of money as a policy (Crase 2019; DAWE 2020a).

2.3.5 The Interim Inspector-General of Murray–Darling Basin Water Resources

On 1st October 2019, the Commonwealth created a new role, the Interim Inspector-General of Murray-Darling Basin Water Resources, appointing Mick Keelty, a former Australian Federal Police commissioner, who previously served as the Northern Basin commissioner (IIGMDBWR 2020). His role is to support the implementation of the *Basin Plan* by engaging stakeholders on critical issues and undertaking an inquiry into the management of Murray–Darling Basin water resources. Mr Keetly’s terms of reference for investigation changed as a direct consequence of a protest convoy of approximately 1,000 irrigators, mainly from NSW, to Canberra on 3rd December 2019 (Sullivan and Jasper 2019). His current terms of reference include assessing whether the water sharing arrangements between the basin states, namely the *Murray-Darling Basin Agreement,* are still appropriate, with a report due soon.

While at face value water sharing arrangements are worthwhile to question, answers and insights that may be provided by Mr Keelty are arguably inconsequential for future water policy. Contention between states, and Basin communities, about transboundary water sharing dates back to pre-federation times (see section 2.2.1). A reformulation of the *Murray-Darling Basin Agreement* is only possible if agreed-on by all states, which is highly unlikely. NSW’s interest, and indeed that of the aforementioned protestors, would be a renegotiation towards better terms and more water for NSW. SA has zero interest in revisiting water-sharing to its detriment, given a) its historic experiences (Guest 2016); b) its already precarious situation at the end of the river; and c) concerns about further deterioration in the environmental health of the Coorong and Lower Lakes system. Likewise, Victoria, experiencing environmental damage from over-extraction and high water delivery requirements, would be unlikely to give up water, nor agree to changing the 50:50 split with NSW in order to provide SA’s entitlement under the *Murray-Darling Basin Agreement* and towards a more favourable split for NSW. Finally, that Queensland is not inclined to extract less water for NSW’s sake is reflected by the latest conflict over overland flow harvesting in southern Queensland (Gooch et al. 2020).

2.4 Conclusion

This chapter has provided a comprehensive overview of MDB water resources, physical characteristics, historic, and current water policy reform. Importantly, the reform processes and initiatives presented in this chapter have enabled, shaped and still dictate current MDB water market systems, which are described in more detail in the next chapter. This chapter has illustrated that conflict over water sharing has been a dominant feature of MDB water reform. States' self-interest and powerful irrigation interests have shaped environmental water recovery volumes and preferences, resource expenditure and allocation, and tilted the balance of power to an 'irrigation first' paradigm. Despite this, significant effort has been undertaken to address over-allocation in the Basin through a variety of infrastructure and market-led solutions, notably the Commonwealth buyback of water entitlements through the *RtB* program. Given current policy developments, and the continuous attempts of certain groups to calculate away environmental water recovery volumes required under the *Basin Plan*, there is real danger of a backsliding towards yet higher consumptive extraction and reduced environmental sustainability. The current drought has emphasised distributional issues in water sharing, both between consumption and environment, and town water supply and irrigation. Adapted to emerging challenges, the MDB water market system presented in the next chapter can provide solutions and avenues to allocate ever-scarcer water resources. However, the challenges of equity and distributional fairness are firmly in the realm of strong governance and policies.

Chapter 3 The MDB water market

This chapter introduces and describes the MDB water market system, with a special focus on the sMDB water markets.

3.1 The economics of water and market-based allocation

Water allocation is a classic common-pool resource problem in the spirit of Hardin (1968): access to water is non-exclusive, in the sense that one cannot easily be hindered from extracting water from a river or groundwater aquifer. It is also rival in its use: if too much of the resource is extracted/used, its availability and or quality is diminished for all water users. This leads to over-extraction of the resource, as water users aim to maximise private benefit, and will likely generate negative externalities for all other users (Ostrom 2008). Reducing the externalities from over-extraction may come with the trade-off of limiting resource access for all, or for one user group. Both water access (e.g. in form of infrastructure) and externalities (e.g. lower water quality) can be costly. Water economics aims to measure and effectively manage trade-offs and costs associated with competing water uses across time and different locations. In this context, effective management aims to meet societal water use objectives by facilitating water allocation to higher value uses, while simultaneously maintaining basic water needs (Grafton et al. 2014b). Applying economic instruments to water management therefore contributes to addressing key global water challenges: water scarcity and over-extraction of resources, deteriorating water quality, and conflict over allocation between competing water uses. By identifying and quantifying trade-offs and costs associated with water management and allocation, economic analysis plays an important role in improving water decision-making (Grafton and Wheeler 2015).

However, water has several unique characteristics, setting it apart from other common-pool resources. Water can be a private good (e.g. potable household water), and a public one (e.g. environmental water), corresponding to the specific type of water use (Hanemann 2006). Private good water use is subject to competing and excludable use. Public good water use has elements of being non-rival and non-exclusive: one individual's water consumption does not limit others' consumption and excluding individuals from using water is excessively expensive or impossible (Grafton and Wheeler 2015; Griffin 2016). Public good characteristics make water value assessment more complex and may lead to free-riding behaviour (Grafton et al. 2020a; Grafton and Wheeler 2015). Although water can be stored and transported, this involves infrastructure that typically requires large capital expenditures. Together with economies of scale inherent in water infrastructure, this may result in monopolies and socially inefficient water allocation (Dinar et al. 1997). With free-riders often difficult to identify, and political pressures to keep water prices low, water tariffs charged to water users typically do not recover the costs of provision (Grafton et al. 2020a). Consequently, under-investment in water infrastructure, over-allocation of water resources and corresponding negative externalities are common. To encapsulate the value of water's public good components, non-market valuation techniques are often used (Hanemann 2006).

In particular, water resources are characterised by an inherent set of diverse public good values, such as recreational, environmental, cultural, social and ecosystem services. These tend to go unnoticed by private water market participants, who maximise private rather than societal benefits (Howe 1999). The concept of total economic value has often been employed to highlight the diversity of values attached to water. This comprises direct values, for example benefits from consumption and use of water and indirect values, for example non-use values, such as bequest values (Bark et al. 2011; Grafton and Wheeler 2015). The existence of these characteristics means there is therefore a need for government involvement, in the form of regulation, the creation of water management institutions and by minimising transaction costs (Easter et al. 1999).

The previous chapter described the climatic variability and water scarcity physically inherent in the MDB. Combined with irrigation development and historic water management policies, this has led to over-allocation, environmental degradation and water quality deterioration of MDB water resources. Water policy from 1994 onwards (see section 2.2.2) attempted to address this increasingly introducing a suite of water demand management strategies, with water markets one of these most important economic instruments (Grafton et al. 2016).

Water markets provide a flexible, efficient and voluntary allocation of a scarce resource (Howe et al. 1986; Randall 1981), and are able to provide an efficient allocation of common pool resources, as long as property rights are well defined and transaction costs are low (Coase 1960; Ruml 2005). Consequently, water markets have been proposed and advocated widely for many decades (Gardner and Fullerton 1968; Howe 1999). Indeed, a substantial number of scientific studies point towards material public gains stemming from the reallocation of water resources through markets (e.g. (Easter et al. 1999; Knapp et al. 2003; Vaux and Howitt 1984). Water markets use the price mechanism to allocate water to its highest value use. Optimal allocation therefore requires the assessment of water value for all types of competing uses, including environmental and non-consumptive uses (Grafton and Wheeler 2015).

Water markets can be formal or informal, but typically involve water users in the same region or catchment sharing the same water source. Informal water markets generally sit outside publicly regulated institutions, operate directly between private parties, and can take many different forms: the trade of water between neighbouring farmers, small private enterprises drilling for groundwater and on-selling to capital-poor farmers, or private water vendors of potable water from trucks when municipal water infrastructure is inadequate or incomplete (Bjornlund 2004; Kariuki and Schwartz ; Mukherji 2008; Stoler 2017; Venkatachalam 2015). Formal water markets are less common; they allow the legal transfer of water rights on a perpetual basis, require complex institutions and a greater degree of administration (Bjornlund 2004). One key prerequisite for well-functioning formal water markets are enforceable, transferrable and well-defined water use rights (Wheeler et al. 2017b). Consequently, transboundary water markets are less common, mainly due to the complexity of defining and enforcing rights across borders.

In comparison to other water allocation systems[16], water markets have a number of key advantages: they: 1) involve only willing sellers and buyers; 2) allow for flexible and swift reallocation in response to demographic, economic, climatic and social-value changes; 3) provide security of tenure through property rights; 4) confront water users with the real opportunity cost of water through values and prices; and 5) allow for policies and measures to reduce and limit transaction costs (Howe 1999).

Typically, water markets and other water allocation regimes aim to be economically efficient (wealth creation through resource use) while maintaining social equity principles, which take account of wealth distribution across individuals and sectors (Dinar et al. 1997). To guarantee optimal resource allocation, water allocation systems, including water markets, can be evaluated in relation to flexibility, security, opportunity cost, predictability, equity, and

[16] Such as marginal cost pricing, administrative water allocation and user-based allocation [e.g. water user groups, irrigation trusts] (Dinar et al. 1997).

political and public acceptance (Howe et al. 1986), but also administrative sustainability and efficacy (Winpenny 2005). Key assessment criteria, specifically tailored to water markets are: 1) the shape and strength of water property rights and institutions; 2) knowledge and incorporation of hydrological and climatic realities into the market and trading system; 3) strong governance arrangements in regards to monitoring, enforcement and externalities; 4) efficient and sustainable water trade; and 5) transparent and accurate market information systems (Wheeler et al. 2017b).

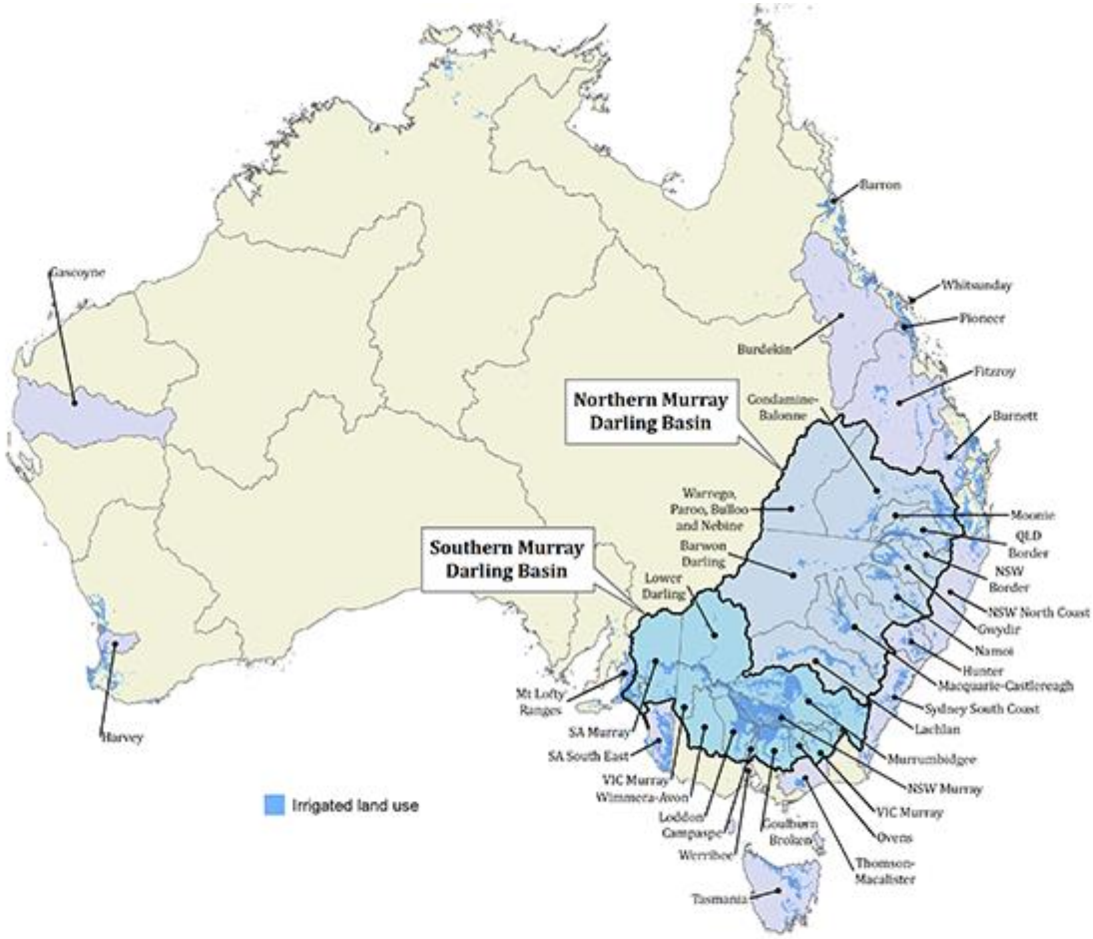
While water markets are in principle not limited to a particular sector or user group, most water market systems and their participants are in (irrigated) agriculture. This is evident in agriculture’s high use of available water resources (up to 70% in some countries) (Wheeler et al. 2014a). Although formal water markets can be slow to develop, often due to political circumstances or the complexities of water use [e.g. return flows or hydropower] (Vaux and Howitt 1984; Young 1986), water markets now exist in many countries around the world, such as Spain, India, Chile and the United States, albeit with different levels of sophistication and development (Grafton et al. 2011; O'Donnell and Garrick 2019; Palomo-Hierro et al. 2015). The water market of the sMDB is internationally regarded as the most advanced (Grafton et al. 2011), with its current and emerging circumstances often foreshadowing future developments in other water markets.

There are three broad types of water trading: 1) short-term transfers of already allocated water that is available for immediate use (e.g. allocation trade); 2) medium-term leasing of water allocations that enables secure water access for a period of time as specified via a contract (e.g. water leasing); and 3) permanent transfers of the on-going property right to a proportion or fixed quantity of the available water at a given source (i.e. water entitlement trading). These can exist for surface and groundwater (Wheeler and Garrick 2020).

3.2 MDB water trading development over time

Although water trading happens all across Australia (see Figure 3.1), the most active and advanced water markets are situated in the MDB, which accounted for 97% of allocation trade and 77% of entitlement trade in 2016/17 (Goesch et al. 2019).

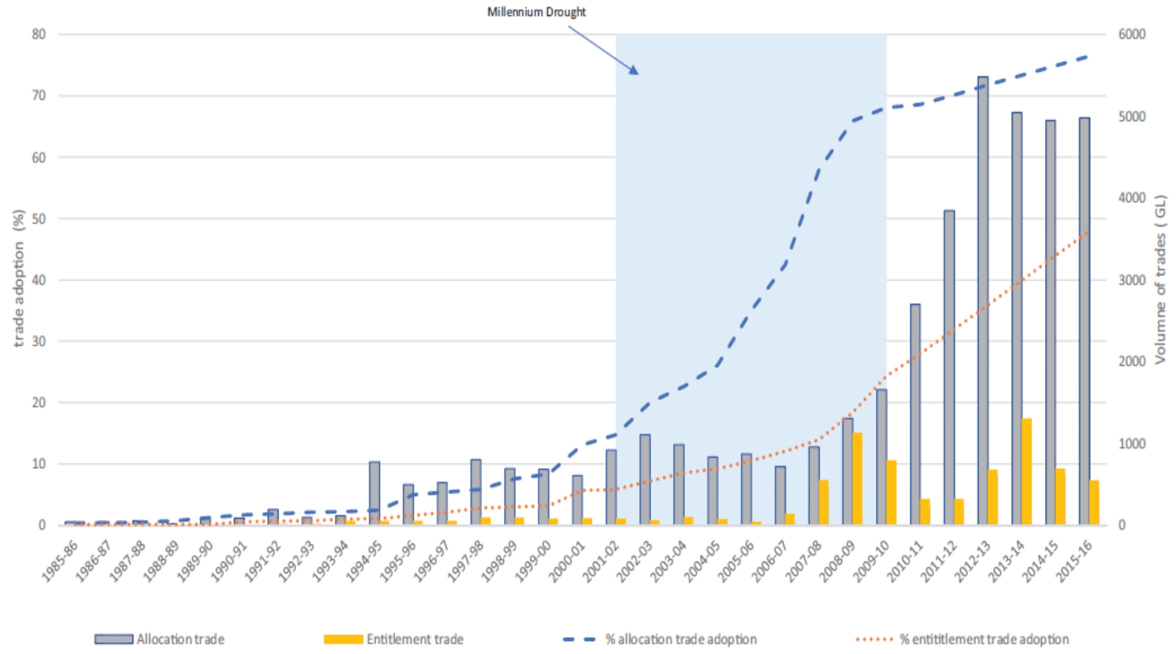
Figure 3.1 Australian water systems with water allocation trade activity in 2015–16



Source: ABARES (2019a)

Informal water trading has existed in the MDB since the 1960s (Connell 2007), with formal water trading introduced in the 1980s (Wheeler et al. 2014a). Successive policy reforms (see section 2.2) have fostered water market development by facilitating interstate trading, reducing barriers to trade and building stakeholder confidence through overarching water market trading rules (Grafton et al. 2016). Irrigator participation in water allocation and entitlement trading has increased over time. Although water markets have been in operation for almost 20 years, less than 10 per cent of irrigators had conducted a water market trade by 2000 (Wheeler 2014). Water market participation strongly increased during the Millennium Drought, particularly in trading of allocations as irrigators employed allocation trading as a risk management and drought adaptation tool (Kirby et al. 2014a). Increased scarcity drove participation, which was enabled by water policy reform bringing about water market liberalisation (e.g. the NWI and the *Water Act*), and increased government involvement buying water entitlements as a result of the *RtB* program [see section 3.5.2 for more detail] (Loch et al. 2012). Participation continued to grow even after the drought broke, signifying that water trading is now an established and actively used management tool for irrigators. Figure 3.2 tracks the percentage of irrigators that have conducted at least one water market trade over time. The columns represent the volume of trade within the market.

Figure 3.2 Adoption (and trade volumes) of temporary and permanent markets in the sMDB over time



Source: Wheeler and Garrick (2020, p. 140)

Today's MDB water markets are worth around AUD$2 billion annually (MDBA 2019l), with the majority of trades, both in allocations and entitlements, involving surface water trades in the sMDB. Commercial allocation and entitlement trade values for 2018-19 in the MDB were estimated at AUD$566 million and AUD$699 million respectively (Wakerman Powell et al. 2019).

3.3 Trading products

There are two main parallel water markets in the MDB, trading two main products: 1) the market for permanent water (access) entitlements; and 2) the market for seasonal allocations. Additionally, there is a range of other water market products traded, such as delivery shares (right to deliver water in an irrigation system (Crase et al. 2015)), parking (right to use carry-over space owned by a different entitlement holder), water leases, water forwards and water options. These are described in more detail later in this section. Under the COAG reforms (see section 2.2.2) water allocations and entitlements are defined as (COAG 2004a, p. 30):

Water (access) entitlement: *a perpetual or ongoing right to exclusive access to a share of water from a specified consumptive pool as defined in the relevant water plan.*

Water allocation: *the specific volume of water allocated to the water entitlement in a given season, defined according to rules established in the relevant water plan.*

Although the *Water Act* and other reforms were intended to standardise inter-state water trading and trading products, there is still considerable difference between the states; a consequence of the history of state-based growth of water management systems (see section 2.2). For example, there are more than 150 different entitlements traded in the MDB (MDBA

2019l). Table 3.1 illustrates the main entitlement and allocation products, their naming conventions and the cap factors across different states.

Table 3.1 Allocation and entitlement naming conventions and cap factors across MDB states

State	Water allocation term	Water entitlement term	High security and (Cap factor)	General security and (Cap factor)	Low security and (Cap factor)
NSW	Allocation assignment	Water access licence	High security (95-100%)	General security (36-81%)	Conveyance and supplementary (14-21%)
QLD	Seasonal water assignment	Water allocation	High priority (n/a)	Medium priority (n/a)	Unsupplemented* (100%)
SA	Water allocation	Water access entitlement	High security (90%)	n/a	n/a
VIC	Water allocation	Water share	High reliability (95-95%)	n/a	Low reliability (24-49%)

* Unsupplemented entitlements are over-land flow harvest licences. They allow for harvesting full licence amounts during floods, leading to a cap factor of 100%. However, outside flood conditions, these licences yield no water.

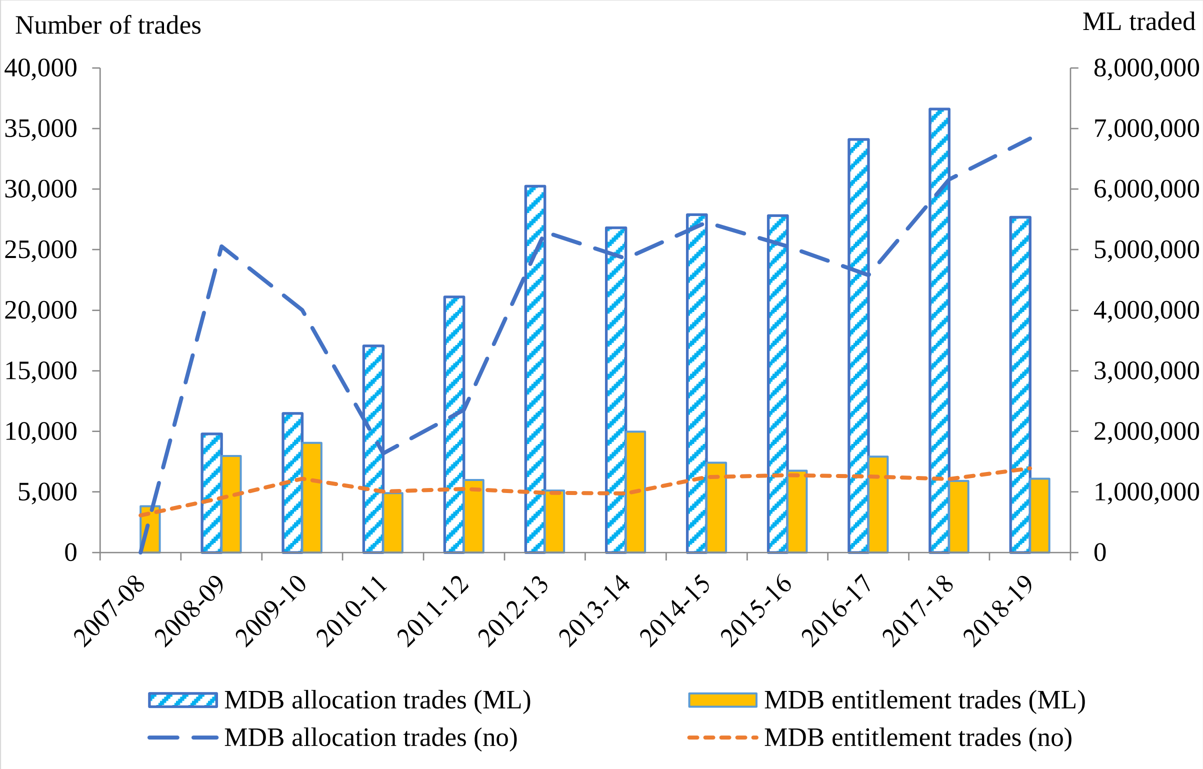
Source: Adapted from BOM (2020a) and Cheesman and Wheeler (2012)

To avoid confusion and ambiguity, this thesis refers to the perpetual right to access a share of water from a consumptive pool as a “water entitlement”, and to the volume allocated to a specific entitlement in a given season as a “water allocation”.

Water entitlements can be regulated or unregulated, supplementary, supplemented or unsupplemented. They also come in three general securities (also called reliability), high, general, and low security, indicating how often a specific entitlement receives a full allocation. For example, a high security entitlement receives a full allocation 90-95 out of every 100 years (Zuo et al. 2016). Regulated entitlement refers to regulated river systems, with major dams and water delivery infrastructure in place, as is predominantly the case in the sMDB (Wheeler et al. 2014a). The nMDB has a much higher volume of unregulated entitlements, meaning they are not part of a catchment or river system with major water infrastructure. Supplementary entitlements allow water extraction only in the case that the government (or regulator) has announced a supplementary event— a flood event (DPIE 2019). This is not to be confused with supplemented and unsupplemented entitlements, which refer to whether extraction from a water system is supplemented by water releases from upstream water storages (Hargraves et al. 2013).

Water allocation trade is significantly larger, both in volume and number of trades, than entitlement trade in the MDB (see Figure 3.3). Furthermore, the majority of trading activity is in surface water, with ground water trading more limited.

Figure 3.3 MDB annual allocation and entitlement trade: number and volumes 2007/08-2018/19



Source: Own figure, data sourced from BOM (2020g)

Delivery shares in Irrigation Infrastructure Operator (IIO) systems (e.g. irrigation trusts) are also traded, but MDB-wide trade numbers are not available. The terms and conditions of these delivery shares varies widely between different IIOs: for example, one delivery share in the Murrumbidgee Irrigation District guarantees the delivery of 1.2 ML and it can be traded annually (MI 2015). By contrast, one delivery share in the Goulburn-Murray Irrigation District (GMID) guarantees the delivery of 270 ML[17] and is transferred in perpetuity (GMW 2018). These differences have a strong impact on the price and trading activity of the particular delivery share: Murrumbidgee delivery shares are traded quite regularly with the buyer paying a price, whereas Goulburn delivery shares are traded infrequently and the **seller pays the buyer** to take on the delivery share (around AUD$10,000 per share), due to the extremely high administration and termination fees incurred (Seidl et al. 2020b).

In recent years, new water trading products have emerged in the sMDB, such as water forward and options contracts (Bayer and Loch 2017), water leases and parking (ABARES 2018; Brennan 2008; Wheeler et al. 2013a), often driven by new types of water market participants (see section 3.7). These products follow ideas and concepts commonly observed in financial and derivative markets; this thesis therefore refers to them as “derivative-type temporary” water products. Table 3.2 provides an overview of derivative-type temporary products.

[17] 1 ML/day for 270 days of irrigation season.

Table 3.2 Derivative-type temporary water market products and data visibility

Water product	Definition	Identifiable in water registers
Water forwards	A contractual arrangement whereby the seller guarantees to deliver a defined volume of allocation, for a predetermined price, at a predetermined point future time to the buyer. The buyer guarantees to honour the contract.	Indistinguishable from allocation trades
Water leases	A contractual arrangement whereby the lease taker (lessee) receives all allocation attributed to a leased water entitlement. The entitlement remains the property of the lease giver (lessor).	Some visibility in NSW register data as "Temporary Transfers"
Water options	A contractual arrangement whereby the buyer has the option, but not obligation, to deliver/have delivered a defined volume of allocation, for a predetermined price, at a predetermined point in time the future to/by the seller.	Indistinguishable from allocation trades
Water parking	A contractual arrangement permitting the buyer to store their water allocation on the carry-over of the seller, usually from one water accounting period to the next.	Indistinguishable from allocation trades

Source: Own figure, adapted from ABARES (2018) and H2OX (2019b)

Derivative-type products are usually indistinguishable from allocation trades in water register data (ABARES 2018; Seidl et al. 2020b). There is limited potential to identify lease trades in the NSW water register, reported as "temporary transfers", but actual reported trade numbers are very low, pointing towards trades either not being registered as leases, or errors in water register data entry. Consequently, price discovery and assessing traded volumes of these products is at best very challenging. Some consultancies have claimed that clusters of allocation trades significantly deviating from the median/mean market price are probably forward contracts (Baker et al. 2017) but, without contractual data, that claim cannot be verified.

3.4 Trading zones and restrictions

There are a number of hydrologically connected catchments in the MDB allowing for inter-region and inter-state water trading. Water trade is structurally administered within and between trading zones, which represent hydrological catchment areas. Each water resource plan[18] under the *Basin Plan* typically represents one trading zone, although in the nMDB, water resource plans may include multiple zones. Figure 3.4 shows a map of the main trading regions in the MDB.

[18] Water resource plans is the general term since the *Basin* Plan. NSW and pre-Basin Plan legislation refers to them as water sharing plans.

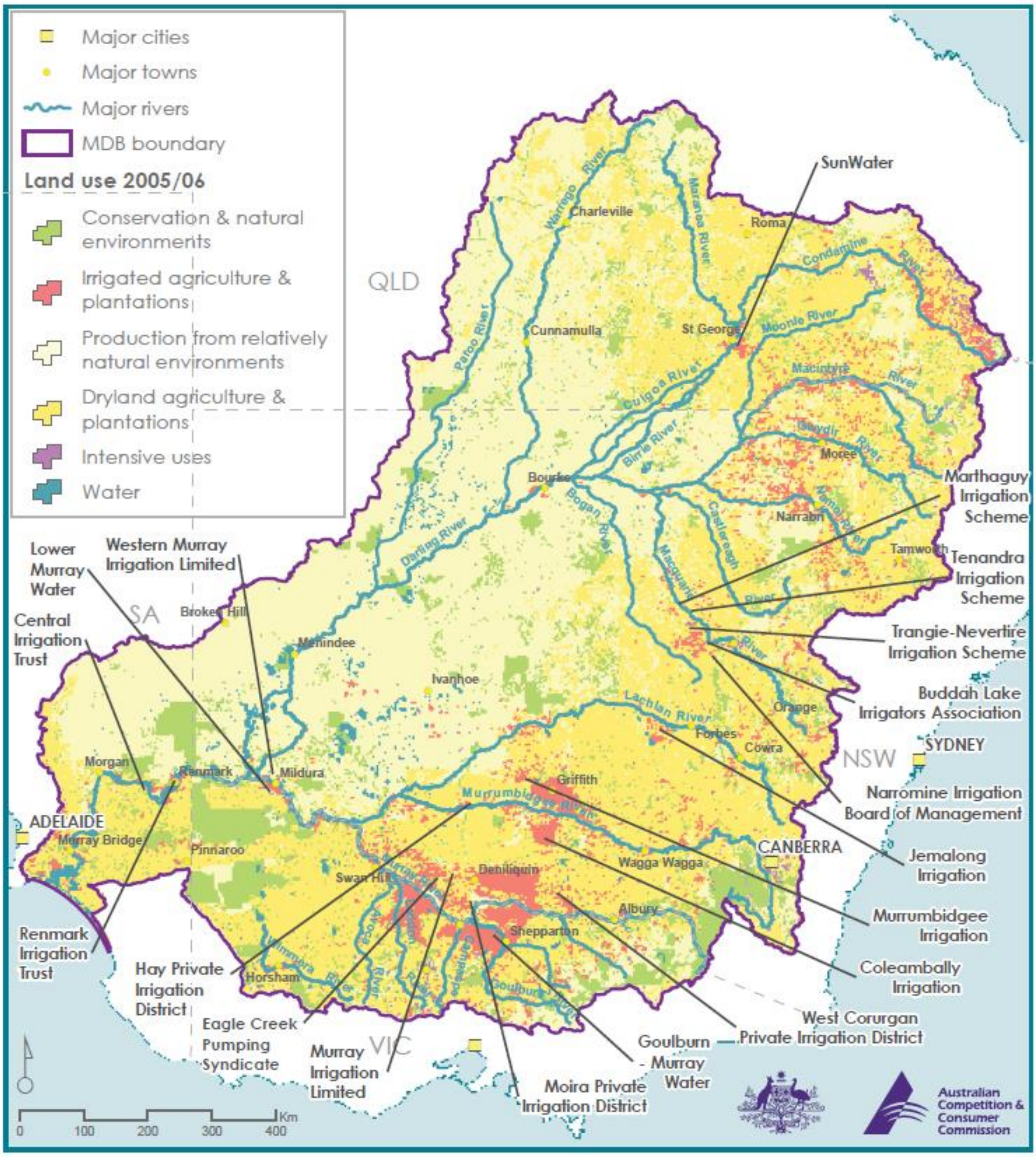
Figure 3.4 Water trading regions in the MDB

Source: MDBA (2017d)

Water trading between catchments is possible within the nMDB and sMDB themselves, however, trading between nMDB and sMDB is not, because the two areas are hydrologically not connected (apart from very high flood years). Schedule D of the *Murray-Darling Basin Agreement* outlines permissible transfer between different catchments and trading zones (MDBA 2010c). A table of permissible transfers can be found in the appendix (Table A.1).

Water trade also occurs between irrigators within the same IIO, although these trades are subject to the IIO's trading rules and may therefore be subject to very different conditions than trades between participants outside IIOs. Figure 3.5 shows the location of IIOs in the MDB, while Table 3.3 provides an overview over the main IIOs' water holdings and their corresponding trading zones.

Figure 3.5 Infrastructure operators in the MDB



Source: ACCC (2017, p. 14)

Table 3.3 Important IIOs, their entitlement ownership and serviced trading zones

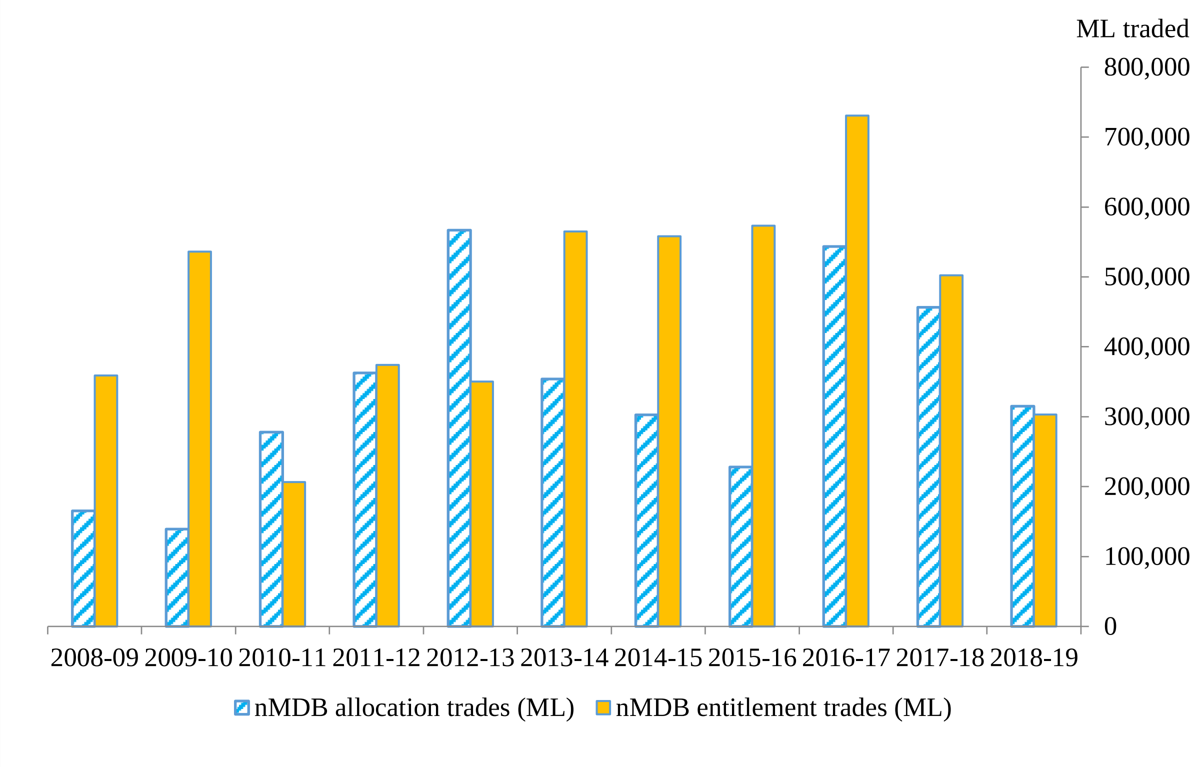
State	IIO	River valley	Trading zones	Volume of water entitlements owned (ML) in 2017/18
NSW	Murray Irrigation Ltd	NSW Murray	Zone 10, Zone 11	1,305,620
	Murrumbidgee Irrigation Ltd	Murrumbidgee	Zone 13	504,820
	Coleambally Irrigation Corporation Ltd	Murrumbidgee	Zone 13	849,099
	Jemalong Irrigation Limited	Lachlan	Upper Lachlan, Lower Lachlan	94,420
	Western Murray Irrigation Ltd	NSW Murray	Zone 11	38,044
VIC	Goulburn-Murray Water	Goulburn, Broken, Loddon, Campaspe	Zone 1A, Zone 1B, Zone 2, Zone 2a, Zone 2b, Zone 3, Zone 4a, Zone 4c Zone 5a, Zone 5b Zone 6, Zone 6b, Zone 7	1,389,157 (based on 2015-16)
	Lower Murray Water	VIC Murray, Goulburn	Zone 1A, Zone 7	129,160
SA	Central Irrigation Trust	SA Murray	Zone 12	109,995
	Renmark Irrigation Trust	SA Murray	Zone 12	37,039

Source: Own Figure, adapted from (ACCC 2019b) and (ACCC 2017)

3.4.1 The northern Basin

The nMDB encompasses the Macquarie, Namoi, Gwydir, Border Rivers, Condamine-Balonne, Warrego, intersecting streams and the Barwon-Darling regions of northern NSW and southern QLD. Although water trades take place in the region (see Figure A.1 for a map of trading zones), it is characterised by rather thin water markets and low numbers of trades. Figure 3.6 shows nMDB allocation and entitlement trades over time.

Figure 3.6 Allocation and entitlement trades in the nMDB



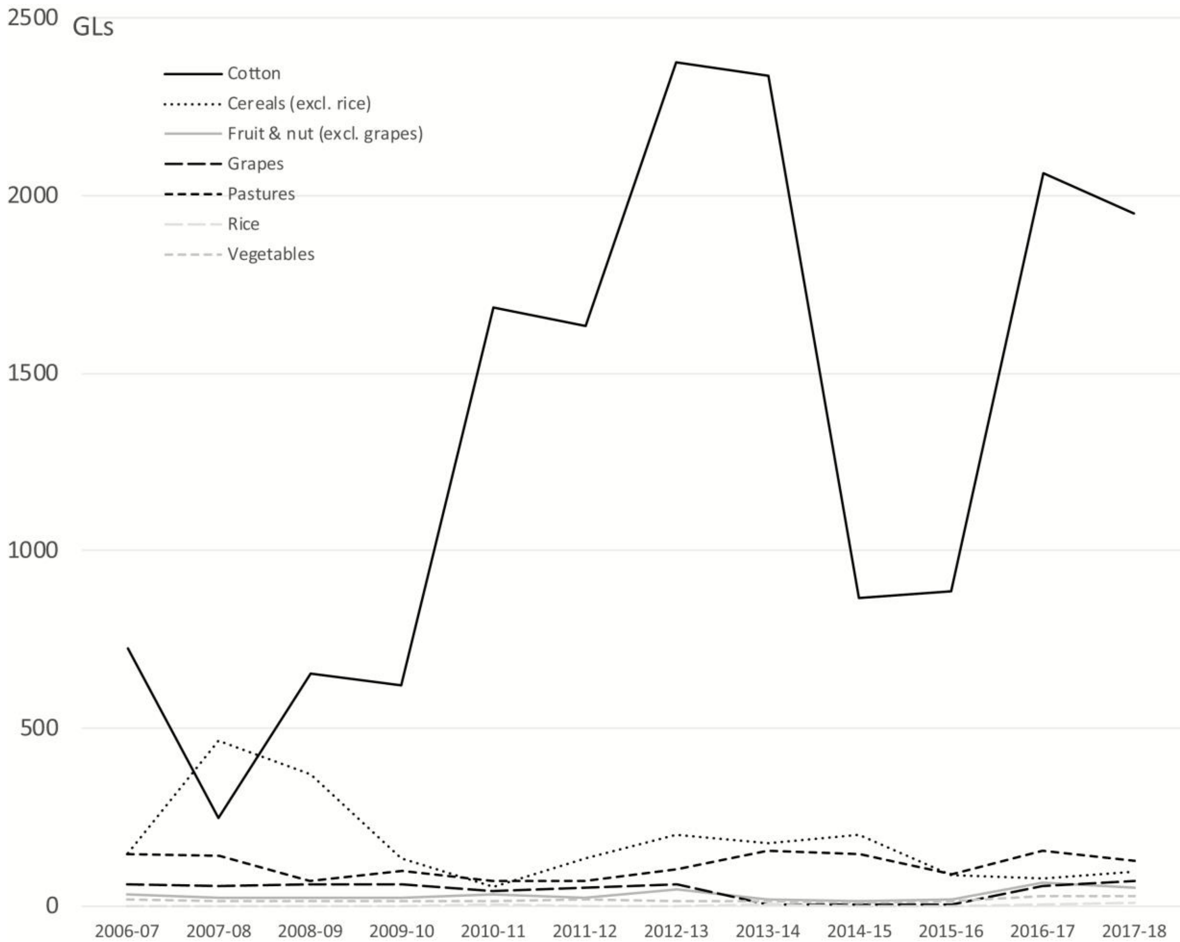
Source: Own Figure, data sourced from BOM (2020g)

Thin markets are characterised by relatively few market participants and low number of trades or transactions (Tisdell 2011). In the nMDB, Wheeler and Garrick (2020) outline why markets are thin because of the following:

1) limited hydrological connectivity between catchments and a high number of unregulated entitlements— 32% of entitlements on issue and limited storage capacity in the North.
2) Lower number of IIOs compared to the sMDB, making water a less valuable commodity.
3) Fewer, but larger, irrigators, reducing potential gains from trade between users.
4) Greater reliance on ground water and on-farm storage, including for floodplain harvesting, which limits incentives to trade.
5) Less water extraction measuring and monitoring, combined with weaker accounting systems and less regulation, leads to insecurity about water rights protection. These factors provide less incentive to trade. And
6) Fewer heterogeneous water users in the nMDB, limiting flexibility of agricultural production and associated water trade between industries.

Cotton is by far the most dominant crop in the nMDB (see Figure 3.7), generally planted on large farms by corporatized agri-businesses. These actors have the financial means to construct on-farm infrastructure for floodplain harvesting to minimise the need to trade. They often own enough water in a given reach to exert market power or even monopolistic behaviour, disincentivising water trade for other actors (Sheldon 2019). Without mandatory price reporting, water trading data are fragmented and incomplete, with particular issues surrounding combined water and land transactions in the Queensland water register (Deloitte 2019; MDBA 2019m). The lack of trading data contributes to price insecurity, further disincentivising water trading. However, where institutional conditions are not in place to govern trade properly, it is best in many situations that trade is limited (Wheeler and Garrick 2020; Wheeler et al. 2017b)

Figure 3.7 Water volumes applied by various irrigation activities in the nMDB



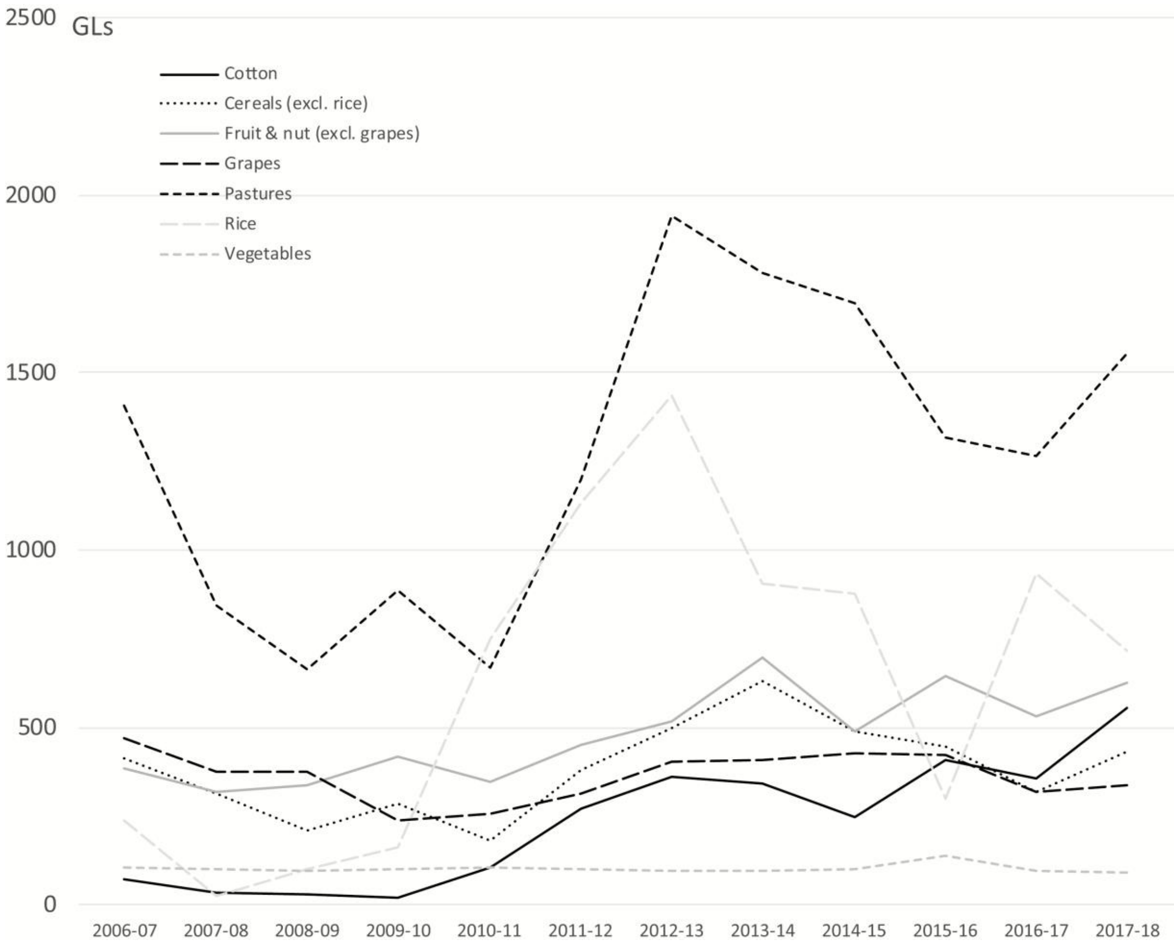
Source: Wheeler and Garrick (2020, p. 147)

As discussed in the previous chapter (see sections 2.3.1 and 2.3.3), water institutions and compliance are weak in the nMDB (Matthews 2017; MDBA 2017b). NSW and QLD have also been uncapable of, or unwilling to, meaningfully regulate overland flow licences (Walker 2019), contributing to the delay of water resource plans and to over-extraction of nMDB water resources (Wheeler and Garrick 2020). With alleged favouritism (DPI 2016) and rent-seeking behaviour by the irrigation lobby [i.e. cotton] (Grafton and Williams 2019), water market development in the nMDB has been slower due to insecurity about water rights, weak institutions and poor water extraction limit enforcement (Wheeler and Garrick 2020). Given its thin markets and concentration of market power, the region has also been the primary focus of strategic purchases under the *Basin Plan*, with eight of ten strategic purchases in the nMDB (DAWE 2019a).

3.4.2 The southern interconnected MDB

In contrast, the sMDB has the most active water markets in Australia (Grafton and Horne 2014b), and the most sophisticated water markets in the world (Grafton et al. 2011). Agricultural production is very diverse (see Figure 3.8), including major annual and perennial cropping systems, with many different stakeholders, providing one of the prerequisites for gains from water trading (Wheeler et al. 2017b).

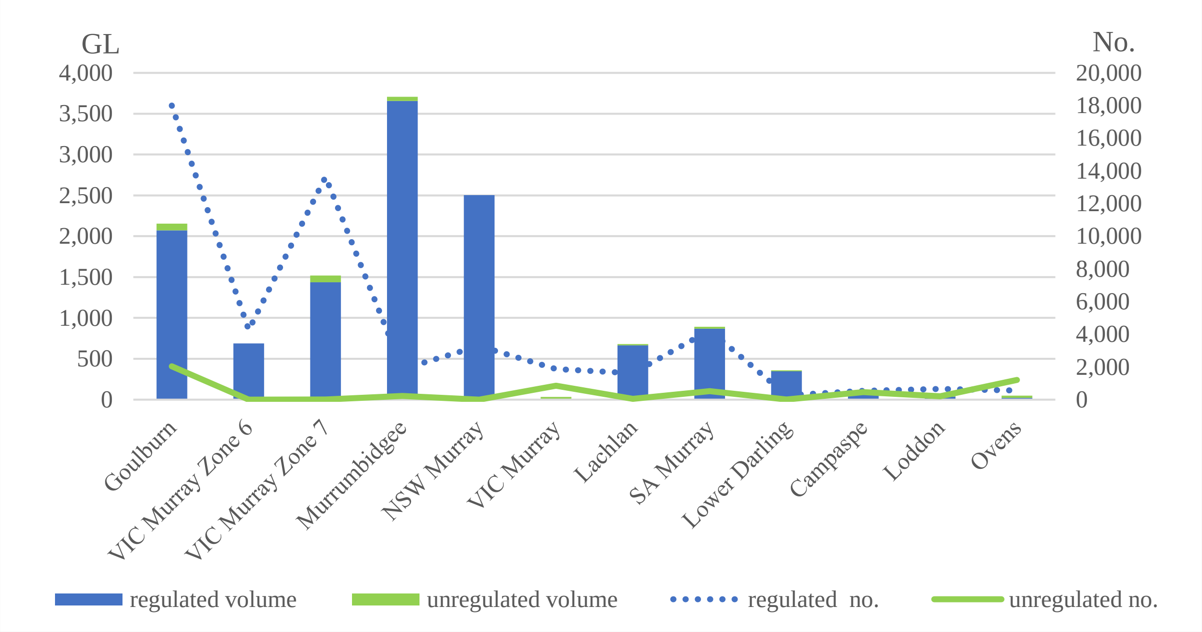
Figure 3.8 Water volumes applied by irrigation industry in the sMDB



Source: Wheeler and Garrick (2020, p. 146)

The presence of major infrastructure and storages, combined with a number of important irrigation districts (see Figure 3.5), makes water a valuable commodity. Storages enable higher security entitlements, because they smooth out the seasonal variability of rainfall, and infrastructure allows for more efficient water management and delivery, making entitlements in regulated systems superior to those in unregulated systems. The different amounts of entitlements on issue across catchments (see Figure 3.9) and their multiple storages, contribute to supply of water market products from different sources, and increases trade options. The regions with a long history of major irrigated production are also the ones where states issued the most entitlements. It is therefore not surprising that these same regions are the most active water trading zones, given both diversity and volume of water entitlements, and concentration of agriculture (Bjornlund 2004; Connor et al. 2013; Wheeler et al. 2008b; Wheeler et al. 2014a).

Figure 3.9 Entitlements on issue in the sMDB in 2018/19

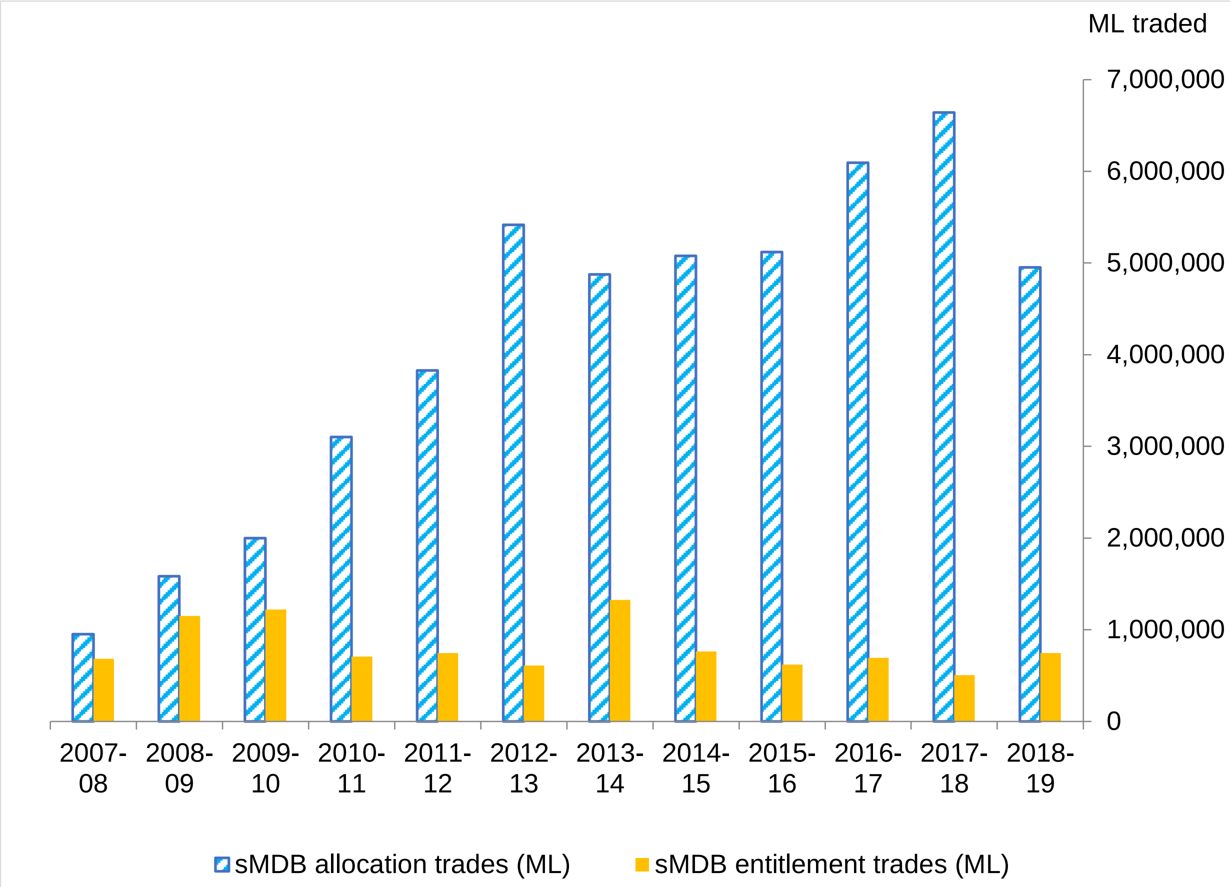


Source: Own figure, data from BOM (2020g)

Dam infrastructure also allows water to be carried-over from one season to the next, extending the live-span of water allocations (beyond a single season) and enabling inter-seasonal trades. With water unbundling highly advanced and river systems highly interconnected (see Figure A.2 for a map of inter-connected trading zones and Table A.1 for permissible trades), water is highly fungible, further increasing trade opportunities. Advanced water regulation facilitating water trading, the NWI reforms and the *Water Act* for example, and readily available water trading information through water registers, has led to enough trust in water entitlements for banks to accept them as collateral for loans, making water entitlements an important part of irrigators' asset bases (Waterfind 2019a). Finally, diverse water sources and water users, good pricing data availability and robust water regulation and institutions were also necessary for new derivative-type temporary water trading products to emerge, further increasing trading possibilities in the sMDB (Grafton et al. 2011; Loch et al. 2018; Wheeler and Garrick 2020; Wheeler et al. 2017b; Young and McColl 2009).

These characteristics combined translate into very high levels of water trading activity in the sMDB, representing over 80% of total Australian water trades. Based on the average transaction per irrigation business from 2008/09 – 2017/18, sMDB irrigators were 4.8 times more likely to have conducted an allocation, and 7.9 times more likely to have conducted an entitlement trade (Wheeler and Garrick 2020). Figure 3.10 shows sMDB allocation and entitlement trades over time.

Figure 3.10 Allocation and entitlement trades in the sMDB



Source: Own Figure, data sourced from BOM (2020g).

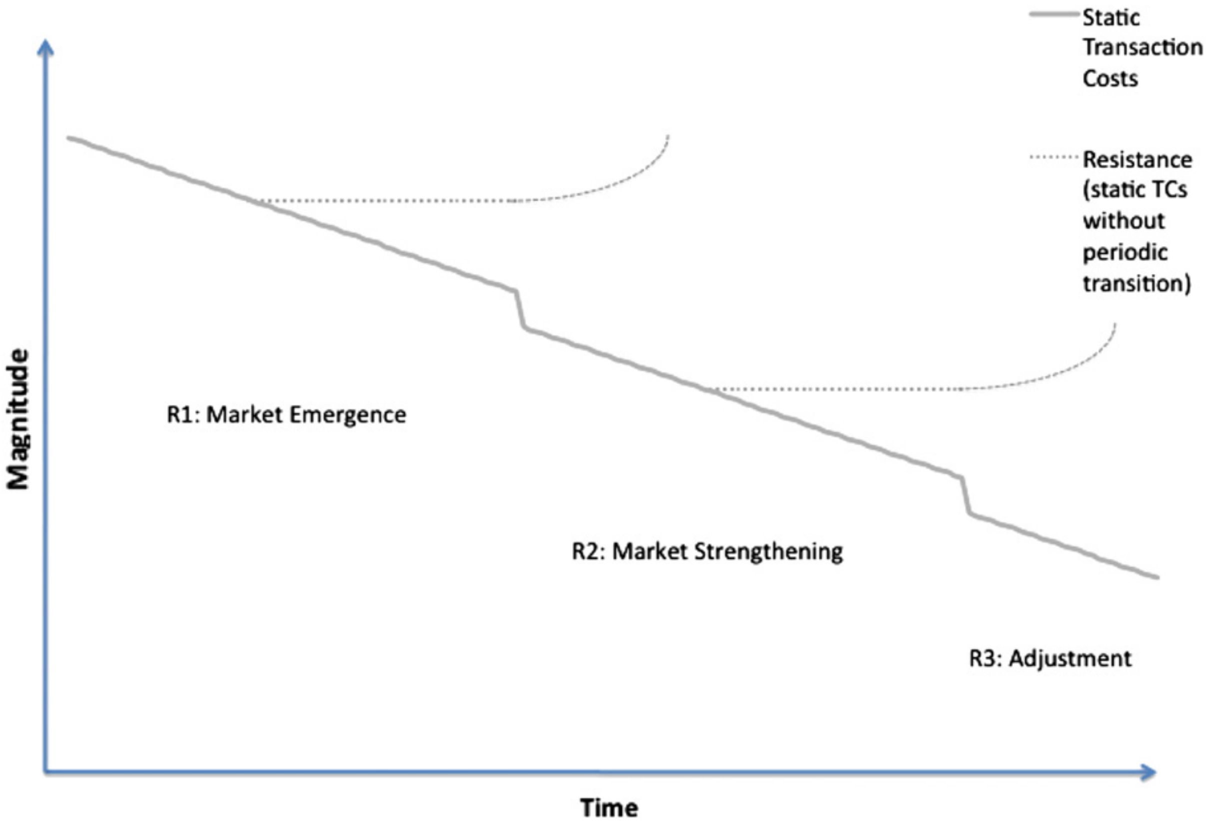
Market participants in MDB water markets have been predominantly irrigators. Since the *Water Act* of 2007, the Commonwealth of Australia has bought significant amounts of water entitlements, through water recovery programs under the *Basin Plan* by the Departments of Agriculture and Environment. Recovered water was then transferred to the CEWH for management, who has done very little trade, apart from some allocation sales. This leads to particular trading patterns, explored later in this chapter (see sections 3.5 and 3.6).

3.4.3 Private transaction costs

Other important features of a well-functioning water market are low transaction costs and timely processing of water trades (Wheeler et al. 2017b). Garrick et al. (2013) describes water market transaction costs as having three components: 1) static transaction costs; 2) institutional transition costs; and 3) institutional lock-in costs. Static transaction costs represent the costs for water users to trade water within an existing institutional setting, including the costs of finding a counterparty. Institutional transition costs are costs for policy reform implementation, development of tradable water rights and diversion limits. This also includes changes to price-discovery mechanisms (such as the introduction of water registers), water-user associations and IIOs, water-rights and licencing systems, and trading rules. Institutional lock-in costs are the costs to make future changes to current water-use patterns or infrastructure, imposed by current institutional choices. The transaction costs most directly relevant to stakeholders' water market participation in the MDB are static transaction costs because they are borne directly by water users. Although also important, institutional lock-in and transition costs are arguably less impactful for trading decision making as they tend to be financed by the government through tax revenue from the general public. This section therefore focuses mostly on static transaction costs in the MDB (Garrick et al. 2013).

With maturing water markets and institutions, static transaction costs should reduce over time through ongoing institutional innovations (Carey and Sunding 2001). Garrick et al. (2013) argued that periodic pulses of investment in institutional transition costs are needed to address unintended consequences of prior reforms, enable gains from trade arising from more complex water market trading products (e.g. dry-year options, futures contracts), and carry-over rules building on market-based allocation reforms. Figure 3.11 shows the stylised development of static transaction costs over time.

Figure 3.11 Average static transaction costs of market-based water allocation



Source: Garrick et al. (2013, p. 201)

The historic experience of water policy reform in the MDB arguably supports this theory. Prior to unbundling water from land ownership in the wake of the COAG reforms in 1994, water trading was associated with high static transaction costs. If one wanted to buy water entitlements, it was necessary to purchase the associated land title, making it very costly, both due to the extra costs attributable to the land, but also the high search costs involved in finding a counterparty and the costs involved in transferring a land title (e.g. registration and application fees for both water and land). Interstate water trading was largely non-existent, with most trades taking place as allocation trades within IIOs via informal markets. This is reflected in the low water market trading participation prior to 1994/95 [see Figure 3.2] (Grafton et al. 2016; Loch et al. 2018; Wheeler 2014; Wheeler and Garrick 2020).

Unbundling under the COAG reforms made it significantly less costly to trade water, given that it made it possible to trade water alone. Yet, water trading was still slow as states struggled to implement the full suite of COAG reforms. The NWI led to an increase in water trade reform. Specifically, improved water accounting and the establishment of water registers made price-discovery significantly less challenging and costly, while also providing information about total water availability (Chalmers et al. 2012; Lee and Ancev 2009; Loch et al. 2013; Slattery et al. 2012). Another component of high static transaction costs was the power and protectionist behaviour of IIOs, and service tariffs set by monopolistic behaviour (ACCC 2016). Restrictions in allowing water to be traded out of IIO boundaries and high operational costs, termination and administrative fees were factors specifically disincentivising water trading. While some of these fees were justified on the basis of cost recovery from remaining irrigators (see the “stranded assets” argument in section 2.2.5.1), they were protectionist measures and lead to inefficiencies in water trading (Grafton et al. 2016). The NWI tackled this issue by requiring fees and tariffs to be cost-reflective and on a per ML basis, combined with further unbundling of water rights, separating out the water use and delivery share components. This represents a significant decrease in transaction costs for trading with IIOs, as the entitlement volume, the right to use water, and the right to have it delivered became individually tradable, providing extra flexibility for irrigators (Crase et al. 2014).

However, interstate and inter-region trading remained difficult, in part due to lack of appropriate institutions and support for trading between the states, and because of challenges in comparing the hydrological and legal characteristics of different water entitlements. The 2007 *Water Act* addressed these issues by tasking states with establishing and harmonizing institutions supporting inter-state trading. This was primarily achieved through new water trade processing time service standards for all MDB states, established in 2008. Ninety percent of interstate trades needed to be processed to completion within 20 days, and 90% of intrastate trades within 10 days. In 2009, this was further shortened to 10 and 5 days respectively (Loch et al. 2018). Technological advances also contributed to reduce static transaction costs: the increased use of computer and digital systems, replacing old paper-based trade application and processing, significantly reduced processing times (see Figure A.3 to Figure A.8 for allocation and entitlement processing times). By 2010/11, all states achieved the required processing times (Loch et al. 2018).

To enable hydrological accounting for cap-compliance and to compare hydrological characteristics of different water entitlements, a system of exchange rates was piloted via the Interstate Pilot Trade Program in 1998 (Bjornlund et al. 2012), converting nominal volumes of one entitlement into nominal volumes of another entitlement from a different catchment (MDBA 2010b). As an example, an exchange rate of 1.0 was used on all transfers from NSW to Victoria or SA. However, an exchange rate of 0.9 was used for upstream transfers from SA into NSW, Victoria to counteract reduced supply security (Loch et al. 2013). This enabled stakeholders to take exchange rates as an indicator into consideration for their trading decisions. However, high transaction costs associated with exchange rate trade limited its expansion beyond the pilot interstate trade program.

Finally, the *Water Act* also mandated the Australian Competition & Consumer Commission (ACCC) to report and monitor IIO fees and charges, tracking progress towards cost effective and non-trade impeding charge structures. Over time, government fees associated with water allocation trade decreased, as have fees in most IIOs except the Murray Irrigation district. IIOs report average annual transaction cost reductions of between 0.48% and 5.29% between 2009/10 – 2016/17 for allocation trades (Loch et al. 2018), demonstrating the positive impact of NWI and *Water Act* reforms. In contrast, entitlement transfer transaction costs remained largely unaffected. Decreasing transaction costs in one trade product were often offset by a fee increase in other products, such as delivery share fees. Overall, transaction costs for allocation trade fell, but increased for water entitlement trades, likely due to the complexity and necessary assessment rigour required for such transfers (Loch et al. 2018).

Under the *Basin Plan* water trading rules, IIOs are required to transparently communicate their fee structure, not impose trading rules which unnecessarily hinder water trade (such as the 10% and 4% rule in Victoria, see section 2.2.3.1). Despite considerable progress in fee structure reporting, both through IIOs' websites and the ACCC's Water Monitoring Report series (ACCC 2019b), challenges remain. IIOs' fee structures can be extremely complicated, sometimes including hundreds of different fees (ACCC 2016; Cooper et al. 2014). Delivery share products and conditions vary significantly between IIOs and high termination fees, up to 10 times the annual fee, remain (Loch et al. 2018). This has the potential to materially affect water trading with IIOs.

Similarly, although water reporting and data accessibility have progressively improved, some regions and water registers have yet to fully implement non-paper-based trade application processing. This slows trade processing times and routinely causes reporting errors in the water register data (MDBA 2019m). Inter-state trading is still marred by differences in trading terminology, and overall complexity arising from permissible trades between different trading zones (MDBA 2010c). This contributes to irrigators' spending up to 8 hours in searching, negotiating and executing allocation trades, and up to 13 hours for entitlement trades, with a substantial amount of time spent on searching for trade partners (Loch et al. 2018). The complexity of identifying a counter party has given rise to a vibrant industry of water market intermediaries, increasing the cost of trade by their charging of service fees, usually based on a percentage of trade value (Elders 2019; Waterexchange 2019; Waterfind 2019b). Additionally, there are concerns about unethical intermediary behaviour in situations where water markets are thin or fragmented, intermediaries may (deliberately or otherwise) cause price inflation when providing information to potential market participants (ACCC 2016; Seidl et al. 2020b).

There is also almost complete absence of information on derivative type products in water register data, making price discovery exceedingly challenging. It seems these products are implemented using standard allocation or entitlement transfers and have therefore generated little or no publicly available data on volumes, number of trades, contractual conditions or who is transacting. This could affect the future reliability of water trade data by skewing reported prices and volumes (ABARES 2018).

3.4.4 Intervalley trade restrictions and tagged trading

Historic and on-going water policy efforts, largely successfully, reduced some barriers to trade and have facilitated more water trading, but some barriers to trade remain. These barriers are often a function of the hydrological necessities and configurations of the MDB, in particular "intervalley-trade restrictions" (IVT), the Barmah Choke constraint, and limits around the use of "tagged entitlements" and associated trades.

The most prominent IVTs are the Murrumbidgee IVT, limiting trade between the Murrumbidgee and the NSW Murray catchments, the Goulburn-Murray IVT, limiting trade between the Goulburn and the VIC Murray catchment, and the Barmah Choke constraint, limiting water trade between NSW Murray trade zones 10 and 11, and VIC Murray zones 6 and 7. Figure 3.12 shows the state of IVTs in the sMDB at 19th January 2019.

Figure 3.12 Trade limits and IVTs in the sMDB

From ↓ / To →	1A	6	7	10	11	12	13	14
1A Greater Goulburn		GOULBURN TO MURRAY LIMIT						
6 VIC Murray - Above Barmah Choke	CHOKE		CHOKE		BARMAH CHOKE LIMIT			
7 Vic Murray - Below Barmah Choke								INTO LD
10 NSW Murr U/S Barmah Choke	CHOKE		CHOKE		BARMAH CHOKE LIMIT			
11 NSW Murr D/S Barmah Choke								
12 SA Murray								
13 Murrumbidgee	OUT OF MURRUMBIDGEE LIMIT							
14 Lower Darling	OUT OF LOWER DARLING LIMIT							

TRADE ALLOWED | TRADE RESTRICTED

Source: MJA (2020, p. 2)

The Goulburn-Murray IVT was introduced in 2012. It was intended to enable volumes stored in dams to supply Victorian Murray water entitlements, and to guarantee that the increasing commitments to meet large volumes of trade between Victoria and the Murray did not adversely impact on storage levels. The IVT stops any allocation trade from Goulburn, Campaspe, Broken and Loddon to the Victorian Murray or to NSW and SA, if a total of 200 GL is owed to the Murray trade zones downstream. Stakeholders can track the status of the trade limit over the inter-valley trade account, with the IVT opening if less than 200GL is owed to the Murray (DELWP 2014).

The Murrumbidgee IVT limits trade between the Murrumbidgee, NSW Murray, NSW Lower Darling, Victorian Murray and South Australian Murray, with its inter-valley trade account representing the net trade of temporary traded or tagged water out of the Murrumbidgee. When water is temporarily traded **out** of the Murrumbidgee the IVT account balance **increases**, whereas it **reduces** when water is temporary traded **into** the Murrumbidgee. In contrast to the Goulburn IVT, the Murrumbidgee IVT operates between a lower and an upper limit of the inter-valley trade account, closing trade when the account balance moves outside these limits. The lower limit is an IVT trade balance of 0GL, closing trade into the Murrumbidgee because water cannot flow uphill; whereas the upper limit is a balance of 100GL, closing trade out of the Murrumbidgee, to minimise third party impacts from large volumes of Murray water sitting in Murrumbidgee storages. While counterintuitive at first glance, water delivery affects the IVT in the opposite direction from trade, in that water delivered to the Murray reduces the IVT, and water delivered from the Murray into the Murrumbidgee increases the IVT.[19] The operation of the IVT is complicated, as trade does not open or close with the lower and upper limit. Instead, trade into the Murrumbidgee opens when the account balance has reached 15GL. Whereas trade out of the region opens when the IVT account balance falls under 85GL (DPI 2018).

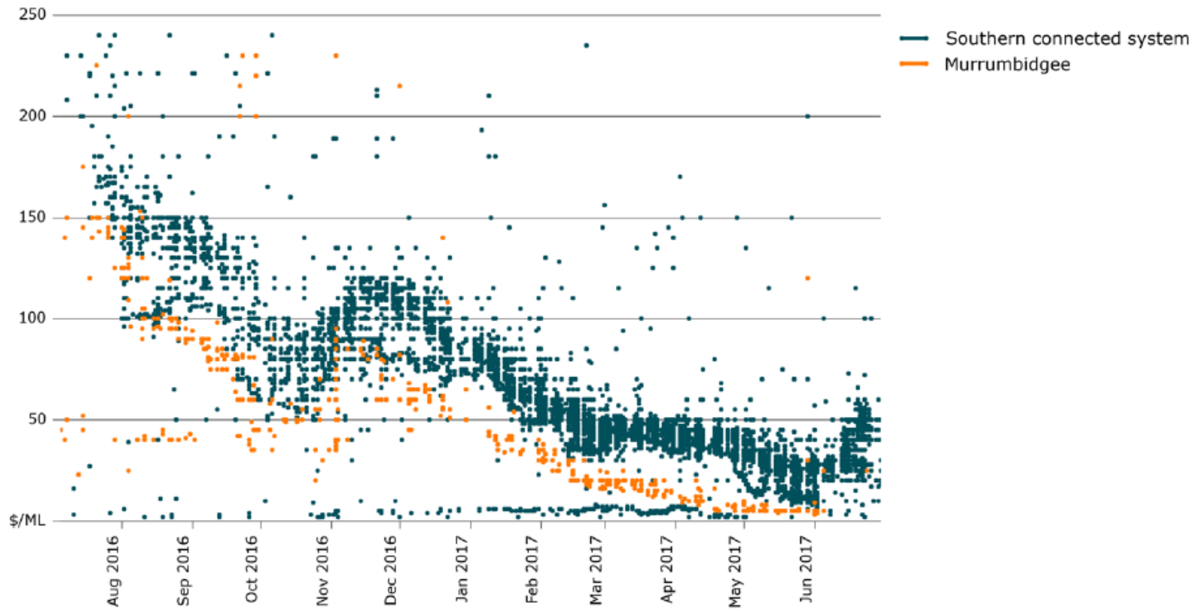
In contrast to the Goulburn and Murrumbidgee IVTs, the Barmah Choke constraint is due to a geological formation limiting the maximum flow through the Murray without flooding the surrounding Barmah-Milawa forest. This formation, the Barmah Choke, named after the nearby town of Barmah in Victoria, only allows daily flows of 7,000 ML/day between the upstream trade zones 6 and 10 to the downstream zones 7 and 11 (MDBA 2019c). Consequently, no water can be traded from upstream to downstream if the 7,000ML flow threshold has already been reached. The Barmah Choke is significant as it separates important irrigation areas in SA, Victoria and NSW from the major upstream storages of Dartmouth and Hume dam. Apart from standard allocation trade, the choke also affects the

[19] Possible by using Murray Irrigation infrastructure, the Mulwala Canal (GMW 2019).

delivery of carry-over from the dams: if the choke is full, carried-over allocations cannot be delivered.

These three IVTs all affect major trading zones (see section 3.4.2) and exert a material influence on water market prices. If the IVTs are closed, price differentials form in the allocation markets separated by the restriction, continuously diverging while trade is closed. Specifically, Murray trade zones 7 and 11 allocation prices increase when the Goulburn IVT and the Barmah Choke are closed. The impact of the Murrumbidgee IVT on prices is harder to generalise about, because it depends on the balance of in- and out-trade, and also on whether the other two IVTs are open. For example, operators in the downstream Murray zones may wish to draw on Murrumbidgee water more if they cannot source their demand from Goulburn or the upstream Murray. Figure 3.13 shows the allocation price differentials between the southern-connected MDB and the Murrumbidgee in 2016/17 due to the closed IVT account balance of 100GL.

Figure 3.13 Allocation prices for sMDB and Murrumbidgee in 2016/17



Source: ABARES (2018, p. 31)

All allocation transfers are supposedly subject to IVTs under the *Water Act* (MDBA 2014b). However, there is an interesting interaction between IVTs and allocations delivered under a tagged water entitlement. Establishing a “tag” on an entitlement enables the owner to extract the associated allocation in a different system/catchment than the one in which the entitlement is registered. This allocation can only be used, not sold. Tags were introduced to enable irrigators to source water from different sources without always having to use the market mechanism (incurring trade costs) to have their water delivered (ACCC 2010; Frontier Economics 2009). Given the high transaction costs associated with exchange rate trade, tagged trade were seen as less complicated and transaction cost intensive solution, as a tagged entitlement retains all its characteristics and does not leave its system of origin (MDBA 2010d).

However, allocation deliveries from tagged entitlements are exempt from complying with IVTs in two cases: 1) the tag had been established before 22nd October 2010 (MDBA 2014b); or 2) they are based in Victoria. Contrary to the intentions of the *Water Act*, Victoria has implemented tagged entitlements as exempt from IVTs, meaning that allocation water from tagged entitlements can be delivered through the closed Goulburn IVT (DELWP 2018). Furthermore, the allocation amount deliverable under a tag was not limited to the nominal entitlement volume, but, rather, stakeholders were able to purchase large volumes of cheaper Goulburn water allocation and deliver them through the closed IVT to the more expensive Murray. Although tagged allocation cannot be on-sold, if stakeholders owned Murray water as well, they can sell their Murray allocation and use their Goulburn tagged allocation, legally arbitraging on the price difference between the two trading zones. This lead to large volumes of allocation water being delivered to the Murray through a closed IVT (120 GL in 2018/19), and prompted Victoria, from December 2019, to subject all tagged entitlements to IVT rules (Neville 2019a). This measure led to considerable uncertainty for Victorian irrigators, many of whom were accustomed to and reliant on water supply from their tagged accounts (Hunt 2019b). At time of writing, the Victorian government is engaged in stakeholder consultation regarding proposed changes to the Goulburn-Murray trade rules and tagged accounts (DELWP 2020a). The review suggests three options: 1) an annual volumetric limit of water tradeable from the Goulburn to the Murray; 2) a dynamic limit, a hybrid between current rules and the annual volumetric limit; and 3) a seasonally-based rule consisting of two parts: the first part concerns spring, late autumn and winter, when it is ecologically beneficial to have high flows and delivery of traded water does not impact the environment. The second part implicates summer and early autumn when access is restricted, and operational limits in the lower Goulburn River are applied to protect the environment (DELWP 2020a).

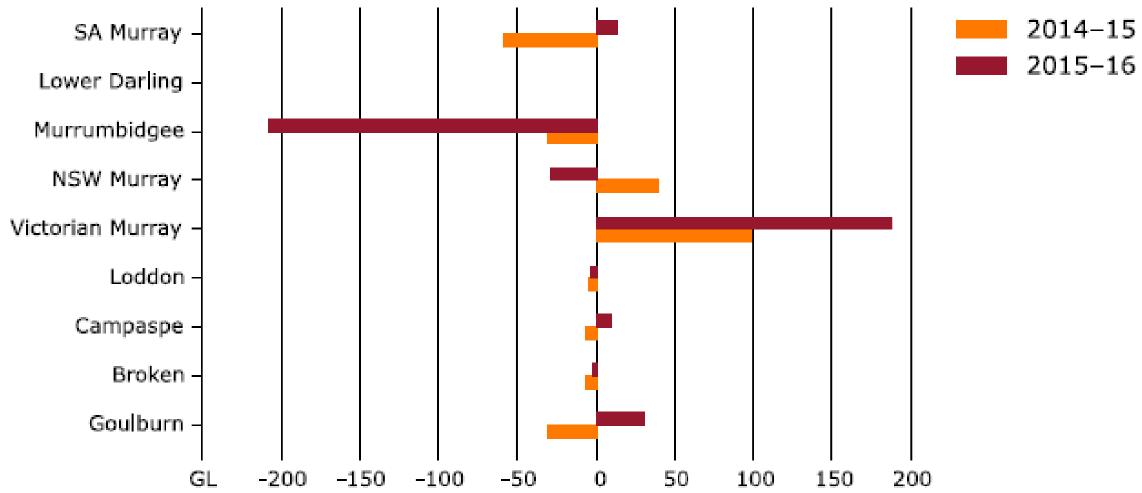
Despite these efforts, tagged entitlements established prior to the 22nd October 2010 remain exempt from IVTs. Additionally, price divergence between catchments will continue to occur, potentially causing adverse effects for some stakeholders. The terms of reference of the current ACCC water market review include assessing the impact of IVTs on trading behaviour and prices (ACCC 2019a).

3.5 Water market trading patterns

Most water market participants are irrigators, using the water market for a variety of reasons. This section reviews trading patterns, both for entitlements and allocations, and irrigators' drivers for trading.

Between 1998/99 – 2010/11 water was largely bought by dairy farmers in Victoria and horticultural irrigators in SA; annual croppers in the Murrumbidgee and Lower Darling were the main sellers (Wheeler et al. 2014a). From 2007 onwards, significant water volumes were traded into SA to maintain supply for high value perennial crops, such as grapes (Wheeler et al. 2014a). Figure 3.14 shows the directions and volumes of net water trade between water trading zones in the sMDB in 2014/15 and 2015/16.

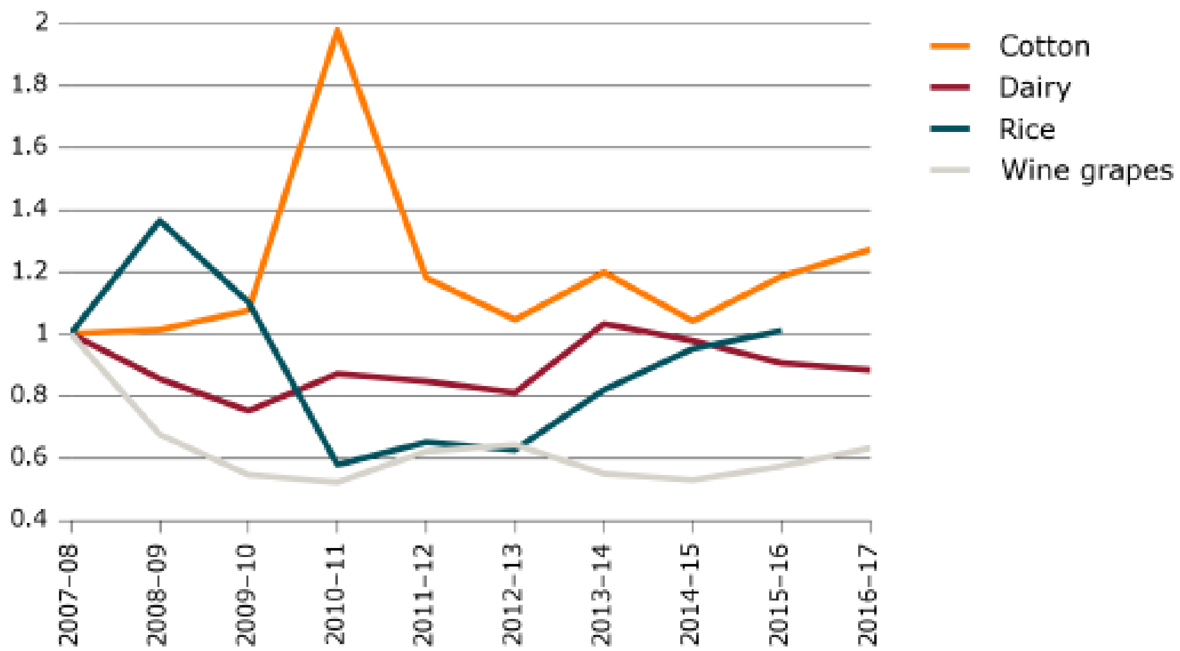
Figure 3.14 Net water trade volumes in the sMDB by catchment in 2014/15 and 2015/16



Source: ABARES (2019b)

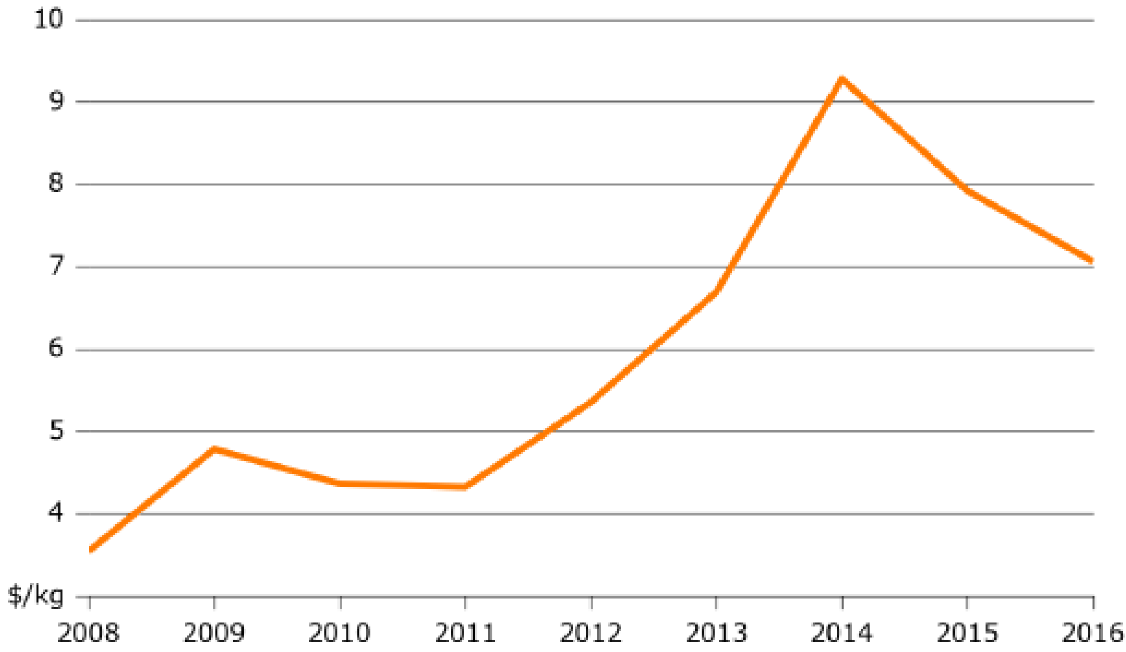
Water trading activity by irrigators is strongly influenced by the type of crop grown, and the associated output prices. Generally, perennial horticultural crops have a higher ability to pay for water, given their higher output prices. Water trading for perennial producers also includes risk and capital maintenance considerations, which are explained later in this chapter (see section 3.5.2). Figure 3.15 and Figure 3.16 shows the price movements of important crops in the sMDB from 2007/08 to 2016/17.

Figure 3.15 Selected agricultural commodity price indexes, 2007–08 to 2016–17



Source: ABARES (2018, p. 22)

Figure 3.16 Almond prices (nominal) from 2008-2016



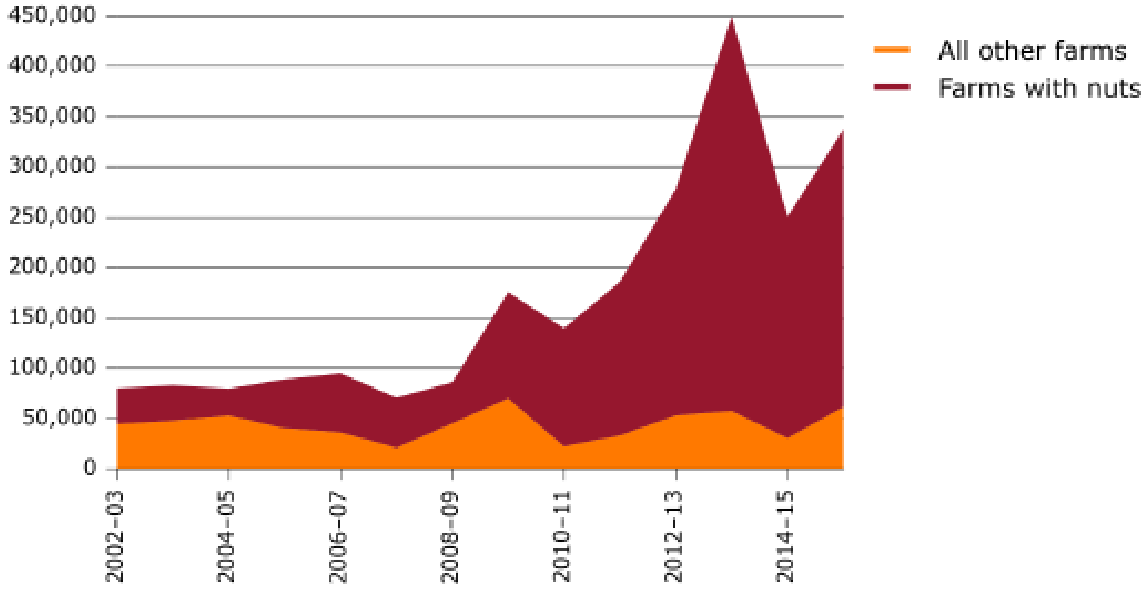
Source: ABARES (2018, p. 23)

Given the flexibility of annual crops, such as cotton and rice, to cease production in dry years and sell their allocation on the market instead, market prices are somewhat determined by their output prices: if the rice price is high, the allocation price needs to be proportionally higher to incentivise rice irrigators to stop producing. Douglas et al. (2016) discusses the various motivations of irrigators' planting decisions.

In recent years, there has been a material increase in almond plantations in the sMDB, driven by good almond prices, growing and unmet global demand, stemming from a production shortfall in California[20] due to drought (Reisman 2019). The area planted for almonds has increased more than 12-fold, from 3,546 ha in 2000 to 45,088 ha in 2018. Of these, 53% is planted in the Sunraysia district (VIC), followed by 24% in the Riverina (NSW) and 20% in SA (ABA 2019). This has translated to substantially increased water use by almond and nut farms since 2002/03 in the Lower Murray (see Figure 3.17).

[20] California is the world's most important almond producing region, supplying about 80% of global almond demand (Fulton et al. 2019).

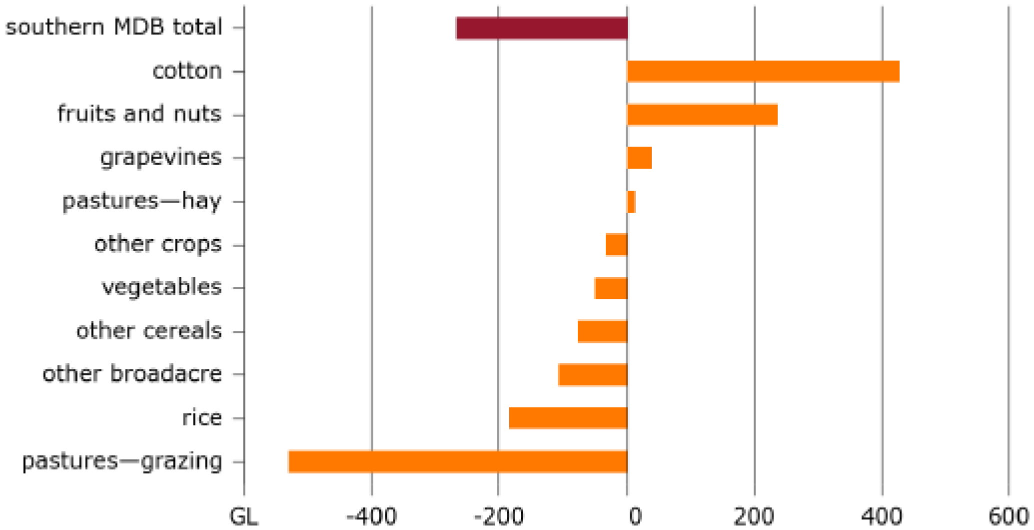
Figure 3.17 Water used (ML) by farm type in the VIC Murray zone 7 from 2002/03 to 2015/16



Source: ABARES (2018, p. 24)

Cotton is the dominant annual crop in the MDB, with larger areas planted in the nMDB, but growing area in the sMDB, and almonds and nuts are the dominant perennial crops. ABARES modelling shows that irrigated activity in the sMDB has moved from other irrigated activities towards these sectors [see Figure 3.18] (ABARES 2018).

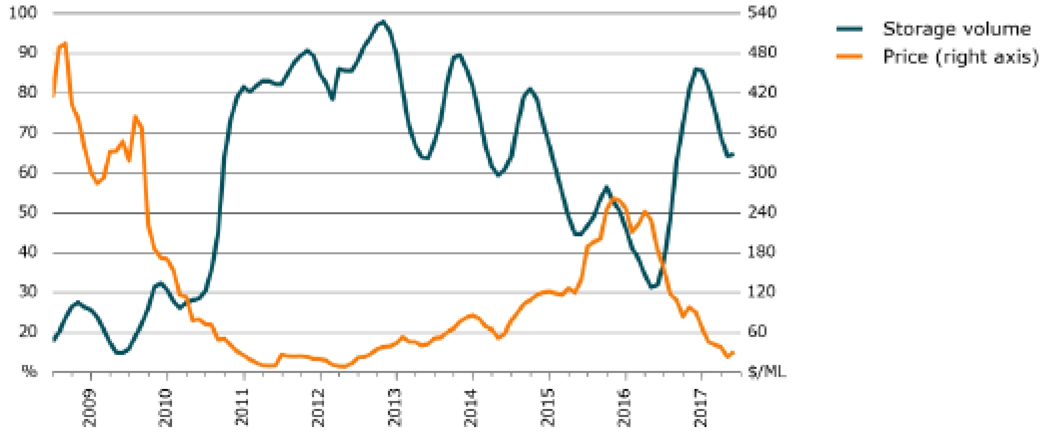
Figure 3.18 Modelled change in sMDB irrigated activity water demand from 2003–2017 by the ABARES water trade model



Source: ABARES (2018)

Water trading and prices are not only driven by cropping systems, changes in the agricultural industry and commodity prices, but also by physical scarcity, caused by the highly variable rainfall in the Basin (see section 2.1.1). While entitlement trading is less impacted by short-term climatic conditions, allocation prices are driven by rainfall and drought, showing a close inverse relationship with MDB water storage levels [see Figure 3.19] (ABARES 2018; Wheeler et al. 2008a; Zuo et al. 2015a; Zuo et al. 2019).

Figure 3.19 Average monthly nominal sMDB allocation prices and storage volumes from 2008/09 to 2016/17



Source: ABARES (2018, p. 29)

While water availability, output prices and changes in the agricultural industry are important influences on irrigators' trading behaviour and on water market prices, there are also other considerations, as highlighted in the following two sections.

3.5.1 Selling permanent water to the government

Government involvement in form of environmental water recovery through *RtB* and SRWUIP had a marked impact on irrigators' intentions to trade entitlements (Wheeler et al. 2012b). While in the direct sense, only buyback is a sale of water entitlement to the government, irrigation infrastructure programs also exchange a portion of one's water entitlement (50% of the water savings) for a monetary subsidy. Therefore, this chapter regards both modes of environmental water recovery as selling water entitlements to the government.

Irrigators sell water to the government for a variety of reasons. Wheeler and Cheesman (2013) surveyed sellers to the RtB and found that 30% of irrigators selling to the *RtB* did so to reduce farm debt and thus improve their financial situation during the Millennium Drought. Another 22% participated in order to supplement farm income and make their farm more viable, whereas 8% used funds acquired by the sale to make on-farm investments. The majority (60%) of irrigators only sold a part of their entitlements. However, 10% sold all of their entitlement holdings but continued to farm, demonstrating that entitlement sales to the government were part of a strategic decision to adjust farming and production systems. Indeed, irrigators nominated the generation of cashflow as the main driver for selling water to the government (Wheeler and Cheesman 2013). This is in line with other studies, finding that lower farm income and higher debt positively impacted on irrigators' willingness to sell water to the government (Wheeler et al. 2012b). Irrigators with higher security entitlements were found to be more willing to sell (Wheeler et al. 2012b), likely related to more revenue from higher security entitlement sales, while still retaining enough water supply security due to high expected water yield from these entitlement classes. Additionally, larger entitlement holdings also increased willingness to sell entitlements, partly due to some irrigators owning surplus water or having underutilised water entitlements, which could be sold without impacting farm production (Wheeler and Cheesman 2013; Wheeler et al. 2014c; Wheeler et al. 2012b).

Counter the popular narrative in rural communities and findings by a number of consultancies (e.g. (Aither 2016; RMCG 2016)), Zuo et al. (2019) found that government recovery of water entitlements did have no statistically significant impact on entitlement prices and trading volumes, nor on allocation prices. Rather, the main driver for allocation prices was water scarcity, whereas entitlement prices were driven by previous entitlement prices and current allocation prices. However, government water recovery had a statistically significant negative impact on traded allocation volume (e.g. a 1% increase in water recovery led to a 0.14% reduction in allocation volume traded) and increased the volatility of allocation market prices and trading volumes. This may be due to different methodologies used: Connor et al. (2014) find econometric estimates of marginal revenue changes due to water allocations are lower than results from the two mathematical programming (ABARES 2011; Adamson et al. 2011) and one Computable General Equilibrium model (Wittwer and Griffith 2011), which potentially overestimate the effects of water recovery under the *Basin Plan*.

Other research investigating the impacts of selling permanent water on farm finances (both current and lagged) have found that there was only very weak evidence that selling water entitlements lead to negative consequences for farm income in the longer term (Wheeler et al. 2014c; Wheeler et al. 2014d).

Engaging in entitlement sales to the government was also used by some irrigators (30% of *RtB* participants) as a way to exit farming (Wheeler and Cheesman 2013), with the willingness to sell all water and exit irrigation increasing at higher AUD$/ML prices for entitlements (Zuo et al. 2015b). This may have contributed to the popular perception in irrigation communities that selling water to the government is a main driver of farm exit (Wittwer 2011). Interestingly, Haensch et al. (2019) found a neighbourhood effect for entitlement sales to the government, with an increased probability of entitlement sales if a neighbour has sold to the government. This is likely due to decreasing social pressure to retain entitlement ownership if other community members have already participated in buyback programs. Indeed, Wheeler et al. (2020b) found that the major causes of farm exit in the MDB are climatic and socio-economic factors, such as drought and output prices, not water trade.

Irrespective of scientific evidence pointing to its economic inefficiency (Adamson and Loch 2018; Grafton and Wheeler 2018; Productivity Commission 2010; Wittwer and Dixon 2013; Wittwer and Young 2020), the main mechanism for government purchase of water from irrigators from 2013 onwards has been through irrigation infrastructure grants (Grafton and Wheeler 2018).

However, recent research has found that irrigators who participated in irrigation infrastructure programs are more likely to increase their utilisation of existing water entitlements (including groundwater) and buy water allocations and entitlements on the market (Wheeler et al. 2020a). This creates artificial demand in the water market, potentially leading to increased entitlement prices.

Irrigation infrastructure subsidies incentivise irrigators to increase the utilisation of existing water resources and adopt perennial production systems, to maximise the benefit from more efficient infrastructure (Adamson and Loch 2014; Loch and Adamson 2015). While accelerating change in agricultural systems (e.g. towards almonds) and therefore potentially contributing to higher water prices based on crop output prices, it also leads to inflexibility in production systems, because perennial producers cannot easily change production systems without loss of capital. This causes a hardening of water demand, given that perennial producers tend to be net water buyers in all but the wettest years. Perennial producers are also willing to pay very high allocation prices, above the level of generating operational losses (short-term choke price), to prevent catastrophic loss of capital in drought or periods of water scarcity (Adamson et al. 2017). This may lead to higher allocation prices in periods of water scarcity, potentially crowding out lower value perennial industries, particularly under an expanding area of perennial production.

Additionally, being locked into perennial production may increase water entitlement demand in general, plus increasing water electricity prices, which is a main form of stress for perennial producers (Wheeler et al. 2018). Following Adamson et al. (2017), a risk-averse perennial producer aims to secure enough water to maintain plant health even in the driest scenarios, requiring significant water entitlement holdings. With MDB perennial producers risk averse to downside risk [namely catastrophic capital loss] (Nauges et al. 2016), this likely translates to increased demand for high security water entitlements and correspondingly high prices.

Adamson and Loch (2014) find that the largest water savings through infrastructure can be achieved by upgrading off-farm supply, rather than on-farm irrigation infrastructure. Investment in efficiency thus increases the asset value of IIO systems and associated agricultural properties, as public investment in irrigation infrastructure necessarily improves its value, resulting in private capital gains for farmers (Loch and Adamson 2015). Furthermore, upgrading irrigation infrastructure to pivot and drip systems is often a worthwhile investment for irrigators, even without government subsidies; subsidising these upgrades can inflate the value of irrigation enterprises (Lee et al. 2012). These gains will then be realized by farmers selling their properties, potentially increasing water entitlement prices if property value increases are distributed to the land and water component of the farm. This is particularly likely in NSW, where water entitlements' stamp duty exemption status incentivises overvaluing of water versus land assets (Revenue NSW, personal communication, 11/11/2019).

In summary, contrary to the claim that buyback has led to higher water entitlement prices, due to less water in the consumptive pool, there is the real potential that irrigation infrastructure subsidies are having unintended consequences on irrigators' water trading behaviour and contributing to increased water entitlement and allocation prices.

3.5.2 Trading in the private market

There are also other factors driving irrigators' water trading behaviour within the private market. Irrigators have been using water trading as an important risk management tool for years. Allocation trading allows irrigators to manage risk without having to modify their entitlement ownership (Bjornlund 2006). Intra- and inter-seasonal trading strategies enable irrigators to remain in production in times of water scarcity, generate opportunistic income from price fluctuations or to protect asset values (Bjornlund 2002). Allocation demand becomes more price elastic in later stages of the season since temperatures generally drop, requiring reduced irrigation, and crops are then harvested. However, a considerable amount of end of season trades are undertaken to balance water allocation accounts (Wheeler et al. 2008b), and to manage carry-over between seasons[21] (Brennan 2008; Loch et al. 2012).

Allocation trading has provided significant drought mitigation benefits: dairy producers were able to sell their allocations and buy fodder during the Millennium Drought, generating good returns from water sales while also avoiding the need to destock (Kirby et al. 2014a). Additionally, allocation trading significantly limits the negative impacts of water scarcity through drought and climate change: Kirby et al. (2014a, pp. 157, table 1) found that real adjusted gross value of irrigated production in the MDB during the Millennium Drought from 2000–2001 to 2007–2008 fell by just 10%, despite a 70% decline in irrigated surface-water use. Additionally Kirby et al. (2014b) estimated a climate change induced 25% reduction in future annual average water availability corresponds to only a 10% contraction of GVIP, as water allocations get traded from lower to higher value irrigation activities.

Loch et al. (2012) found that it was predominantly perennial irrigators who bought allocation to keep crops alive in seasons with low water availability and drought, whereas annual producers were able to achieve higher incomes from selling allocations to perennial producers rather than by growing a crop. Trading allocations early in the season is used as a strategy to mitigate the risk of developing water scarcity and higher prices later in the year. Allocation trading allows sMDB irrigators to adjust to seasonal fluctuations in commodity prices, precipitation, evaporation and water allocation levels, especially during prolonged drought, with irrigators experiencing higher variability in profit and increased downside risk, purchasing more allocations (Loch et al. 2012; Zuo et al. 2015a).

Overall, there are five main drivers for water allocation trading identified by the NWC (2012):

- Generation of additional income
- Minimising input costs
- Maintaining productive capacity during drought and water scarce periods
- Improving farm productivity/production
- Enabling water to be carried over to the next season

Irrigators' non-government water entitlement trade motivation is strongly impacted by whether an irrigator is an annual or perennial producer. As mentioned earlier, perennial producers tend to prefer a larger holding of higher security entitlements to minimise downside risk (Adamson et al. 2017; Nauges et al. 2016). Perennial producers have further incentive to buy entitlements when prices are low, due to the high marginal profit of one extra megalitre of water, estimated at an average of AUD$547 for horticultural and AUD$61 for broadacre producers (Nauges et al. 2016). However, Zuo et al. (2016) find that entitlement price elasticities of supply and demand are inelastic between AUD$1,700 – AUD$2,100, with supply more inelastic than demand. This supports findings by Wheeler and Cheesman (2013) that it is primarily farmers with higher debt levels and lower incomes who opt to sell entitlements, with other irrigators generally preferring to hold on to their entitlements.

However, irrigators also trade entitlements to relocate their production, for example to a region experiencing less dryland salinity, or to substitute between surface water and

[21] In drier years, extra allocation may be bought to build up carry-over, whereas in wet seasons allocation may be sold in order to avoid carry-over spill in the next season.

groundwater (Wheeler et al. 2010; Wheeler et al. 2016b), with higher groundwater salinity leading to less volume of entitlement sales (Haensch et al. 2016b).

Irrigators employ diverse water ownership and trading strategies, ranging from owning little or no water and relying on water allocation markets to meet annual demand, to holding a large proportion, or in excess, of their annual needs in water entitlements, enabling the sale of excess (allocation) water. While some irrigators do not engage in water trade, this proportion has decreased significantly over time, with almost 80% and more than 40% of irrigators having conducted at least one allocation and entitlement trade respectively, in the sMDB (Wheeler and Garrick 2020). However, no specific ownership and trading strategy seems superior to others. Rather, different strategies are suited to different production systems. Wheeler et al. (2014d) found that water received (from allocation to entitlement holdings) was a more important influence on farm income for perennial (horticulture) irrigators, than for dairy, pasture or annual (broadacre) farmers. Given the seasonal nature of broadacre crops, such as cotton and rice, it is the optimal strategy for many broadacre farms to severely reduce or stop farm production and to sell water in times of water scarcity and drought.

3.6 Environmental water holders' market participation

Since *The Living Murray* and the *Water Act*, the environment is now a participant in the water market through the establishment of the CEWH and other EWHs, and their growing engagement in water markets (Loch et al. 2011). However, the motivations and trading patterns of environmental actors are very different to those of irrigators.

There are two types of environmental water in the MDB: planned and held environmental water. The *Water Act* (Part 1, Section 4; Part 1, Section 6) and *Basin Plan* (Chapter 10, Part 3, Division 1, Section 10.09) define them as follows:

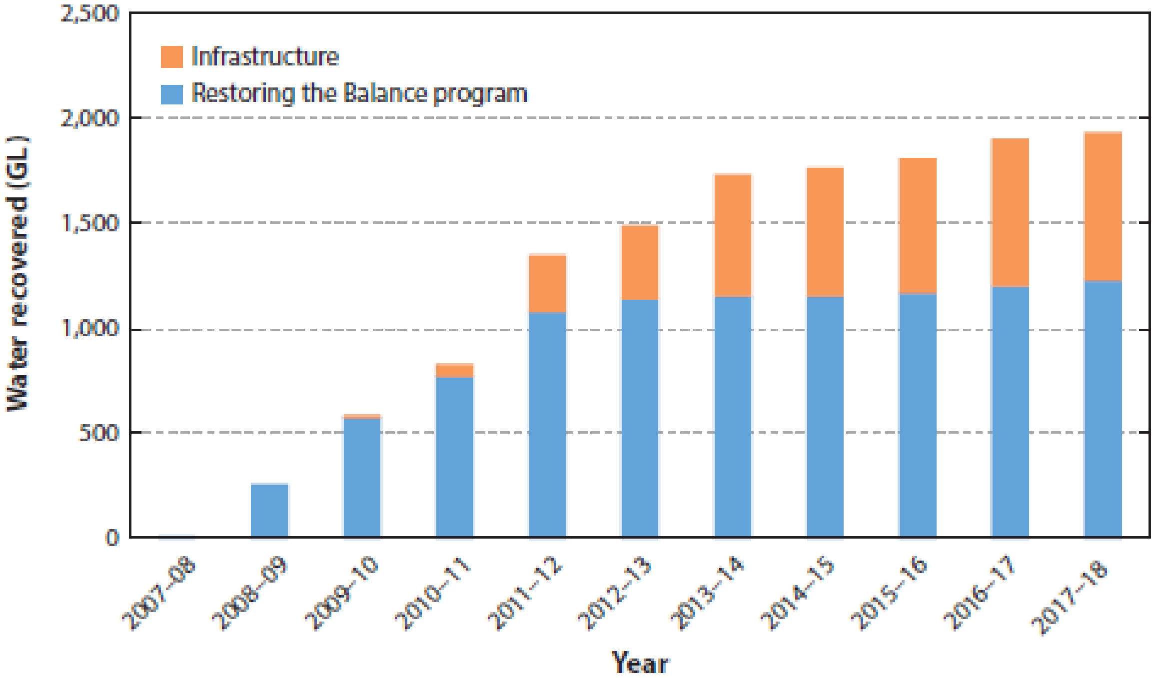
Planned environmental water (also called rules-based water) is prescribed under water resource plans, the *Basin Plan* or state legislation. In unregulated rivers, planned environmental water can be achieved through water take restrictions (i.e. no pump embargos) to ensure a minimum of environmental flow to specific environmental assets. In regulated rivers, water resource plans determine the frequency, volume and timing of water to be released for environmental purposes. Planned environmental water cannot be used for any purpose except environmental watering and cannot be traded on the market.

Held environmental water is water attributed to water entitlements, water delivery or irrigation rights and is owned (held) by an environmental water holder. This water is managed to achieve environmental outcomes. Held environmental water retains the characteristics of the underlying water right, and is therefore subject to the same trade restrictions, allocation and storage rules. Most of the held environmental water is owned by the CEWH and was recovered by the *RtB* or infrastructure programs (SRWUIP).

As of 31st December 2019, the Commonwealth owned about 2103.8GL of LTAAY of water entitlements, which is about 77% of the original 2750GL water recovery target under the *Basin Plan* (DAWE 2020b). fifty-nine percent[22] of this volume has been recovered through the *RtB* program, with the remainder through infrastructure upgrades [see Figure 3.20] (Grafton and Wheeler 2018).

[22] 1231GL of LTAAY recovered by *RtB*, divided by 2103.8GL LTAAY of entitlement holdings at 31st December 2019.

Figure 3.20 Commonwealth environmental water recovery entitlement volume as of 30/09/2017



Source: Grafton and Wheeler (2018, p. 495)

The main objective of EWHs is to maximise environmental outcomes with the planned and held water available to them. Outcomes are defined in ecological terms, such as number of bird breeding pairs or the time flood plain areas are inundated, with priority in dry years given to environmental assets of great ecological significance, referred to as the "icon sites" (MDBA 2014a).

Under the *Water Act*, environmental outcomes are to be achieved through adaptive management, with the *Basin Plan* defining and implementing particular practices (Walker 2019). Indeed, a number of studies have explored the benefits of EWH water market participation and trading as a form of adaptive management (Ancev 2015a; Carr et al. 2016; Connor et al. 2013; Kirby et al. 2015; Loch et al. 2011; Tisdell 2010; Wheeler et al. 2013a).

Tisdell (2010) found that allocating tradeable water to an environmental agency maximized market efficiency, suggesting that strategies for effectively trading water for environmental use may include opportunistic trading in order to be cost effective, potentially through leasing water out when not needed, and leasing water in to support environmental flows. Loch et al. (2011) suggest that rules-based water rights should be utilised to meet environmental instream flow targets, whereas governments should also employ targeted opportunistic temporary (allocation) and permanent (entitlement) water market purchases to contribute over-bank floods and flushes.

Ancev (2015a) found that active allocation trading by the CEWH was beneficial for the environment and society. This enables to maximise environmental outcomes by purchasing extra water allocation at times when they have the largest environmental benefit, e.g. after a drought breaking or in wet years to increase over-bank flows and flood plain inundation events. However, entering a drought after a multi-year wet period or in dry periods, the CEWH can sell water allocation to irrigation, as the environmental benefit of this water is comparatively less than the benefit it generates through irrigation. Expanding on the previous study, Ancev (2015b) finds the benefits from an actively trading CEWH extend to climate change, with larger benefits manifesting under more severe climate change scenarios. While increasing the volume of environmental water available, active trading also provides benefits to irrigated production through the trading patterns suggested in Ancev (2015a). Although it is a good policy to accumulate environmental water rights, this water should not be barred from active water allocation markets, but rather active trading employed to realise the significant gains from environmental allocation trade, both for the environment and the society at large (Ancev 2015a, 2015b).

The yield characteristics of irrigation water entitlements (held water) do not necessarily match environmental hydrological requirements: while entitlement yield is typically lower early in the irrigation season (July-October) and rises over time to its high point towards the end of the season (April-June), many MDB ecosystems benefit from floods early and late in the season, but receive no material benefit from high water levels in summer (October-February). Connor et al. (2013) examine whether temporary trading around these temporal dimensions can increase environmental outcomes. They find that there is scope for EWHs to improve outcomes through temporary trading, particularly in drought and by increasing the frequency of moderately large floods. An environmental trading regime of buying water when prices are low, and selling when prices are high, seems to have relatively small impacts on water market price outcomes due to EWH water trading (Connor et al. 2013). Indeed, the strategy of "buying low and selling high" (countercyclical trading) is exactly how the MDB Balanced Water Fund achieves the dual targets of improving environmental health and generating investor returns (Carr et al. 2016). Water allocation is bought in wet periods to expand environmental watering events, and sold to irrigation in dry periods when prices are high and environmental assets are adapted to experience drying.

Given the focus of *RtB* and infrastructure programs on recovering water entitlements, Wheeler et al. (2013a) explored alternative water recovery options, such as allocation trade and water leases. The CEWH was found to be able to recover more environmental water/deliver more environmental outcomes over the 10-year funding horizon of the *RtB* by employing a mix of entitlement and allocation purchase. This mixed strategy is also significantly cheaper, particularly if purchases are made strategically in non-drought periods (Wheeler et al. 2013a).

Kirby et al. (2015) examined a range of different water management and trading strategies for irrigators and environmental water holders under potential climate change scenarios, including the countercyclical trading described above (Carr et al. 2016; Connor et al. 2013), and rebalancing water entitlement holdings by selling in less and buying in more desirable catchments. Both rebalancing the portfolio and countercyclical trading result in higher than base flows for the projected median climate change scenario, while also increasing flows in most months. These increases occur without significant negative impacts for overall irrigation gross income. Therefore, greater river flows (and consequently greater environmental benefits) can be obtained without much impact on overall gross income of irrigators through market acquisition of permanent water entitlements and portfolio rebalancing, or the temporary trade of annual allocations (Kirby et al. 2015).

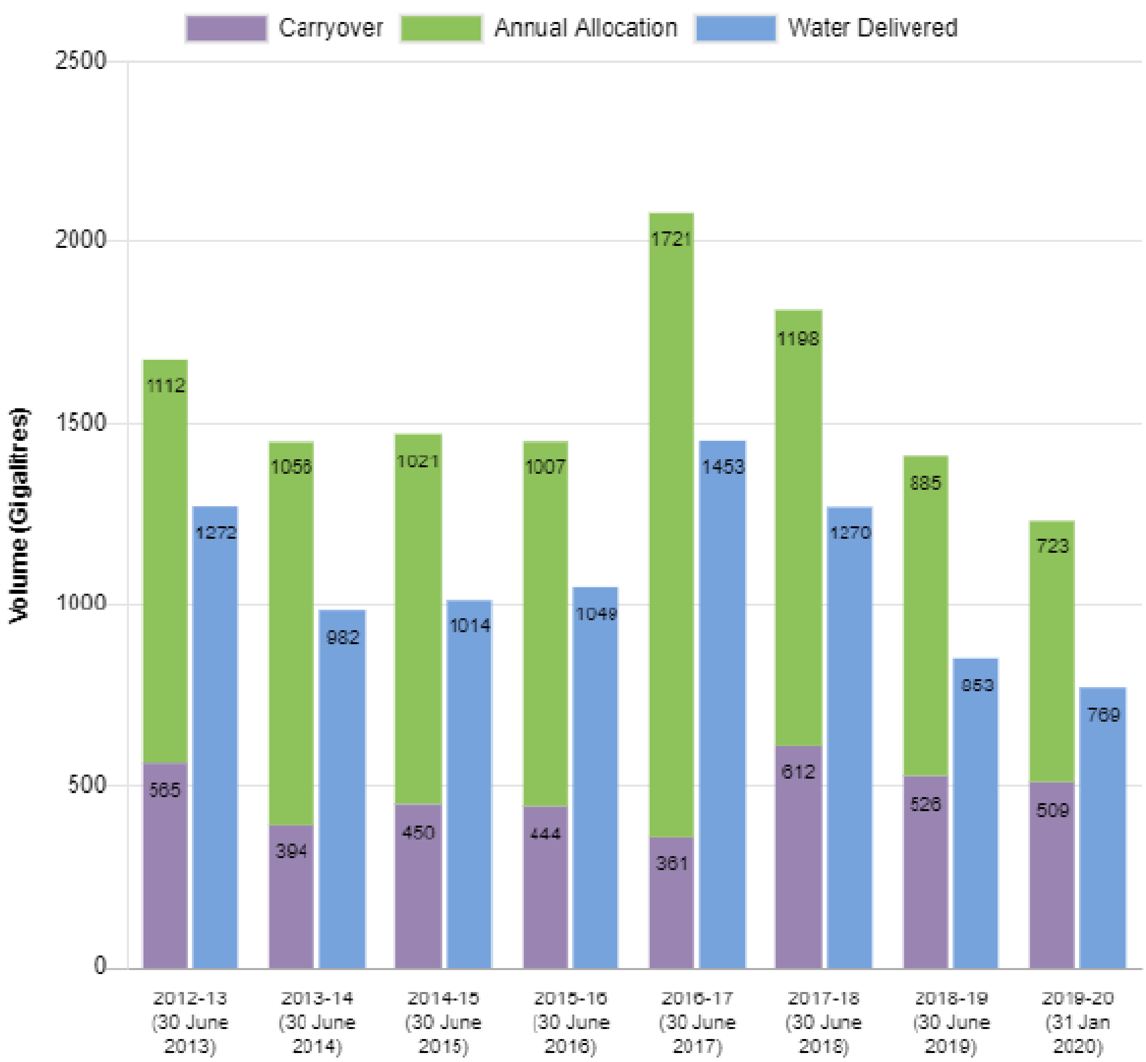
Evidence suggests that adaptive environmental water management should incorporate active trading decisions, in particular (countercyclical) allocation trading, leases, and rebalancing of water portfolios. Fortunately, these adaptive management strategies have not been found to negatively impact irrigators' positions in water markets, while also achieving higher environmental benefits for less cost, compared to a recovery of environmental water through entitlements only. In a sense, EWHs ought to utilise the same diverse set of trading and ownership strategies observed in the irrigation industry. This would both achieve allocative efficiency—recovering water for least cost—and environmental water productive efficiency—maximising the benefits of environmental watering while keeping managing costs low (Horne et al. 2018).

However, observable (public) EWH trading and ownership strategies do not fully reflect the findings and suggestions of the scientific literature. For example, the composition of the CEWH water portfolio under the *Basin Plan* is a function of individual water recovery targets in every catchment, rather than targeted entitlement acquisition in certain key areas.

3.6.1 Non-commercial trading: environmental water delivery and transfers

The majority of public EWH water market participation consists of using carry-over and non-commercial transfers of water allocation within, or between, environmental organisations. Figure 3.21 shows CEWH water transfer and carry-over volumes from 2012/2013 – 2019/20.

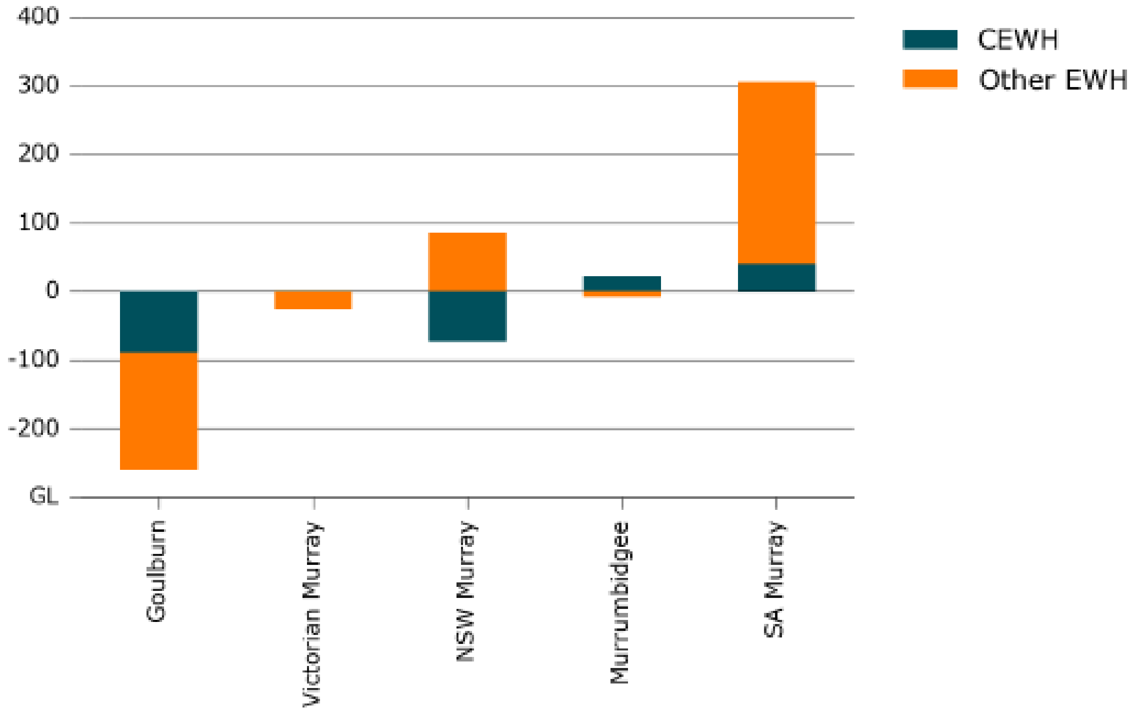
Figure 3.21 Commonwealth environmental water allocation and carry-over 2012/13 to 2019/20



Source: CEWO (2020a)

Given the structure of water registers, these transfers are listed as AUD$0/ML trades and make up a material part of water allocation trades each year (MDBA 2019m). Figure 3.22 provides an overview of EWH transfer volume across sMDB catchments in 2016/17.

Figure 3.22 Environmental water holders' net water allocation transfers in the sMDB as at 2016/17



Source: ABARES (2018, p. 32)

This phenomenon is based on a number of factors. For one, the CEWH does not undertake environmental watering actions itself, but rather enlists the assistance of partnering organisations on the ground, often environmental NGOs or IIOs (CEWO 2019). These organisations receive a transfer of environmental water into their allocation bank account from one of the CEWH's allocation bank accounts to then apply water to environmental assets. Consequently, every environmental watering action the CEWH participates in has at least one associated AUD$0/ML trade. Often multiple EWHs combine their efforts, e.g. to create a larger flood to reach onto the floodplain, pooling water resources from: 1) multiple sources; or 2) multiple organisations. Many of these will lead to transaction records in the water registers. Large EWHs may also wish to move allocations between catchments within their organisation; for example to enable releases from upstream storages later in the year. These transfers will also appear as AUD$0/ML trades if they take place between different allocation bank accounts.

This can have interesting interactions with IVTs: as environmental water transfers are treated like allocation trades, they contribute to the balance of inter-valley trade accounts, potentially closing IVTs. Given their large water holdings, both the CEWH and the Victorian Environmental Water holder have adapted a so called "good neighbour" policy, giving priority to any private/commercial allocation transaction/delivery, if the environmental transfer has the potential to negatively affect deliverability of private trades (CEWO 2019). This essentially makes held environmental water second-class entitlements, with irrigated and consumptive use still given priority, despite identical legal entitlement conditions.

3.6.2 Commercial trading: the CEWH water trading framework

Commercial allocation and entitlement trading by public EWHs is rare and follows strict guidelines, mainly based on the CEWH Trading framework (CEWO 2014), defining under what conditions environmental water allocation and entitlements can be traded. The framework (CEWO 2014, p. 4) states that trade can be used to:

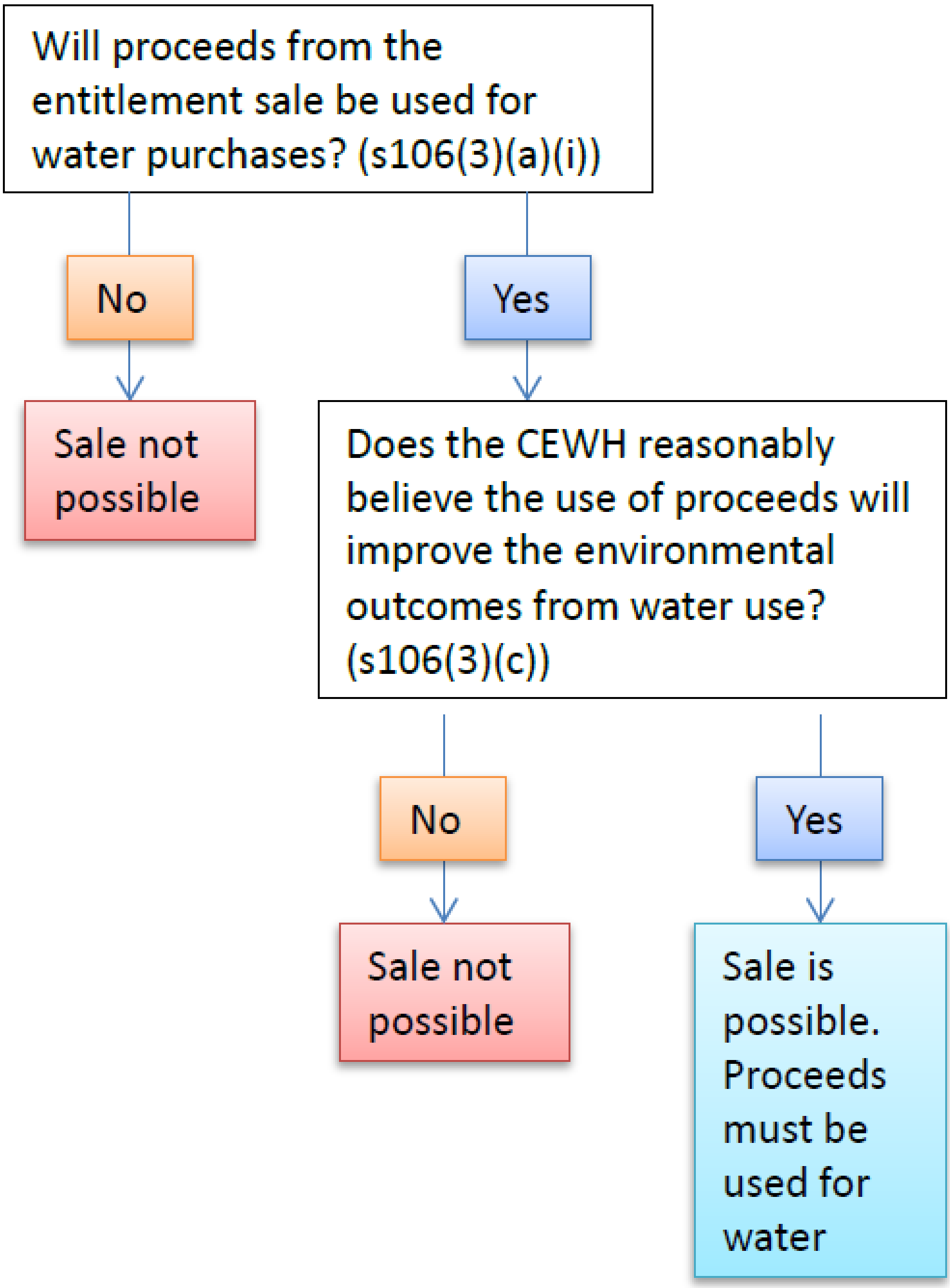
- Manage inter-spatial variability in water availability and environmental water demand across the MDB, for example by selling allocation in one catchment where environmental watering needs have largely been met and purchasing in another catchment where additional environmental water would be particularly beneficial.
- Manage inter-temporal variability, for example by selling allocations when environmental needs have largely been met and/or market conditions are favourable and setting aside the proceeds for a later purchase of allocations that will result in a net improvement in environmental outcomes.
- Re-balance the portfolio of entitlements based on improvements in the knowledge of environmental watering requirements.
- Overcome constraints on the delivery of environmental water, for example by selling allocations in one location and using the proceeds to purchase in another location should it not be possible to otherwise transfer the allocations between locations.
- Realise a return on allocations that are not required for environmental watering within a given water year and cannot be carried over into the following year.

At large, public EWHs have generally refrained from actively purchasing allocations to deliver environmental outcomes due to concerns over adversely impacting irrigators' allocation trade prices and market access. However, as at March 2020, the CEWH is currently considering purchasing water allocations (AUD$2 million worth) in the nMDB from Queensland agribusiness Eastern Australia Agriculture (Davies 2020). To the author's knowledge, this is the first time the CEWH buys water allocation. EWHs usually rely on water allocations received on their entitlements and their carry-over to undertake environmental watering actions.

By contrast, EWHs have sold allocations to irrigators on the open market (VEWH 2018b). While these sales are often justified by claiming the allocation would be lost due to insufficient carry-over availability and could not be used for environmental outcomes (VEWH 2018c), there are arguably political considerations at play. EWHs do not want to increase tensions with irrigators, particularly in drought, and therefore sell allocations to signal they are "doing their bit" by ensuring that the environment shares the pain of drought, while also supporting struggling farmers. For a visualisation of permissible CEWH water allocation sales, see Figure A.9 and Figure A.10.

With the ban on buybacks in 2015 [see section 2.2.5.2] (Parliament of Australia 2015), entitlement buybacks to increase water holdings are impossible, although EWHs may still sell and buy entitlements to rebalance their current holdings, as suggested by Kirby et al. (2015) and Wheeler et al. (2013a). Figure 3.23 provides a visualisation of CEWH entitlement trading decision parameters.

Figure 3.23 CEWH entitlement trade under the Water Act



Source: CEWO (2017, p. 22)

At the time of writing, the CEWH has not traded any entitlements for rebalancing or other purposes (CEWO 2020b), other than receiving entitlements recovered by the Department of Agriculture.

In contrast to suggestions within the literature, public EWHs in Australia have in practice mostly limited themselves to selling unused allocations, but do not engage in commercial entitlement trade and only tentatively start to opportunistically purchase allocation. The focus on using ones' own water, from carry-over or allocations to entitlements, likely constrains the potential to achieve environmental outcomes, and is less cost-effective than utilising opportunistic, countercyclical trading and rebalancing of water portfolios (Kirby et al. 2015;

Wheeler et al. 2013a). This limitation is mainly due to the political considerations of potentially adverse impacts for irrigators arising from environmental trading activity. However, Wheeler et al. (2013a) and Loch et al. (2014b) have shown that irrigators' willingness to engage in water allocation trade is much higher than water entitlement trade. Other research is unable to establish negative impacts from environmental trades on irrigators' gross revenues (Ancev 2015a, 2015b; Tisdell 2010). In summary, limiting EWHs to not actively trade may undermine EWHs' capabilities to manage their held environmental water portfolios, with good neighbour policies relegating EWHs to second class water market stakeholders in practice.

3.7 The gap: non-landholder investors, derivative-type water products and water as an investment asset

Overall, the review of water market functionality, trading patterns and motivations of irrigator and EWH stakeholders has shown they use similar ownership and trading strategies, albeit within policy frameworks that constrain the choices of EWHs to a greater extent. However, new derivative-type temporary water market products are largely unexplored in the MDB literature.

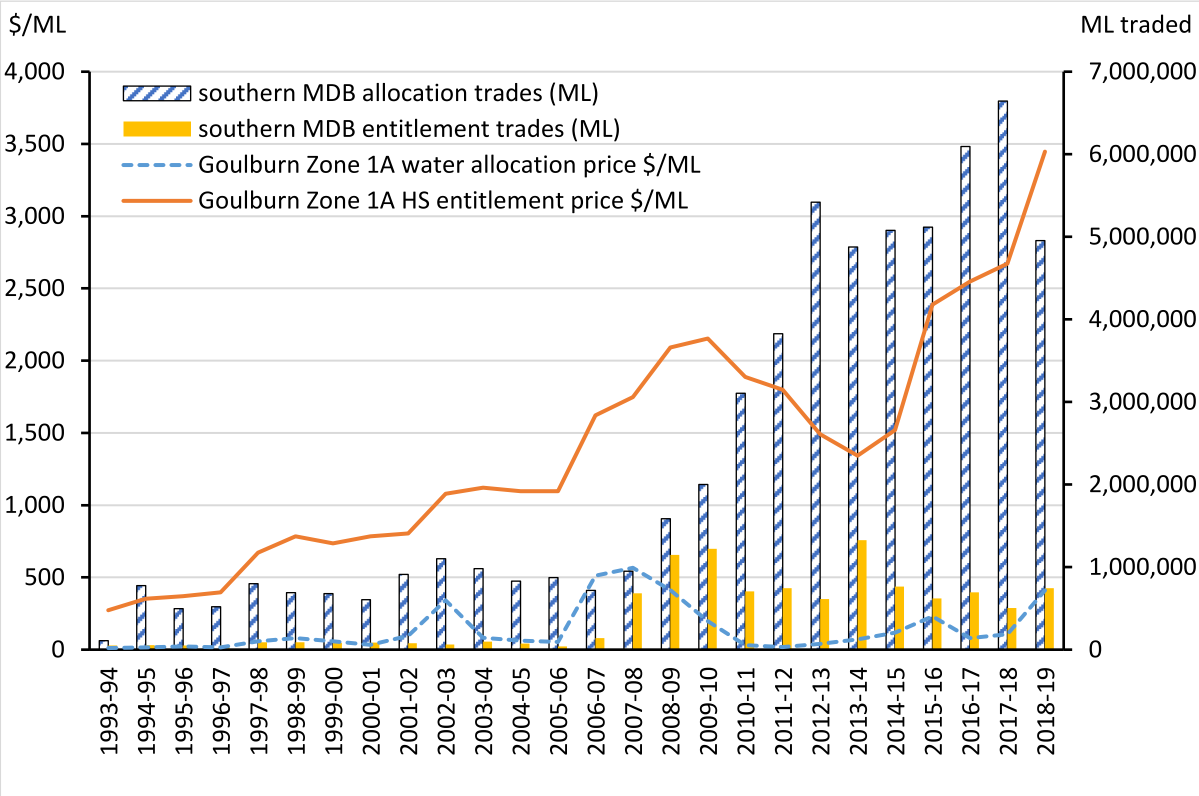
Bayer and Loch (2017) discuss water forwards in an experimental setting, Brennan (2008) discusses the potential of trading carry-over space between irrigators (what are now known as water parking products) and Wheeler et al. (2013a) suggest water leases as an alternative way to recover water for the environment. Less is known about whether stakeholders will embrace these products, apart from research in Loch et al. (2014b) regarding irrigator willingness to participate in selling water allocations. The lack of studies can be at least partially attributed to the difficulty of assessing data on these products: they are indistinguishable from allocation and entitlement transactions in the water registers (ABARES 2018; MDBA 2019m), making quantitative assessment challenging. However, understanding derivative-type products and their use is important in answering a number of pressing questions:

- How do water market participants view derivative type products, in terms of their risks and benefits for water management? Do different stakeholder groups have different views on these questions?
- Do derivative-type temporary products accompany or replace existing water entitlement portfolio management strategies for irrigators?
- Do EWHs use derivative-type temporary products more proactively than they use allocation and entitlement trading?
- Are there significant differences in the use of derivative-type temporary products between different water market stakeholders?
- Is water market trading behaviour changing due to these new products?

Given the maturing of MDB water markets over time, it is likely that derivative-type temporary products represent the next step in water market evolution, making timely answers to the questions raised above important.

Successive water policy reforms in the MDB (see section 2.2), and the unbundling of water rights in particular, have led to increasing water market liberalisation and trade facilitation, up to a point where water entitlements are now a mortgageable asset (Waterfind 2019a). They can yield water market returns from trading water allocation and capital gain from the recent strong increase in water entitlement prices (Bjornlund and Rossini 2007; Wheeler et al. 2016a). Prices particularly increased for high security entitlements in important sMDB water trading zones, such as Murrumbidgee, Greater Goulburn, and VIC and NSW Murray below the Barmah Choke (see Figure 3.24 regarding the increase in high reliability entitlement prices in the Goulburn district).

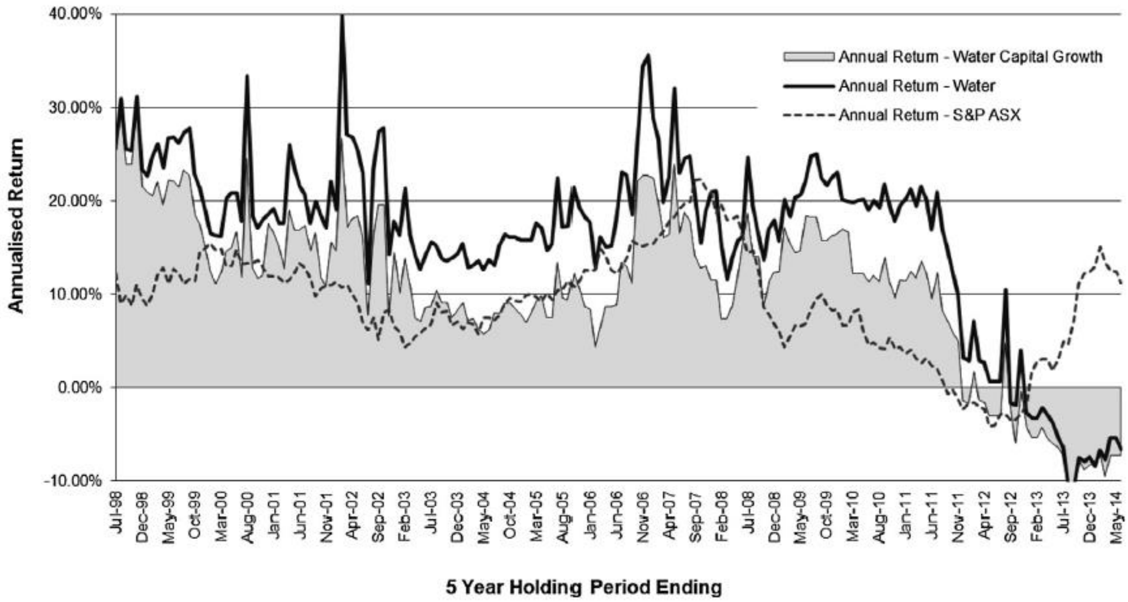
Figure 3.24 Temporary and permanent annual nominal water prices in the Goulburn and sMDB water trade volumes from 1993-94 to 2018-19



Source: Own figure, data sourced from NWC (2011a), BOM (2020g) and DELWP (2019b)

Indeed, Wheeler et al. (2016a) found that returns from investing water entitlements are competitive to returns from investing in the ASX 200 (see Figure 3.25), making water a lucrative option for investors.

Figure 3.25 Return from water market investment, compared to the S&P ASX accumulation index



Source: Wheeler et al. (2016a, p. 382)

This raises some important questions regarding water as a financial asset and as collateral:

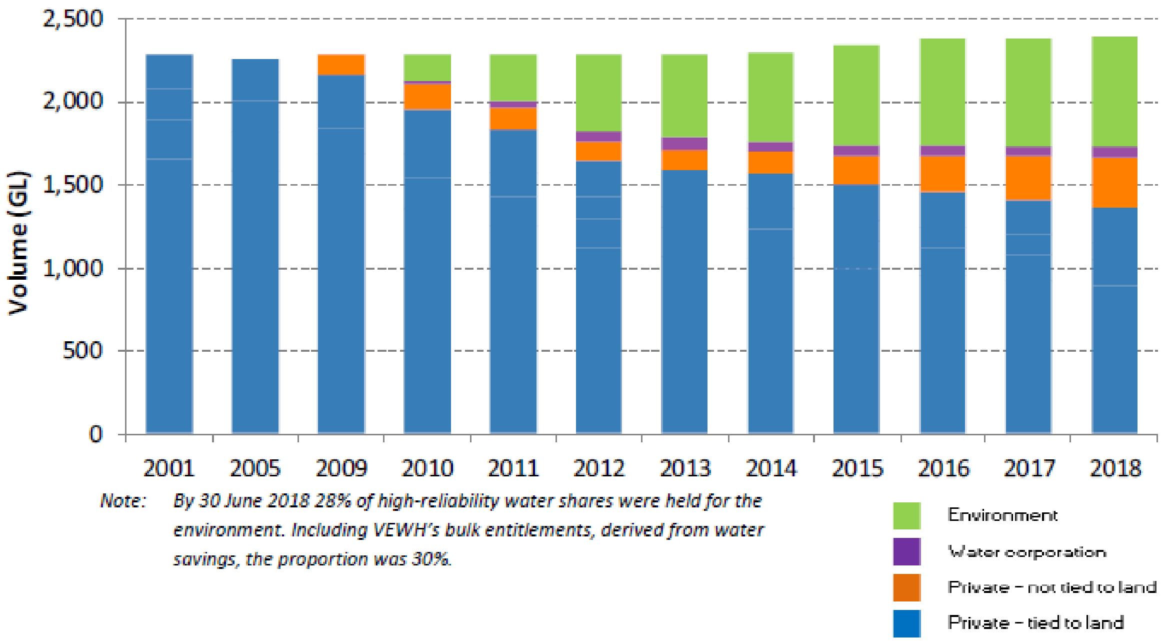
- Do MDB stakeholders view water primarily as an investment asset?
- How does the risk and return from water investment compare to other investment assets?
- How is water valued for financial, investment and mortgage purposes?

MDB water entitlements have moved into the focus of the financial investment community (Roca et al. 2015) and have attracted some investors over the last 10 years. Investment takes two general forms: 1) as part of investing in corporate agricultural production, owning land and water [often high value horticultural crops like almonds] (ISA 2017); or 2) investing directly into water entitlements to generate water market returns, without owning land or engaging in agricultural production. For this thesis, we refer to these actors as "agri-corporates" and "non-landholder[23] financial investors".

Quantitative information on both agri-corporate and non-landholder financial investor water ownership and trading behaviour is extremely limited. There is no publicly available register of agri-corporate land and water ownership, apart from what companies publish in their annual financial reports. For non-landholders, the closest approximation of water ownership is provided by DELWP (2019a) in form of water entitlements owned by the "non-user group" [not-tied to land] (see Figure 3.26).

[23] Note that most EWHs also do not own land. We therefore include them in the definition of non-landholder stakeholders.

Figure 3.26 Ownership of northern Victorian high-reliability water entitlements by stakeholder group



Source: DELWP (2019a, p. 9)

Non-user ownership of high-reliability water entitlements increased from 5% in 2009 to 12% in 2018 (DELWP 2019a). The definition of "non-user" applies to every allocation bank account without an irrigation or land-use licence attached to it. It therefore also applies to irrigators' water held in self-managed superannuation accounts, likely making up the majority of the non-user group. Therefore, true non-landholder financial investors' ownership is likely still small, but is increasing (DELWP 2019a). There has been a lack of research into why financial investors choose to invest in water entitlements and markets. One reason could be the attractive returns from water investment (Wheeler et al. 2016a). Another argument is that water investment provides diversification benefits (Roca et al. 2015), and is an alternative way to invest in agriculture (ISA 2017). Ultimately, which of those arguments is the main driver, or if there are others, is currently unknown. Similarly, how non-landholders own and trade water, including derivative-type products, is unexplored in the peer reviewed literature, albeit there has been some experimental work done (Bayer and Loch 2017). However, there is some evidence from newspaper reports that non-landholder investors are significant sellers of derivative-type temporary water products (Testa 2019). Given the increasing share of ownership by non-landholder financial investors, this gives rise to the following questions:

- What motivates agri-corporate and non-landholder actors to invest in water?
- What ownership and temporary trading strategies are employed by agri-corporates and non-landholder investors?
- What is the impact of non-landholder and agri-coporate trading behaviour in the water market?

Combining the three topics of derivative-type temporary water products, water investment asset characteristics and emerging non-landholder water market stakeholders may pose challenges for current water market capabilities and institutions. Indeed, the way how water trading data is currently captured and reported seems unequipped to appropriately reflect these new developments. A new round of water policy reform to further facilitate water markets and a reduction in static transaction costs (Garrick et al. 2013) may be necessary to tackle the following questions:

- Are current policy and water market institutions equipped to engage with derivative-type temporary products and non-landholder water market stakeholders?
- If necessary, how can water market institutions and water policies be improved to keep pace with an evolving water market system?

The gaps identified in the water market literature are addressed in the following chapters, by combining different qualitative and quantitative data sets, containing information on irrigator, agri-corporate and non-landholder stakeholders.

Stemming from irrigators' discontent during the current drought and their historical uneasiness about non-irrigator water ownership (Bjornlund et al. 2011; Sullivan 2019), at the time of writing, the ACCC has been tasked with performing a review of current water market systems and institutions, paying particular attention to water investor ownership and trading behaviour, and to the influence of derivative-type temporary water market products (Frydenberg 2019). The reporting period of this inquiry is from the 9th August 2019, with the interim report to be published 31st May 2020, and the final report to be handed to the Commonwealth by 20th November 2020. The final report is expected to address a number of the questions raised in this section.

3.8 Conclusion

This Chapter has shown the complexity of MDB water markets. It showed that water markets in the sMDB are more active than those in the nMDB, for a number of institutional, historical, geographical and agricultural reasons. Water market products include permanent water entitlements, and temporary allocation trade, with new derivative-type temporary water products recently emerging within the market. Although water market participation has increased over time, enabled by continuous policy reform and falling static transaction costs, barriers to trade remain, mainly in the form of intervalley-trade restrictions.

The water market in Australia is now used by a multitude of different stakeholder groups, including irrigators, environmental water holders and non-landholder financial investors. Each stakeholder group has different motivations for trading and owning water, with irrigators using the water market mainly to secure production against periods of low water availability, and for income from opportunistic water allocation sales. EWHs have the potential to employ active and adaptive trading strategies to improve environmental outcomes but are historically have only sold water allocations, albeit the CEWH are looking to buy water allocations for the first time in 2020.

What is clear is that non-landholder stakeholders' ownership and trading strategies, as well as the use of derivative-type temporary products by all stakeholders, is currently unexplored. Similarly, it is unclear whether current water market instructions and regulations are equipped to deal with these new stakeholders and trading products. These gaps in water market research are the focus of Chapters six and seven of this thesis.

Chapter 4 Methods and data

The previous chapters of this thesis have reviewed the literature and identified the research gaps in irrigators' water market ownership and trading strategies. While each analytical chapter contains a dedicated methods and data section specific to the particular research question analysed, there is no justification of why these methods were appropriate for the completion of this thesis. This chapter therefore provides a brief overview of the methods and data used in this thesis, and how they are the appropriate approach for the overall research conducted in this thesis. It is complimentary and therefore only contains information not discussed fully in the analytical chapters. The analytical chapters provide a detailed description of the data sources and modelling approaches used.

4.1 Mixed method approach for thesis

As outlined in previous chapters, in relation to the different topics addressed in this thesis, the availability of quantitative data varies. First of all, there were high quality quantitative data sets of irrigation trade and farm behaviour available, that were appropriate to answer irrigator related research questions. In particular, irrigator adaptation behaviour is strongly driven by socio-economic factors and irrigator characteristics, justifying the use of quantitative data to explore adaptation behaviour. Given that before unbundling irrigators were the primary water market stakeholders, their traditional allocation and entitlement trading behaviour is to a large extent, well reflected in publicly available water trading data repositories, such as the state water registers (although the differences in quality of water registers and level of information must be noted (Wheeler and Garrick 2020)). Applying quantitative research seeks to test and allow for generalisations about irrigators' planned adaptation and associated drivers (Hoepfl 1997).

In contrast, derivative-type water market products and non-landholder water market stakeholders are new and emerging phenomena (Bayer and Loch 2017). As such, trading and ownership strategy expectations based on peer-reviewed literature are limited, and trading of derivative-type water market products is indistinguishable from allocation and entitlement trades in the publicly available water trading data (ABARES 2018; Seidl et al. 2020b). Furthermore, publicly available quantitative non-landholder and agri-corporate water ownership and trading data are not available or are not collected. Motives for non-landholder financial water market investment are largely unexplored, with the exception of Roca et al. (2015) and Wheeler et al. (2016a). Exploring these topics requires the extension of theoretical understanding or the identification of emerging theory, appropriately applied in a qualitative research setting (Bazeley 2013). In this context, it requires specifying non-landholder trading and ownership patterns, and their relationship with water investment motives, to provide a deeper understanding of these factors and allow for extrapolation to similar situations in the field (Hoepfl 1997).

Both approaches, qualitative and quantitative, have their strengths and weaknesses. This thesis uses a combination of both approaches to provide a comprehensive understanding and exploration of research topics; a task not possible by only using one approach (Creswell 2003; Russek and Weinberg 1993). Employing quantitative methods to investigate irrigator adaptation and water trading behaviour complements the qualitative analysis of the related issue of non-irrigator trading behaviour. Using quantitative water trading and brokerage data enables the triangulation and verification of results identified in the qualitative research component (Palinkas et al. 2011). In practice, the quantitative data that were available resulted in qualitative and quantitative methods almost exclusively addressing separate, but closely related, components of the overall research questions.

4.2 Thesis data sets

This thesis mainly uses three distinct data sets; two quantitative ones of secondary data and a primary qualitative one:

1. A University of Adelaide quantitative data set of a sMDB irrigator telephone survey, conducted in late 2015 and containing the answers of 1000 irrigators across the states of NSW, SA and VIC.
2. A qualitative data set compiled from 64 (albeit 63 were analysed due to one missing information) mainly face-to-face interviews with water experts representing agri-corporates, banks, environmental water holders, financial investors, property evaluators and water brokers.
3. A quantitative unit record data set on water forward and parking trade data from 2016/17 - 2018/19, provided by the private water trading platform H2Ox.

4.2.1 Irrigator quantitative survey data

The irrigator survey was conducted in October–November 2015 with 1000 irrigators, not dryland farmers, from NSW (n=419), SA (n=209) and Victoria (n=372) in the sMDB. Irrigators were randomly sampled from lists of irrigator names (compiled from a variety of sources including publicly available information on websites and farm business mailing lists), and were surveyed (after receiving ethics approval) using computer assisted telephone interviews by a professional survey company (Wheeler et al. 2018). The final response rate was 51% (or 73% including irrigators who agreed to be surveyed but were not rung back as the target sample size was reached). The survey collected information from 957 (95.7%) conventional and 43 (4.3%) certified organic irrigators (Daghagh Yazd et al. 2019). Given the actual irrigator population in the sMDB states, their sample sizes resulted in relative standard errors (RSE) of 4.7%, 5.1% and 6.6% respectively (e.g. indicating low RSEs), for an estimated proportion of 0.5. As an indication, the Australian Bureau of Statistics suggests that RSEs>25% are subject to high sampling error and should be used with caution in relation to irrigators living in the sMDB (Wheeler et al. 2018). This data set has previously been used by Wheeler et al. (2018) and Daghagh Yazd et al. (2019), albeit with different foci and research questions.

4.2.2 Semi-structured expert qualitative interview data

This section provides additional details about the interview sampling and participant selection criteria which are not explained in chapters six and seven. To explore the topics of derivative-type water trading products, financial water investment attitudes and agri-corporate and non-landholder water ownership and trading strategies, data from a highly knowledgeable, but hard to identify, group of stakeholders were needed (Creswell and Plano Clark 2011). Members of this group needed to fulfil a number of criteria:

- Represent an organisation with a “large” water portfolio/trading volume
- Represent an organisation that is an agri-corporate, a financial water investor or an environmental water holder

- Have managerial responsibilities over this water portfolio, including strategic decision-making capabilities
- Have an in-depth understanding of MDB water markets

Or

- Represent an organisation with a "large" involvement in water mortgaging, or financial water valuation
- Have managerial responsibilities over water lending or water valuation processes
- Have an in-depth understanding of MDB water markets, and water lending or water valuation

This represents a "Criterion-i" purposeful sampling approach as described by Palinkas et al. (2015), in that sampled cases need to meet important criteria which have been predefined. As there is no publicly available database containing names of agri-corporates and financial investors in the MDB, this group of stakeholders is also hard to identify. However, a characteristic of agri-corporates and financial investors in the MDB is that there are few of them, and they are highly interconnected. We made use of this characteristic and employed a chain-referral sampling approach, also known as "snowball method", suggested by Biernacki and Waldorf (1981) to identify and recruit additional research participants after our initial recruitment stage. We therefore combined the "Criterion-i" and snowball sampling methods to recruit participants who satisfied our sampling criteria, while making use of their professional networks to extend the reach of our research (Palinkas et al. 2015). Following Corbin and Strauss (2015), we aimed to interview at least 30 experts to achieve appropriately robust results that were relevant to our research aims.

After gaining ethics approval (approval number H-2017-192), we started initial recruitment of interview participants in mid-April 2018, with the last interview conducted in October 2018. The initial potential participants and organisations were identified from a wide range of publicly available sources, including newspaper articles, reports by government departments and NGOs, conference attendance, company annual and financial reports, personal and professional networks, company websites and web searches. Potential candidates and organisations were first approached via email, which included information about the research in form of a participant information sheet. The initial contact emails and the participant information sheet can be found in Appendices B.1 - B.5. Different email versions were sent, depending on whether the recipient was known by name or not, and whether they were based in South Australia or in other states. To comply with research ethics, we slightly modified our snowball approach in that we requested initial email recipients to forward our recruitment email, including participant information sheet, to other eligible stakeholders and subsequently have them contact us. This was to make sure no private information was used without prior consent: no potential interview participant was approached via contact information not publicly available.

If we did not receive a response to our initial email within 10-15 business days, we sent a follow-up email, including an automated read-request via Microsoft Outlook. If there was no response for another 10-15 business days, we then called the potential participant to ensure the research participation request has been received. If the stakeholder indicated that they did not want to be involved in our research they were not contacted again.

In case of a positive response to our request, we then sent another email to arrange a time and date for the interview to take place (see Appendices B.6 and B.7). This email again included the request for chain referral and had the participant consent form attached (Appendix B.8).

When conducting the interview, we brought spare copies of the consent form and a research hand-out with us, which summarised the key points of the research, in case participants needed a refresher on the research topic and the questions which would be asked of them. This hand-out also collected voluntarily provided information about participants' experience in current and previous professional roles (Appendix B.9). After establishing participants' consent, the interviews were voice-recorded to facilitate transcription. Notes were taken during the interview. If interviews needed to be undertaken remotely (over the phone), the consent form was read out to participants and their response was voice recorded as proof of consent. They were also advised when recording commenced and terminated. Interviews were terminated at a participant's request, or after all interview questions had been answered and no new topics were discussed. We used two specific, but closely related, sets of interview questions, one for agri-corporates, financial investors and environmental water holders (Appendix B.10), and another set for banks, property evaluators and water brokers (Appendix B.11). Interview questions and transcripts were provided to participants upon request.

Overall, 64 of the 83 identified contacts agreed to be interviewed, and semi-structured personal interviews were conducted. Although it is strictly not a survey response rate, this represents a response rate of 77% (with one of two written responses excluded due to incompleteness). We received one eligible written response and conducted 25% of the interviews by phone, and discarded one other written response as it was incomplete and did not answer all the questions. Of the final 63 interviews used for analysis in this thesis, they included 20 agri-corporates and investors, 15 environmental water holders (EWHs) and NGO employees, 10 water and property evaluators, 7 financial investors, 6 bankers and 5 water brokers (see Table 4.1). Because of the decentralised local organisational structure of some environmental water holders, with decisions made at the local level, it was necessary to interview a few respondents from the same organisation. Interview transcripts and notes were analysed in Nvivo 11 and manually coded according to major themes.

Table 4.1 Interviews and response rates by stakeholder type

Stakeholder Type	Approached	Interviewed	Response rate in %
Agri-corporates	32	20	63
Banks	7	6	86
EWHs	17	16 (one excluded)	94
Financial investors	10	7	70
Property evaluators	12	10	83
Water Brokers	5	5	100
Total	**83**	**64**	**77**

4.2.3 Individual water forward and parking trades data set

Given the difficulties in accessing information on forward and parking data from state registers, we requested access to a quantitative private water broker data set of 92 individual forward and parking trades from 2016/17 until 2018/19, provided by H2OX in June 2019[24]. This allowed us to triangulate stakeholder interview responses in regard to water forwards and parking trading. Note that chapters six and seven do not report the H2OX data summary statistics provided in this section. Trading data were anonymised, but contained information on stakeholder groups, specifying whether trades were undertaken by financial investors, agri-corporates, IIOs, EWHs or private irrigators. The data-set contained traded volumes, prices, delivery and contract dates, and source and destination trade zones. Table 4.2 provides some summary statistics of forward and parking trade data by year.

Table 4.2 H2OX water forward and parking data summary

Contract type	Observations	Mean volume (ML)	Min volume (ML)	Max volume (ML)	Mean price ($/ML)	Water year
Forward	4	1,100	400	2,500	212	2016/17
	12	3,517	200	10,000	139	2017/18
	32	673	200	2,000	227	2018/19
Parking	0	-	-	-	-	2016/17
	19	646	62	2,000	23	2017/18
	21	736	36	3,800	21	2018/19

Source: Own figure, data provided by H2OX

4.3 Summary

This chapter provides the reasons why a mix of quantitative and qualitative data sources for a mixed methods approach was used in this thesis. It also provided complementary detail to each data source used, with each following analytical chapter giving a more in-depth account and discussion of corresponding methodologies and data used.

[24] Of these 92 trades, 88 were for the period of 2016/17-2018/19 and four forwards were for 2019/20. These four were excluded because the 2019/20 data are incomplete, given we received the dataset in June 2019.

Chapter 5 Accommodating, contractive or expansive: drivers of Murray-Darling Basin irrigators' planned adaptation

This chapter presents an unpublished paper manuscript, yet to be submitted to a journal for review. It is formatted in submittable manuscript form. There is therefore some repetition with other chapters of this thesis, particularly the background sections.

Abstract:

Irrigators in the Murray-Darling Basin will need to adapt to future uncertainty, because of changes in markets, industry structures and climate. Such planned adaptation can be classified as expansive, accommodating or contractive strategies. Expansive adaptation strategies expand irrigation, accommodating strategies modify existing processes or crops without changing the size of the irrigation component of the farm, whereas contractive strategies reduce irrigation. Using data from a 2015-16 survey of 1,000 southern Murray-Darling Basin irrigators, 19 distinct planned adaptation strategies are aggregated into expansive, accommodating and contractive adaptation indices to analyse drivers of irrigators' future adaptation. While 90% of all irrigators are planning for at least one form of adaptation, there is limited evidence that they prefer expansive adaptation strategies over accommodating and contractive adaptation strategies. In particular, succession planning and past adaptation experience have a statistically significant positive influence on all planned adaptation indices. The influence of financial, human, natural, physical and social capital varies between adaptation types, with financial capital variables the strongest statistically significant driver for accommodating adaptation. Expansive and contractive adaptation are more strongly impacted by human and social capital variables.

Keywords: Adaptation, climate change, planned behaviour

Statement of Authorship

Title of Paper	
Publication Status	☐ Published ☐ Accepted for Publication ☐ Submitted for Publication ☑ Unpublished and Unsubmitted work written in manuscript style
Publication Details	N/A

Principal Author

Name of Principal Author (Candidate)	Constantin Seidl		
Contribution to the Paper	Undertook the literature review. Prepared data for analysis and performed econometric data analysis in Stata. Interpreted data and wrote the manuscript.		
Overall percentage (%)	70%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	03/04/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sarah Ann Wheeler		
Contribution to the Paper	Supervised development of work, edited the manuscript, provided research data, supervised and suggested econometric modelling approaches		
Signature		Date	03/04/2020

Name of Co-Author	Alec Zuo		
Contribution to the Paper	Supervised development of work, editing of the manuscript, supervised and suggested econometric modelling approaches		
Signature		Date	03/04/2020

5.1 Introduction

Climate change, changing economic circumstances and markets are major sources of uncertainty for farmers across the globe, requiring continuous adaptation well into the future (WEF 2019; Wheeler et al. 2020b). Utilising economies of scale and irrigation technology to make farms more productive has traditionally been used by farmers to deal with uncertain economic circumstances and a drier climate (de Roest et al. 2018; Turral et al. 2010). Although the drive to increase farm productivity through economies of scale likely will need to continue to satisfy the increasing demand for food associated with global population growth, this process is severely constrained by land degradation and projected pressures on water resources stemming from climate change (IPCC 2019). In particular, irrigators' face increased uncertainty compared to dryland farmers (Wheeler et al. 2018). Irrigators' plans for future adaptation can therefore be highly varied. Some will consider strategies that expand irrigation in the face of uncertainty, while others will seek to contract the irrigation component of the farm, and others will seek to accommodate changes to production and irrigation systems without significantly altering the size of irrigated production. Understanding what influences irrigators' adaption plans is important, especially for policy-makers who design policies to influence both a) farm profitability and b) incentives to exit an industry (Zuo et al. 2015b). Although there has been considerable research on general farmer adaptation and adoption behaviour (e.g. (Adger et al. 2007; Chavas and Nauges 2020; Feder et al. 1985; Llewellyn and Brown 2020; Pannell and Zilberman 2020; Park et al. 2012; Prokopy et al. 2008; Zampaligré et al. 2014; Zilberman et al. 2012)), empirical quantitative analysis of farmers' planned adaptation decisions, addressing complex, forward-looking and site-specific characteristics of adaptation processes (Below et al. 2012; Wheeler et al. 2013b) has been less common. The majority of the literature has also explained past adaptation rather than predicting future adaptation/ adoption (Llewellyn and Brown 2020).

The case study that this paper focussed upon is irrigators in the southern Murray-Darling Basin (sMDB) of Australia. Irrigators in this region are at the forefront of experiencing changing weather patterns, farm structures, commodity and input prices. Those in NSW are currently in the grip of the worst drought in 120 years (BOM 2020c). Indeed, the future climate in the sMDB is predicted to be drier, with a higher frequency of extreme events (CSIRO 2008, 2012; Timbal et al. 2015). Driven by world demand for high value crops (e.g. almonds and cotton), agricultural change in the sMDB is occurring such that horticultural demand may exceed water availability in drought years (Loch and Adamson 2015; Loch et al. 2019). Although sMDB irrigators are historically highly experienced in adapting to changing and extreme weather, adapting to changes in both climate and business environments will be especially challenging (see sections 2.1.1 and 2.1.3). Given the combination of changing climate and the changing structure of agricultural production, the sMDB provides an excellent case study to investigate the drivers of planned expansive, accommodating and contractive adaptation strategies.

This study uses a survey of 1,000 sMDB irrigators from 2015-16 to answer the following two research questions:

1) Do sMDB irrigators prefer to rely solely on planned expansive, accommodating or contractive adaptation, or a mix of these?
2) What are the drivers of sMDB irrigator's planned expansive, accommodating, and contractive adaptation?

Insights from this study may be of significant assistance to policy makers in Australia, and abroad, when designing policies aimed at increasing irrigators' planned adaptation behaviour in an environment of profound climatic and economic uncertainty.

5.2 Adaptation literature review and background

Changing climatic and business environments lead to increased uncertainty for irrigators arising from imperfect information about future events (Hardaker 2015). Uncertainty relates to the nature, the magnitude and the speed of change, both in regard to climate, but also other factors, such as commodity prices, interest rates and industry structure. These can be independent of, but also indirectly affected by, a changing climate. For example, the price for cotton is determined by global demand and supply, with supply potentially impacted by changes in climate. As socio-economic factors and available information change over time, so does the impact of uncertainty for adaptation decisions (Chavas and Nauges 2020). This includes missing information about the impacts of future uncertainty (Hardaker 2015). For example, how does an increase of 2°C in mean temperature translate into grape yield per hectare? A key distinction between two types of uncertainty is risk and ambiguity (Adamson et al. 2009). Risk arises when the probability distribution of a given variable is known, e.g. the probability of a 2°C increase in mean temperature by 2030. Ambiguity, also sometimes referred to as Knightian uncertainty (Ellsberg 1961; Knight 1933), arises when probabilities are unknown, or when it is impossible to describe all possible future outcomes.

Faced with multiple dimensions of uncertainty about the future, irrigators plan to implement measures and actions which they believe will provide net benefits for either one or more dimensions (Adger et al. 2007; Chavas and Nauges 2020). These strategies can be seen as planned adaptations in response to future uncertainty.

5.2.1 Adaptation strategy types and typologies

Corresponding to the many dimensions of uncertainty and risk, irrigators have an extensive set of adaptation strategies available to them. In this context, we define adaptation as changes in public and private decision making and resource allocation in anticipating or responding to the prospect or reality of large-scale and long-lasting changes (Zilberman et al. 2012).

Due to this multi-dimensionality, Smit and Skinner (2002) suggest employing different adaptation categorisations to allow for concise analysis of adaptation behaviour. An overview of some of the more commonly used adaptation categories and their definitions in Table 5.1.

For example, irrigators in the MDB use different strategies to adapt to water scarcity or drought, which can be categorised as related to information, water trade, land, farm structure, agronomy, infrastructure and environment [see Table C.1] (AFI 2019; Wheeler et al. 2014a). Utilising available water trade and climatic information enables better predictions around the risk of crop failure or enables trading for most financial gain. Employing different water market trading products (Seidl et al. 2020b) help to smooth seasonal variability in rainfall and farm income, while adjusting land and irrigation area allows for economies of scale and flexibility in production systems. Changing farm ownership structures and increasing off-farm income spreads the risk associated with relying only on farming income and increases responsiveness to water scarcity. Changing crop mix, farm management strategies, utilising more efficient irrigation infrastructure and environmental friendly practices also has adaptation benefits for water scarcity (AFI 2019; Wheeler et al. 2014a).

The categorisation suggested by Smit and Skinner (2002) is used to highlight one (or more) aspects of adaptation, for example the timing of adaptation in relation to the change event (Fankhauser et al. 1999; Zilberman et al. 2012) or the type of adapting actor (Adger et al. 2005). Considerable work has been done on the adoption of individual, often crop-based, adaptation strategies, such as crop diversification or no-till agriculture (Bradshaw et al. 2004; D'Emden et al. 2006; de Sousa et al. 2017; Deressa et al. 2009; Moniruzzaman 2015; Pannell et al. 2006; Wang et al. 2015b). A smaller, but growing, number of studies explore the adaptation of multiple strategies, often in form of different adaptation indices, with index components weighted or unweighted (Below et al. 2012; Dinh et al. 2017; Nicholas and Durham 2012; Wheeler et al. 2013b).

This study is interested in how irrigators' planned adaptation, across a range of potential strategies, shapes the structure and size of a farm's irrigation component. Therefore, planned adaptation is analysed in three indices: 1) expansive adaptation that increases or enhances the irrigation component of a farm enterprise; 2) accommodating adaptation that changes the farm structure without impacting the irrigation component; and 3) contractive adaptation that reduces the irrigation component. Wheeler et al. (2013b) found that farmers who believe in climate change occurring are more likely to plan accommodating, but not expansive strategies. The paper also found an often endogenous relationship between climate change belief and planned adaptation strategies, especially pronounced for accommodating adaptation. Although a similar approach has been employed by Wheeler et al. (2013b), our analysis differs substantially in that we include a much more comprehensive list of 19 strategies compared to eight strategies in Wheeler et al. (2013b), undertake an improved modelling approach by analysing expansive, accommodating and contractive strategy indices separately, and employ a more recent data set (2015 vs 2010 data). Wheeler et al. (2013b) aggregated expansive, accommodating and contractive adaptation into one overall adaptation index, with expansive and accommodating strategies positively contributing, and contractive strategies negatively contributing to the overall index count.

.

Table 5.1 Overview of common adaptation strategy categories

Dimension of interest	Adaptation category	Definition and source	Example
Adapting actor	Autonomous/unintentional	Natural spontaneous adjustment undertaken by independent actors (Adger et al. 2005; Smit and Skinner 2002)	Changed harvesting schedule
	Planned/purposeful	Conscious adjustment/intervention requiring coordination with other actors (Adger et al. 2005; Smit and Skinner 2002)	Government Investment in irrigation infrastructure
Adaptation intent	Facilitating	Enhances actors' ability to adapt (Fuessel and Klein 2006)	Research developing drought resistant crops
	Implemented	Directly reduce actors' exposure or sensitivity to impacts of uncertainty (Fuessel and Klein 2006)	Crop/yield insurance
Adaptation scale	Micro level	Small scale (Zilberman et al. 2012)	Irrigation scheduling by individual farmer/plot
	Macro level	Large scale (Zilberman et al. 2012)	No-tillage agriculture across a whole region
	Global	At global scale (Brooks and Adger 2005)	New global production standards
	Local	At local scale (Brooks and Adger 2005)	Solar-powered farm irrigation system
	Incremental	Uses existing technologies and institutional frameworks (Park et al. 2012; Zilberman et al. 2012)	Fodder substitution for irrigating pasture
	Transformative	Major change in resource allocation across large temporal and spatial scales (Park et al. 2012; Zilberman et al. 2012)	Change from dryland to irrigated agriculture
Adaptation duration	Short-term/tactical	Provides adaptation benefits for a short time period (Smit and Skinner 2002)	Fodder substitution for irrigating pasture
	Long-term/strategic	Provided adaptation benefits for an extended period of future stresses (Smit and Skinner 2002)	Upgrading to drip irrigation
Adaptation timing	Reactive	The response to the impacts of change/uncertainty after they materialised (Fankhauser et al. 1999; Zilberman et al. 2012)	Relocation after flood/bush fire
	Anticipatory	Anticipates future and seeks to address changes before they materialised (Fankhauser et al. 1999; Zilberman et al. 2012)	Farm/crop insurance
Adaptation technology	Hard	Tangible and mechanised, similar to hard technology (Wheeler et al. 2017c)	Farm machinery which causes less emissions
	Soft	Change of management and skills, often intangible, similar to soft technology (Wheeler et al. 2017c)	Change of planting dates
Influence on size/structure of adapting actor	Expansive and Accommodating	Designed to expands efforts and production, or accommodate change in existing size or structure (Wheeler et al. 2013b)	Increased water ownership, Change in soil management practices
	Contractive	Designed to reduce effort, resource ownership and size (Wheeler et al. 2013b)	Sale of land in change-affected areas
General	Technological development	Research and development of new technologies or managerial innovations (Smit and Skinner 2002)	Weather and climate information systems
	Government programs and insurance	Government assistance or incentive programs, insurances against different uncertainties (Smit and Skinner 2002)	Agricultural support programs and subsidies, farm/crop insurance
	Farm financial management	Including different financial tools and management practices into the farm system (Smit and Skinner 2002)	Crop derivatives (options and futures), income diversification
	Farm production practices	Changing farm production systems to better cope with uncertainty (Smit and Skinner 2002)	Crop diversification, land use change

5.2.2 A framework and drivers of irrigators' planned adaptation

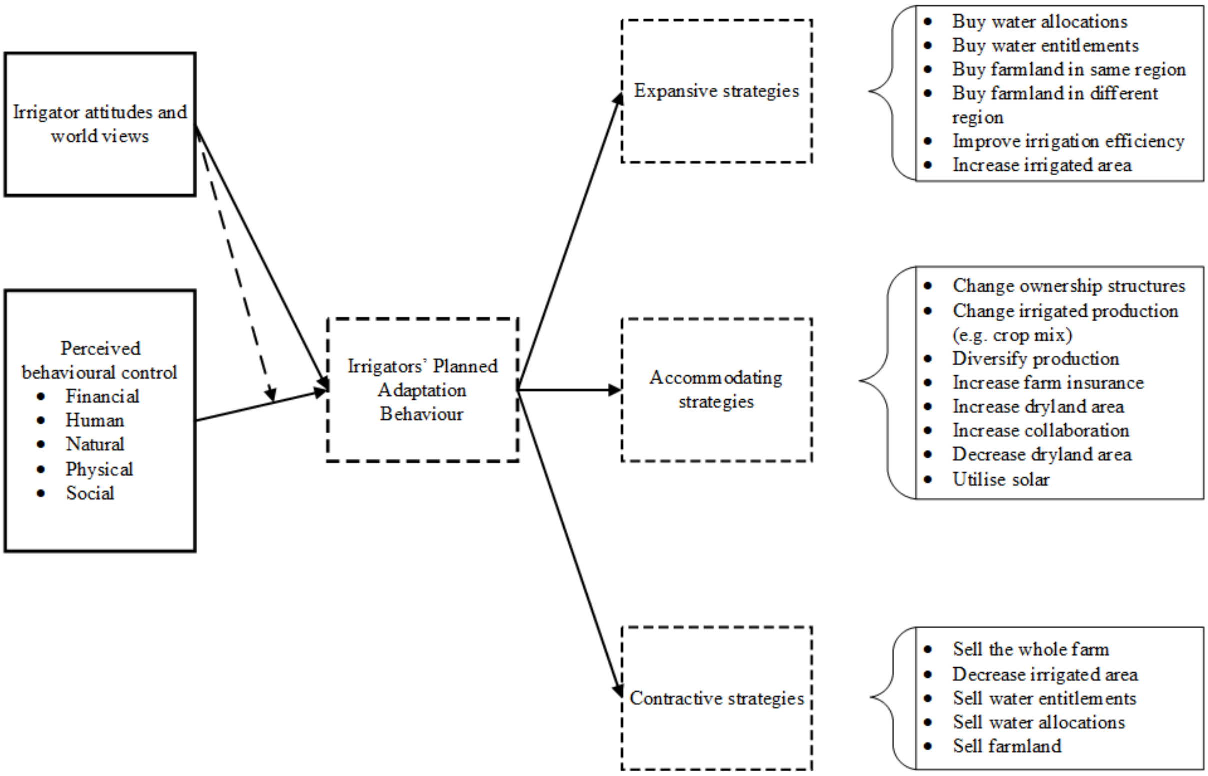
Many adaptation studies analyse the drivers for implemented adaptation behaviour; observing what strategies were implemented and why (Abid et al. 2016; Below et al. 2012; Dinh et al. 2017; Moniruzzaman 2015; Prokopy et al. 2008; Wang et al. 2015a). One particular issue with this is controlling for endogeneity between past behaviour using current socio-economic characteristics. This study focuses on adaptation behaviour irrigators *plan* to implement in the mid-near future (the next five years in our case). As future implementation cannot be observed, we have to rely on irrigators' self-reported intent to implement adaptation strategies.

However, although intention to implement a behaviour is not the same as enactment, other research comparing irrigator stated and actual behaviour suggest high correlation (Wheeler and Zuo 2017; Wheeler et al. 2013b). Although Väre et al. (2010) report a large gap between planned and actual farm investment, Fielding et al. (2008) found that Australian farmers' planned and actual adoption of sustainable farming is influenced by past behaviour, perceived behavioural control, social identity variables, and attitudes. This further supported by Wheeler et al. (2013b) who found that Goulburn irrigators intentions for farm management and water trading reasonably closely matched their actual behaviour, with intentions slightly higher than actual behaviour, and periods of significant drought changing planned behaviour considerably.

To model future adaptation a number of studies (Feola et al. 2015; Li et al. 2017; Wheeler et al. 2013b) employ various versions of the Theory of Planned Behaviour (Ajzen 1991) or related frameworks, such as the Theory of Reasoned Action (Ajzen 2012). The Theory of Planned Behaviour describes how the intention to perform a certain behaviour is formed and how it translates into actual enactment, with stronger intention more likely leading to enactment. This intention is influenced by three components: attitudes, subjective norms, and perceived behavioural control. Attitudes are influenced by beliefs about behaviours, subjective norms represent social pressures to perform or not perform certain behaviours, and perceived behavioural control represents the (perceived) ease or difficulty of performing a behaviour. Conversely, if behaviours are not subject to serious constraints in form of perceived behavioural control, intention alone can predict the performance of behaviour (Ajzen 1991).

A critical consideration is how to empirically incorporate difficult to observe or unobservable Theory of Planned Behaviour concepts, particularly perceived behavioural control. Limited resource access and availability corresponds with low behavioural control (Ajzen 1991). Wheeler et al. (2013b) adapted the traditional Theory of Planned Behaviour by expressing perceived behavioural control as a function of observable resource access and availability in form of financial, human, natural, physical and social capital (based on Ellis (2000)). As we analyse 19 planned adaptation strategies, compared to the eight in Wheeler et al. (2013b), we have further modified their framework to better distinguish between planned expansive, accommodating and contractive adaptation (Figure 5.1). While attitudes may directly influence planned adaptation behaviour, e.g. in form of preferences for particular adaptation strategies, this chapter also allows irrigators' world views to impact the influence of perceived behavioural control on planned adaptation behaviour, by analysing different attitudinal clusters of irrigators. This is signified by the dotted arrow in Figure 5.1.

Figure 5.1 Theory of Irrigators' Planned Behaviour



Source: Adapted from Wheeler et al. (2013b)

Table 5.2 provides an overview of key findings in the literature in regard to significant drivers of farm adaptation behaviour, from the perspective of the five types of capital. We define financial capital as the economic and financial characteristics of an irrigation farm (e.g debt, farm income, farmland value, off-farm income), human capital as unique characteristics of the irrigator (e.g. education, age, farming experience, health, marital status, household size), natural capital as the physical setting of the farm (e.g. temperature, rainfall, evaporation, soil quality, region), physical capital as the characteristics and technology of irrigated production (e.g. farm size, irrigation technology, farm machinery, number of employees, tenure), and social capital as the characteristics of the irrigator's social unit (e.g. membership in social groups, farm extension, succession, government programs and subsidies).

These five types of capital are commonly used in the climate change adaptation (e.g. (Harrison et al. 2013; Jäger et al. 2015; Li et al. 2017; Ng'ang'a et al. 2016; Wheeler et al. 2013b)) and the adoption literature (e.g. (Awotide et al. 2015; García de Jalón et al. 2017; Mumuni and Oladele 2016; Siepmann and Nicholas 2018), allowing us to summarise their impact on adaptation. Given the vastness of this body of literature, some general trends in adoption of new practices can be observed: adoption processes typically begin with a small number of farmers ('innovators'), with the technology adoption then diffusing to other farmers as information spreads (Ryan and Gross 1943). This process follows an S-shaped curve, with early adoption fairly slow, followed by a rapid increase and finally plateauing off. Correspondingly, there are different types of adopters at different stages of adoption: innovators, early adopters, early majority adopters, late majority, and laggards (Rogers 2003; Ryan and Gross 1943). A large literature subsequently focused on the characteristics of the adopting actors (Beal et al. 1957; D'Emden et al. 2006; Feder et al. 1985; Feder and Slade 1984; Fischer et al. 1996; Fuglie and Kascak 2001; Ghadim and Pannell 1999; Griliches

1957; Knudson 1991; Lindner et al. 1982; Morrison 2005; Pannell 1999; Rogers 2003; Shampine 1998) finding that innovator farmers (as compared to nonadopters) tended to be younger, more educated, more cosmopolitan, have higher incomes, have larger farm operations, and be more reliant on primary sources of information (Stephenson 2003). The seminal study of the diffusion of hybrid corn by Griliches (1957) linked adoption with profitability, rejecting the influence of many sociological variables thought previously important. For various types of agricultural innovations, economic and sociological factors may be of differing importance. For example, economic factors may play a more important role in the adoption of innovations that are easy to implement and provide demonstrable benefits [i.e., hybrid corn] (Wheeler et al. 2009). On the other hand, sociological factors may play more of a role for adoption of innovations that involve investment in new skills, such as sustainable agriculture (Morrison 2005). With study contexts very heterogeneous, a large diversity of research questions, different attributes of adapting/adopting actors, and the varied technologies explored (Pannell and Zilberman 2020), this leads to a lack of clear convergence between various studies of agricultural adoption, with different explanatory variables highlighted in different cases (Montes de Oca Munguia and Llewellyn 2020).

Table 5.2 Overview of different capitals and their impact on adaptation in the agricultural economics and climate change adaptation literature

Type of capital	Description	Common examples	Influence on Adaptation	How often studied	Selected sources
Financial capital	Economic characteristics of the actor's enterprise	Access to credit	(+)	Occasionally	(Bryan et al. 2009; Deressa et al. 2009; Touch et al. 2016)
		Debt	Unclear	Rarely	(Wheeler et al. 2013b)
		Income/wealth	(+)	Often	(Below et al. 2012; Deressa et al. 2009; Li et al. 2017)
		Off-farm income	Unclear	Occasionally	(Deressa et al. 2009; Gbetibouo et al. 2010; Wang et al. 2015a)
Human capital	Characteristics of the actor	Age	Usually (-)	Occasionally	(Pannell et al. 2006; Roco et al. 2014; Wheeler et al. 2013b)
		Climate change belief	Usually (+)	Rarely	(Dang et al. 2014; Deressa et al. 2009; Tambo 2016)
		Climate change risk perception	Usually (+)	Rarely	(Alam 2015; Arbuckle et al. 2013; Jianjun et al. 2015)
		Education	Usually (+)	Often	(Abid et al. 2016; Alam 2015; Deressa et al. 2009)
		Farm experience	Usually (+)	Occasionally	(Abid et al. 2016; Alam 2015; Bryan et al. 2013)
		Female gender	Usually (-)	Occasionally	(Below et al. 2012; Deressa et al. 2009; Jianjun et al. 2015)
		Health	(+)	Rarely	(Wheeler et al. 2013b)
		Household size	Usually (+)	Occasionally	(Bryan et al. 2009; Bryan et al. 2013; Zampaligré et al. 2014)
		Past experience	(+)	Rarely	(Ghadim et al. 2005; Nicholas and Durham 2012; Wheeler et al. 2013b)
		Risk preference/aversion	Unclear	Rarely	(Ghadim et al. 2005; Tambo 2016; Wheeler et al. 2013b)
		Farm succession	(+)	Rarely	(Li et al. 2017; Wang et al. 2015b; Wheeler et al. 2013b)
Natural capital	Environmental characteristics	Rainfall	Usually (-)	Occasionally	(Deressa et al. 2009; Gandure et al. 2013; Moniruzzaman 2015)
		Region	Unclear	Occasionally	(Abid et al. 2016; Li et al. 2017; Wheeler et al. 2013b)
		Soil quality	Usually (-)	Occasionally	(Azad and Ancev 2020; Gadédjisso-Tossou 2015; Touch et al. 2016)
		Temperature	(+)	Occasionally	(Deressa et al. 2009; Gandure et al. 2013; Moniruzzaman 2015)
Physical capital	Technology and characteristics of production	Farm size	Usually (+)	Often	(Bryan et al. 2013; Ghadim et al. 2005; Li et al. 2017)
		Farm technology/inventory	Usually (+)	Occasionally	(Bryan et al. 2013; Wang et al. 2015b; Zampaligré et al. 2014)
		Tenure	Unclear	Occasionally	(Abid et al. 2016; Alam 2015; Li et al. 2017)
Social capital	Characteristics of the actor's social unit	Extension services	(+)	Occasionally	(Below et al. 2012; Bryan et al. 2013; Li et al. 2017)
		Government programs and subsidies	Usually (+)	Rarely	(Bryan et al. 2013; Gandure et al. 2013; Zampaligré et al. 2014)
		Membership of Social networks	Usually (+)	Occasionally	(Below et al. 2012; Li et al. 2017; Wheeler et al. 2013b)

5.3 Data and Methodology

This section outlines the study area, the survey data, and the modelling.

5.3.1 Study Area

The sMDB spans three states New South Wales (NSW), South Australia (SA), Victoria (VIC) and the Australian Capital Territory (ACT) in south-eastern Australia (Figure 5.2).

Figure 5.2 Map of the Murray-Darling Basin

Source: MDBA (2016a)

The MDB produces food and fibre worth around AU$22 billion annually (MDBA 2019k), is home to about 9,200 irrigators (ABS 2016), with the majority stemming from the sMDB's irrigation regions and districts: Sunraysia (VIC and NSW), Riverina (NSW), Goulburn-Murray Irrigation District (VIC), Murrumbidgee Irrigation district (NSW), Murray Irrigation district (NSW), and the Riverland (SA).

Irrigation in these regions is supported by water entitlements of different security/reliability and corresponding water allocations. There are three main securities (high, general and low); a water entitlement is the right to extract a share of the available water resource.[25] An

[25] A high security entitlement yields the full extraction amount in 90-95 out of 100 years (Zuo et al. 2016).

allocation is the actual volume of water extracted on an entitlement in a given year. Entitlements and allocation can be traded. For further information on water trading and ownership strategies, see Seidl et al. (2020b), and Grafton and Wheeler (2018) for water trading and water reform history.

5.3.2 Data

We use data from an irrigator telephone survey, conducted from October-November 2015 in the sMDB. The data consists of 1,000 responses (overall response rate 51%)[26] by randomly sampled irrigators (not dryland farmers) across three states (NSW, Victoria and SA).[27] Our data include the Sunraysia, NSW Murray and Murrumbidgee irrigation districts (mostly annual cotton and rice), the VIC Goulburn-Murray Irrigation District (mostly dairy and livestock), and the SA Riverland (mostly perennial citrus, grapes, fruits and nuts). With the high response rate, the large sample size and irrigator demographics which are very similar to other commonly used data sources (Australian Bureau of Statistics, Australian Bureau of Agricultural and Resource Economics and Science), our survey is strongly representative of the general irrigator population. The survey collected information on farmers' attitudes, socio-economic and farm characteristics, past farm management and adaptation strategies and future/planned management and adaptation strategies in the next 5 years. For more discussion on the survey data collection see Daghagh Yazd et al. (2019) and Wheeler et al. (2018).

Gridded historic temperature, rainfall and evaporation data from the Bureau of Meteorology was geo-matched to the post-codes of each survey respondent and incorporated into the survey data set. This allows us to also examine the impact of climatic influences on planned adaptation.

5.3.3 Dependent variable

This section illustrates dependent variable construction for the different modelling approaches. Table 5.3 to Table 5.5 provide an overview of dependent variables and summary statistics for the individual planned adaptations and the planned adaptation indices models.

[26] Or a response rate of 73% if irrigators who agreed to be surveyed but were not rung back as the target sample size was reached were included.
[27] Given irrigator populations in the three states, the final sample sizes of NSW (419), VIC (372) and SA (209) will result in relative standard errors (RSE) of 4.7%, 5.1% and 6.6% respectively (e.g. indicating low RSEs), for an estimated proportion of 0.5. As an indication, ABS suggests that RSEs>25% are subject to high sampling error and should be used with caution.

Table 5.3 Irrigators' planned individual adaptation strategies and response percentages (n=1,000)

Planned adaptation strategies (1= yes, 0= otherwise) In the next 5 years, are you planning to:	**% of 'yes' responses**
Expansive strategies	
purchase water allocations	56
purchase water entitlements	30
purchase any farmland near your current properties	29
purchase any farmland in different zones/regions for risk purposes	11
improve the efficiency of your irrigation infrastructure	67
increase your irrigated area	29
Accommodating strategies	
change ownership structures	29
changed your irrigated production	48
diversify your production	40
increase farm insurance	39
decrease your area of dryland production	9
increase any collective bargaining or collaboration with other farmers	22
increase your area of dryland production	20
utilise solar-power energy and battery system for your irrigation pumping	31
Contractive strategies	
think about selling the whole farm	53
decrease your irrigated area	15
sell water allocations	38
sell water entitlements	15
sell any farmland	22

Table 5.4 Planned total, expansive, accommodating, and contractive adaptation indexes variable definitions and summary statistics (n=1,000)

Dependent variable	**Index mean** (std. dev.)	**Min**	**Max**	**Dependent variable**	**Index mean** (std. dev.)	**Min**	**Max**	**Construction variables: Planned adaptation strategies; yes=1, 0=otherwise)** In the next 5 years, are you planning to:
Planned total adaptation index	**6.5**(3.2)	0	16	Planned expansive adaptation index	**2.2**(1.7)	0	6	purchase water allocations purchase water entitlements purchase any farmland near your current properties purchase any farmland in different zones/regions for risk purposes improve the efficiency of your irrigation infrastructure increase your irrigated area
				Planned accommodating adaptation index	**2.3**(1.8)	0	7	change ownership structures changed your irrigated production diversify your production increase farm insurance decrease your area of dryland production increase any collective bargaining or collaboration with other farmers increase your area of dryland production utilise solar-power energy and battery system for your irrigation pumping
				Planned contractive adaptation index	**1.3**(1.4)	0	5	think about selling the whole farm decrease your irrigated area sell water allocations sell water entitlements sell any farmland

Table 5.5 Frequency of expansive, accommodating and contractive planned adaptation indices (n=1,000)

Index count	Expansive index observations	%	Accommodating index observations	%	Contractive index observation	%
0	182	18.2	170	17.0	261	26.1
1	196	19.6	220	22.0	331	33.1
2	216	21.6	190	19.0	217	21.7
3	166	16.6	166	16.6	109	10.9
4	123	12.3	117	11.7	58	5.8
5	80	8.0	80	8.0	20	2.0
6	33	3.3	40	4.0		
7			13	1.3		
Missing	4	0.4	4	0.4	4	0.4
Total	1000	100	1000	100	1000	100

5.3.3.1 Individual and compound planned adaptation

Each of the 19 individual planned adaptation strategy questions (see Table 5.4) serve as the dependent variable for one biprobit model (see section 5.3.5.1). See Table C.2 for correlation analysis of the individual strategies.

To test for planned compound adaptation, a number of combinations of the aforementioned individual strategies was considered, serving as the dependent variables for the multivariate probit models described in section 5.3.5.2. These combinations were designed with particular themes in mind, based on the literature and experience of irrigator behaviour in the MDB. Broad themes concerned water trading, change in irrigated area, the influence of infrastructure grants, change of land ownership, farm business structure and farm exit (see Table 5.6).

Table 5.6 Potential planned compound adaptation and components

Combination	Planned adaptation 1	Planned adaptation 2	Planned adaptation 3
Water trading 1	purchase water entitlements	sell water allocations	purchase water allocations
Water trading 2	sell water entitlements	sell water allocations	purchase water allocations
Less irrigation	decrease irrigated area	sell water entitlements	increase area of dryland production
More irrigation 1	decrease area of dryland production	purchase water entitlements	increase irrigated area
More irrigation 2	utilise solar-power	Improve irrigation efficiency	increase irrigated area
More irrigation 3	sell water entitlements	Improve irrigation efficiency	increase irrigated area
More irrigation 4	changed your irrigated production	Improve irrigation efficiency	increase irrigated area
More irrigation 5	Improve irrigation efficiency	purchase water entitlements	increase irrigated area
More irrigation 6	change irrigated production	purchase water entitlements	increase irrigated area
Land ownership 1	purchase any farmland in different zones/regions	diversify your production	sell any farmland
Land ownership 2	decrease irrigated area	sell water entitlements	sell any farmland
Farm business	increase collective bargaining	change irrigated production	diversify production
Farm exit	selling the whole farm	sell any farmland	sell water entitlements
Irrigation grant influence 1	purchase water entitlements	Received infrastructure grant*	increase irrigated area
Irrigation grant influence 2	change irrigated production	Received infrastructure grant*	increase irrigated area

* Receiving an irrigation infrastructure grant since 2010 was modelled as a function of the independent variables. While not a planned adaptation strategy, we wanted to understand whether planned adaptation is dependent upon receiving a grant, based on irrigators' socio-economic characteristics.

5.3.3.2 Indices

The planned total, expansive, accommodating and contractive adaptation indices are constructed by summing up irrigators' positive responses to 19 questions about planned implementation of expansive, accommodating and contractive adaptation strategies (see Table 5.4).

Since we make no assumptions about the relative importance of different strategies, and since our data contain no information about the degree of implementation of these planned strategies, the indices' components are unweighted, following the approach in Wheeler et al. (2013b). The implicit assumption is choosing more strategies (a higher index count) represents a higher degree of adaptation. However, given the data limitations we see this methodological choice as appropriate.

Index construction also assumes that planned adaptation strategies are chosen independently. However, we find a correlation coefficient of 0.53 between the planned expansive and planned accommodating, and -0.28 between the planned expansive and planned contractive adaptation indices (see Table C.3). While well below the value of 0.7, considered as problematic correlation, we used a SUR model (see 5.3.5.3) to minimise any potential bias in our estimations. These correlations may stem from the existence of compound adaptation strategies (e.g. sell dryland to increase irrigated area), making the choice of planned adaptation strategy not independent. We tested for this by modelling potential compound strategies using multivariate probit models, and examined the statistical dependence of the planned adaptation strategies involved. We found some limited evidence of compound strategies existing (i.e. strategies not being statistically independent [see Table C.17-Table C.31]), for example *selling entitlement and more dryland* or *less irrigated area and more dryland*, possibly causing the moderate and weak correlation of the dependent variables.

5.3.4 Independent variables

The literature (see Table 5.2) was used to identify the total amount of explanatory variables. To limit the large number, of variables available for analysis from the survey, we used correlation analysis to identify and exclude any collinear variables (at a correlation coefficient of 0.7 and above (see Table C.4 for independent variable correlation matrix). After removing variables with a variance inflation factor above 10 (see Table C.5 to Table C.10), step-wise elimination of insignificant variables was undertaken, provided this improved model fit (decreasing Akaike's and Schwarz's Bayesian information criteria), leading to the set of variables used in the final model (Table 5.7). The same approach was used for different variable transformations (e.g. natural logarithm or square of variable).

Table 5.7 Independent variable definitions and summary statistics by capital types

Capital	Variable definition	**Mean** (std. dev.)	Min	Max
Financial capital	Farm debt ($m)[28]	0.4(0.5)	0	1.25
	Farmland value ($m)	1.4(1.0)	0.125	3
	Net farm income ($m)	0.1(0.1)	0	0.25
	Number of insurance contracts[29]	4.6(1.4)	0	7
	Off-farm income (%)	24.8(31.1)	0	100
	Productivity change (last 5 years: 1 = strongly decreasing; 5 = strongly increasing)	3.2(1.2)	1	5
	Received irrigation infrastructure grant since 2010 (1=yes, 0=otherwise)	0.2(0.4)	0	1
Human capital	Believes climate change is a risk for their region (1= yes, 0 = otherwise)	0.4(0.5)	0	1
	Irrigator's age (years)	58.7(11.4)	24	90
	Low education (1 = highest education level is year 10 or below, 0 = otherwise)	0.2(0.4)	0	1
	Male (1= male, 0= otherwise)	0.9(0.3)	0	1
	Marital status (1=married/partnered; 0=otherwise)	0.9(0.3)	0	1
	Number of Children	2.8(1.4)	0	10
	Plans for climate change on their farm (1= yes, 0= otherwise)	0.5(0.5)	0	1
	Succession (1 = succession plan in place, 0= otherwise)	0.4(0.5)	0	1
	Risk taker (1 = strongly disagree; 5 = strongly agree)	3.1(1.3)	1	5
	Whole farm plan (1= has a farm plan, 0 = otherwise)	0.7(0.4)	0	1
Natural capital	Average annual pan evaporation over the last 10 years (mm)	1712.1(225.3)	1115.1	2232.7
	Average annual rainfall over the last 10 years (mm)	378.4(82.6)	265.3	925.3
	Average annual temperature over the last 30 years (°C)	23.3(0.9)	20.1	25.2
	Average final water allocation over the last 10 years (%)[30]	0.58(0.26)	0	0.96
	Millennium Drought dummy (1 = experienced drought; 0 = otherwise) [31]	0.9(0.2)	0	1
	Net rainfall over last 10 years (average of annual rainfall minus evaporation, mm)[32]	-1333.7(282.6)	-1943.1	-207.3
	State dummy NSW (1 = yes; 0 = otherwise)	1.8(0.8)	1	3
	State dummy VIC (1 = yes; 0 = otherwise)			
	State dummy SA (1 = yes; 0 = otherwise)			
	Temperature volatility over last 30 years (std. dev. of temperature)	0.75(0.07)	0.53	0.83
Physical capital	Water application rate (ML/irrigated ha)	11.3(179.0)	0	5634
	Broadacre (1= main income from broadacre, 0= otherwise)[33]	0.3(0.4)	0	1
	Carry-over use between 2014-2016 (1= used carry-over, 0= otherwise)	0.6(0.5)	0	1
	Dairy (1= main income from dairy, 0= otherwise)	0.2(0.4)	0	1
	Farm size (irrigated plus dryland; 100ha)	9.0(27.3)	0	368
	Livestock (1= main income from livestock, 0 = otherwise)	0.2(0.4)	0	1
	Majority of farm area under drainage (1= drainage on more than 50%, 0= otherwise)	0.6(0.5)	0	1
	Majority of farm area under drip irrigation (1= drip irrigation on more than 50%, 0= otherwise)	0.2(0.4)	0	1
	Number of employees	2.6(3.4)	1	60
	Owns excess water entitlements (1= owns more water then needed, 0= otherwise)	0.2(0.4)	0	1
	Water ownership size (Ln of long-term annual average yield of water entitlements)[34]	5.3(1.8)	0	10.3
Social capital	Social group membership (1= member in any group; 0=otherwise)	0.6(0.5)	0	1
Past experiences	Expansive adaptation strategies used in last 5 years	2.1(1.5)	0	6
	Accommodating adaptation strategies used in last 5 years	2.0(1.5)	0	7
	Contractive adaptation strategies used in last 5 years	1.1(1.0)	0	4

[28] Net farm income, debt and farmland value figures were semi-continuous variables converted from the middle point range value. Specifically, net farm income values were: 0, 25k, 62.5k, 87.5k, 112.5k, 137.5k, 200k and 250k; debt values were: 0, 25k, 75k, 125k, 200k, 375k, 625k, 875k, 1125k and 1250k; and farmland values were: 125k, 375k, 625k, 875k, 1125k, 1375k, 1750k, 2500k and 3000k

[29] include crop insurance, private health cover, home and content insurance, live insurance, car insurance, work cover and income protection

[30] Allocation factor is the seasonal amount of water received as a percentage of nominal water entitlements based on security and location

[31] Irrigators were seen as having experienced the Millennium Drought if they started farming in 2008 or earlier.

[32] Rainfall, evaporation, and temperature data over 30-year period (1986–2015). No significant difference between 10- and 30-year net rainfall, temperature volatility over 30 years provides better model fit.

[33] Horticulture acted as the base case

[34] LTAAY is the long-term annual average volume of water permitted to be taken for consumptive use under a water access entitlement. Currently all LTAAY figures are calculated using the long-term diversion limit equivalent factors, with these factors to be accredited in finalised state water resource plans (Cheesman and Wheeler 2012). We used irrigators' postcode to attribute LTAAY figures to water ownership across different products. For NSW irrigators living between the Murrumbidgee and the Murray, and VIC irrigators between the Goulburn and the Murray, we attributed 50% of their holdings to each entitlement class respectively.

Attention has to be given to the influence of climate change believe on adaptation decisions. While irrigators likely adapt more if they believe in being at risk from climate change, irrigators conversely may believe more strongly in being at risk from climate change *because* they plan to adapt for it. Some adaptation studies (e.g. (Hogan et al. 2011; Park et al. 2012)) argue that the causal relationship runs from climate change belief to adaptation, and TPB theory dictates that attitudes should influence behaviour (e.g. (Ajzen 1991)), but the true relationship might be endogenous, with each influencing the other. Leviston and Walker (2011) recognised the causal influence of the Australian public's climate change attitude and their behavioural and Wheeler et al. (2013b) tests and controls for an endogenous relationship between belief and adaptation. We address this potential endogeneity between irrigators' climate change risk perception and their planned expansive, accommodating and contractive adaptation by using irrigators' climate change planning on farm as the instrument for the instrument variable approaches (see sections 5.3.5.1 and 5.3.5.2) and the control function approaches (see 5.3.5.3), following Nauges and Wheeler (2017) and Wheeler et al. (2013b).

5.3.5 Model

This section introduces the different modelling approaches undertaken in this chapter, namely the modelling of planned adaptation strategies in a number of forms (individual, compound, and indices), and clustering the data around different irrigator attitudinal groups. All modelling was done in Stata 16. To arrive at the final models, different statistical tests were used. 1) correlation analysis to eliminate correlated independent variables (see Table C.4); 2) collinearity diagnostics using variance inflation factors; 3) step-wise elimination of insignificant variables; 4) determining model robustness by lowest Akaike's and Schwarz's Bayesian information criteria values, 5) tests for goodness-of-fit and overdispersion; and 6) the stability of independent variable significance and direction across the different model iterations.

5.3.5.1 Individual planned adaptation strategies – dependent variables

We modelled 19 individual planned adaptation strategy questions using probit models. The correlation matrix for the 19 planned adaptation strategies can be found in Table C.2. There may be endogeneity between the individual planned adaptation strategy as the dependent variable and irrigators' climate change risk perceptions (see 5.3.4 for more detail). We use a recursive bivariate probit model with robust standard errors, as suggested in Greene (2008), simultaneously estimating an irrigator's individual planned adaptation strategy, and the instrument variable approach to deal with endogeneity, with the irrigator's climate change planning on farm (CC_plan_j) as the instrument variable (*biprobit*, *vce(robust)* in Stata 16). For each individual adaptation strategy, the reduced form equation is:

$$(1) \quad Y^* = X'\beta_Y + D\alpha + \varepsilon_1, \qquad Y = \mathbb{I}(Y^* > 0)$$
$$D^* = X'\beta_D + Z'\gamma + \varepsilon_2, \quad D = \mathbb{I}(D^* > 0)$$

Where $\mathbb{I}(\cdot)$ denotes the indicator function. X contains the common independent variables and Z is our instrument (climate change planning on farm (CC_plan)). The latent variables Y^* and D^* are mapped into the observed outcome Y (strategy adoption) and the observed (potentially endogenous) regressor D (climate change risk perception (CC_risk)), using threshold crossing conditions, and the joint distribution of Y and D conditional on X and Z, giving the probability of adoption as (Li et al. 2019):

$$(2) \quad P(Y = y, D = d | X = x, Z = z)$$

A good instrument needs to be correlated with climate change risk perceptions, but uncorrelated with the error term in our main equation ε_1. As our data set is similar, we followed Wheeler et al. (2013b), who used climate change planning on farm as an appropriate instrument for climate change risk perception. Following Greene (2008), the Wald statistic given by the Stata command enables to test for endogeneity, with a rejection of H0 translating into the presence of endogeneity between the dependent variable and irrigator's climate change risk perception. We also tested addressing endogeneity with a control function approach suggested by Wooldridge (2010, 2015), but the instrument variable approach provided more robust results, based on lower Akaike's and Schwarz's Bayesian information criteria (AIC and BIC) values.

5.3.5.2 Compound adaptation strategies

There is the possibility that irrigators do not plan individual adaptation strategies independently, but rather that several individual planned adaptations together comprising one strategy set (Kassie et al. 2015; Manda et al. 2016; Vigani and Kathage 2019; Wainaina et al. 2016). We call them compound strategies. If the error terms of individual planned adaptation strategies are inter-dependent, it is more efficient to model them simultaneously. An example of a compound strategy may be irrigators planning to buy more farmland, more water entitlements and planning to expand irrigation. We considered a range of individual planned adaptation combinations to make up compound strategies (see Table 5.6). Following Greene (2008), we model combinations (15 compound strategies) of three individual planned adaptation strategies, as a recursive multivariate probit model with robust standard errors, and the instrument variable approach as the 4th equation (*mvprobit, robust* in Stata). For one set of compound strategies, the equation is:

$$(3) \quad Prob[Y_s = 1, Y_r = 1, Y_t = 1, CC\_risk = 1 \,|\boldsymbol{X_s}, \boldsymbol{X_r}, \boldsymbol{X_t}, \boldsymbol{X_{risk}}] = \phi_4(\boldsymbol{X'_s\beta_s} + \gamma\, CC\_risk, \boldsymbol{X'_r\beta_r} + \delta\, CC\_risk, \boldsymbol{X'_t\beta_t} + \eta\, CC\_risk, \boldsymbol{X'_{risk}\beta_{risk}}, \rho_{sr}, \rho_{st}, \rho_{srisk}, \rho_{rt}, \rho_{rrisk}, \rho_{trisk})$$

Where $\phi_4\,(\cdot,\cdot; \rho_{sr}, \dots, \rho_{trisk})$ denotes the cumulative distribution function of the multivariate standard normal distribution with coefficients of correlation $(\rho_{sr}, \dots, \rho_{trisk})$. The dependent variables of the model are:

Y_s = 1 if plans to implement adaptation strategy *s*; 0 otherwise

Y_r = 1 if plans to implement adaptation strategy *r*; 0 otherwise

Y_t = 1 if plans to implement adaptation strategy *t*; 0 otherwise

CC_risk = 1 if sees climate change as a risk for their region; 0 otherwise

with $s \neq r \neq t$. The independent variables of the model are:

X_s = X_r = X_t = vector of independent variables (see section 5.3.4)

CC_plan = climate change planning on farm (the instrument variable)

The regressor vectors are:

$$\boldsymbol{X_s} = X_s, \quad \boldsymbol{X_r} = X_r, \quad \boldsymbol{X_t} = X_t, \quad \boldsymbol{X_{risk}} = X_s, \text{CC\_plan}$$

In contrast to the individual strategy models, the Wald statistics have a different interpretation: if $\rho_{sr} = 0$ or $\rho_{sr} = 0$ or $\rho_{st} = 0$ or $\rho_{rt} = 0$ can be rejected, it means that the error term of respective planned adaptation strategies are not independent, and may have common unobservable correlation left in the error terms, making it more efficient to be estimated simultaneously. If $\rho_{srisk} = 0$ or $\rho_{rrisk} = 0$ or $\rho_{trisk} = 0$ cannot be rejected, endogeneity may exist between the corresponding dependent variable and irrigator's climate change risk perception. This is repeated for all 15 compound strategies.

5.3.5.3 Indices

Finally, we also aggregated the 19 binary irrigators' planned adaptation questions into four indices: the planned total, expansive, accommodating and contractive adaptation indices, serving as the dependent variables for the model. A variety of different models were tested, including negative binomial, Poisson and multivariate linear regression, but Seemingly Unrelated Regressions [SUR] (Zellner 1962, 1963) ultimately provided the most robust results[35] for expansive, accommodating and contractive indices. The planned total adaptation index was modelled using a standard linear regression approach. Pairwise Pearson correlation analysis revealed a low and medium correlation between planned expansive, accommodating and contractive indices (see section 5.3.3.2 and Table C.3 for more detail). To address this, we followed Oliveira and Teixeira-Pinto (2015) and compared standard errors of the individual multivariate linear regressions and SUR. SUR model results were more robust, displaying higher R^2 values and lower root mean squared errors. The SUR method applies generalised ordinary least-squares (OLS) simultaneously to a system of equations; coefficient estimators so obtained are asymptotically more efficient than those obtained by an equation-by-equation approach. For simplicity of notation, we discuss the modelling equations by using only one index as an example.

In our case, the equation for one index is as follows:

$$(5) \quad y = X\beta + u$$

The dependent variable y is the value for the planned adaptation index value. X is the matrix of all independent variables (note every index uses the same set of independent variables). β is the vector of regression coefficients and u the vector of random error terms.

There may be endogeneity between the independent variable climate change risk perception (CC_risk) and the dependent variables (see 5.3.4 for more detail). We use a control function approach, suggested in Nauges and Wheeler (2017) and detailed in Wooldridge (2010, 2015), to address the issue of endogeneity and to receive consistent and asymptotically normal estimates:

$$(6) \quad CC\_risk = V\theta + \kappa CC\_plan + E\_instr$$

An irrigator's climate change risk perception (CC_risk) is the dependent variable regressed on the vector of independent variables (V)[36] and irrigators' climate change planning on farm (CC_plan), our instrument variable. A good instrument needs to be correlated with climate change risk perceptions, but uncorrelated with the error term in our main equation u. As our

[35] Model robustness was determined on lowest Akaike's and Schwarz's Bayesian information criteria values, tests for goodness-of-fit and overdispersion, and stability of independent variable significance.
[36] Note that V contains the same variables as X, but without CC_risk: (X = V + CC_risk).

data set is similar, we followed Wheeler et al. (2013b) who used climate change planning on farm as an appropriate instrument for climate change risk perception.

We first estimate (6) using OLS and obtain the estimated residuals $\widehat{E\_instr}$. We then estimate (7) using SUR, an augmented version of (5) which includes the estimated residuals as an additional independent variable:

$$(7) \quad y = X\beta + \lambda\widehat{E\_instr} + \omega$$

Note that the SUR model estimates equation (3) for every index simultaneously. Assuming climate change planning on farm is a valid instrument, the SUR estimation provides unbiased estimates of β and λ. The term $\lambda\widehat{E\_instr}$ is the "control function" used to test for endogeneity. A rejection of the null assumption that $\lambda = 0$ would be evidence for endogeneity of the climate change risk perception variable, and a positive (negative) λ coefficient would indicate that the impact of irrigators' climate risk perception on the planned adaptation strategy indices is under-estimated (over-estimated) if endogeneity is not controlled for.

5.3.5.4 Clustering

The data were clustered using a range of attitudinal clustering variables and a variety of clustering approaches. We constructed clusters based on four to six different attitude statements about water trading, motivations for farming, environmental considerations, and flexibility about changing residence and profession, in various combinations, representing traditional, environmentally friendly and business mindsets. Cluster appropriateness was decided based on a minimum cluster size of 150 observations[37], interpretable and meaningful attitudinal differences between the clusters, and statistical criteria, such as stopping rules and unique cluster membership of observations. We also employed a Pearson correlation matrix for all the attitude statements, because severe multicollinearity can jeopardize the outcomes of cluster analysis (Aldenderfer and Blashfield 1984). No severe multicollinearity was revealed. The most robust clusters emerged from using a partitioning clustering method, determining cluster membership based on the Euclidian distance as the dissimilarity measure ("*cluster kmeans*" in Stata 16). We then utilised the Caliński–Harabasz pseudo-F stopping rule to determine the optimal number of clusters as indicated by a larger F-value (Caliński and Harabasz 1974), leading to three optimal attitudinal clusters (see Table 5.8, and Table C.11 for numeric results).

We labelled irrigators belonging to the clusters as traditional, corporate-minded or environmentally friendly, based on their agreement/disagreement with the statements used to construct the clusters. These clusters were used in all planned adaptation models (individual, compound, and indices) to encapsulate potential differences in planned adaptation preferences and the drivers between different types of irrigators.

Other clustering methods and distance measures were also tested but did not lead to satisfying results. Following the approach employed by Kuehne et al. (2008), we created clusters based on hierarchical clustering with seven different dissimilarity measures (Single link, average link, complete link, weighted average link, median link, centroid link, Ward's link) and both the Caliński–Harabasz pseudo-F and the Duda pseudo T-squared stopping rule (Duda et al. 2012). Resulting clusters often contained less than 150 observations, displayed little

[37] A minimum of 150 observations in each cluster was necessary to allow for model convergence for planned individual and planned compound adaptation strategy modelling.

differences in attitudes, and cluster membership was not unique, indicated by frequent dendrogram reversals (Rencher and Christensen 2012). Attempting to generate clusters via latent class analysis as shown in Morey et al. (2006) was equally unsuccessful: when latent class models rarely converged towards results, the statistically optimal clusters were too small and displayed no meaningful attitudinal differences.

Table 5.8 Optimal irrigator clusters and corresponding attitudes

Cluster description	**Traditional irrigator**	**Corporate-minded irrigator**	**Environmentally friendly irrigator**
Observations	401	283	316
I could never imagine living anywhere other than this area*	Agree	Disagree	Agree
Farming is the only occupation I can imagine doing*	Agree	Disagree	Agree
We would be willing to have our seasonal allocations reduced to ensure sufficient water for the environment*	Strongly disagree	Disagree	Disagree
It is essential to make allocations to the environment otherwise irrigation will not be long-term sustainable*	Disagree	Neutral	Agree
I believe water trading has been a good thing for farming*	Disagree	Neutral	Agree

* Attitudes were measured on a Likert scale with 1 = strongly disagree; 5= strongly agree

5.4 Results and discussion

This chapter focuses on the planned expansive, accommodating, and contractive adaptation indices results; results for individual and compound strategies, and the total planned adaptation index, are not discussed (but regression tables for the full models can be found in Table C.12, Table C.13, and Table C.17 to Table C.31). Similarly, the impact of our three clusters for total, expansive, accommodating and contractive planned adaptation indices is also not reported here in order to simplify results, but can be found in Table C.14 to Table C.16. The results and discussion are structured in three parts. We first analyse whether irrigators prefer one type of adaptation strategies (one index) over others. The second part reports on significant drivers of planned expansive, accommodating and contractive adaptation, comparing them with total planned adaptation. The last section summarises the results across different indices, discusses limitations and draws attention to overarching themes. Results from individual and compound models, as well as clustered indices results, can be found in the Appendices.

5.4.1 Descriptive statistics of expansive, accommodating and contractive indices

Ninety percent (90%) of irrigators plan to employ more than one type of index strategy (Table 5.9). Comparing the proportion of individual adaptation strategies chosen per index,[38]

[38] Since the indices do not comprise the same number of questions, we compared $\frac{number\ of\ planned\ strategies\ chosen\ (index\ count)}{number\ of\ possible\ planned\ strategies\ (maximal\ possible\ index\ count)}$. Unpaired t-tests revealed that the mean

irrigators seem to choose on average a higher proportion of available expansive adaptation strategies (37%), as compared to accommodating (29%) and contractive adaptation (29%) strategies. There is no statistically significant difference between the proportion of accommodating and contractive adaptation strategies chosen. This reflects findings in Wheeler et al. (2013b), where the majority of irrigators preferred expansive and accommodating adaptation strategies.

Table 5.9 Descriptive statistics of expansive, accommodating and contractive indices

Index	Mean proportion of all index strategies chosen	Irrigators using more than one individual adaptation strategy (out of 19 adaptations)	Irrigators using only one type of index strategy (out of 3 index types)	Most nominated individual adaptation strategy
Expansive index	37%***	81%	3%	Improve irrigation infrastructure efficiency
Accommodating index	29%	83%	1%	Change irrigated production
Contractive index	29%	74%	7%	Selling the whole farm
All strategies	31%	98%	10%	Improve irrigation infrastructure efficiency

*** Using unpaired t-tests show irrigators choose a higher proportion of planned expansive adaptation strategies than planned accommodating and contractive strategies (p<0.01)

While in line with conventional wisdom, irrigators prefer growing rather than shrinking the farm, the strength of this result should not be overestimated due to the construction of the planned expansive adaptation index. A high incidence of planned water allocation purchase (56% of irrigators, see Table 5.3) is not surprising, given that water allocation trading is common place for sMDB irrigators (Seidl et al. 2020b).

Many irrigators would like to purchase extra water entitlements, to increase water supply security to deal with increasing water scarcity, to expand operations, or as an investment (Haensch et al. 2019), provided they can afford it given increasing water entitlement prices. Our data do not allow controlling for these factors, in particular for the effect of increasing entitlement prices on irrigators' willingness and affordability to buy water entitlements. However, Zuo et al. (2016) find that demand for high security water entitlements is inelastic in the range of AUD$1,700-2,100/ML, with price elasticity for general security in an almost identical range, and low security entitlements extremely inelastic. Therefore, planning to buy entitlements within this price range seems to be a fairly fixed decision by irrigators, experiencing little impact from rising entitlement prices. This may change if entitlement prices are higher than AUD$2,100/ML: the plan to buy entitlements may then potentially be more optimism than a fixed decision.

At time of data collection, the Commonwealth has been, and has continued, to heavily subsidise irrigation efficiency upgrades under various water recovery programs (Grafton and Wheeler 2018). We cannot know whether irrigators' plans to improve irrigation efficiency

percentage of chosen planned accommodating and contractive strategies are not significantly different, but the mean percentage of planned expansive strategies is statistically significantly larger compared to both others (p<0.01).

are contingent upon securing government subsidies, making this planned strategy choice somewhat relative, however, given that it is known that subsidies probably will be available given the remainder of water recovery as at 2015, it is highly likely they expected some sort of subsidy.[39]

Three of six planned expansive strategies may represent ‘business as usual’ water trading behaviour or optimism. Therefore, a large part of irrigators’ preference for planned expansive over accommodating and contractive adaptation strategies may be based on cheap talk and ideal conditions. This result should therefore be interpreted cautiously.

5.4.2 SUR Results

The SUR analysis shows different capital drivers have varying influence on irrigators’ planned expansive, accommodating and contractive adaptation (Table 5.10). Due to a number of missing observations in some variables (e.g. farm debt, farm income and land value), the final SUR model uses 903 of the 1,000 surey observations.

Comparing Table 5.2 and Table 5.10 reveals a number of factors broadly follow the directions predicted by the literature. Farm debt (access to credit) is a significant positive driver ($p<0.01$) for the expansive and accommodating index, farm income is statistically significant positive ($p<0.1$) for the accommodating adaptation index, climate change risk perception is statistically significant positive ($p <0.01$) for the expansive and accommodating index, male gender is statistically significant positive ($p<0.01$) for the expansive index, succession planning is statistically significant positive ($p<0.01$) for expansive and accommodating indices and statistically significant negative ($p<0.01$) for the contractive index, while past adaptation experience is statistically significant positive ($p<0.01$) for all indices. In the following, we discuss statistically significant drivers by the various capitals.

[39] We controlled for irrigators receiving an irrigation upgrade grant since 2007 and since 2013 onwards in our modelling. These were insignificant.

Table 5.10 SUR regression of planned expansive, accommodating and contractive adaptation

	Planned adaptation indices		
	Expansive	**Accommodating**	**Contractive**
VARIABLES	**coefficient** (standard error)		
Financial capital			
Farm debt	**1.271*****(0.374)	**1.092*****(0.415)	**-0.198**(0.365)
Farm debt squared	**-0.827*****(0.293)	**-0.743****(0.326)	**0.383**(0.287)
Farmland value	**-0.231**(0.210)	**-0.808*****(0.233)	**-0.024**(0.205)
Farmland value squared	**0.071**(0.061)	**0.221*****(0.067)	**0.005**(0.059)
Net farm income	**2.100**(1.995)	**3.967***(2.218)	**2.452**(1.949)
Net farm income squared	**-6.637**(7.496)	**-16.666****(8.329)	**-12.452***(7.320)
Number of insurances	**0.076****(0.031)	**0.091*****(0.035)	**-0.034**(0.031)
Off-farm income	**-0.004****(0.001)	**-0.002**(0.002)	**0.000**(0.001)
Productivity change	**0.087****(0.034)	**-0.005**(0.038)	**-0.138*****(0.033)
Human capital			
Age	**-0.011**(0.026)	**0.006**(0.029)	**0.013**(0.025)
Climate change risk perception	**0.543*****(0.155)	**0.679*****(0.174)	**0.091**(0.151)
Low education	**0.032**(0.111)	**0.092**(0.124)	**0.248****(0.109)
Male gender	**0.398*****(0.118)	**0.174**(0.131)	**0.006**(0.116)
Succession	**0.537*****(0.086)	**0.464*****(0.096)	**-0.629*****(0.084)
Whole of farm plan	**0.120**(0.097)	**0.303*****(0.107)	**-0.008**(0.094)
Natural capital			
Average historic water allocation	**-0.001**(0.178)	**-0.003**(0.198)	**-0.161**(0.174)
Historic net rainfall	**-0.000***(0.000)	**-0.000**(0.000)	**-0.000**(0.000)
Historic temperature volatility	**-0.748**(0.744)	**0.060**(0.823)	**1.779****(0.724)
Physical capital			
Broadacre	**0.166**(0.161)	**-0.241**(0.179)	**-0.268***(0.157)
Carry-over use between 2014-2016	**0.112**(0.100)	**0.145**(0.110)	**-0.098**(0.097)
Dairy	**0.031**(0.174)	**-0.258**(0.193)	**-0.298***(0.171)
Excess water	**-0.228****(0.104)	**-0.060**(0.114)	**0.618*****(0.100)
Farm Size	**-0.000**(0.002)	**0.001**(0.002)	**0.000**(0.002)
Livestock	**0.098**(0.166)	**-0.339***(0.185)	**0.445*****(0.162)
Majority of farm area under drainage	**-0.002**(0.096)	**-0.015**(0.106)	**0.044**(0.093)
Majority of farm area under drip irrigation	**-0.296****(0.142)	**-0.339****(0.159)	**-0.136**(0.139)
Number of employees	**0.014**(0.013)	**0.011**(0.015)	**-0.019**(0.013)
Water application rate	**-0.001**(0.009)	**-0.015**(0.010)	**0.001**(0.009)
Water ownership	**-0.054***(0.028)	**0.000**(0.031)	**0.037**(0.027)
Past experiences			
Past index	**0.495*****(0.031)	**0.611*****(0.030)	**0.225*****(0.037)
Control function residual	**-0.564*****(0.180)	**-0.639*****(0.201)	**-0.070**(0.175)
Constant	**0.864**(0.964)	**0.294**(1.067)	**-0.124**(0.944)
AIC	8562.493	8562.493	8562.493
BIC	9052.676	9052.676	9052.676
Observations	903	903	903
R-squared	0.541	0.493	0.239

*** p<0.01, ** p<0.05, * p<0.1

5.4.3 Financial capital

Financial capital variables have a pronounced influence on planned expansive and accommodating adaptation. As expected, farm debt levels are highly statistically significant (p,0.01) and positive drivers for planned expansive and contractive adaptation, albeit at a decreasing rate signified by the statistically significant negative ($p<0.05$ and $p<0.01$) influence of farm debt squared. In contrast to other studies, which often treat access to credit as a qualitative/binary variable (Bryan et al. 2009; Bryan et al. 2013; Deressa et al. 2009; Touch et al. 2016), our results allow us to quantify the benefits of credit access versus the hampering effect of large farm debt. At a threshold level of around AUD$765,000 for expansive and AUD$736,000 for accommodating adaptation, the negative influence of very large farm debt squared outweighs the positive influence of farm debt..

The statistically significant positive influence ($p<0.1$) of farm income on planned accommodating adaptation, as well as the statistically significant positive (negative) influence ($p<0.05$ and $p<0.01$) of increased farm productivity on planned expansive (contractive) adaptation is in line with expectations: higher income increases adaptation affordability, while irrigators which have been improving productivity over the last five years would be less likely to plan to employ contractive measures, such as far exit or decreased irrigation area.

The strong statistically significant negative impact ($p<0.01$) of farmland value on planned accommodating adaptation is surprising: contributing to irrigators' wealth, one would expect a positive relationship mirroring the findings of studies examining farmer wealth (Harvey et al. 2014; Li et al. 2017; Roco et al. 2014). Upon reviewing the index component models (see Table C.12), the result is driven by a statistically significant negative impact of farmland value on planned insurance uptake. One possible explanation is that wealthier irrigators, expressed by higher farmland values, may prefer to self-insure rather than take out insurance. This is in line with Nauges et al. (2016) who find that Australian farmers are encouraged through drought policy to self-insure as there is an absence of yield insurance available (Hatt et al. 2012). The relationship between farmland values and insurance uptake has also been found in other studies (Mishra and Goodwin 2006; Shaik et al. 2008; Sherrick et al. 2004).

The current level of insurance, expressed by the number of different insurance contracts, is a statistically significant positive impact ($p<0.05$ and $p<0.01$ level) on planned expansive and accommodating adaptation. We interpret current insurance level as a proxy for irrigators' risk aversion, with more insurance corresponding to higher risk aversion.[40] Thus, our results support findings in other studies that increasing risk aversion increases adaptation (Tambo 2016; Wheeler et al. 2013b).

5.4.4 Human and social capital

Human and social capital factors play an important role in planned adaptation. Past adaptation experience, expressed by the past adaptation index value, and succession planning are highly significant drivers. Past experience is a uniformly statistically significant positive driver ($p<0.01$) for all three planned adaptation indices, as it shows familiarity with, and learning about, the technologies/strategies involved (Chavas and Nauges 2020), while succession planning is statistically significant negative ($p<0.01$) for planned contractive

[40] Using self-reported risk aversion (see Table 5.7) instead of current level of insurance was not significant and did not improve model quality.

adaptation, and statistically significant positive ($p<0.01$) for planned expansive and accommodating adaptation indices. This intuitively obvious, as irrigators would prefer to hand over a larger and or improved, rather than a smaller, farm, whereas with farm exit, there would be no succession. Our results are in line with results from other studies (Ghadim et al. 2005; Nicholas and Durham 2012; Wang et al. 2015b; Wheeler et al. 2012a; Wheeler et al. 2013b).

Irrigators' climate change risk perceptions are statistically significant positive drivers ($p<0.01$) for planned expansive and accommodating adaptation, confirming growing evidence in the literature (Alam 2015; Jianjun et al. 2015; Wheeler et al. 2013b). Note that in contrast to earlier studies, which focus on farmers' *belief* in climate change (e.g. see (Arbuckle et al. 2013; Dang et al. 2014; Deressa et al. 2009; Tambo 2016)), we use the concept of *perceived affectedness* by climate change as a factor driving planned adaptation behaviour (Leiserowitz 2005; van der Linden 2017).

We find only limited statistically significant influence for gender and education: male gender and low education are statistically significant positively ($p<0.01$ and $p<0.05$) for planned expansive and contractive adaptation respectively. Together with age not statistically significant influencing any type of planned adaptation, this is somewhat surprising given the strong influence of gender, higher education, and age in countless adaptation studies (Abid et al. 2016; Alam 2015; Below et al. 2012; Deressa et al. 2009; Huffman 2020; Jianjun et al. 2015; Roco et al. 2014). With age fairly homogeneous and with little variation, it is not an important factor in our data. The small number of female respondents in our sample (12%) may not provide enough variation to lead to a significant gender impact.

The impacts of social group membership overall, as well as the how many social groups an irrigator is a member of was statistically insignificant in our data and subsequently removed from analysis. This is in contrast to Wheeler et al. (2013b) who find membership in an environmental group is a statistically significant positive influence on the future purchase of farmland.

5.4.5 Natural capital

Natural capital variables, such as geography, location and climate are common drivers for adaptation behaviour in many studies. In our case, rainfall-evaporation balance over the last 10 years (signifying dryness/drought) is a statistically significant negative ($p<0.1$) influence on the expansive adaptation index. Mean annual temperature variability over the last 30 years (signifying changes in extreme events) has a statistically significant positive influence ($p<0.05$) on the planned contractive adaptation index. This supports recent findings by Wheeler et al. (2020b) that farm exit (and or shrinking of irrigation in our case) in the sMDB is strongly driven by climatic factors. Going beyond the common approach to focus on nominal temperature or rainfall values (Deressa et al. 2009; Gandure et al. 2013; Moniruzzaman 2015; Wheeler et al. 2013b), our results expand the literature addressing changing volatility of climatic patterns as a main influence on adaptation.

As quantitative climate and geographic data is often challenging to collect or source, particularly in developing countries, many studies opt to use regional dummies to encapsulate this information (Abid et al. 2016; Bryan et al. 2013; Roco et al. 2014). Some use region or state dummies together with observable climate and geographic data (Deressa et al. 2009; Wheeler et al. 2013b). This was unsuccessful in our study as state dummies (NSW, SA, VIC) and the Millennium Drought dummy (2001/02-2009/10) were statistically insignificant.

5.4.6 Physical capital

Finally, physical capital variables also influence planned expansive, accommodating and contractive adaptation. Excess water holding has a statistically significant positive influence ($p<0.01$) on planned contractive adaptation and all but one index components (see Table C.12). This finding is in line with results by Wheeler and Cheesman (2013), showing irrigators sell excess water entitlements for environmental water recovery but keep irrigating. That irrigators sell more water allocations if they own excess water makes intuitive sense and is well documented (Loch et al. 2012).

The statistically significant negative influence ($p<0.05$) of excess water holding on planned expansive adaptation is interesting. One might expect that irrigators plan to increase their irrigated production or buy extra land to make use of the available water (Adamson and Loch 2014; Loch and Adamson 2015; Wheeler et al. 2020a). The models for the planned expansive adaptation index components (see Table C.12) reveal no statistically significant impact on planned land purchase or plans to increase irrigated area. Rather, owning excess water results in irrigators' planning to buy less allocations and entitlements, leading to an ultimately a statistically negative influence for the overall index.

We find a statistically significant negative impact ($p<0.05$) on planned expansive and accommodating adaptation if the majority of farm area (more than 50%) is under drip irrigation. This may be due to a few factors: drip irrigation leads to a significant technological lock-in, constraining the flexibility to modify the planted area and crop types (i.e. only high value and water intensive crops make drip irrigation worthwhile) (Adamson and Loch 2018; Adamson et al. 2017). There also may be less incentive to further increase irrigation efficiency if the majority of the farm is already under drip irrigation (Adamson and Loch 2018; Loch et al. 2014b). Finally, higher plant water use efficiency through drip irrigation can limit the amount of water (allocations and entitlements) irrigators plan to buy.[41]

Industry (broadacre, dairy and livestock)[42] has a (weak) statistically significant negative influence ($p<0.1$, $p<0.1$ and $p<0.01$) on planned contractive behaviour, but it is statistically insignificant for planned expansive and accommodating adaptation. Examining planned contractive adaptation index components (see Table C.12) reveals that livestock irrigators in particular seem less willing to sell entitlements, farmland, and consider farm exit less than horticultural irrigators.

5.4.7 Summary

Faced with multiple dimensions of future uncertainty and risk, sMDB irrigators plan to use a mix of expansive, accommodating and contractive adaptation. Although there is some evidence that planned expansive adaptation is preferred, this might be an artefact of index construction, 'business as usual' in water allocation trading, and optimism in regard to entitlement purchases.

Financial, human, natural, physical and social capital influence planned adaptation, but their influence can vary between planned expansive, accommodating and contractive adaptation.

[41] Note that drip irrigation only "saves" water on-farm, given that irrigated area does not increase. On a catchment scale, it can increase overall water extraction by the associated reduction of return flows (Grafton et al. 2018; Williams and Grafton 2019).

[42] The base category for industry is horticulture.

Human and social capital play an important role: past adaptation experience and succession planning are highly significant factors for all three planned adaptation types. Climate change risk perception is a significant positive driver for planned expansive and accommodating adaptation, illustrating the importance of climate change affectedness, rather than mere belief in climate change (van der Linden 2017). The human and social capital factors of past experience, succession planning and climate change risk perception, are the most important drivers for planned expansive and contractive adaptations.

In contrast, financial capital variables are the most important driver for planned accommodating adaptation, but also play an important role for planned expansive adaptation. Farm debt, risk aversion (expressed by number of insurances), and productivity change are the most influential financial capital variables, confirming the results of other studies (Li et al. 2017; Tambo 2016; Touch et al. 2016; Wheeler et al. 2013b).

Surprisingly, planned contractive adaptation is largely unaffected by financial capital, despite the expected link between poor farm financials (high debt, low income) and land sale, water entitlement sale, and farm exit. Instead, industry dummies and historic temperature variability have a more pronounced impact, showing the importance of climate and industry characteristics. This supports Wheeler et al. (2020b) who find farm exit in the sMDB is mainly driven by climatic factors and producer prices.

The influence of industry characteristics notwithstanding, we find physical capital is not a major driver for planned adaptation. For planned expansive and accommodating adaptation, the lock-in effect of drip irrigation limiting flexibility to change farm area, structure and crops, is the only material physical capital influence. Owning excess water entitlements does not influence the planned expansion or contraction of irrigation, but rather the water trading side of an irrigation farm: less allocations and entitlements need to be bought, while also enabling the sale of allocations and entitlements for extra income. This manifests as a negative (positive) impact of excess entitlement holding on planned expansive (contractive) adaptation. This is in line with findings of Wheeler and Cheesman (2013), that irrigators tend to sell excess water entitlements but continue production.

Although the data used in this study is rich and of high quality, data limitations exist about the quality of adaptation strategies, impacting the design of our dependent variables. We acknowledge modelling planned adaptation as unweighted count indices is a fairly coarse, but necessary approach, given the binary planned adaptation strategy data, which does not capture the degree of planned adaptation.

Future research should aim to include the intensity of planned adaptation into the analysis to provide a more nuanced picture of drivers for adaptation, and to allow for a ranking/weighting of different (and compound) planned adaptation strategies. Our study provides valuable insights for irrigators' planned adaptation behaviour. Although some variables, such as past adaptation experiences and succession planning, influence planned expansive, accommodating and contractive adaptation simultaneously, the majority of drivers vary between different adaptation types. Financial capital variables (farm debt, farmland value, income, and number of insurances) are the major driver for planned accommodating adaptation, whereas human and social capital (climate change risk perception, succession and past experiences) are more important for planned expansive and contractive adaptation.

Nauges et al. (2016) find that MDB irrigators may be willing to pay for insurance products protecting them against the risk of yield or revenue losses. Through subsequent drought policies (e.g. the National Drought policy, the Farm Household Support Scheme, and the Farm Household Allowance), the Australian government have always encouraged farmers to be self-reliant and develop their own risk management strategies (Alston and Kent 2004; Botterill 2003, 2005). These policies relied on financial incentives, such as, the Income Equalisation Deposits scheme, the Farm Management Bond and the EC Interest Rate Subsidy (Botterill 2003, 2005, 2010; Peterson 2016). However, although refraining from subsidising insurance premiums, the government has traditionally provided drought assistance for ‘exceptional’ droughts through the aforementioned programs, hence indirectly compromising the establishment of a competitive insurance pooling farmers’ risks, and thus contributed to the failed introduction of yield insurance products (Hatt et al. 2012). For example in the Millennium drought, 23% of Australian farms received some drought financial support (Productivity Commission 2009).

As another drought response policy, the Commonwealth implemented the *Water for Fodder* program in 2019/2020: an agreement to use the Adelaide desalination plant to produce an extra 100GL of water for SA water consumption in exchange for Commonwealth funds (DAWE 2020a). In turn, 100GL of Murray water (40GL in 2019/20 and 60GL in 2020/21) from the SA state entitlement will be made available to irrigators, in blocks of 50ML for $5,000 per water allocation account, to produce fodder at a discounted price of AUD$100/ML (DAWE 2019d). At the time of writing, of the 40,000 ML available in round 1, 14,250 ML were delivered to irrigators in NSW, 25,100 ML to irrigators in VIC, and 650 ML to irrigators in SA (DAWE 2020c). Drought assistance for ‘exceptional droughts’ and the *Water for Fodder* program are examples of how Australian Drought policy is indirectly compromising irrigators’ risk management efforts (Nauges et al. 2016). Irrigators with appropriate risk management practices would not have to rely on ad hoc government support or subsidised cheap water allocations for their livelihoods. In essence, this rewards poor individual risk management and incentivises irrigators’ reliance on the government as the insurer of last resort (Watson 2019)

Given the findings of this chapter, an over-reliance on ad hoc financial support may do little for or even disincentivise planned adaptation to drought and climate change. Stronger emphasis should be given to support irrigators’ risk management efforts, by financial incentives on those which support irrigators’ risk management, such as Revenue Contingency Loans or the Farm Management Deposit Scheme (Botterill 2010; Botterill et al. 2017). Providing non-monetary incentives and better support for irrigators’ private risk management efforts, potentially through improved climate change forecasting, also translating into tangible risk implications, could increase planned adaptation and potentially foster the emergence of commercial insurance products. Policy makers aiming to incentivise planned adaptation should clearly identify which type of adaptation they are targeting and which capital factors have the strongest corresponding influence. This allows for more targeted and potentially cheaper incentive policies, particularly because the inclusion of human and social capital factors can have large benefits, while likely being less resource intensive than financial capital stimuli.

5.5 Conclusion

With increasing pressures from climate change, agricultural industry restructuring and globalisation, Irrigators will continuously need to adapt to an uncertain and risky future. While sMDB irrigators have historically proven flexible and adaptive, these attributes are ever more important going forward. Having access to a large variety of adaptation strategies, irrigators may prefer some adaptation types over others, and/or their adaptation decision may be influenced by different drivers. This study explores sMDB irrigators’ preferences and drivers for different planned adaptation types, using three indices: 1) planned expansive adaptation that aims to increase irrigation of a farm; 2) planned accommodating adaptation that alters farm structure and production practices while leaving the irrigation component unchanged; and 3) planned contractive adaptation that aims to decrease irrigation.

The majority of irrigators plan adaptation from more than one type, with limited evidence that planned expansive adaptation is preferred over accommodating and contractive adaptation. While financial, human, natural, physical and social capital variables all influence planned adaptation, their role varies between planned expansive, accommodating and contractive adaptation strategies.

Financial capital drivers are the most influential for planned accommodating adaptation, in particular farm debt, farmland value and farm income. There is less influence of financial capital for other planned adaptation types. Farm debt, off-farm income and productivity change influence planned expansive adaptation, whereas planned contractive adaptation is only influenced by productivity change. Natural and physical capital factors play an important role for planned contractive adaptation, with historic temperature volatility and industry specificity as major factors. This supports recent research showing that sMDB farm exit is driven mostly by climate factors and low production prices in certain industries. Human and social capital are common drivers across all types of planned adaptation. Farm succession planning and past adaptation experiences strongly impact planned expansive, accommodating and contractive adaptation. Furthermore, climate change risk perception has a significant positive influence on both planned expansive and accommodating adaptation, supporting results from other studies showing that not the belief in climate change happening, but personal affectedness is driving climate change adaptation.

Our study illustrates the importance of incentivising irrigators' private risk management efforts and of non-financial factors for irrigators' planned adaptation, particularly of succession planning and adaptation experience. Knowing what drives planned expansive, accommodating and contractive adaptation allows policy-makers to design targeted and effective policies to incentivise increased adaptation of a particular type. Aiding irrigators' risk management efforts by employing forward-looking financial support rather than ad hoc relief measures such as the Farm Management Deposit Scheme, and improving climate change forecasting or succession planning support, reforming drought policy such that it also draws on non-monetary incentives, and policies targeting different types of adaptation directly could increase future adaptation to climate change and water scarcity. This has the potential to achieve better policy outcomes and avoid costly one-size-fits-all approaches, which may have an overly strong focus on ad hoc financial relief that only has a small impact on improving irrigators' risk management and planned adaptation.

Chapter 6 Treating water markets like stock markets: Key water market reform lessons in the Murray-Darling Basin

Constantin Seidl[*,a], Sarah Ann Wheeler[a], Alec Zuo[a]

[a]Centre for Global Food and Resources, Faculty of Professions, University of Adelaide

This chapter presents a paper published in the *Journal of Hydrology* (2020). The paper is included in its published form, with only minor changes to formatting to bring it in line with the overall thesis. There is therefore some repetition with other chapters of this thesis, particularly the background sections.

Abstract

Water markets are well known in improving the efficient use and reallocation of water, and the southern-connected Murray-Darling Basin water market is recognised as the most advanced water market globally. In recent years, the market has matured considerably with new water ownership and trading strategies emerging, along with increased participation from non-landholders (i.e. environmental water holders and financial investors, such as pure traders and superannuation companies). This study draws on a quantitative survey of 1,000 southern Basin irrigators plus qualitative interviews with 63 water experts from banks, environmental water holders, investors/agri-corporates, financial investors, property evaluators and water brokers to illustrate the different water ownership and trading strategies employed. Findings suggest that many stakeholders, including non-landholders, prefer to own most of their water needs in higher security water entitlements and use temporary trade to mitigate water supply shortfalls. However, some own no water entitlements (or land) at all, while financial investors and large agri-corporates are more likely to use/supply highly sophisticated temporary trading products, such as water forwards and parking contracts. In addition to the need to reinforce the fundamentals of water institutions in the Murray-Darling Basin (i.e. robust accounting of water extraction and use, and continual monitoring, compliance and enforcement of water extraction/trades), we suggest three major reform areas: 1) data reform: improving the quality and availability of trade and water data plus standardised water market and water forwards terminology; 2) rules and regulation reform: increased transparency of trade and allocation/carry-over restrictions plus increased water market regulation and enforcement; and 3) new water market institutional development: a central exchange and clearing house.

Keywords: water investment; water markets; permanent trade; market maturity; temporary trade; non-landholders.

[*]Corresponding author. Mailing Address: University of Adelaide, Faculty of Professions, Centre for Global Food and Resources, 10 Pulteney Street, Adelaide, SA 5005, South Australia. Phone +6188313 0490. E-mail: constantin.seidl@adelaide.edu.au

Statement of Authorship

Title of Paper	Treating water markets like stock markets: Key water market reform lessons in the Murray-Darling Basin
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Seidl, C, Wheeler, SA, Zuo, A 2020. "Treating water markets like stock markets: Key water market reform lessons in the Murray-Darling Basin", Journal of Hydrology, vol. 581, p. 124399, https://doi.org/10.1016/j.jhydrol.2019.124399

Principal Author

Name of Principal Author (Candidate)	Constantin Seidl		
Contribution to the Paper	Undertook the literature review. Collected majority of the data. Prepared data for analysis and performed quantitative data analysis in Stata and qualitative data analysis in Nvivo. Interpreted data and wrote majority of the manuscript. Acted as the corresponding author.		
Overall percentage (%)	70%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	21/02/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

iv. the candidate's stated contribution to the publication is accurate (as detailed above);

v. permission is granted for the candidate in include the publication in the thesis; and

vi. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Sarah Ann Wheeler		
Contribution to the Paper	Supervised development of work, edited and wrote parts of the manuscript.		
Signature		Date	21/02/2020

Name of Co-Author	Alec Zuo		
Contribution to the Paper	Supervised development of work, editing of the manuscript.		
Signature		Date	21/02/2020

6.1 Introduction

Water scarcity and climate change are two of the biggest global strategic risks faced by humanity. Many countries will have to deal with both a drier and more volatile climate in the future, requiring substantial adaptation in agricultural systems and production (IPCC 2019). Continued increase in water extraction and decline in quality and quantity of water resources requires the production of more crops with less water (Perry et al. 2017) without compromising ecosystems. Increasingly, water markets are seen as a key demand management strategy to address water scarcity (Rey et al. 2019), and Australia plays a leading role in this space given it has the most advanced water market system in the world in the Murray-Darling Basin (MDB) (Grafton et al. 2011).

Since their inception a number of decades ago, MDB water markets have been continuously evolving and maturing, and in recent years new water market products such as forwards and parking have emerged (ABARES 2018; Bayer and Loch 2017). The separation of land from water ─ known as unbundling ─ has allowed for new market participants, such as Environmental Water Holders (EWHs) and non-landholder financial investors (such as superannuation companies and trade speculators) to own and trade water. The reason financial investors have increasingly invested in water is because of the long-term increase in water asset values – to diversify their investment portfolios with water assets which share little correlation with other asset classes (Roca et al. 2015; Wheeler et al. 2016a), and the fact that variability in water market prices presents significant opportunities for investment trade returns. In other words, there has been a significant increase in various stakeholders treating the water market like a stock market over the past five to ten years. Although investment in water entitlements by corporate non-landowners is still relatively small, it is increasing – estimated at around 12% in some areas in 2018[43] (DELWP 2019a). Additionally, 9% of MDB water entitlements are held by companies with some level[44] of foreign ownership (ATO 2019). The Commonwealth of Australia is the largest EWH water owner in Australia, currently owning over 2,000GL (gigalitres) of long-term average annual yield (LTAAY – see Appendix A for a glossary of terms) in water entitlements, which it has been recovering from consumptive use since 2007-08 (Zuo et al. 2019).

With large parts of south-eastern Australia currently experiencing the most severe drought in 120 years (Doyle 2019), and high water allocation and entitlement prices, increasingly questions have been raised regarding water market functionality and equity issues. In particular, questions surround the role that non-landholders and EWHs play in influencing water market prices, along with their water ownership and trading behaviour (Miller 2019). Public concerns culminated in the Australian Government commissioning a current review of MDB water markets. Although recent academic evidence (Zuo et al. 2019) shows water market prices are driven primarily by water scarcity rather than government water recovery,

[43]The Commonwealth minister for water resources stated in an interview on 09/09/2019 that 14% of all southern MDB entitlements are owned by entities "that don't have land attached to it". This figure is based on 2018 internal Department of Agriculture and Water Resources (DAWR) estimates of non-landholder ownership of 7-14%. DAWR advised that this estimation is no longer used due to physical variations and changes in water investment strategies in 2019 (DAWR, personal communication, 2019).

[44]The ATO (2019) defines companies with a level of foreign ownership as: 1) owned by an individual not ordinarily an Australian resident; 2) owned by a foreign government or government investor; 3) a company or trust where an individual not ordinarily resident in Australia, a foreign corporation or government holds a substantial interest of at least 20%; or 4) a company or trust where two or more foreign persons hold an aggregate substantial interest of at least 40%.

there are still considerable knowledge gaps around water corporate and non-landholder (namely EWH and financial traders/investors) water market strategies.

This study seeks to understand the water ownership and trading strategies used by MDB stakeholders, both landholders and non-landholders. We draw upon 1,000 telephone interviews with irrigators in the sMDB and 63 in-depth interviews with water experts in banks, large agri-corporates, environmental water groups (generally non-landholding), financial investors (non-landholding), property evaluators and brokers. In particular, our study sought to answer three research questions in regards to water ownership, trade and water market improvements:

1) What motivates land-holders and non-landholders to own water entitlements in the MDB and what ownership strategies are employed?
2) What are the water market trading strategies employed by various stakeholders in the MDB and is there a difference in trading strategies between land-holders and non-landholders?
3) What do various stakeholders think are the key lessons for water market improvement?

We conclude with our recommendations for MDB water market design reform and a number of key insights for the development of water markets in other countries.

6.2 Background of MDB Water Trading

The benefits from introducing water ownership rights (otherwise known as entitlements and licences) and water trading markets have been well established, both in theory and in practise (Bjornlund 2006; Grafton et al. 2016; Pujol et al. 2006). Water markets have been adopted in a number of countries, such as Spain, Mexico, Chile and the United States, however the most advanced water market operates in Australia's MDB – routinely serving as the exemplar of best-practice (Grafton et al. 2011; Leonard et al. 2019; Rey et al. 2019).

Informal water markets have been operating in the MDB since the 1960s, with water swapping even known during the World War II drought, but were more formally established from the 1990s onwards, and driven by the cap of water diversions implemented in 1995, with the annual permitted extraction from watercourses and regulated rivers set at 1993–94 levels of development (although Queensland was set at 1999-2000 levels (AAS 2019) and South Australia where the Cap was set at an average use of 90% of entitlements which was considerably above its 1993-94 levels of use). The 2000s saw the separation of land and water ownership (e.g. Victoria unbundled water from land in 2007), which allowed non-landowners to own water for the first time. Water markets developed from the late 1980s and early 1990s onwards. Trade generally occurs through two main products: 1) water entitlements (permanent water – a right to extract water from a watercourse/body); and 2) water allocations (temporary water – the seasonal allocation received by a given water entitlement) (Wheeler et al. 2014a). Water entitlements come in three main forms within the southern system: high, general and low security (reliability in Victoria), reflecting the probability of receiving a full water allocation. For example, a high security entitlement is meant to yield, on average, a full allocation in 90-95 out of 100 years (Zuo et al. 2016). Other relatively common trade products include water delivery shares (right to deliver water in an irrigation network (Crase et al. 2015)), parking (right to use carry-over[45] space owned by a different entitlement holder), water leases, water forwards and water options.[46] For a Glossary of important water market products and expressions, see Table D.1.

Over 150 different types of water entitlements currently exist in different parts of the Basin (MDBA 2019l). Table 6.1 illustrates the main types of water products traded, along with some price examples of what each product traded for in recent water seasons.

[45]Carry-over allows water owners to store allocation in dams for future use, minus 5% loss for storage evaporation losses.

[46]To date only "call options" were traded, giving the contract buyer the option, but not the obligation, to buy an agreed volume of water for an agreed price and timeline. It seems "put options", giving the contract buyer the option to sell an agreed volume of water for an agreed price, have not yet been transacted (H2OX, personal communication, 2019).

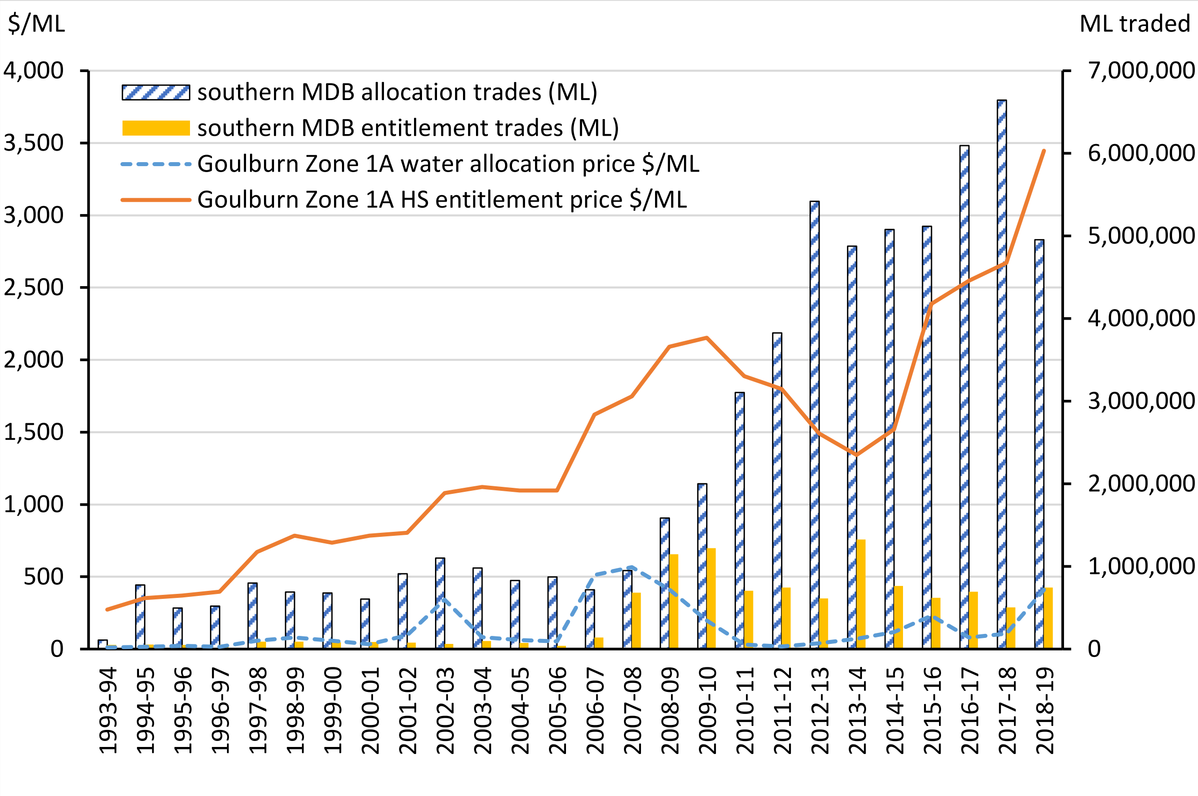
Table 6.1 Overview of the main MDB water market products

Permanent water products	***Murrumbidgee $AUD/ML price 2018-2019****	***Goulburn (1A) $AUD/ML price 2018-2019****	***Temporary water products***	***Murrumbidgee $AUD/ML price 2018-2019****	***Goulburn (1A) $AUD/ML price 2018-2019****
Entitlements (regulated and unregulated)			Allocation		
• High security (HS)	4850-7000	3000-4000	• Surface water	250-550	230-540
• General security (GS)	1600-2200	not available (n/a)	• Groundwater	200-250	n/a
• Low security (LS)/ supplementary/ conveyance	310-2575	400-550	Water lease		
• Unregulated	175-800	n/a	• 1 year	n/a	LS: 20-30 HS: 250-350 (p.a.)
• Groundwater	4000-4500	n/a	• Multi-year (mostly up to 5 years)	GS: 80+ (p.a.) HS: 350+ (p.a.)	LS: 25-35 (p.a.) HS: 250-350 (p.a.)
Water delivery shares**	150-250	37 **(seller pays)**	Carry-over space (parking)	21-33	5-15
			Water forwards		
			• 1 year	160-385	140-350
			• Multi-year (up to 5 years)	n/a	n/a
			Water options	n/a	n/a

<u>Notes</u>: *Water allocation and entitlement prices are based on monthly median prices, excluding prices of AUD$0/ML, and are sourced from BOM (2019c) for Murrumbidgee and DELWP (2019b) for 2018-19 Goulburn water season. H20X water trading platform data provided values for groundwater, delivery shares, leases, parking and forwards. **One delivery share in the Murrumbidgee allows the delivery of 1.2 ML and can be traded annually (MI 2015). One delivery share in the Goulburn delivers 270 ML (1ML per day per irrigation season (270 days)) and are valid indefinitely. Licencing fees amount to $2,925–5,333 per year per share, with a termination fee of $29,250–53,333 (GMW 2018). Therefore, sellers in the Goulburn pay the buyer around $10,000 per share, or $37/ML, to take on the ongoing liability.

Figure 6.1 illustrates the development of water allocation and entitlement volume traded from the early 1990s in the sMDB, and also displays nominal annual water allocation and high security (HS) entitlement prices for the Goulburn system of Victoria, one of the most active and mature trading regions.

Figure 6.1 Temporary and permanent water prices in the Goulburn and sMDB water trade volumes from 1993-94 to 2018-19



Source: Adapted from Seidl et al. (2020a).

Under an entitlement lease, the buyer gains the right to extract water allocated to the seller's entitlement for a given time-period. Water forward/options contracts deliver a predetermined volume of allocation at a set date and price to the buyer. Forward delivery is mandatory, whereas under option contracts the buyer can choose not to acquire the water. In contrast to forwards and options, where the seller bears (part of the) supply risk and guarantees physical delivery, these risks are borne by water lease buyers.

From 2007 onwards, an organisation can buy water entitlements on the market irrespective of land-ownership, and achieve a return by selling temporary water through the market to agriculturalists (Wheeler et al. 2016a). As a result, non-landholder ownership (i.e. superannuation companies, trade speculators and arbitrageurs, NGOs, EWHs) of water entitlements in the MDB has been growing (DELWP 2019a).

Market participation by irrigators in general has also grown over time with 52% and 78% of irrigators in 2015-16 having conducted at least one entitlement or allocation trade respectively (Grafton and Wheeler 2018). Corresponding to the increase in market use, water market transaction costs and trade barriers have reduced over time (Loch et al. 2018), although a number of legal barriers, such as inter-valley trade restrictions (IVTs – see glossary in Table D.1), and physical barriers (e.g. the 7,000 megalitres per day (ML/day) Barmah-Choke flow constraint[47] (MDBA 2019c)) remain. There is also evidence that regulations are improving market conditions. For example, there is some quantitative evidence that insider trading potentially declined after the introduction of relevant legislation in 2014 (de Bonviller et al. 2019). At the same time, market participants have become more sophisticated and willing to speculate in the past decade, which can have both benefits and costs for various stakeholders in the market.

Although reasons for water market participation vary markedly between stakeholders, they can be associated with two broad themes: 1) water trading and ownership to mitigate shortage and secure water supply; and 2) water trading and ownership for direct financial gain (from water use).

A dominant strategy for many irrigators (both past and present) is to own more water than needed in order to achieve a buffer. Trading surplus water can be dependent upon prices and/or output prices (Wheeler and Cheesman 2013). Another recent strategy is to diversify water ownership, e.g. owning entitlements across different securities and regions (Leroux and Martin 2016). Carry-over has also allowed stakeholders to mitigate future scarcity. Water scarcity is often mitigated using temporary water trading (although irrigators also employ many other farm strategies (Gaydon et al. 2012; Kirby et al. 2014a)). The simplest approach is to buy water allocations to supplement water supply during times of scarcity (Loch et al. 2012). Generally, at higher water allocation prices, dairy irrigators are usually the first to switch from buying to selling allocations, followed by broadacre irrigators; whereas perennial horticulturalists continue to purchase allocations even at higher prices to avoid capital loss (Adamson et al. 2017; Wheeler et al. 2014d; Zuo et al. 2015a). In the last few years, derivative-type temporary water trading products such as water forwards, options, and parking have emerged (Bayer and Loch 2017).

Water entitlement trading is often used by irrigators to restructure existing water portfolios, increase supply security and relocate farm enterprises (Haensch et al. 2016b). Water entitlements are also sold when an irrigator wishes to exit farming, restructure farm finances or retire farm debt (Wheeler and Zuo 2017; Zuo et al. 2015b). For some, having buffer/surplus water enables irrigators to sell unused entitlements to the government and therefore maintain farm production (Wheeler et al. 2014c; Wheeler et al. 2014d).

However, stakeholder trading strategies can vary significantly. For example, the Commonwealth Environmental Water Holder (CEWH) owns a large and diverse portfolio of water entitlements, but only rarely trades this water (CEWO 2019). Also, some irrigators and financial investors treat water trading similar to trading on stock markets. Trading returns from temporary trade can result from the change in price when selling one's own allocation, but also from the price difference between seasons or catchments when the allocation was purchased – by selling in a different catchment or water year (Loch et al. 2012). Financial gain from selling parking or lease contracts can be seen as a service fee for using the seller's water entitlement/carry-over space and usually takes the form of a nominal price per megalitre. The water forward price includes a risk premium (above the allocation price when entering the contract) as the seller bears the risk for the buyer. The risk premium for options is higher than that for forwards, as the seller bears the additional risk if the buyer chooses not to exercise the contract at the due date.

[47]Note that the official maximum flow per day capacity figure can be 7,000 ML/day or 9,500–10,600 ML/day, depending on the source and the point at which it is being measured (MDBA 2019c; MDBBOC 2019).

Revenue from water ownership is derived from temporary trading and capital appreciation, for example, Zuo et al. (2019) highlight that water entitlements are driven by temporary prices and hysteresis – plus it has been shown that MDB water ownership has often had higher internal rates of returns than stock markets (Wheeler et al. 2016a). Furthermore, some investors choose water entitlements as another avenue to invest in agriculture, with the advantage of non-depreciation (ISA 2017). This increasing investment, especially by non-landholders, has raised issues of undue influence in water markets.

One issue in seeking to investigate this question of non-stakeholder trading strategies is that there is a lack of publicly available water market/ownership data across all stakeholders. Water register transaction data only encompasses entitlement and allocation trades, and provides no information on other products such as leases or forwards (MDBA 2019m) or who conducts such trades. Hence this is one reason why, to date, there has been little research on agri-corporates or non-landholder water market trading strategies. This study seeks to extend the literature through a mix of qualitative and quantitative research, to provide a detailed analysis of non-landholder and landholder water ownership and trading strategies, as well as identifying areas for water market reform.

6.3 Material and methods

We employed a mix of qualitative and quantitative methods to explore the questions surrounding water trade and water ownership in the MDB by type of stakeholder (landholder versus non-landholder). For an overview of data sources used and corresponding analysis, see Table D.2.

6.3.1 Qualitative information

A total 64 semi-structured interviews were conducted with key stakeholders across the MDB. As water register data on agri-corporate and non-landholder investor ownership is not publicly available, we chose the method of targeted qualitative expert interviews to understand these stakeholders' trading strategies. To specifically target prominent agri-corporate and non-landholder organisations with a "large" holding of sMDB water entitlements, we used publicly available information[48] to first identify relevant organisations (and individuals within), and employed a chain referral approach to recruit additional interview participants (Biernacki and Waldorf 1981). We also approached large organisations with expert knowledge in water entitlement valuation, water trading and agri-business lending in the sMDB, such as banks, evaluators and water brokers. Consequently, the qualitative interviews focus on the views and behaviours of large and corporatised organisations, rather than the typical irrigator. Overall, we approached 83 eligible individuals or organisations for interview and hence obtained a response rate of 77%. The stakeholders interviewed included: 20 investors and agri-corporates (very large landholders owning and/or trading water but generate their main income from farming); 15 EWH and NGO employees[49] (public or private entities, owning or delivering water entitlements or allocations for

[48]This included reviewing stakeholders' annual and financial reports before interviews.
[49]Note we interviewed a few respondents who worked for the same organisation. This was because some EWHs operate across multiple states with water management decisions made at the local level, making it necessary to interview a variety of local representatives. While some EWHs own land, their primary function is water management so they are classified as non-landholders. Three respondents from environmental NGO organisations are not included in our data analysis as their NGO did not own water.

environmental purposes); 10 water evaluators (consultants etc. specialised in water valuation); 7 financial investors (non-landholders trading water for financial gain[50]); 6 bankers (employees from financial institutions who were the key individuals responsible for significant lending portfolios in water entitlements); and 5 water brokers (who earn commission-based revenue from water market transactions).

The interviews were mostly conducted face-to face during 2018-19, at times and locations convenient for respondents across the MDB. A quarter of interviews were undertaken by phone and two provided written submissions. The incompleteness of one written submission meant it was excluded, hence only 63 responses are included here. The interviews had a median length of 60 minutes, with interview recordings and transcripts compiled into Nvivo11 and coded into major themes. A range of open-ended questions were asked on topics of water ownership, trading, water accounting, water markets and valuation. 84% of our respondents were male, while 70% of our female respondents worked for EWHs. This gender balance is (unfortunately) reflective of the industry in general.

This study focuses mainly on understanding water ownership and market strategies by land-holders versus non-landholders, hence, it uses information from a range of quantitative sources plus our interviews with 1) investors and agri-corporates; and 2) EWHs and financial investors. Hence, most of the analysis is focussed on 38 of our interviews[51], however we also use responses from the full set of 63 interviews in the final section to explore suggestions for water market design improvements.

6.3.2 Quantitative data

This study also used quantitative data to illustrate stakeholder water entitlement ownership, along with allocation, entitlement, carry-over and forward trading behaviour. We utilised data from a representative telephone survey of 1,000 sMDB irrigators[52] undertaken in 2015-16 (see Wheeler et al. (2018) for further detail) to supplement the personal interview information and establish general MDB water ownership and trading behaviour. We also analysed transaction data made available by one of the MDB's leading water trading platforms[53] to illustrate the extent of water forward and parking trading.

6.4 Results

The results are presented in three sections: 1) an overview of water market participation using the survey of 1,000 irrigators and interviews with 38 landholder/non-landholder investors and EWHs; 2) qualitative data on 38 water investors' and EWHs' trade strategies and motivations; and 3) qualitative data on all 63 interview expert participants' beliefs about water market improvements.

---

[50]Investment and ownership structures of financial investors are complex. Some own agricultural land in other investment funds. Generally financial investor respondents manage an exclusive water asset portfolio, therefore are classified as non-landholders.

[51]12 EWHs, 19 investors/agri-corporates and 7 financial investors. One investor interviewed was not included in our data analysis as they owned no water in the Basin, but were interviewed originally as they were considering it.

[52]Includes 419 NSW, 209 SA and 372 VIC irrigators.

[53]H20X had a market share of 11% of all non-zero MDB allocation trade volume in 2018/19.

6.4.1 Water market participation and strategies – quantitative data

About 65% of Victorian (VIC) irrigators own a diverse water portfolio of at least two types of entitlements, with diverse ownership less common in New South Wales (NSW) (28%) and South Australia (SA) (7%) – where ownership is mostly concentrated in general and high security surface-water entitlements respectively (Table 6.2).[54] These ownership patterns are mainly because of historical factors of water ownership by states.

Table 6.2 Surface-water entitlement ownership and carry-over for MDB irrigators and landholder/non-landholder interview participants

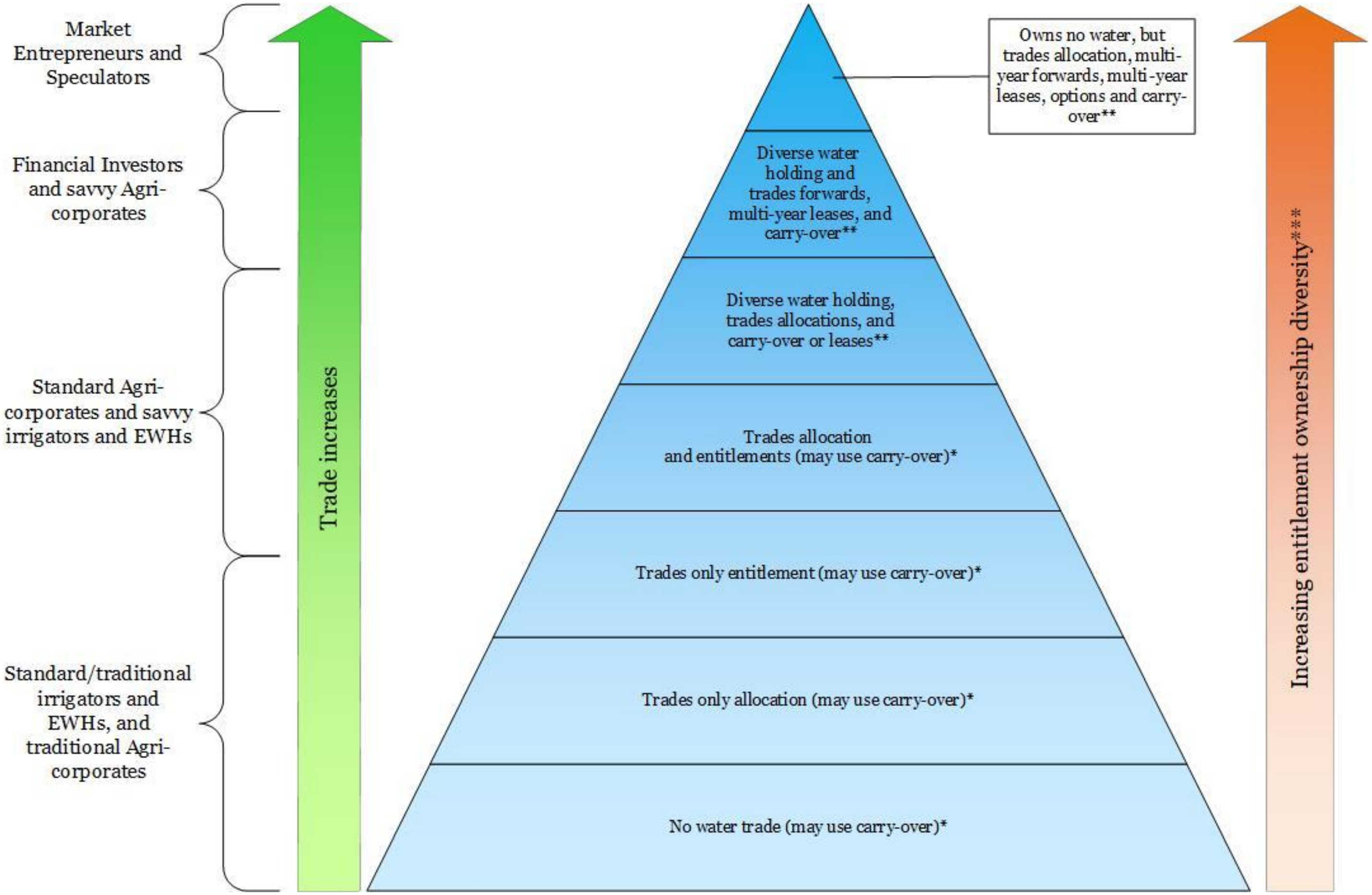
Method	***State/ stakeholder***	***Own surface-water entitlements? (% answering yes)****				***Diverse entitlement ownership (% owning more than one security type)****	***Used carry-over? (% answering yes)*****
		High	*General*	*Low*	*No ownership*		
2015-16 Irrigator survey – southern MDB	NSW (n=419)	37%	65%	12%	4%	28%	67%
	VIC (n=372)	94%	3%	62%	2%	67%	84%
	SA (n=209)	81%	9%	5%	8%	7%	11%
2018-19 landholder and non-landholder interviews	EWHs (n=12)	100%	75%	42%	0%	83%	67%
	Financial Investors (n=7)	86%	86%	72%	14%	86%	78%
	Investors/agri-corporates (n=19)****	95%	26%	37%	0%	58%	39%

Notes: *More than one type of water entitlement can be owned.
**Does not include delivery share ownership
***Question asked for the 2014-15 water season in telephone survey. Carry-over was not available on SA entitlements in 2014-15, but some South Australians own water elsewhere with carry-over availability.
****Investors/agri-corporates own land, EWHs and financial investors generally do not.

Synthesised and created from both our qualitative and quantitative data, Figure 6.2 illustrates the overall different water ownership and trading strategies employed by sMDB stakeholders. The majority of sMDB stakeholders have established water trading and ownership strategies to secure water for production, such as using their own carry-over and trading allocation. Entitlement trade was less common. Table 6.2 and Figure 6.2 both illustrate that standard irrigators own less diverse surface-water portfolios than larger agri-corporates, with non-landholders' surface-water ownership the most diverse. Between 58% and 86% of our interviewed respondents had a diverse water entitlement portfolio across stakeholder groups.

[54]While all SA water entitlements are high security, stakeholders could decide to own different security entitlements in other states.

Figure 6.2 An overview of sMDB water ownership and trading strategies



Notes: Diagram is not drawn to scale, and classifications of irrigators into groups (e.g. standard irrigators, standard agri-corporates etc are approximate only).
*Based on trade results for 1,000 irrigators in the sMDB in water season 2014-15: irrigators conducted no water trades=38%; traded only allocations=51%; traded only entitlements=4%; traded allocations and entitlements=7%.
**Based on 38 landholder and non-landholder interviews: 55% trade carry-over and/or allocations/leases; 29% trade forwards, multi-year leases and carry-over; and 3% own no entitlements but trade carry-over, multi-year leases, multi-year forwards, and options.
***The exception to this trend is the top of the pyramid: speculators own no water entitlements.

Various stakeholders undertake differing levels of sophisticated trading strategies. A “standard/traditional” irrigator, EWHs, and “traditional” agri-corporate (which represent the majority of MDB irrigators at the base of Figure 6.2) use their own carry-over, and trade allocation to either supplement water supply or to earn income from surplus water. Note this typology relates to water trading and ownership strategy sophistication, is indicative and not to scale. A significant number own all or an excess of their water needs under one type of regional entitlement. More “savvy” irrigators, EWHs, and “standard” agri-corporates (a smaller proportion of irrigators in the MDB) own diverse portfolios of entitlements, occasionally trade entitlements, and make regular use of their own carry-over, allocation and lease trading for farming. “Savvy” agri-corporates and financial investors (which note represent a very small proportion of MDB stakeholders), own diverse entitlement holdings, and frequently trade sophisticated temporary products such as water forwards and parking, not just for water supply but also for price arbitrage differences.

Finally, there is an even smaller number of highly “sophisticated” market entrepreneurs and speculators who, while not owning water, trade and arbitrage daily across the whole diverse range of temporary products, often developing and trading new temporary derivative-type water products.

6.4.2 Water Ownership rationale and strategies – participant qualitative data

The qualitative data provided rich information on participants’ views of water assets and their surface-water ownership strategies. Table 6.3 classified rationales for water ownership into eight broad reasons: historic; supply security; asset investment; diversification; proximity to (agricultural) operations; price; deliverability; and liquidity. Rationale for water ownership varies between and within our landholder/non-landholder stakeholder groups.

Table 6.3 Water asset characteristics and rationales for surface-water ownership strategies

Water Asset Characteristics	*Sub-total (n=38)*	*EWHs (n=12)*	*Financial Investors (n=7)*	*Investors/agri-corporates (n=19)**
Do you view water entitlements primarily as a financial/investment asset? *(% of yes responses)*	79%	75%	100%	74%
How do water entitlements compare to other financial/investment assets? *(% of respondents believing entitlements represented an unique asset)*	50%	33%	57%	58%
Answers to the open-ended question: "Reasons why you own the water portfolio that you do?"*				
Historic (e.g. water bundled with land)	21%	21%	4%	32%
Supply security (e.g. high security)	17%	21%	13%	18%
Strong investment (e.g. expected value appreciation)	16%	13%	25%	12%
Diversification (e.g. different entitlements across regions)	13%	13%	17%	12%
Proximity to operations (e.g. entitlements in the farm region)	12%	13%	8%	15%
Price (e.g. "cheap" purchase price opportunity)	11%	8%	13%	12%
Deliverability (e.g. can trade allocation to most other MDB catchments)	9%	13%	17%	0%
Liquidity (e.g. entitlements in active trading zones)	1%	0%	4%	0%

Notes: *Investors/agri-corporates own land, EWHs and financial investors generally do not.
**Multiple answers were allowed.

Around four-fifths of investor/agri-corporate, EWH and financial investor respondents (79%) saw water entitlements as an (investment) asset, with half perceiving water entitlements to be an extremely attractive, but unique asset class.

> *"There is no depreciation, there's no goodwill, there is no maintenance and repairs. There is really very few costs in the ownership of it. There are not many asset classes that are that good." (Investor/Agri-corporate)*

Although 75% of EWH respondents regard water entitlements as an investment asset, they found it challenging to compare water to other assets. Since EWHs typically do not own water entitlements for financial gain, entitlement risk and return characteristics are of little relevance:

> *"It is completely different because we are putting water out there for environmental purposes, so it depends on how you end up valuing the environmental benefit which is associated with that." (EWH)*

Unsurprisingly, all financial investor respondents saw water entitlements as an investment asset, particularly pointing to their unique risk profile, good returns, non-depreciation and non-correlation to other assets:

> *"That is the attraction, it does not trade in the same pattern as real estate or infrastructure assets, it has different drivers of return. Probably 10% return per annum: we derive that from 4-6% income yield and 4% capital appreciation over the longer term. Your yield can be pretty volatile, which would demand a higher return and we do get that. Often real estate has some material financial leverage, whereas we are acquiring water at 100% equity basis, which de-risks it again." (Financial Investor)*

However, some respondents highlighted that water entitlements are a statutory asset, subject to regulatory changes[55] and are therefore legally very different from property and consequently has less protection:

> *"[legal] Accuracy around the entitlements comes from the bipartisan nature of water policy. Commonwealth and states, through agreement and through practice over the last 25 years, really reduced the sovereign risk in the water market to an extent where people are prepared to invest in it. As if it were a solid property right, what it is not." (EWH)*

Despite the legal status of entitlements as non-property as determined by the high court (Fisher 2010), our findings suggest that most market participants treat water entitlements as property.

The most frequently cited motivation for water ownership strategies was historic reasons, as water entitlements were acquired with agricultural land prior to unbundling and had not been traded since. Many EWHs had their water portfolio legislated into existence. Water supply security was identified as the second-highest motivation. This related both to the strategy of owning excess/buffer water and the preference for more secure entitlement classes or large carry-over capacity. Other important factors highlighted in Table 3 include the need for proximity of water entitlement holdings to the relevant farm/environmental asset; the ability of a particular entitlement class to trade allocation into different catchments (deliverability); diversification of water holdings across regions and entitlement classes; and entitlement price.

When considering the motivations of non-landholder stakeholder groups: historic reasons and supply security were the most important factors for EWHs, whereas financial investors ranked strong investment, diversification and deliverability the highest. Similar to EWHs, landholders' ownership strategies were largely influenced by historic reasons, supply security and agricultural proximity. Financial investors saw water entitlements as a growth asset due to increasing high-value horticultural production and climate change:

> *"We often see dramatic changes in the commodity mix that is being produced throughout the Basin, to much more horticulture and higher value crops. We think that over time, not only do those crops need more water, but they become more inelastic to pricing. They will have to water their permanent crops and they have*

---

[55]States can change the security of an entitlement, rules regarding use and access to allocation, or the overall allocation volume to a catchment based on sustainable diversion limit considerations (*Water Act 2007 (Cwlth)*, pt2 d4 sdA s77). For example, a change in the Barwon-Darling water sharing plan allowed entitlement holders to extract water at lower river levels, with increased extraction (and drought) substantially contributing to a mass fish-kill event in 2018-19 (AAS 2019).

higher margins so they can support higher prices." (Financial Investor)

Overall, there appeared to be three major themes influencing the ownership of water entitlements: 1) supply and operational factors; 2) water trading and delivery; and 3) financial factors.

Owning water close to operations is seen as a strategy that reduces the need for water trading, exposure to trade restrictions and transaction costs.[56] On the other hand, concentrating entitlements in one region increases exposure to localised climate uncertainty.

Another strategy as already highlighted is diversification: owning a variety of highly tradable water entitlements (e.g. see MDBA (2010c)) across different regions. For example:

> *"The portfolio was very focused on the southern MDB, we want the interconnectivity, that is what attracted us to start there. The portfolio focused on the tradability of water and the movability of water around [trading] zones, the maturity of the market, and the liquidity it provides. In terms of the portfolio construction, we want a mix of high security, general and low." (Financial Investor)*

This strategy maximises water trading and reduces the impact of localised climate, at the cost of more exposure to trade restrictions and transaction costs.

Some respondents discussed the impact of IVTs on ownership and water markets, particularly the Barmah-Choke trade restriction. As water portfolio structure was influenced by historic factors, so is landholders' exposure to IVTs. Interestingly, only a few respondents, mainly non-landholder financial investors, stated that they diversified their entitlement portfolio around minimising the impacts of IVTs. An exception is the Barmah-Choke constraint, with most respondents preferring entitlement ownership below the choke:

> *"Five years ago, we would have bought NSW Murrumbidgee. Now with the difficulty of getting out of the 'Bidgee, first to the Murray, and then from the Murray, down to here. That is our strategy, to now only look at Victoria below the Choke." (Investor/Agri-corporate)*

Water entitlements below the choke (i.e. unaffected by constraints), such as Victorian Murray trade Zone 7, are seen as more desirable. While respondents identified the Goulburn system and the Mulwala canal (10,000 ML/day capacity (GMW 2019)), which is part of the Murray Irrigation area, as important to mitigate the choke constraint, they acknowledged the limits of these mitigations due to the Goulburn-Murray IVT and the higher cost of delivering water through Murray Irrigation infrastructure. IVTs and in particular the Barmah-Choke trade restriction disproportionately affect EWHs, as one EWH stakeholder explained:

> *"So whenever we do an inter-valley transfer, we have got a watering action that we are doing, and we have moved some water from below the choke to above the choke. Our water is included as water going through the choke and it opens up the choke for water going the other way, when in fact we have moved the water up there so that we can bring it back to fill the choke up. IVTs are something we have to keep a very close eye on. If you could move 1GL of water between valleys A and B, we have probably got that gigalitre of water. We choose not to do it because it would choke the industry out and good neighbour policy means that you do not do that." (EWH)*

[56]While subject to negotiation, it is convention that the allocation buyer shoulders transfer and register fees (Elders 2019; H2OX 2019a; Waterexchange 2019; Waterfind 2019b; Wilks 2019).

Larger and more sophisticated agri-corporates often mix strategies of concentration and diversification: they own a diversified portfolio of water entitlements but use them to run operations in the corresponding catchments. This approach would reduce the exposure to IVTs. Financial investors' lack of land ownership means their main strategy is to sell temporary water to producers, requiring a highly deliverable, diversified water portfolio capable of mitigating the effects of IVTs.

The majority of EWH, financial investor and investor respondents generally own their complete water needs (for a typical year) in entitlements. A fifth of our investor participants chose not to own their entire water needs in entitlements for capital reasons, supplementing their entitlement ownership with temporary trading, while other investors own only a small fraction of water in entitlements and trade frequently, be it for farming purposes or for making money from delivering forwards and options.

> *"Our standing position is generally not to own water. That is about capital sheet efficiency, and not tying up a lot of capital." (Investor/Agri-corporate)*

A few respondents commented on owning water delivery shares, and utilised a strategy of owning more delivery shares than water entitlements – or even owning most of the delivery shares within an irrigation system, in order to guarantee priority of water delivery.

6.4.3 Temporary trading strategies: carry-over, parking, forwards – Qualitative data

Figure 2 illustrated that the majority of MDB stakeholders have used allocation and carry-over. We found that our interviewees with more diverse water portfolios employed more sophisticated trading strategies (Table 6.4). Table 6.4 illustrates that many employ lease and forward contracts, and use carry-over opportunistically (e.g. parking trade, carry-over allocation for price gains between years).

Table 6.4 Temporary trade strategies by landholder/non-landholder stakeholders

Trade product	*Use*	*EWHs/Financial Investors/investors with diverse portfolio (n=27)*	*EWHs (n=12)*	*Financial Investors (n=7)*	*Investors/agri-corporates (n=19)**	*Sub-total (n=38)***
Carry-over	Do not use	19%	50%	0%	42%	37%
	Farming/environmental use	41%	42%	0%	37%	32%
	Parking trade	37%	8%	100%	16%	29%
Leases	Do not use	56%	100%	0%	42%	53%
	One year	0%	0%	0%	11%	5%
	Multi-year	41%	0%	100%	37%	37%
Forwards	Do not use	41%	83%	0%	53%	53%
	One year	41%	17%	57%	26%	29%
	Multi-year	15%	0%	43%	11%	13%

Notes: * Investors/agri-corporates own land, EWHs and financial investors generally do not.
**A few stakeholders did not answer these questions; hence not all totals add up to 100%.

Land-owning stakeholders (investors/agri-corporates) use temporary products such as leases, forwards and carry-over primarily as tools to manage water supply risk. Water lease contracts seem to be a standard tool and are well established; whereas only more sophisticated agri-corporates employ a mix of parking, forwards and lease contracts. This approach aims to minimise the capital cost of water ownership, while maintaining supply security.

> *"We take a portfolio approach, we own some, we lease some, we have got forward positions, we use carry-over, and we use the spot market. We have got half of the water needs covered with forward positions, 10% with leasing and 30% is in the spot market. Moving forward, we see ourselves building more exposure with leases and forwards." (Investor/Agri-corporate)*

Carry-over was the most employed strategy by stakeholders. EWHs and investors/agri-corporates use carry-over mainly for their own surplus water, however at least one EWH sells parking contracts to generate extra revenue:

> *"We also use carry-over as a market-based mechanism, essentially carrying over dollars but in water, but also as a product we can offer to sell. We use the carry-over capacity on our licences to offer space to irrigators." (EWH)*

All financial investors use carry-over opportunistically; employing parking for extra allocation to supply forward arrangements, or to speculate on temporary prices. In addition, more sophisticated investors/agri-corporates employ parking contracts to expand their carry-over capacity, or use carry-over to substitute between different water sources:

> *"We might have carry-over capacity on our accounts and [when] the price in the temporary market is acceptable, we buy-in to carry-over. Or we have got a mix of water types…where we might turn off the bores, buy temporary river water for production and carry-over allocation volume on the bore water account" (Investor/Agri-corporate)*

Financial investors and investors/agri-corporates use and sell multi-year leases. Financial investors explained that they prefer a large part of their water portfolio to be leased long-term (up to five years) as this provides stable income with less risk, whereas investors/agri-corporates often employ leases to avoid water entitlement ownership:

> *"We have the long-term view that we lock at least 70-80% of the portfolio into leases which gives us a nice steady, climatic risk free, return." (Financial Investor)*

> *"Water is so expensive to buy…so it is a lot of capital you need to put up-front when you are doing a development. We have had a strategy of putting in place some long-term leases, at least five years, and as we start producing almonds and generate some cash flow, then we will buy entitlements." (Investor/Agri-corporate)*

Financial investors and investors (along with one EWH) are also regularly using forwards – namely one-year contracts. Analysis of private water trading platform data shows that 92% of forwards traded since 2016 have been one-year contracts. Given that water forwards have only been commercially available since 2014, and participants are still learning about the product, multi-year forward supply is limited by the small number of vendors willing to bear the extra risk. Although financial non-landholding investors only own around 10% of MDB water entitlements (DELWP 2019a), they trade a significant proportion of forwards (37% of forwards sold since 2016 based on our analysis of private water trading platform data). Many of the interviewees see forwards as a valuable risk management tool, but also cited a number of dangers in relation to reputation, counterparty and market immaturity. For example, EWHs currently do not trade forwards due to reputational and political risk issues:

> *"EWHs use [forward trading] very cautiously because there is just as much risk around their social licence to operate as there is around portfolio management…And it is a huge political risk. They [public EWHs] are at the whims of the government and need to be seen as not skewing the market, so they have got to be above board like you would not believe." (EWH)*

Counterparty risk occurs where the forward seller has incentive to default during times of high temporary prices, whereas the buyer has incentive to default at low prices. Another aspect of counterparty risk is non-delivery:

> *"Parties that only own about 100-200ML write a 400ML forward, hoping they can buy the allocation on the market and deliver against it on a multi-year basis. If we get a really dry year they are not going to deliver." (Financial Investor)*

Due to the fact that respondents are cautious who they trade with and that often 20% of contract value is required as a down payment, counterparty default was described as rare. However, greater water market institutional reform was called for, such as standardised forward contracts, a regulatory body, and a central exchange and clearing house:[57]

> *"The issue with forwards in the water markets is, it is a semi-sophisticated product in a very unsophisticated market…. We are trying to move into these more sophisticated products but we have not got the underlying infrastructure in the market to do that, a central exchange and clearing house for example." (Water Broker)*

Forwards are seen as more expensive than using temporary allocation plus carry-over fees (or parking), and less secure due to counterparty risk. Carry-over and forwards have different cash-flow implications for the buyer: the full costs of temporary trade combined with parking need to be paid immediately, whereas forwards only require an initial deposit, with the

[57]In financial markets, the clearing house is the counterparty for all trades, guaranteeing delivery in case of counterparty default (Pirrong 2011).

remaining costs paid at delivery. Some respondents argued that carry-over and forwards are essentially identical – to guarantee delivery, the forward seller has to store the contracted temporary volume in carry-over (adjusted for spill risk and evaporation). A few financial investors underwrote forwards with other temporary products, abstracting forward delivery from entitlement holdings and carry-over.

6.4.4 Water market design improvements – Qualitative data

Finally, respondents were asked an open-ended question to nominate and comment on any aspects they would like changed or improved in relation to the MDB. 59% of the total 63 surveyed participants responded to this question with comments relating to water market reform and ownership (Table 6.5).

Table 6.5 Stakeholder views on improvements to MDB water markets and ownership

*Improvements suggested (self-nominated)**	*Total participants naming water market improvements (n=37)***	*Banks (n=4)*	*Evaluators (n=7)*	*EWHs (n=6)*	*Financial Investors (n=4)*	*Investors/agri-corporates (n=12)****	*Water Brokers (n=4)*
Water trading and storage data and standardisation (e.g. more complete and transparent water register data)	25%	40%	62%	0%	44%	11%	14%
Relaxed catchment trade restrictions (e.g. IVTs)	13%	0%	0%	33%	14%	22%	0%
Greater transparency in allocation and inter-valley trade restriction announcements (e.g. better explain reasons behind decisions)	12%	0%	0%	0%	0%	16%	44%
Change legal status of water (e.g. reverse unbundling; make water property)	12%	20%	0%	50%	0%	11%	0%
Introduce regulation and accreditation for intermediaries (e.g. water broker licence)	10%	20%	0%	17%	14%	6%	14%
Simplify carry-over arrangements (e.g. SA carry-over access)	8%	0%	25%	0%	0%	6%	14%
More public EWH trading capabilities (e.g. sell environmental allocation)	8%	0%	0%	0%	14%	16%	0%
Better understanding and regulation of agricultural development (e.g. limit on permanent planting area)	4%	0%	13%	0%	0%	6%	0%
Decrease water trade transaction costs (e.g. faster processing)	4%	0%	0%	0%	14%	0%	14%
Environment to contribute to water delivery costs (e.g. delivery fees for environmental transfers)	4%	20%	0%	0%	0%	6%	0%

Notes: *Some respondents addressed multiple topics in one interview.
**Responses based on those 37 respondents in the total 63 interviews that named water market/ownership reform issues.
***Investors/agri-corporates own land, banks, evaluators, EWHs, financial investors and water brokers generally do not.

The primary issue identified by all stakeholders concerned the quality of dam storage and water trade data. Consistent with the findings of Grafton and Wheeler (2018) about lack of consistency in MDB water data, many participants argued that MDB storage volumes differ depending on the data source, and that water market data via registers was outdated and of poor quality.

> *"Accessing current information is very challenging. All that information exists but the quality of it is very poor. For example, if you want to know how much water is in Lake Hume at any one time, I can go to GMW, I can go to NSW water and I can go to the MDBA, and I will get three different figures, which is absurd. Likewise, if I want to know the states' share of water in the Murray system storages, the MDBA releases that information once a month, two weeks after the end of the month, at best." (Water Broker)*

Additionally, standardised water market terminology and a central water register containing all trading information was seen as needed, with others suggesting a central water exchange and clearing house, similar to the ASX. This reflects findings from other studies, suggesting insufficient water trade and ownership data quality and access. Current data capturing processes are ill-equipped to support emerging temporary products such as parking, forwards and options.

Another important issue raised was the transparency of trade restrictions and allocation announcements. Respondents advocated both for more transparency in announcing allocations and IVTs, a particular issue in the Murrumbidgee, and for relaxing restrictions in general. For example:

> *"Farmers have zero idea of what the allocation is going to be, particularly in NSW. And it seems that that information is almost made up. It is often nonsensical, it often has errors in it and people are trying to make investment decisions, not only around trading water but also around growing crops." (Water Broker)*

> *"[The Goulburn IVT] limits that region to become just a regionalized trading region rather than sit across the whole southern connected MDB. NSW does the same in the Murrumbidgee. Effectively, they stop water being traded across the basin and make life difficult." (Financial Investor)*

There is no clear pattern of landholders or non-landholders advocating for relaxing trading restrictions and IVTs. Rather, respondents owning diverse water portfolios and personally affected by IVTs suggested this improvement.

A significant number of bank, EWH and investor/agri-corporate respondents desired the reversal of unbundling, or alternatively restricting non-irrigator ownership of entitlements, believing it would decrease speculation and lower water market prices. This view was not shared by financial investors and water brokers. EWH respondents argued that unbundling has put a price on biodiversity via the cost of allocations needed to achieve environmental outcomes and led to calls for EWHs to pay water licencing and delivery fees. The lack of market intermediary regulation and its implications for misconduct was also raised. For example:

> *"You need some rules around the way brokers operate. I know brokers who have interest-bearing accounts and they keep the interest from customers' acquired funds that sit there. In theory you should have an allocation trust account which holds water on behalf of the clients which you never touch. There are situations where that water*

gets traded by the brokers for their own profit. I also know brokers that are the counterparty to their client, they are not intermediary, they are actually the principal. They see a really good deal and instead of passing that on to a seller, they sell it themselves." (Financial Investor)

While the Australian Water Broker Association provides a voluntary code of conduct for its members (AWBA 2019b), an industry-wide legally binding code of conduct does not exist, leading to some industry calls for more regulation (Waterfind 2019a). Claims of intermediary misconduct are contested (Miller 2019), but difficult to show quantitative evidence for without corresponding reporting and regulatory requirements.

Other less common responses included issues surrounding more accessible, greater and standardised carry-over. Some respondents advocated for a more proactive role of public EWHs in water trading, especially during drought. The least discussed topics included faster and more efficient water trade processing; the size and impacts of MDB permanent plantings; and the financial contribution of EWHs to water delivery and storage operations. EWH respondents rejected making monetary contributions to the delivery of environmental water based on their limited ability to raise funds:

"The environment cannot make a return in order to pay those fees. So where does this return come from? It can only come from the taxpayer." (EWH)

In regards to the issues concerning increases of MDB permanent plantings, a few respondents worried whether there was enough water to satisfy the existing and future needs of plantings, and the ability to physically deliver the water to these areas:

"There will be a risk of delivery failure. They cannot get water to certain parts of the system. They have all the trees being planted downstream in the Basin and there is a lot of trade restrictions. Do they expect to get water from all of the tributaries upstream?" (Financial Investor)

Some respondents called for a restriction on permanent planting area until the impacts have been fully assessed. Indeed, the Victorian government recently stopped processing applications for water extraction permits until delivery concerns have been assessed (Neville 2019b).

6.5 Discussion

While MDB irrigators have become more sophisticated in their water ownership and trading strategies, the majority still own all or most their water needs under one type of entitlement (in one region) and use the temporary market to supplement supply. While a typical irrigator in the sMDB owns mainly high or general surface-water security entitlements and use this as their main water source (Wheeler and Garrick 2020), non-landholders and investors/agri-corporates tend to own a variety of entitlements across different regions. Hence, there appears to be two broad philosophies underpinning water entitlement ownership strategies: 1) concentrate ownership in one catchment; and 2) diversify water ownership across multiple entitlements and catchments. Groundwater entitlements are also playing a role in this diversification by many agri-corporates (Davies and Burns 2019). Interestingly, most landholder respondents diversify around water entitlement security and carry-over capacity - with the exposure to trade restrictions, apart from the Barmah-Choke constraint - rarely stated as a driver for diversification. The two strategies are not mutually exclusive: some respondents source water for farming locally but own operations across different catchments, potentially to limit the exposure or impact of trade restrictions. Financial investors prefer the second of these strategies, owning large and diverse water portfolios with significant proportions of high and low security entitlements and the capability to mitigate trade restrictions. As the larger part of their portfolio is leased out on a long-term basis, having a diverse portfolio of attractive high security entitlements is paramount, while low security entitlements provide the carry-over capabilities to supply forwards or sell parking. In contrast, some stakeholders, particularly agri-corporates, own little to no water entitlements, relying on temporary trading. Although this strategy can have capital outlay benefits, particularly for industries pairing high upfront capital requirements with delayed revenue, it is susceptible to high temporary water prices.

Most respondents see water entitlements as an investment asset, with some pointing to the unique characteristics of the asset class. The vast majority of respondents ignore the legal status of water entitlements as a statutory asset (Fisher 2010), potentially leading to an illusion about the legal security and protection of water assets in practice.

Forwards, leases and parking are only used by small number of MDB stakeholders, with parking mostly used by financial investors and some investors/agri-corporates. This reflects some landholder respondent comments that they prefer plant-based management strategies (e.g. mulching, improved irrigation scheduling – see Wheeler and Marning (2019) for more detail) over managing their water portfolio to address water shortage. Forwards are recognised as an important risk management tool, but questions remain around counterparty, reputational risk, and market maturity. Although trade to date has been limited, the forward and options market is likely to grow given its capability to reduce supply risk and guarantee physical delivery.

Respondents identified a need to improve water data quality and accessibility, which has been well documented previously (de Bonviller et al. 2019; Grafton and Wheeler 2018; Seidl et al. 2020a). However, standardised water product contracts, intermediary regulation, market integrity rules and a water market central exchange and clearing house have yet to receive much attention (although Leonard et al. (2019) discusses advantages of a central exchange and clearing house for western US water markets). Currently, publicly available water market data is unable to identify and support transparent reporting of parking, water forwards and options trading – which will require increased attention in a maturing water market. Indeed, the call for more transparent data is now also backed by the water broker peak industry body (AWBA 2019a) and the Australian Competition & Consumer Commission (ACCC 2019a), while the Commonwealth Government recently invested over AUD$1 million to develop the Waterflow app to improve water storage and trade information (Business.gov.au 2019). Respondents saw a need for intermediary regulation to provide minimum quality standards and address conflicts of interest (such as intermediaries owning and principally trading water, and unethical handling of customer accounts). While the intermediary industry seems to regard self-regulation, rather than standardised and enforceable rules for code of conduct, as sufficient (AWBA 2019a), the recent findings of the Royal Commission into Misconduct in the Banking, Superannuation and Financial Services Industry cast doubts on the effectiveness of such approaches (Hayne 2019). Indeed, with the water market increasingly behaving like a financial derivatives market, regulation may be especially relevant in the MDB. Particularly with regards to conflict of interest and insider trading, the Australian Securities & Investment Commission (ASIC) market integrity rules could provide guidance (ASIC 2018).

Issues also surround different terminology and allocation, IVTs, and carry-over announcements. Increased transparency in allocation, carry-over and IVT rules may address some implementation issues, which we suggest may increase trust in water market institutions (Wheeler et al. 2017a; Wheeler et al. 2017b). Arguably, addressing water accounting issues, particularly around water use versus water extraction and consumption accounting (Young 2014); water valuation and methodology issues (Seidl et al. 2020a) and addressing issues in current water resource plans (Productivity Commission 2018), could contribute to improved decision-making. Given the prevailing criticism of hydrological water accounting in the MDB (Walker 2019; Wheeler and Garrick 2020; Williams and Grafton 2019), it seems unlikely that rule transparency can be forgone due to improved accounting.

Further, we share the view that an examination of the appropriateness of IVTs and trade restrictions would be beneficial (ACCC 2019a). While a necessity of the hydrological realities of operating in the MDB, some IVTs arguably tend to isolate particular catchments (and industries) from the water market system, keeping water prices low and preventing the politically undesirable exodus of water licences and industry from catchments. In particular, respondents often claimed the Goulburn-Murray IVT is a protectionist measure for the Goulburn dairy industry, albeit that potentially increased flow levels in the Goulburn river associated with the removal of the IVT could lead to increased river bank erosion. Generally, it is possible that trade restrictions and IVTs can lead to price distortions in the rest of the inter-connected water markets and to distorted trade patterns as stakeholders scramble to trade water out of/into a catchment while the IVT is open. In particular, investors/agri-corporates and financial investors, often with the help of water brokers, seem to have a comparative advantage (as compared to smaller operators) to act upon an IVT opening, pushing large volumes across catchments and subsequently closing the IVT often in a matter of hours.

Despite the fact that many irrigators call for water to be linked again to land-ownership, driven by the perceptions about the negative impacts of non-landholder entitlement ownership (Hunt 2019a), and the view that increased demand by non-stakeholders has led to higher water entitlement prices[58] and gauging behaviour by some operators, it is also true that unbundling has brought material benefits for irrigators. It enabled drought adaptation through water trading (Kirby et al. 2014a), allowed irrigators to reduce debt by selling water to the government (Wheeler et al. 2014c), and saw water entitlement values increase significantly (Seidl et al. 2020a). Our results also indicated that non-landholders can be beneficial for the water market: new water market products are often developed/called for and first used by non-landholders, and financial investors and EWHs are major sellers of forward and parking contracts. This view is shared by the Australian Water Brokers Association, pointing out that restricting non-landholders in owning and trading water could have detrimental consequences for the water market (Testa 2019). While water market speculators exist – generating revenue from temporary price differences without owning entitlements – their current small numbers suggest limited market impact, however this impact is dependent upon: a) the liquidity of the local water market they operate within; and b) the volume of their trade or any insider information knowledge. Although non-landholder entitlement ownership and speculative trading in general is rising, and there are calls for increased regulation of this type of investor in the market, we suggest that growth is likely limited by the required financial investment and derivative trading skills, and consequently the opportunity cost of trader involvement given the lower annual turn-over of water markets as compared to financial derivative markets. However, monopolistic concentration of entitlement ownership and market power can lead to price gauging by landholder and non-landholder actors alike, particularly in

[58]It is important to note that increases in water market prices benefit water allocation sellers and water entitlement holders, but disadvantage water market buyers. Issues often surround who is benefiting and who is losing.

illiquid markets or when combined with insider information (de Bonviller et al. 2019). As a clear example of this, some respondents claimed that information available in regards to regulatory and water delivery consultation (e.g. such as being part of a relevant water steering committee) enables a range of insider trading to take advantage of changed rules. Therefore, and given the material data challenges for quantifying their water ownership and trading, non-landholder regulation should be delayed until more quantitative evidence (such as linking both ownership and trading register data) has been collected and analysed.

Although some respondents expressed the desire for EWHs to sell their allocation in drought to support irrigation, there is evidence that EWHs are disadvantaged during drought[59] (Pittock 2013), and current water holdings are insufficient to deliver ecological targets (Walker 2019). However, proactive temporary trading for environmental purposes may be beneficial for more EWHs to adopt, by extending flood events (Connor et al. 2013) or by sourcing water cheaper (and more socially acceptable by irrigators) than buying more entitlements (Wheeler et al. 2013a). Indeed, EWHs seem to be more disadvantaged compared to irrigators in regards to transmission losses associated with delivering water. For example, EWHs have transmission losses associated with environmental watering activities attributed to their water account (MDBA 2019h), albeit associated return flows are credited (which one may view as surprising given the incomplete crediting of return flows by the Commonwealth government in recovering water through irrigation infrastructure (Williams and Grafton 2019)). On the other hand, while transmission losses from supplemented water transactions are attributed towards irrigator accounts in the nMDB, there is no such adjustment in the sMDB; transmission losses are attributed to conveyance water[60] and socialised. While acknowledging that socialising may not be appropriate, the ACCC (2010) argues that transmission losses in the sMDB are negligible and difficult to attribute to individual users due to the large number of storages. This topic has since received further attention: the MDBA (2019h) states that while water extractions between regions is shifting, the corresponding impact on transmission losses is too difficult to quantify. However, the unequal treatment of market participants and EWHs and the subsequent impact on water markets deserves further investigation.

Another topic that has received limited attention includes tagged trading[61] (DELWP 2018). While the contingencies of tagged trading (low irrigator uptake, perceived delivery guarantee and high administrative burden) were initially discussed by the ACCC (2010), subsequent discussions highlight a continuing low uptake of tagging and the potential violation of IVTs (Productivity Commission 2018). Current practice in Victoria allows owners of tagged accounts and entitlements to deliver unlimited allocation volume across the Goulburn Murray IVT, legally arbitraging on price differentials between the zones (use cheap and sell expensive water) (DELWP 2018), and circumventing the intentions of the *Water Act 2007*. This is also the case across the sMDB for tags established before 22nd October 2010, which are exempt from IVTs (MDBA 2014b). There are claims that some operators use this to illegally sell water allocations across IVTs (Hunt 2017). As the magnitude of tagged trading

---

[59]A substantial part of water for the environment is “rules-based” water: the difference between the total water available and the water allocated for consumption (including conveyance water). In drought, this rules-based water contracts disproportionally more than the consumptive pool (CSIRO 2008).
[60]Conveyance water is set aside by states to ensure the river system connectivity. Conveyance loss can be around 12,000GL in one year, depending on hydrological and climatic factors (MDBA 2019h).
[61]Establishing an entitlement tag allows extraction and use of temporary water in a different region than the entitlement’s system of origin. It is illegal to sell this water (MDBA 2010d).

is hard to quantify,[62] further analysis of this issue may be advisable. As also identified by some EWH respondents, high water levels in the Goulburn river, stemming from high water delivery, caused environmental river bank damage,[63] prompting Victoria to subject all tagged trading to IVT rules, which will begin in December 2019 (Neville 2019a). At the time of writing, this announcement was said to lead to temporary price increases in the affected trading zones (Hunt 2019b).

These findings provide insights into needed water market design reform. It is important to first remember that water markets only exist within institutions and hydrological and scientific knowledge (Wheeler et al. 2017b). There is a continuing fundamental need in the MDB for robust accounting of water extraction and use (at both a catchment and basin scale); continual monitoring; compliance and enforcement of water use; and water market institutional conditions – in order to ensure transparency and confidence in the market – as well as continual adaptation over time (e.g. (Grafton and Wheeler 2018; Wheeler et al. 2017b). Many commentators (e.g. Productivity Commission (2018); Walker (2019); AAS (2019)) have also made a large number of recommendations on the need for changes in water policy, with some of these relevant for water markets in general. This also includes the need to review river water operations – as changes in where water is being used are having a potentially negative environmental impact. We suggest that there is a great need for further water design reform, using new insights from the economics market design literature (e.g. Bichler et al. (2019)). In particular, our above discussion suggests the need for three key water market design changes: 1) data reform; 2) rules and regulation reform; and 3) new institutional development.

Firstly, water register data reform includes the need within registers to identify water forward, lease, option, and parking transactions – including counterparty type – in order to support emerging water market products. Entitlement transactions in conjunction with land must be identified, along with mandatory price reporting and rigorous quality controls of different water register data enforced (MDBA 2019m). Entitlement ownership by stakeholder type data should be analysed at a catchment level to identify and address concerns of market power and monopolistic behaviour. These issues have also been identified as critical by the ACCC and the Victorian government (ACCC 2019a; DELWP 2019c).

Second, improving and making transparent rules and standards for water forwards and options, carry-over access, allocation and IVT determinations would contribute to better decision-making of MDB stakeholders. In absence of clear standards for water forwards and options, product comparability is problematic. Counterparty risk for forwards is significant. Water futures would offer similar risk management benefits for lower risk, as they are standardised and exchange traded, where a central clearing house mitigates counterparty risk through daily cash settlement of profits and losses. However, water futures would require a water market central exchange and clearing house (see glossary in Table D.1). With the increasing use of derivative type products and increasing incentives for counterparty default in times of water scarcity, particularly in drought, the topic of standardisation and counterparty risk requires urgent attention. Unified water market terminology for comparable water products, such as water entitlements or allocations could improve interstate trading by

[62]Tagged entitlement data is fragmented and reported differently between water registers. For example, Victorian data suggests that allocation delivered under a tag in the Goulburn increased to 120GL in 2017/18 (Neville 2019a).

[63]Respondents explained that environmental watering in spring may lead to recruitment of native river red gums, while high river levels from delivery of irrigation water in summer through tagged trades regularly drowns young saplings.

removing confusion and ambiguity; whereas a review of tagging and transmission losses through trading should identify and quantify corresponding third party impacts. Conversely, very careful assessment needs to be given to any change in unregulated entitlements to allow trading, such as allowing trading in floodplain water harvesting rights. Legal loopholes enabling stakeholders to bypass trade restrictions and extraction embargoes need to be closed. Administrative arrangements and structures minimising insider trading and rent-seeking are key for robust water sharing systems (Young 2019). Therefore, membership of consultation bodies, such as water steering committees, and standards for water brokers needs to be fully transparent and publicly declared to avoid rent seeking by vested interests.

Finally, the more that stakeholders treat water markets like stock markets, then the more that water markets will require sophisticated institutional development to avoid negative consequences/externalities. ASIC market integrity rules could provide guidance for water market changes. Institutional development is particularly important for derivative type temporary products, where consideration should be given to additional water market infrastructure, such as a central exchange and clearing house, along with a well-resourced market regulatory agency with competency in derivative products that monitor and enforce compliance. While a central exchange and clearing house provides benefits in regards to counterparty risk and transparency of trades (Duffie and Zhu 2011; Pirrong 2011), it likely will increase the transaction costs of trade initially, both monetary and temporal, and require substantial regulatory reform. Sophisticated derivative type products require comprehensive spot price data, in this case allocation and entitlement data. This data is challenging to provide in a timely manner without a central exchange trading allocation and entitlements. However, this does not necessitate one central exchange for all products; a number of central exchanges, e.g. one for allocation and entitlements and another for derivative products may also be appropriate. In addition, greater water market intermediary regulation is needed, particularly in defining, policing and sanctioning conflict of interests, along with establishing minimal brokerage requirements. Potential regulation is also needed to stop water market intermediaries from commercial water entitlement ownership and principal trading, to avoid conflict of interest. Water market institutions and regulation need to enforce product standards and code of conduct, and limit rent-seeking from privileged information, as well as having prosecution powers to effectively limit counterparty risk in derivative type products and unlawful intermediary behaviour. As the water market continues to evolve, institutions and regulation need to keep pace in order to support an effective and fair market for all stakeholders.

Although we suggest that non-landholder and corporate trading behaviour can be beneficial for the water markets, large knowledge gaps remain. In particular the water ownership, trading patterns and potential concentration of market power are difficult to quantify due to lack of publicly available water trade and ownership data. Further research should aim to quantify how much water is held and traded by investors/agri-corporates and non-landholders, and assess whether this has quantifiable impacts for the water market to influence its long-term dynamics (e.g. see Zuo et al. (2019)), including a consideration of concentration of market power, price gouging or unequal access to carry-over and inter-valley transfers.

While the importance of water accounting and data quality for water markets is internationally well-understood, the Australian case draws attention to the importance of water ownership and the use of different trading products by non-landholder stakeholders. Additionally, it exemplifies the need for adaptable institutions capable of designing and enforcing regulation and monitoring of intermediary behaviour, as well as still encouraging innovation within markets. Finally, the Australian case emphasises the ongoing need for assessment and research of any negative externalities created from unintended behaviour in water markets, to enable institutional change as a response.

6.6 Conclusion

This study draws upon key insights provided by 63 qualitative interviews with key water experts and landholder (investors and agri-corporates) and non-landholder (EWHs and financial investors) MDB stakeholders. Combined with market intermediary and large-scale representative irrigator survey data, it highlights issues around major themes of water entitlement ownership, water trading strategies, and water market reform.

We found that MDB water markets have evolved and matured considerably: market participation has increased, and new trading products, ownership and trading strategies have developed with non-landholders actively trading water and fulfilling important market functions. The majority of stakeholders own most or all of their water needs under high/general reliability water entitlements in their region and trade water allocations occasionally to supplement their water supply, although some investors/agri-corporates own little to no entitlements for capital reasons. Diverse water entitlement portfolios are more prevalent for non-landholder EWHs and financial investors. More sophisticated investors/agri-corporates and financial investors use parking contracts, multi-year water leases, and water forwards. However, the market for parking and multi-year forwards is still under-developed. Results suggest non-landholders act as major sellers of leases, forwards and parking to irrigators, potentially having positive market impacts. While current public debate in Australia revolves around the perceived negative impacts non-landholders may be having in the water market (i.e. increased water demand leading to higher prices or market power), without further quantitative research it is unclear if, or to what extent, negative impacts exist and how much these are offset by the benefits from increased diversity of water market products.

Water markets are an important tool to drive efficiency and provide risk-management benefits to irrigators. As Wheeler and Garrick (2020) conclude, water market participation is driven fundamentally by robust government regulation and institutional rules; low transaction costs; and homogeneous marketable products (and heterogeneous market users). There is a continuing fundamental need in the MDB for robust accounting of water extraction and use at both a catchment and basin scale, continual monitoring, compliance and enforcement of water extractions. The MDB experience of market maturity has led to evolving market challenges, and provides important lessons for other countries. Three associated water market reform policy recommendations were made, namely the need for more transparent and cohesive: 1) water market data and terminology; 2) rules and regulation reform; and 3) water market infrastructure and intermediary regulation and standards (such as ASIC market integrity rules, a central exchange and clearing house and a regulatory and policing organisation). It is important that maturing MDB water markets draw on best practice guidelines and structures from financial markets wherever possible, and continue to adapt their institutions and rules as needs arise. Hopefully such reform will address negative externalities, prevent conflicts of interest and unethical behaviour from market intermediaries, as well as supporting and fostering the development of new derivative type water products to provide greater water market adaptation benefits for irrigators.

Funding sources

This work was supported by the Australian Research Council [DP140103946 and FT140100773], and a University of Adelaide International Postgraduate Scholarship.

Acknowledgements

The authors acknowledge helpful comments from two anonymous reviewers on this manuscript. We thank H2OX for providing specialised water market data, and Adam Loch, Jeff Connor, Simo Tervonen and Mike Young for their advice and research support. We are also very grateful to interview participants for generously contributing their time, knowledge and expertise for this research.

Chapter 7 High turbidity: water valuation and accounting in the Murray-Darling Basin

Constantin Seidl[a*], Sarah Ann Wheeler[a], Alec Zuo[a]

*Corresponding author

[a]Centre for Global Food and Resources, Faculty of Professions, University of Adelaide, Adelaide, South Australia 5001; constantin.seidl@adelaide.edu.au; sarah.wheeler@adelaide.edu.au; alec.zuo@adelaide.edu.au

This chapter presents a paper published in *Agricultural Water Management* (2020). The paper is included in its published form, with only minor changes to formatting to bring it in line with the overall thesis. There is therefore some repetition with other chapters of this thesis, particularly the background sections.

Abstract

Australia's sophisticated and advanced water market legislation has allowed direct investment by non-landholder stakeholders in water ownership, which over time has increased the volume of water entitlements owned by government, non-governmental organisations and non-landholder investors (e.g. superannuation companies, trade speculators). The growing market value of Australian water rights, driven by increased water scarcity and international commodity prices, has meant that water is now one of the most valuable assets owned by many irrigators. However, to date, there is no standard practise of financial water valuation and accounting, nor is there an understanding of the most common methods used by various stakeholders. We report information from 63 in-depth expert interviews with bankers, environmental water holders, investors, property evaluators and water brokers in the Murray-Darling Basin to establish the current practices employed. The most common valuation methods used current market prices based on water register and water broker data. Water entitlements were valued with historical cost or fair value water accounting, depending on the stakeholder. However, given the lack of standardised methodology, evaluator discretion and fast moving (or thin) markets can lead to considerable divergence in water valuation values. Recommendations are made for the need for greater transparency and standardised water valuation methods.

Keywords: water asset; water rights; water value; water markets; Australia.

Statement of Authorship

Title of Paper	High turbidity: water valuation and accounting in the Murray-Darling Basin
Publication Status	☑ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	Seidl, C, Wheeler, SA, Zuo, A 2020. “High turbidity: water valuation and accounting in the Murray-Darling Basin”, Agricultural Water Management, vol. 230, p. 105929, https://doi.org/10.1016/j.agwat.2019.105929

Principal Author

Name of Principal Author (Candidate)	Constantin Seidl		
Contribution to the Paper	Undertook the literature review. Collected all of the data. Prepared data for analysis and performed qualitative data analysis in Nvivo. Interpreted data and wrote majority of the manuscript. Acted as the corresponding author.		
Overall percentage (%)	70%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	21/02/2020

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

vii. the candidate’s stated contribution to the publication is accurate (as detailed above);

viii. permission is granted for the candidate in include the publication in the thesis; and

ix. the sum of all co-author contributions is equal to 100% less the candidate’s stated contribution.

Name of Co-Author	Sarah Ann Wheeler		
Contribution to the Paper	Supervised development of work, edited and wrote parts of the manuscript.		
Signature		Date	21/02/2020

Name of Co-Author	Alec Zuo		
Contribution to the Paper	Supervised development of work, editing of the manuscript.		
Signature		Date	21/02/2020

Please cut and paste additional co-author panels here as required.

7.1 Introduction

Much of the world's agricultural systems and regions face a drier future with increased frequency of extreme events, such as droughts (IPCC 2019). This is especially true for Australia's Murray-Darling Basin (MDB), a region already experiencing a highly variable climate. Much of south-eastern Australia has been experiencing drought from 2017 onwards, leading to a rapid increase in permanent and temporary water prices (albeit temporary prices have still not reached the heights of the Millennium drought time-period from 2001-02 to 2009-10) (DELWP 2019a). The rapid rise of water prices means that sometimes water is one of the most valuable commodities owned by an irrigation farmer.

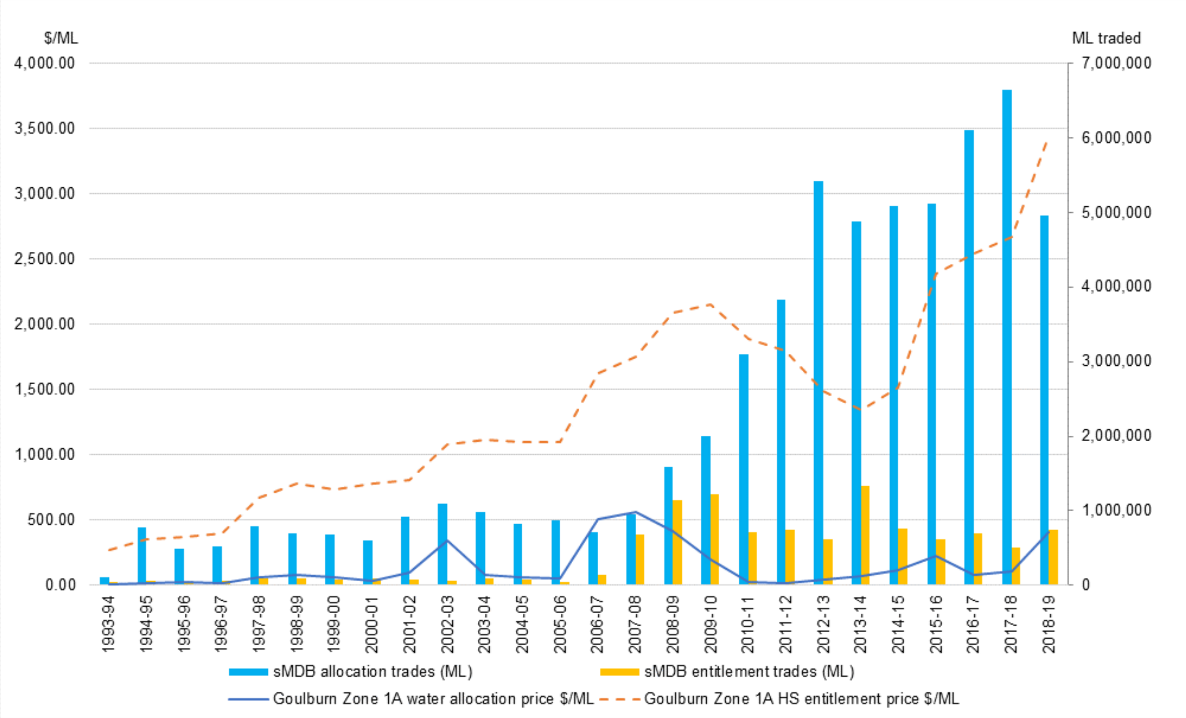
In the MDB, water ownership has been separated from land, allowing non-landholders like financial investors and environmental water holders (EWHs) direct ownership of water rights via water markets (Grafton and Horne 2014a). With MDB water markets routinely recognized as the most advanced water markets globally (Grafton et al. 2011), their challenges and best practice solutions are highly relevant for other water market systems world-wide. Water markets have existed formally in the MDB since the 1980s but developed more rapidly since water entitlement ownership was separated from land from 2004 onwards (COAG 2004a), the further unbundling of water rights in use and delivery rights (NWC 2011b), and the stepwise reduction in trade limits and barriers across the MDB (ACCC 2010). Although there now is a large variety of tradable water rights (e.g. more than 150 different tradeable entitlements (MDBA 2019l)), trade concentrates in two main products: 1) water entitlements (permanent water – a right to extract water from a watercourse/body); and 2) water allocations (temporary water – the seasonal allocation received by a given water entitlement from a watercourse/body) (Wheeler et al. 2014a). Water entitlements come in three main forms: high, general and low security, reflecting the probability of receiving a full water allocation. For example, a high security entitlement is meant to yield, on average, a full allocation in 90-95 out of 100 years (Zuo et al. 2016). MDB water markets seek to allocate water to its highest and best use, and have historically provided significant economic and drought adaptation benefits (Grafton and Horne 2014b; Kirby et al. 2015). Yet a number of rights, such as water use licences, are still tied to land-ownership and not fully unbundled. Similarly, trading rural water for urban use is restricted, although with some exceptions, such as irrigation infrastructure organisations and water utilities purchasing water entitlements to support country towns' or Adelaide's water supply, during the Millennium Drought (NWC 2012). From 2007 onwards, an organisation can buy water rights in the sMDB[64] on the market place without owning any land, and achieve a return by selling water through the market to end-users like irrigators (NWC 2011b; Seidl et al. 2020b; Wheeler et al. 2016a). Water market development in the MDB is now very advanced. Figure 7.1 illustrates water entitlement and allocation trade over time in the sMDB, and high reliability entitlement and allocation prices in Victoria's 1A Goulburn, one of the most active trading regions in the sMDB.

Combined with the removal of barriers to ownership (e.g. 10% limit on entitlement ownership not tied to land in Victoria (ACCC 2010)), non-landholder ownership (e.g. superannuation companies, trade speculators and arbitragers, NGOs) of water entitlements in the MDB has been growing. This has been shown by DELWP (2019a) as increasing ownership of entitlements held by the 'non-user' group – estimated at around 12% in Northern Victoria. Water also attracts international investment, with 9.4% of MDB water

[64]Unbundling has been slower in the nMDB, with some systems/entitlements still linked to land. However, greater institutional and regulatory reform is required before increased trade can occur without causing additional negative externalities.

entitlements held by companies with a level[65] of foreign ownership (ATO 2019). However, without publicly available non-landholder ownership data (Seidl et al. 2020b), and with a significant proportion of entitlements in the 'non-user' group held by irrigators (i.e. in self-managed superannuation accounts), discerning the volume of entitlements owned by non-landholders is challenging.

Figure 7.1 Temporary and permanent water prices in the Goulburn and sMDB water trade volumes from 1993-94 to 2018-19



Sources: Historical water prices (based upon nominal average annual prices for Goulburn 1A Zone allocation and high security entitlement trade) datasets held by GFAR, and Victorian water state registry (DELWP 2019b). sMDB trade volumes were sourced from NWC (2011a) and BOM water market dashboard (BOM 2019d).

The importance of the value of water entitlements to irrigators can be illustrated with an example. An average sized Victorian irrigation farm with average water entitlement ownership in 2015-16 held land and water assets worth about AUD$2,285,000 - with water entitlements representing around 41% of the combined land and water value.[66] The same water portfolio would be worth AUD$1,315,000 under 2018/19 prices, almost the same as their land value. The importance of water and its financial value, combined with the emergence of non-landholder water entitlement owners, such as financial investors or EWHs, has led to the following issues: i) how irrigators can borrow against their water entitlements

[65]The ATO (2019) defines companies with a level of foreign ownership as: 1) owned by an individual not ordinarily a resident of Australia; 2) owned by a foreign government or government investor; 3) a company or trust where an individual not ordinarily resident in Australia, a foreign corporation or government holds a substantial interest of at least 20%; or 4) a company or trust where two or more foreign persons hold an aggregate substantial interest of at least 40%.

[66]Average farmland value (AUD$1,360,000) and average water holding (370 ML of high security and 160 ML of low security) was based on Centre for Global Food and Resources 2015-16 survey data for a Victorian farm (see Wheeler et al. (2018) for detail on survey). Water value (AUD$925,000) was based on revenue of selling entitlements (before costs and fees) at 2015-16 median entitlement prices for Zone 1A Goulburn (DELWP 2019b).

and the credit for corporates versus family farms[67]; (Australian Property Institute 2016); ii) how there is different access to information for various irrigators[68]; and iii) how water assets are valued by different stakeholders. The lack of standard practice and consistency in valuing water can have many financial and political ramifications.

In conjunction with this reform in water property rights, there has been a large-scale effort to achieve environmental sustainability in the Basin to deal with issues such as water scarcity (drought), water over-allocation and severe environmental degradation. The *Water Act 2007* (Cwlth) and the MDB Plan 2012 (Basin Plan) aimed to return 2,750GL of water from consumptive to environmental use by mid-2019. The existence of water markets and the unbundling of water from land allowed the Australian Federal Government (Commonwealth) to purchase water entitlements from willing sellers. As a result, the Commonwealth now owns a large amount of environmental water entitlements (Grafton and Wheeler 2018), estimated at around 20% at mid-2019. There are three main ways the Commonwealth has acquired water entitlements for the environment under the Basin Plan: 1) through open reverse-auction tenders buying water entitlements directly off willing sellers in various regions (from 2007-08 to 2012-13); 2) through subsidising upgrades of irrigation and supply infrastructure, both on and off-farm (from 2008 onwards); and 3) through closed tenders (strategic purchases) buying water entitlements (and occasionally land) from large sellers (mainly from 2013-14 onwards) (Grafton and Wheeler 2018). The Commonwealth states that strategic purchases target water entitlements with substantial ecological or hydrological importance for the MDB that are difficult to acquire with buybacks or infrastructure upgrades (DAWR 2018). However, many strategic purchases have been heavily criticised for being inefficient and costly, with little environmental water received for the dollars spent (Productivity Commission 2018; Slattery and Campbell 2019; The Senate 2018). For example, water recovered through one such strategic purchase from a Queensland property in 2017, Kia Ora, has come under public scrutiny, receiving significant media attention regarding the fair value of the recovered entitlements (e.g.Davies (2019b)). As non-landholder water investment is increasing and with strong public interest in Commonwealth water investment activities, the methods used to assess and report water value are therefore highly relevant. While improvements in physical water accounting was a key requirement under the National Water Initiative (NWI) (COAG 2004a), there has been very little work done to date on ensuring consistency in how different stakeholders assess and account for financial water value in practice (Tingey-Holyoak 2019). Indeed, there is a lack of understanding about what water market valuation practices are actually used by organisations such as banks, brokers, governments, non-governmental organisations, superannuation companies and large corporates.

Water accounting and valuation is especially relevant as governments around the globe spend considerable resources to improve irrigation efficiency with the aim of reducing water consumption, with the need to demonstrate value for money on the expenditure. However, without comprehensive physical water accounting, increased irrigation efficiency can actually lead to more water consumption (Grafton et al. 2018), whereas flawed financial water accounting can lead to overpayments for water licences and budget blowouts. With Australia at the forefront of both water commodification through water markets, and extensive resources spent on water recovery through irrigation infrastructure efficiencies (Grafton and

[67]Family farms are said to be disadvantaged in comparison to corporate actors when borrowing against their water entitlements (Waterfind 2019a).
[68]Loch et al. (2018) found irrigators on average spent 5.2 hours per transaction searching for trade opportunities. Intuitively, smaller (non-corporate) farms have less time available, disadvantaging them when water trading.

Wheeler 2018), learnings from Australian water accounting and valuation practices have valuable insights for the approaches in other countries.

This study identifies the valuation methods and accounting practices used for MDB water entitlements, drawing on 63 in-depth interviews with bankers, environmental water holders, investors, property evaluators and water brokers. In particular, it seeks to address the following research questions: 1) what accounting practices and valuation methods are used by different MDB stakeholders; and 2) how does the employment of various valuation methods significantly impact water entitlement actual values?

We provide lessons for water accounting and water entitlement valuation in the MDB. The lessons learned from the MDB can provide key insights for water accounting and water valuation other countries.

7.2 Water accounting and valuation principles literature

This background literature section is structured in three parts: 1) a review of international water accounting systems and frameworks; 2) a discussion of water financial valuation methods; and 3) an overview of the current practice of water valuation and accounting in Australia.

7.2.1 International water accounting systems

Water accounting systems or frameworks report water-related data for a number of different purposes and areas. There are a variety of water accounting frameworks used globally, all differing in purpose and scope (Godfrey and Chalmers 2012). The majority focus on physical water accounting, the reporting of volumes and quality of water, on different scales. Each framework has a particular purpose, for example: the *System of Environmental-Economic Accounting for Water* and the *International Water Management Institute Water Accounting Framework* report on water flows, water stocks, water use and consumption, and water quality on the basin scale (Karimi et al. 2012; Vardon et al. 2012). On the company or product level, water footprint accounting shows the water volume necessary to manufacture a unit of product and water management accounting aims to increase businesses' water management by illustrating water use and associated costs in production and supply chains (Christ and Burritt 2017a; Hoekstra 2012).

A common trait of water accounting frameworks is their limited capacity to incorporate financial/monetary water data. The *System of Environmental Economic Accounting for Water* attempts to include monetary flows that correspond to water flows by linking into a country's system of national accounts, mainly for delivery and treatment cost, and by having dedicated water valuation accounts. However, due to data limitations, water valuation accounts remain experimental and unimplemented (Vardon et al. 2012). *The International Water Management Institute Water Accounting Framework* attempts to capture water value by relating water use to agricultural output, yet this is of minor consideration in the framework and seldom implemented (Godfrey and Chalmers 2012). Additionally, in this framework, water is only valuable as a function of agriculture, ignoring the potential value to non-agricultural water users (Karimi et al. 2012). Water value in water management accounting is highly dependent on the costs of water supply and wastewater treatment. These are determined by water utilities' tariffs, often set low for political reasons in many countries (Mungatana and Hassan 2012), limiting the benefit of financial water management accounting and its implementation.

Water accounting frameworks describe what data ought to be reported, but rarely provide guidance on how this data should be measured and compiled. This is particularly true for data concerning monetary/financial valuation of water assets.

7.2.2 Financial valuation for water assets

In the absence of international agreement on how to value water resources, the *System of Environmental Economic Accounting for Water* suggests water valuation methods commonly applied in economics (e.g. residual methods, revealed and stated preferences, production functions) should act as the default approach. Alternatively, asset valuation methods from finance and accounting could also be used. Economic tools based on the concept of total economic value can be applied to the valuation of water resources based on their direct, indirect and non-use value (United Nations 2012).

As the aforementioned water accounting frameworks focus mostly on direct water use, water as an investment asset receives no mention and therefore no corresponding water valuation technique is discussed. However, a mainstay of finance and accounting is the valuation and reporting of asset value, therefore financial asset valuation techniques could be applied for water rights. Financial asset valuation follows three approaches: 1) discounted cash-flows (e.g. ascertains value based on an asset's fundamentals such as associated cash-flows; expected growth of the asset; associated risk to cash-flows; and the asset's terminal value); 2) value of comparable assets (relative valuation - price of comparable assets in the market place, adjusting for difference in asset characteristics, or cost of replacing the asset); and 3) option pricing models (contingent claim valuation - dependent upon the occurrence of a particular event) (Damodaran 2012b, 2012c).

In contrast to financial valuation, accounting determines the value of an asset as the historical cost of the asset less its accumulated depreciation, or fair value. If historical cost accounting is used, this can result in significantly different book and market values for an asset, especially for assets such as water which can move in value very quickly (Damodaran 2012a). If fair value is used, water market prices need to be readily available. Hence, although possible, financial water valuation and financial water accounting in the absence of water market prices is difficult.

7.2.3 Water accounting and valuation in Australia

Although Australia has employed continuous water accounting since 1983 (Connell 2007), water accounts were primarily used for internal agency management purposes. From 2004, the *National Water Initiative* (COAG 2004a) required a water accounting framework to be developed, which provides information for internal and external stakeholders to facilitate planning, monitoring, trading, and environmental and farm management. This led to the *Australian Water Accounting Standards* for "*General Purpose Water Accounting*" (GPWA) currently used at the basin scale around Australia, including in the MDB (Water Accounting Standards Board 2012a). GPWA employs water accounts to report physical levels of water assets, water liabilities, net water assets, changes in water assets, and changes in water liabilities, with application mainly on the catchment/basin/country scale, although the framework was intended to be used also by companies/businesses (Water Accounting Standards Board 2012b). On the basin/catchment scale, these water accounts underpin water resource plans and water market activity in the MDB, providing transparent information on how much water is managed, how much is extracted, and how much is traded (Chalmers et al. 2012). The implementation of GPWA remains challenging; the definition of relevant water assets is not standardised and often left to practitioners, leading to inconsistencies between regions. Another significant methodological challenge is poor quality and lack of hydrological data (Tello and Hazelton 2018). Due to this lack of data, GPWA assumes water extraction equals consumption. This approach ignores return flows back to the river, and hence has the potential to overestimate consumption and underestimate negative externalities, which has been widely canvassed in the international literature (Grafton et al. 2018; Perry et al. 2017). Reflecting global practice, GPWA also focuses on physical water accounting and does not incorporate economic/financial data[69] (Godfrey and Chalmers 2012).

While basin-level physical water accounting has dramatically improved with GPWA, monetary water accounting is still underdeveloped. The only monetary data readily available is water market data, either an abridged version of the trade in state water registers and the Bureau of Meteorology water dashboard or analysed in report form (ABARES 2018). However, reviews have highlighted a number of issues with water register data (Deloitte 2019; MDBA 2019m). First, there is no mandatory price reporting, leading to a large number of trades without price, or with a price of zero. Second, entitlement transactions as a part of a land transaction are not always identified, potentially skewing reported prices, and this is a particular problem in the Queensland water register. Third, even if reporting errors have been identified, they are either not corrected, or a correct transaction gets inserted into the data, without removing the erroneous transaction record (MDBA 2019m). Additionally, and in contrast to land registers, water ownership registers are not accessible publicly. Individual water licence information is often behind a pay-per-record paywall, making it difficult to discern the size and value of various water holdings. This is complicated by the fact that authorities often require stakeholders' permission to share water licence information, even in case of paid requests.

At the individual business level, water accounting is voluntary and not standardised (Christ 2014; Tingey-Holyoak 2019). For financial reporting, the Australian Accounting Standards Board (AASB) recommends treating (unbundled) water rights as intangible assets with an indefinite lifespan. Water rights get valued at initial cost, or purchase price, less impairment. Contingent upon an active market, a fair value assessment is undertaken at revaluation (AASB 1995, 2019b, 2019c). The AASB (2019a) recommends three techniques for fair valuation: 1) market (namely relative valuation); 2) replacement cost (amount required to replace the asset); and 3) income (discounted cash-flow). However, it does not provide a detailed valuation method for water entitlements, nor does it recommend any of the fair valuation techniques.

There is also no industry-recommended water valuation method. Although the Australian Property Institute (2017) touches on water valuation in its guidelines for rural and agribusiness property valuation, and runs water evaluator courses, it only advises evaluators to understand water trade and budget issues. Similarly, how to value water entitlements is only sparsely addressed in legislation, if at all. The *Water Act 2007* (Cth) mentions the "market value" of entitlements and that methods to establish this value are subject to "regulations". These regulations seem not to exist on the Commonwealth level. On the state level, there is a similar but nuanced picture. Prior to unbundling, water entitlements were valued as part of the land and governed by the relevant acts in every basin state and the Australian Capital Territory (ACT) ((*Rates Act 2004* (ACT); *Valuation of Land Act 1916*

[69]The framework theoretically allows for monetary values to be used if appropriate for users' information needs. This is not implemented in practice.

(NSW); *Land Valuation Bill 2010* (QLD); *Valuation of Land Act 1971* (SA); *Valuation of Land Act 1960* (VIC)). Since unbundling, no state in the MDB has passed a legislative instrument dedicated to financial water valuation. While some states refer to land valuation in their water legislation, others make no mention of the issue. NSW excludes water entitlements as part of land valuation but prescribes no methods for valuation in the *Water Management Act 2000* (NSW). The Queensland *Water Act 2000* (QLD) mentions the market value of entitlements for compensation purposes, but does not identify a corresponding valuation method. It seems that the Victorian *Water Act 1989* (VIC) addressed financial water valuation the most comprehensively, requiring water entitlements to be valued by a certified valuer, and exit fees in irrigation districts should represent the present value of all future fees payable. But, while the Act prescribes discounted cash flow valuation for exit fees, it provides no guidance on water entitlement valuation. In contrast, the ACT and SA have no provisions for water valuation in their legislation (*Water Resources Act 2007* (ACT); *Natural Resources Management Act 2004* (SA)). For an overview of relevant water valuation legislation see Table E.2.

Hence, in the absence of dedicated guidelines in the MDB, the choice of water valuation and financial water accounting practice lies with the evaluator, and raises the research question of what methods are stakeholders applying, and what are the potential consequences that arise from various valuation methods.

7.3 Methods

7.3.1 Data collection and analysis

A mix of qualitative and quantitative methods were employed to explore a variety of water trade, water ownership, strategic risk management, water valuation and accounting methods issues in the MDB.

This paper reports the findings from 64 semi-structured interviews conducted with bankers, evaluators, EWHs, investors and water brokers across the MDB. Given the fact that there are 1) no standard industry and legislative valuation methods; 2) no publicly available register of water entitlement valuations; and 3) the commercial in-confidence practise of valuations, we chose a qualitative method of data collection to understand these stakeholders' water valuation strategies. To specifically target large and prominent organisations with expert knowledge in water entitlement valuation, water trading and agri-business lending in the sMDB, such as banks, evaluators and water brokers, we used publicly available information to first identify relevant organisations (and individuals within), and as a second step, a chain referral approach to recruit additional interview participants (Biernacki and Waldorf 1981). Consequently, the qualitative interviews focussed on the views and valuation approaches of large and corporatised organisations. Given that the common approach to valuation employed both by government and industry, is to contract large evaluation firms to undertake water entitlement valuations, then our method of recruitment was aimed at understanding the methods by these firms. The interviews were conducted mostly face-to face in mid to late 2018 at times and locations convenient for respondents (with 25% of interviews undertaken by phone and two respondents provided written submissions). Overall, we approached 83 eligible individuals or organisations for interview and hence obtained a response rate of 77%.

Recruitment continued until saturation was reached, namely when no new information and themes were identified. The incompleteness of one written submission meant it was excluded, hence only 63 responses are included here. Interview recordings and transcripts were compiled into Nvivo11 (a qualitative data analysis software package) and manually coded into major themes; the interviews had a median length of 60 minutes and comprised three main stakeholder groups, namely: 1) 15 EWH employees; 2) 27 water market investors; and 3) 21 bankers (6), water brokers (6) and water evaluators (10)[70]. EWHs are public or private entities, owning or delivering water entitlements or allocations for environmental purposes. Investors own and or trade water to generate non-commission income from water trading or revenues from growing crops. The majority (e.g. 20) of these were investors and agri-corporates (very large landholders owning and/or trading water but generated their main income from farming), while 7 were financial investors (non-landholders trading water for financial gain). Bankers represent financial institutions with significant portfolios in agribusiness (and water entitlement) lending. Water brokers generate commission-based revenue from water market transactions. Evaluators are specialised in rural, agribusiness and water valuations. The socio-economics were that 84% of our respondents were male, with 70% of the female respondents working for EWHs, and 75% of respondents have had experience in their current or a similar previous role for more than 10 years. However, our analysis suggested responses were mainly driven by the stakeholder group rather than by job experience or gender.

In addition, this study applied a quantitative case study methodology to illustrate the monetary impact of using different water valuation methods. The case study is the strategic water purchase by the Commonwealth from Kia Ora, a Queensland property owned by Eastern Australian Agriculture, for the purpose of returning water from consumptive to environmental use. We collected relevant water register data and various water valuation methods to illustrate the differences in water values from different techniques applied.

7.4 Results and discussion

The results are broken down into two main themes: water valuation methods and water accounting methods. Over two thirds (68%) of all participants discussed water valuation and water accounting in detail during the interviews, with most comment respectively provided by bankers, evaluators and water brokers, investors and then EWHs.

7.4.1 Water valuation methods

Table 7.1 summarises the valuation methods and data sources considered by respondents (43 respondents commented on water valuation methods). Relative valuation methods based on current water market entitlement prices and transaction data were most commonly used. Other methods included adopting the broker price/purchase price or using volume weighted average prices based on different lengths of data (6-18 months). Respondents explained that

[70]Note we interviewed a few respondents who worked for the same organisation. This was because some EWHs and evaluators operate across multiple states with water management or valuation decisions made at the local level, making it necessary to interview a variety of local representatives. We grouped bankers, water brokers and water evaluators together in the analysis as they do not own water and base their income on water-related services, rather than primary production.

only transaction data between non-distressed, at arms' length counterparties[71] is considered, excluding transactions resulting from liquidation or bankruptcy[72], and 19% of respondents mentioned other valuation methods. These alternative methods included: 1) valuation based on historic and future allocation volume; 2) associated production; 3) long-term average annual yield (LTAAY) (e.g. see Cheesman and Wheeler (2012, p. 68)); 4) statistical and time-series analysis; and 5) capital asset pricing type valuation models.

In the stakeholder interviews, respondents discussed in-depth some water valuation challenges. In particular, comments were made in regards to thin water markets ─ also called illiquid markets ─ which refers to areas of trade with only a small number of market participants or very few trade transactions over multiple years (Tisdell 2011). The biggest challenge with thin markets was the absence of high quality data. Stakeholders addressed this gap by using water trade data from comparable water products in other regions (based on reliability) or property sales data. For example, evaluators consulted stock and station agents for the water value proportion of a property transaction:

> *"We take out the value of the land, structures, apportion value to all those things and then work back to what an in-situ value of water might be. But it can be very difficult in those instances and people can have a wide variety of opinions as to what they think it might be worth"* (Evaluator)

Table 7.1 Water valuation method and data sources mentioned by respondents who discussed water valuation and accounting (n=43)

	Answers to: 1) What method do you use to value water entitlements? and 2) What data sources do you use?	***Banks % (n=6)***	***Evaluators & water brokers % (n=15)***	***Investors % (n=19)***	***EWH % (n=3)***
Methods Used*	Current market price	50	53	16	67
	Volume weighted average	33	27	0	33
	Original purchase price	17	0	0	0
	Other	17	13	32	0
Data sources*	Water registers	67	73	16	67
	Water brokers	67	80	11	33
	Own data	67	20	0	0
	Property sales	0	27	0	0
	Other evaluators	17	7	0	0
	Test listing**	0	7	0	0

Note: *Multiple mentions of methods and data sources per interview possible.
**Where a water broker offers an entitlement for sale to collect bidding data, but then does not go through with the sale.

[71]There is no standard legal definition of non-distressed counterparties. Rather, evaluators apply an economic definition, similar to the definition in *Land Valuation Bill 2010* (QLD), meaning a transaction under reasonable terms without time pressure. This is a core principle of commercial valuation.

[72]This stems from land valuation practices, where transactions from liquidation are significantly discounted. The NSW water register tracks water trades as a result of liquidation as '71X' trades, but they are unidentified in other state registers.

Only very rarely is a competing valuation undertaken by a different company to negotiate a valuation outcome, or an entitlement valued at a discount to the market in an attempt to adjust for scarce or biased data. There is a fair amount of discretionary space to choose data sources and methods for valuation, but strong personal contacts in the real estate sector and to other evaluators are considered paramount to improve data availability.

On the other hand, in a highly liquid water market, respondents rate data quality and availability less of a concern for water valuation:

> *"There are components of the water market that are still immature, but largely across the southern connected system, I think it's a very dynamic, very well informed market."* (Evaluator)

However, Table 7.1 highlights there is still an element of discretion even for liquid markets, particularly around data cleaning and data sources used. Another area of discretion is the time-period. All participants used entitlement trade data from the relevant state water registers, but problems with data reported meant the need to clean data-sets. For example, there are a large number of zero-priced transactions (representing either trades without a valid contract (e.g. EWH trade or transfer) or price not reported), low and high outlier prices, and data reporting lags of up to a few months (de Bonviller et al. 2019; MDBA 2019m). It is common practice to exclude zero price trades from valuation, or use median prices, but adjustment for outlier values is less straight forward, especially in less liquid markets. Abnormally high prices for water entitlements can appear for a number of reasons. In NSW for example, there is incentive to over-value the water component of a bigger land transaction in order to minimise stamp duty fees given water's exempt status (Revenue NSW, personal communication, 11/11/2019). The ACT, NSW, Queensland and SA water registers currently do not contain information on combined land-water transactions, allowing inflated water prices to enter unrecognised (MDBA 2019m). Water registers also do not contain information on whether an entitlement transaction included allocation or carry-over volume (Deloitte 2019). These are called 'dry' and 'wet' water sales, with 'wet' sales containing allocation or carry-over volume. Prices of wet entitlement sales are higher as a portion of the value is in the form of water allocations. Some respondents adjust their valuation by referring back to a dry entitlement price, others implicitly assume that entitlements are wet/dry at certain times of the year and this reflects in market prices:

> *"I try and go back to a dry value if I can, but obviously our evaluations are at a certain period of time, we're taking it as at that date and if you're selling water that's got a bit of temporary water included then you're going to get a little bit of a premium."* (Evaluator)

The scale of a particular water entitlement transaction can also lead to outlier prices, referred to as "scalability" by respondents. The issue arises from water entitlements trading at a premium (or discount) corresponding to its transaction size. Some respondents' argued that larger parcels of water trade for a premium, with the buyer paying for the convenience and lower transaction costs of not having to aggregate the volume from smaller parcels.[73] A single large transaction can also incur a premium due to perceived less reputational risk and backlash in rural communities compared to many small transactions:

[73]Entitlement transactions require on average 13.2 hours per trade to finalize, can include trading fees of on average AUD$24-1064/transfer when crossing Irrigation Infrastructure Operator boundaries, and water broker commission of 1.5% or 3.0% of transaction value for sellers and buyers respectively (Loch et al. 2018).

> *"I think a continuing trend that's witnessed is that we typically see a premium of some sort for a larger parcel when compared to a smaller parcel.*" (Evaluator)

On the other hand, some respondents noted that smaller parcels of water trade at a premium, because they are more affordable and attract a bigger pool of buyers:

> *"Smaller parcels have the higher premium. Someone has got 100ML and they buy this 10ML parcel for $4,100/ML, all they've done is made the average cost of their water go from $2200/ML to $2300/ML and the addition of throwing in 10ML. And they slowly accumulate on the basis of being able to afford it."* (Investor)

Bankers, evaluators and water brokers pointed to water broker data as an important source of information to mitigate shortcomings in the water registers, particularly to address time lags. While some respondents rely on a single broker, many consult a number of water broker platforms in order to get a comprehensive market picture. Evaluators use property sales data, sourced from real estate agents or the parties involved, to identify the value apportioned to water in land-water transactions. Some organisations also maintain internal databases on transactions or valuations undertaken:

> *"Our best evidence is what our clients are actually selling and buying…I see every formal valuation that's done so we have a big database of what other valuers are putting on water."* (Banker)

Respondents also discussed the time-period used to value water entitlements. While some include data from the last month only, others consider up to the previous 18 months of data. Investors seem to prefer more recent data, whereas bankers and EWHs use longer periods:

> *"We tend to have a rolling benchmark, so that looks back 18 months, what the price has been doing…Another way in which we look at it, we look at the last six to twelve months."* (Banker)

While most MDB water valuations use relative valuation methods in liquid markets, discretion is exercised around what periods of data and what data sources to draw upon, and around water value assumptions. This often makes it difficult to compare different valuations, as assumptions and methodology are often scarcely documented or commercial-in-confidence. Although some valuations contain explanatory footnotes, these likely do not attract much attention as managers fixate on the valuation number as the main source of information (Briers et al. 1997).

While variations in valuations based on different approaches might be minor in liquid markets and where water values are not rapidly increasing, it can have a substantial impact for thin markets as demonstrated in the following case study.

7.4.1.1 Case study: strategic purchase of water from Eastern Australian Agriculture

The strategic purchase of water from Eastern Australian Agriculture by the Commonwealth Department of Agriculture and Water Resources (DAWR and now titled the Department of Agriculture), as part of the Basin Plan to return water from consumptive to environmental use, illustrates the impact of different valuation methods, assumptions and evaluators' discretion. The DAWR acquired 28,740ML of overland flow water entitlements in the Condamine-Balonne region from Eastern Australian Agriculture's properties Kia Ora and Clyde via a strategic purchase in August 2017 (DAWR 2018). For a definition of overland flow licences and their difference to unbundled water entitlements, see the glossary in Table E.1. The purchase included the condition that Eastern Australian Agriculture must decommission levee banks and structures which allowed it to harvest the overland flows for the licences in question. The publicly available documents state that this removal is done by the company “at no cost” (The Senate 2018, p. 412). Of the purchase value of AUD$78.9 million, AUD$38.95 million was apportioned to 14,190ML of unsupplemented Condamine-Balonne water entitlements - overland flow licences - from Kia Ora. While the purchase received initial attention in the Senate in 2018 (Slattery and Campbell 2018b; The Senate 2018), it attracted major public interest in the 2019 Federal election campaign (West 2019; Wroe 2019).

One key issue was whether the price paid by strategic purchase (namely in negotiation with the company, not on the open market) was value for money for the type of water entitlements acquired (Davies 2019b), given the relevant water valuation documentation was not publicly available (DAWR 2019; The Senate 2018). Grafton and Williams (2019) have argued that the Kia Ora purchase in particular was an example of rent-seeking behaviour by vested irrigation and corporate agriculture interests, seeking to benefit from unduly high water entitlement valuations.

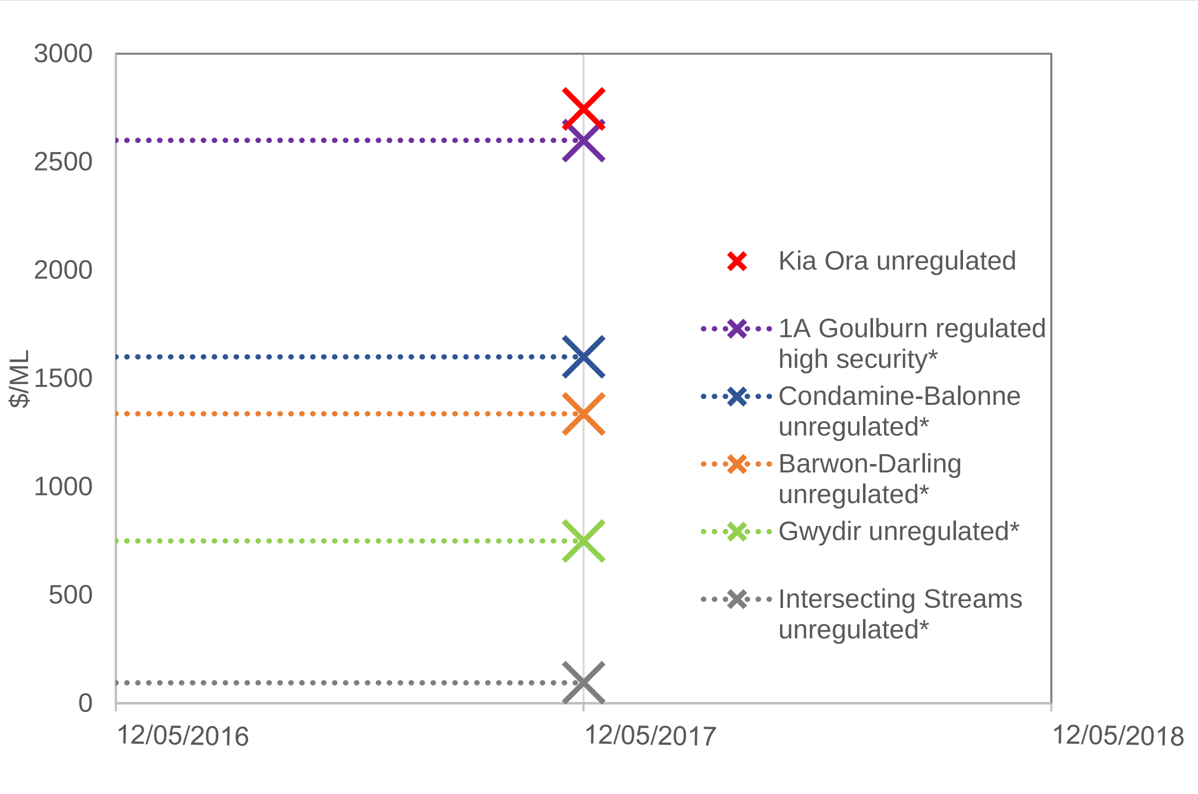
Although government policy regarding strategic purchases is meant to give regard to socio-economic impacts[74] (DAWR 2018), a government commissioned assessment by NCEconomics deemed the Kia Ora water purchase to have negligible socio-economic impacts for the region[75] (The Senate 2018). In 2017, an evaluator estimated a value for Kia Ora water entitlements based on: 1) historic sales evidence; 2) an estimation of the LTAAY based on 1922-1995 data; and 3) the difference in property value with and without water, leading to a negotiated price of AUD$2,745/ML. The government’s competing valuation by NCEconomics reduced the estimated LTAAY of Kia Ora water from 14,190ML to 12,983ML, based on 1985-2009 data, leading to a 9% difference in purchase cost (The Senate 2018). To illustrate the impact of an evaluator’s discretion and the implications for water prices, we undertook a relative valuation of comparable water products, such as unregulated water licences in the Gwydir, the Barwon-Darling and the NSW intersecting streams, and the more reliable[76] water entitlement of regulated high security (HS Reg) 1A Goulburn in Victoria for the given time-period (Figure 7.1).

[74]The government has stated it prefers strategic water purchases over voluntary water buybacks, as they are believed to have less socio-economic consequences (DAWR 2018). Part of a strategic purchase application is to demonstrate that the purchase has no or negligible socio-economic impacts (The Senate 2018, pp. 369-371). However, socio-economic impacts (on a farm level) are then used to justify a particular water price by evaluators, based on the in-production value of water and its impact on farm viability (if the farm is less viable, a higher price is seen as justified) (The Senate 2018, p. 389).

[75]The NCEconomics assessment established that the strategic purchase: 1) has a negligible impact on regional production and employment; 2) would reduce Eastern Australian Agriculture’s land under irrigation by only 9% in higher-flow years and less in normal years, without adverse impacts on farm viability; and 3) would constrain regional peak production (higher-flow years) by 2-3%, or 14,900 – 19,100 bales of cotton, and 8-10 seasonal labour positions, offset by alternative dryland cropping (The Senate 2018).

[76]Goulburn high security water yields a full allocation 95 years out of 100, with this allocation supported by storage infrastructure. It also provides access to carry-over. A Gwydir general security entitlement yields a full allocation 36 years out of 100, a Kia Ora unregulated overland flow licence 12 years out of 100, and are not supported by storage infrastructure. This makes Goulburn HS Reg a more valuable entitlement (Cheesman and Wheeler 2012; Hargraves et al. 2013; The Senate 2018).

Figure 7.2 Median price and purchase price for unregulated Kia Ora, Condamine-Balonne, NSW intersecting streams, Gwydir and Barwon-Darling, and Goulburn HS Reg licences as at 12/05/2017



Notes: *Median based on previous 12 months, prices based on BOM (2019a) and The Senate (2018).
**Median price of 1A Goulburn HS Reg is stable for last 12, 6, and 3 months.

Table 7.2 Comparing Kia Ora water purchase price and transaction value for 14,190ML with similar area unregulated water entitlements

	Water price/median price (AUD$/ML)	*Total cost (AUD$m)*	*% Difference compared to Kia Ora Price Paid*
Purchase price Kia Ora (in Condamine-Balonne)	2,745	38.95	n.a.
Condamine-Balonne unregulated	1,600	22.70	-42%
NSW Intersecting Streams unregulated	95	1.34	-97%
Gwydir unregulated	750	10.64	-73%
Barwon-Darling unregulated	1,337	18.98	-51%
1A Goulburn HS Reg Victoria	2,600	36.89	-5%

It would have been within the evaluator’s discretion to value the water at the median of Condamine-Balonne or comparable overland flow licences, as it was also in their discretion to choose 1922-1995 or 1985-2009 as the LTAAY base.

Given the lack of transparency and information regarding the purchase price of Kia Ora, it is not possible to state why the value seemed higher than what could be expected. However, what can be verified is that if the Commonwealth paid the median market price, the purchase cost would have been around 42-97% less, depending on the unregulated reference licence (see Table 7.2). While Kia Ora water could have traded at a premium due to its size (14,190ML – given government does prefer larger parcels to decrease its transaction costs per water transfer), other aspects of its unregulated nature arguably do not warrant a price premium, to the extent of making the water more expensive than the more reliable entitlement of Goulburn high security.

7.4.1.2 Water Valuation summary

This study is limited by its focus on primarily qualitative data, which hinder attempts at quantifying the impacts of different valuation methods. Future studies should analyse a dataset of real water valuations (which was not available for this study[77]) to quantify the monetary impacts of different assumptions and methods, data cleaning and evaluators' discretion on water entitlement valuations.

Nevertheless, our results provide a useful illustration of water valuation practices and their challenges. While water valuation follows similar processes to the valuation of agricultural land (i.e. market value of the asset at valuation date), which may be due to continuation of the practice of irrigated land valuation prior to unbundling, the assets are arguably very different. Water entitlements are more volatile than land, and in many cases extremely liquid, traded routinely in large volumes on active markets. Despite these differences, a dedicated water valuation methodology has yet to emerge: the current legislative and valuation industry's guidelines are fairly inconclusive on the treatment of water assets, leaving large areas to evaluators' discretion. There is a lack of clearly defined methodologies and guidelines in the current practice of water valuation and accounting in the MDB, confirming the findings of other studies (Christ and Burritt 2017b; Tingey-Holyoak 2019). Insights from the case study and respondents' water valuation comments highlight how the valuation process can be sensitive to bias, as it relies heavily on secondary data that is not always reported correctly, nor transparent. This is particularly pronounced in thin markets, where data scarcity and quality arguably require the use of longer time-periods and multiple data sources.

In addition, commercial valuation relies on the notion of non-distressed counterparties. An interesting application of this involves government water recovery. With environmental water recovery targets for each catchment and the corresponding deadline, in form of the Basin Plan, public knowledge, this condition is arguably violated: the government could be seen as a distressed buyer. Under a strategic purchase regime, particularly in thin markets with a high concentration of water entitlement ownership/market power and a significant portion of the environmental water recovery still to recover, various interests may be able to extract unduly high water entitlement prices due to the 'government distress'. Similarly, evaluators' method choices and assumptions could drive valuation outcomes, and hence provides opportunities for rent-seeking.

---

[77]Water entitlement valuations are often commercially in-confidence and not publicly available. If available, valuation methodology and assumptions sections are usually redacted. There is no register containing water valuations. While a public central register for land and property valuations exists in some states, it contains only the final value but not the actual valuation report. However, having access to the valuation report, in particularly the valuation methods and assumptions sections, is necessary to quantify the impact of evaluators' discretion.

7.4.2 Water accounting systems

The other major theme identified by our respondents was how water value was reported in accounting systems, with distinct practices identified for banks, EWHs and investors.

7.4.2.1 Accounting by banks: water as collateral/security

Bankers explained a MDB water entitlement can be accepted as a security for a loan or mortgage. The value of this security is a function of the entitlements' market value, established by water valuation, and a risk adjustment[78] (otherwise known as an "internal lending margin" or "extension rate"). Some banks undertake water valuation in-house, others contract external valuation services due to conflict of interest. Larger or more complex valuations tend to be done externally, whereas simpler valuation tasks stay in-house. Most banker respondents conceded that experience with water as a security is limited, and banks therefore employ a more conservative extension rate for water than for land. In addition, some banks reduce the valuation amount by 10% before applying the extension rate. Most also prefer to mortgage against a mix of water and land assets, leading to a higher extension rate for water as part of an asset mix, and to not lend against water entitlements alone.

It is known that water entitlements are less protected than land in legal terms. First, water entitlements are a statutory property right, making them less protected from regulatory change than a land title (Fisher 2010). Second, banks can directly access the money from a land sale to satisfy their mortgage, whereas such a provision does not exist in every state for water entitlement sales as the money can go straight to the seller.[79] There are cases where the water owner took the money, defaulted on the mortgage and disappeared, leaving it to the bank to chase the money through litigation. Although one-third of the bankers interviewed accepted water entitlements as security by themselves, they are subject to lower extension rates, ranging between 50-70%, representing a 10-20% discount as compared to agricultural land extension rates. Note that banks still negotiate the terms of the mortgage, and extension rates only determine securities' value:

> *"If it's part of a wider transaction that involves farming land, so dirt and water, and water being used on the land, then we'll lend up to 70% of the water value. If it's a transaction where it's not being used specifically by the owner or a related party of the owner for farming purposes, so it's more of a speculative investment type purchase, then we reduce that to 50%."* (Banker)

Once a mortgage has been negotiated, banks do not adjust the value of the water asset until revaluation. Again, revaluation periods depend on the bank: they may, for example, be yearly, every three years, or only for intended re-mortgage.

---

[78]Banks adjust for: the risk of the mortgagor defaulting; the liquidity; and collateral 'security'. Bankers explained that standard lending risk metrics such as debt-equity ratio, historic income and cash-flow are considered, as well as the agribusiness banker's expertise and judgement about the farm enterprise.

[79]NSW, QLD and VIC legislation rule that caveats can be placed on water entitlements, entitlements can only be transferred if agreed by the mortgagee, and in the case of default - proceeds of water sales need to satisfy mortgages first (*Water Act 1989* (VIC); *Water Act 2000* (QLD); *Water Management Act 2000* (NSW)). In contrast, SA legislation allows for caveats to be placed on water entitlements, but does not provide mortgagees with veto powers, nor does it dictate the use of proceeds from water sales in case of default (*Natural Resources Management Act 2004* (SA)).

7.4.2.2 Accounting by EWH: Water as environmental asset

EWH respondents account for the value of their water assets at historic cost less impairment (AASB 2019b). The relevant cost is heavily influenced by the way water was initially acquired: purchase price if the water was bought on the market; or the value apportioned to water recovered as part of a strategic purchase or infrastructure upgrade (DAWR 2018). For strategic purchases, the water value relies heavily on external valuation. For water entitlements acquired through infrastructure upgrades, they can cost a premium of up to 7.1 times the market price once transaction program costs are taken into account (Productivity Commission 2018). Finally, for water entitlements transferred from another entity for free (e.g. gift of environmental water entitlements by the Victorian Government to the Victorian Environmental Water Holder (VEWH 2018a)), the cost is AUD$0/ML.[80]

These costs remain unadjusted in EWH accounts, save annual impairment testing, until revaluation (which only occurs in active markets). However, EWH respondents often argue that there is no active market for environmental water since it is never to be sold. In practice, this leads to environmental water assets being massively undervalued: most water entitlements have appreciated considerably from the time the majority of EWHs acquired their portfolios, and impairment adjustment cannot exceed the initial cost.

The practice of claiming no active market to avoid revaluation has likely evolved within public EWHs with the aim to avoid Treasury calls for revenue from water assets. Although most public EWHs are not required to recover costs or create revenue, but rather manage their water for environmental benefit (O'Donnell 2013, 2018), this is not the case for all, and subject to regulatory change. One respondent explained that as water entitlements are listed on a state’s asset register, they reported that the Treasury argues that water assets are contributing to a state’s bottom line and need to be valued at market value. There is then perhaps an argument that they should therefore recover the associated costs of holding and using the asset (licencing and trading fees), requiring EWHs to create a monetary return through allocation sales. However, EWHs prefer to manage water for environmental benefits, not cost recovery:

> “*The model where government absorbs the costs in some other mechanism and the EWH just has to go about their business as managing the water is the preferred model.”* (EWH)

There are some EWHs that employ a market valuation approach for entitlements acquired through direct purchase, although water recovered through infrastructure upgrades remains at cost. This approach allows EWHs to represent water ownership value closer to the current market, better informing water portfolio rebalancing decisions.

7.4.2.3 Accounting by Investors

All businesses list their water portfolio value in their balance sheets but the accounting framework differs for entitlements held for production or as part of an investment asset portfolio. When water entitlements govern water held for production, water entitlements are treated as intangible assets with an indefinite life-span, accounted for at historic cost less

[80] This is generally the case for EWHs when no cost (purchase price or cost of infrastructure efficiency program) can be attributed to a particular water entitlement, e.g. bulk water entitlements outside of the MDB.

impairment, with the purchase price as the historic cost (AASB 2019b). In contrast to EWHs, investors revalue their entitlements at fair market value. However, this often occurs infrequently. For example, family farms tend to account for entitlements at cost for multiple years without revaluing, and only revalue if required by their bank. While some investors revalue their water assets annually, this was not standard process amongst our respondents.

Non-landholder financial investors hold water entitlements as part of a real asset investment portfolio. They value water entitlements at current market prices and revalue at a high frequency, sometimes every month, making sure the market asset value is represented at all times. This provides transparency and enables shareholders to make swift decisions about portfolio restructure:

> *"We are an investment fund, we have to hold water at its fair market value based on AASB13 (Fair Value Measurement) in our books, rather than historic cost. That's important for us because our members can trade in and out of our product daily. We need to have an up-to-date market valuation so that we can ensure they're trading in and out at fair market value."* (Financial Investor)

Historical cost accounting has implications for investors: having a significant part of their asset value not reflected in financial statements can make communication with shareholders difficult, as well as not reflecting the true value of the company:

> *"My previous employer had water that was at about a tenth of its value on the books. That just suggests that the accounting standards are back to front."* (Investor)

By accounting for water at fair value (AASB 2019a), financial investors have stronger balance sheets, which is advantageous when trying to attract investor interest and credit opportunities. However, one banker respondent claimed that the balance sheet value of water has no bearing on credit decisions:

> *"Financial institutions take no notice of the value in the balance sheet when it comes to property, and that's why they do valuations on water. And at the end of the day, the bank manager and the customer know the true value of the asset."* (Banker)

One potential reason for this may be the difference between the market value of water as represented by comparative valuations versus the value of the water used by the business. All businesses will have differing marginal values of water (e.g. see Wheeler et al. (2014d) estimates for differing buy and sell water trade values for various irrigation industries). The "true value" the respondent refers to is likely the marginal value of water for a particular business, which can be different to the book value[81] and different to the current market value.

7.4.3 Accounting Framework Summary

Financial water accounting practice in Australia broadly follows historical cost or fair value accounting practices set out by the AASB (AASB 2019a, 2019b). However, as AASB standards only have to be used by 'reporting entities', such as ASX200 listed or companies with significant external stakeholders, water accounting by smaller businesses is not impacted. This leads to a wide variety of water values being reported, without much transparency about assumptions or the accounting framework used. This is exasperated by the

[81]However, due to accounting treatment under AASB138 (Intangible Assets) (AASB 2019b), book value is impaired when water prices fall below the initial purchase price. Therefore, the current market value can only ever be equal or larger than the book value.

sometimes poor quality of water entitlement ownership data, misreporting the location and security of stakeholders' water entitlement ownership. Consequently, comparing different water asset portfolios is challenging at best. Historical cost accounting particularly has been criticised as obscuring real performance, providing largely irrelevant information, and leading to poorer business decision-making (Argilés Bosch et al. 2012; Barlev and Haddad 2003). This resonates with the concern that smaller businesses are disadvantaged in accessing capital since an important part of their asset base, namely water entitlements, are often undervalued due to historical cost accounting and infrequent re-evaluation. Given the maturity of sMDB water markets, fair value accounting for water assets is possibly more transparent, more reflective of economic realities, and arguably easier than historical cost accounting. More transparent water accounting frameworks, reflecting the current value of water, provide important information for stakeholders and may enable better water management. Transparency in accounting can also build trust in the water market system (Wheeler et al. 2017b).

The MDB case points to important aspects for water valuation and accounting globally. Current water accounting initiatives on the business scale are not standardized, they focus mainly on physical water information and water use, but do not pay attention to water asset values (Burritt and Christ 2017; Tingey-Holyoak 2019). Future studies should pay more attention to financial water values and attempt to incorporate these values better into existing accounting frameworks. With water increasingly becoming a sought-after investment asset, an important part of irrigators' assets, and with non-landholder ownership increasing, water accounting needs to adequately reflect the fair value of the asset, rather than its historic cost, or just the cost of provision and physical volumes. While some basin-scale water accounting frameworks envision financial water accounting conceptually, they provide little instruction on best practice water valuation methods. Clear standards and methodologies for both accounting and valuation are necessary to enable transparent and comparable assessment of financial water asset value for diverse stakeholders. To underpin the hydrological integrity and financial water asset values, physical accounting considering net water consumption on a basin-scale (Grafton et al. 2018), and financial fair value accounting of water rights, reflecting current market values, are paramount. Transparent valuation of water resources should follow a standardised approach in regards to data cleaning, data sources considered and valuation methods employed. In addition, governance, regulation and corruption have been identified as important issues for water markets globally (O'Donnell and Garrick 2019). Therefore, when water valuations concern government expenditure, we suggest that methods, data and assumptions used should be publicly available, rather than commercial in-confidence, to: 1) increase accountability; 2) demonstrate "value for money"; 3) discourage rent-seeking by vested interests; and iv) engender trust in government processes (Grafton and Williams 2019; Wheeler et al. 2017b). Furthermore, in situations where the government is perhaps classified as a "distressed buyer" to recover water, standard commercial valuation methodology might not be appropriate to discern the value of water rights.

7.5 Conclusion

This study used qualitative information from 63 interviews with water experts (banks, evaluators, EWHs, investors and water brokers) and case study quantitative information to highlight issues associated with 1) water entitlement valuation; and 2) water accounting frameworks.

The majority of respondents used relative valuation (namely current market value) to value water entitlements, as well as other methods such as purchase price and volume weighted average price. Bankers value water on a longer period of water market data (6-18 months), whereas evaluators largely rely on information within the last six months. Water register and water broker data were the most commonly used data sources. Issues associated with valuation include transparency and accuracy of water market data, larger versus smaller water parcels, transaction costs and fees, and 'wet' versus 'dry' trades. These are particularly impactful in thin water markets where data availability and quality are poor. We show that the use of different data and methods can have a meaningful impact on valuation values, as demonstrated in the Kia Ora Commonwealth's strategic purchase case study where the same water entitlement could have been valued anywhere between AUD$95-2,745 per ML, and it is highly likely that the Commonwealth paid considerably more than they should have due to evaluator discretion.

In the MDB, physical water accounting is limited by its focus on gross-extraction, rather than net consumption of water. Financial water accounting frameworks value water at historical cost (less impairment) or fair value. Bankers stated they applied extension rates between 50-60% to water valuations, whereas rates between 60-70% apply to agricultural land, for mortgage and security purposes. On the other hand, financial investors, owning water as part of a real asset investment portfolio, revalue assets monthly at current market prices. EWHs undertake yearly impairment testing, but do not revalue their portfolio, as they claim there is no active market for environmental water. The difference in accounting can lead to a material divergence in reported water portfolio values between stakeholders - making comparisons challenging. The predominant use of historical cost accounting by small businesses could disadvantage them in regards to access to capital.

These findings highlight that there are no clear standards for water valuation and financial water accounting and we illustrated this impact on water asset values. Physical water accounting does not report real availability of water resources as it is based on an assessment of gross-extractions. There is a need for proper water accounting across the whole Basin, accounting for return flows and all water use. The processes of financial water valuation and accounting are confusing and potentially obfuscating, enabling rent-seeking by various interests. As illustrated by a series of inquiries, a MDB Royal Commission, and considerable public interest in government water valuation of strategic environmental water purchases, there is a compelling need for transparent and open water management, valuation and financial water accounting. Greater transparency and a standardised water valuation method, clearly identifying assumptions made, would reinforce the development of water markets, both in the MDB and worldwide. Proper accounting practice is important to discharge organisations' responsibilities for water management and purchase against its stakeholders, contributing to greater trust in institutions and governance, which is a vital issue for all water market systems.

Funding and Disclosure statement

This work was supported by the Australian Research Council [FT140100773], and a University of Adelaide International Postgraduate Scholarship.

Declarations of interest: none

Acknowledgements

The authors acknowledge helpful comments from two anonymous reviewers on this manuscript. We thank Paul Babie, Jeff Connor, Adam Loch, Harish Madan, Aaron Stasi and Mike Young for their advice and research support, and Deborah Peterson and Joanne Tingey-Holyoak for their comments on this manuscript. We are also very grateful to interview participants for generously contributing their time, knowledge and expertise for this research.

Chapter 8 Conclusions and Policy Implications

This thesis has undertaken a multi-method exploration of the drivers of irrigators' planned adaptation behaviour, focussing particularly on water ownership and trading issues. This chapter provides a summary, presents key findings, and makes a series of policy recommendations. Finally, comments about the limitations of this study and future research directions are also made.

8.1 Summary of the thesis and key findings

Table 8.1 summarises the key thesis findings, with the related implications for policy development discussed in the following section.

Following the introduction in Chapter 1, Chapters 2 and 3 provided a detailed description of the MDB, its history of water policy reform and water market systems. Given the already highly variable climate in the MDB, and climate change projections predicting a drier and more volatile future climate, MDB irrigators will be subject to increased future uncertainty and likely worsening water scarcity (CSIRO 2008, 2012; Timbal et al. 2015). This creates the need for continuous adaptation to changing circumstances. Historically, MDB water policy reform has aimed to address water scarcity and volatility, initially by constructing major infrastructure, such as dams, to smooth seasonal rainfall variability (Connell 2007; Guest 2016). From 1994 onwards, water policy focused on enabling flexible demand side responses to water scarcity via water markets and subsequent market liberalisation and unbundling, while also attempting to address over-allocation of water resources and strike a new balance between consumption and the environment (Connell 2007; Crase et al. 2014; Guest 2016; Lee and Ancev 2009). Water markets are now very advanced, with allocations and entitlements routinely traded in large volumes by diverse market participants (Grafton et al. 2016), albeit with the nMDB water market far less developed than the sMDB water market (Wheeler and Garrick 2020). New derivative-type temporary water market products and non-landholder water market stakeholders have recently emerged in the past few years (ABARES 2018; Bayer and Loch 2017; Brennan 2008; Wheeler et al. 2013a). Trading motivations and behaviours are well-understood for irrigators (Haensch et al. 2016a, 2019; Loch et al. 2012; Nauges et al. 2016; Wheeler and Cheesman 2013; Zuo et al. 2015a; Zuo et al. 2015b), and to a lesser extent for EWHs (Ancev 2015a; Connor et al. 2013; Lee et al. 2012; Wheeler et al. 2013a). However, there is a clear gap in the literature regarding water ownership and the trading behaviour of non-landholders and the use of derivative-type temporary water market products across all stakeholder types.

Table 8.1 Summary of Key Thesis Findings

Chapter	Findings	Method
Two MDB climate and policy background	There are 100 years of successive MDB water policy reform that has attempted to address over-allocation of water resources. Major reforms include implementing water markets and driving market liberalisation. Contention remains around the appropriate split between water for consumption and the environment, which is all the more urgent given that the MDB's highly variable climate is predicted to become drier and more volatile with climate change.	Literature Review
Three MDB water market background	Derivative-type temporary water market products and non-landholder stakeholders have recently emerged. While trading in entitlements and allocations by irrigators and environmental water market participants is well understood, very little is known about these new developments. This chapter also introduced the research questions	Literature Review
Four Thesis methods and Data	Given data availability and the research questions, a mixed methods approach was chosen as the most appropriate research methodology for the thesis.	Literature Review
Five Irrigators' planned adaptations	Irrigators' planned adaptation behaviour was modelled using a survey of 1,000 sMDB irrigators in 2015-16. It was found behaviour was strongly influenced by irrigators' financial, human and social capital, but their influence varies between different adaptation types.	Partitioning clustering, recursive bi-probit models, multivariate probit models, seemingly unrelated regression models
Six Water ownership and trading strategies	In-depth interviews with 63 stakeholders (banks, agri-corporates, water traders, EWHs, financial investors) were conducted in 2018-19. Many stakeholders, including non-landholders, prefer to own most of their water needs in higher security water entitlements and use temporary trade to mitigate water supply shortfalls. Financial investors and large agri-corporates are more likely to use and/or supply derivative-type temporary trading products. Most stakeholders view water entitlements as financial assets.	Thematic qualitative interview analysis
	There are three key water market reform areas: 1) data reform; 2) rules and regulation reform; and 3) new institutional development.	Thematic qualitative interview analysis
Seven Water valuation and accounting	Insights from the in-depth interviews were used to find that most MDB water entitlement valuations are comparative valuations, using different data and data cleaning procedures. Irrigators and EWHs use historical cost accounting, financial investors use fair value accounting. Banks extend water entitlements for 50-60% of their valuation value.	Thematic qualitative interview analysis
	Applying different water entitlement valuation and data cleaning protocols can lead to a difference in entitlement value between 5-97%	Case study

Chapter 4 justifies the use of a mixed methods research approach in this thesis and provides extra detail on data sets and data collection protocols, complementing the analytical Chapters 5-7. Due to the recent introduction of derivative-type temporary water market products and non-landholder stakeholders and the water registers not adequately reporting different types of market trades, public quantitative data is not available. It was therefore appropriate to employ qualitative techniques such as expert stakeholder interviews to gather information on these topics.

Chapter 5 investigated MDB irrigators' planned expansive, accommodating and contractive adaptation strategy choices and their related drivers, including the impacts of human and social capital, and attitudinal factors. Planned adaptation is analysed in three indices:1) expansive adaptation that increases or enhances the irrigation component of a farm enterprise; 2) accommodating adaptation that changes the farm structure without impacting the irrigation component; and 3) contractive adaptation that reduces the irrigation component. Expansive adaptation strategies include buying water allocation and/or entitlements, buying more farmland (in the same or a different region), increasing irrigated area and improving irrigation efficiency. Accommodating adaptation strategies include changing farm ownership structures, change irrigated production (e.g. crop mix), diversify production, increase farm insurance, increase dryland area, increase collaboration and collective bargaining, decrease dryland area, and utilising solar for irrigation infrastructure. Contractive adaptation strategies include selling the farm, decreasing irrigated area, selling water allocations and/or entitlements, and sell any farmland. This chapter used a survey of 1,000 sMDB irrigators, conducted in October - November 2015, with 419 responses from NSW, 209 from SA and 372 from VIC. The survey had a final response rate of 51% and contained information on irrigators' socio-economic characteristics, world views, past and planned future adaptation behaviour.

Key results from this chapter included: 1) most irrigators plan to use to use all adaptation types, but have a slight preference for expansive over accommodating and contractive planned adaptation; 2) succession planning and past adaptation experience have a statistically significant positive influence for all planned adaptation; 3) the influence of financial, human, natural, physical and social capital variables varies between adaptation types. Financial capital variables (e.g. farm debt or farm income) were the strongest statistically significant driver for planned accommodating adaptation, whereas planned expansive and contractive adaptations are more strongly statistically significantly impacted by human and social capital variables. These results confirm findings from ex-post adaptation studies, suggesting that farm succession, and experience with, or the ability to trial strategies, are important factors determining farmers' adaptation (Ghadim et al. 2005; Li et al. 2017; Nicholas and Durham 2012; Wang et al. 2015b). The variation in the importance of specific drivers across different adaptation strategies has also been suggested in other studies (Gadédjisso-Tossou 2015; Moniruzzaman 2015; Prokopy et al. 2008). In contrast to many other adaptation studies (e.g. (Abid et al. 2016; Below et al. 2012; Dinh et al. 2017; Moniruzzaman 2015; Prokopy et al. 2008; Wang et al. 2015a)), this study quantitatively explores drivers for planned, and therefore future adaptation, rather than adaptation implemented in the past (Llewellyn and Brown 2020), making prediction possible. This is important to better understand irrigators' future risk management behaviour, enabling the development of more efficient and targeted drought and climate change adaptation policies (Chavas and Nauges 2020; Nauges et al. 2016). To our knowledge, only Wheeler et al. (2013b) has examined MDB irrigators' planned adaptation across a range of adaptation types, albeit using a simpler modelling approach for a smaller number of strategies for an earlier time-period.

Given water trading is an important risk management tool and adaptation strategy for irrigators, Chapter 6 explored MDB water ownership and trading strategies and their role for different stakeholders, including agri-corporates, environmental water holders, and non-landholder financial investors. This chapter utilised the irrigator survey, quantitative water forward and parking trading data from 2016/17-2018/19, and 63 qualitative expert interviews with 20 agri-corporates, 6 banks, 15 EWHs, 7 non-landholder investors, 10 property and water evaluators and 5 water brokers, conducted from April - October 2018. This chapter also addressed the use of emerging derivative-type temporary water market products, and stakeholders' perceptions on water asset characteristics from a financial perspective. Finally, current water market and policy issues identified by different stakeholders were illustrated and improvements suggested. Results show that most stakeholders (79%) see water entitlements as a financial investment asset, with some pointing to its unique characteristics. A majority also own most or all of their annual average water needs under high/general reliability water entitlements in their region/trading zone and trade water allocations occasionally to supplement their water supply, although some agri-corporates (20% of all agri-corporates) own little or no entitlements, preferring to invest capital elsewhere. Diverse water portfolios, made up of entitlements of different securities and in different regions, including groundwater entitlements, are more prevalent among non-landholder EWHs (83% of EWHs) and financial investors (86% of financial investors). Although a few irrigators use some derivative-type temporary water market products, it is mainly the sophisticated agri-corporates and financial investors that use parking contracts, multi-year water leases, and water forwards regularly.

Consequently, the market for parking and multi-year forwards is still underdeveloped, with leases overall the most common derivative-type temporary product, followed by parking (42% of respondents use leases, 29% use parking, and 13% use multi-year forwards). We also found that non-landholders acted as major sellers of derivative-type temporary products to agri-corporates and irrigators (37% of forwards in the available data were sold by non-landholder investors), providing market liquidity. This is in line with Brennan (2008) and Bayer and Loch (2017), who find that forward and parking contracts lead to more efficient water market outcomes. As Wheeler and Garrick (2020) conclude, water market participation is driven by robust government regulation and institutional rules, low transaction costs, and homogeneous marketable products (and heterogeneous market users). These criteria are arguably not completely fulfilled for derivative-type temporary products because transaction costs (due to counter party risk) are high, and in the absence of standardisation, products are not homogeneous. Similarly, robust regulation and institutional rules for non-landholder and agri-corporate market participation do not exist. This chapter therefore suggests three major water market and policy reform areas to tackle these issues: 1) data reform; 2) rules and regulation reform; and 3) new water market institutional development.

The final chapter (Chapter 7) also used the stakeholder qualitative interview data to further investigate water entitlements as a financial asset, specifically how they are valued for investment and mortgaging purposes, and how they are accounted for in an organisation's financial reports. It also investigated whether employing different valuation and accounting methodologies may have an impact on reported entitlement values. While a literature review identified potentially applicable valuation and accounting frameworks, and the Australian rules and legislation in regard to water entitlement valuation and accounting, stakeholder interviews explored the methods and data used in practice. This chapter found that due to an absence of standardised rules, valuation is routinely contracted to large corporatised property evaluators, who predominantly use comparative valuation methods, albeit with different data sources and data cleaning protocols.

The case study of the strategic purchase of Kia Ora overland flow licences in the Queensland Condamine-Balonne region by the Federal Government as a part of the water recovery program in 2017 demonstrated that the choice of data sources and valuation methods can have significant impacts on water entitlement values in the range of 5 - 97% of final value. This issue of valuation is particularly pronounced in thin water markets where data are scarce. Stakeholders account differently for water entitlements: EWHs, private irrigators and agri-corporates use historical cost accounting, which only adjusts to present entitlement market values in the event of revaluation, which in practice is undertaken infrequently. EWHs do not revalue their water portfolios, arguing that environmental water is not to be sold and therefore needs not to be revalued. Non-landholder financial investors account for entitlements at fair market value, often revaluing very frequently, sometimes monthly. Given the recent rise in water entitlement prices, historical cost accounting undervalues water entitlements. With the majority of EWHs' entitlement holdings acquired prior to 2015, EWH entitlement portfolios are substantially undervalued. Banks use 50-60% of the water entitlement book value for mortgage and collateral purposes. Given the unequal accounting treatment, this may disadvantage irrigators, especially smaller irrigators, in accessing credit.

8.2 Policy recommendations

Based on the results discussed, three broad topic policy recommendations are presented: 1) drought and water scarcity adaptation policy; 2) water market policy and regulation; and 3) financial water valuation and accounting policy.

8.2.1 Climate change and drought adaptation policy

Given climatic variability in the MDB and the likely future impacts of climate change, irrigators will continue to experience water scarcity and drought, likely to persist at current, or increased, levels (CSIRO 2008, 2012; Timbal et al. 2015). Future drought and climate change policy therefore needs strong incentives to foster continuous adaptation to changing circumstances. The following elaborates further on drought policy in Australia.

Drought policy

Drought policy has a long history in Australia (Aslin and Russell 2008), with drought treated as a natural disaster until 1989, giving farmers access to associated welfare support payments (Botterill and Chapman 2002), such as the Natural Disaster Relief Arrangements (NDRA). Following a review in 1989, drought was excluded from the NDRA and a National Drought Policy (NDP), based on principles of self-reliance and risk management, was introduced in 1992 (Alston and Kent 2004; Botterill 2003). Drought was thereafter treated as a business risk for farmers. In the same year, the income smoothing schemes of the Income Equalisation Deposits (IED) scheme and the Farm Management Bond (FMB) scheme were introduced, and farmers were encouraged to make use of these to manage drought risk (Botterill 2003). These schemes allowed farmers to deposit pre-tax income for use in later years and encouraged farmers to increase their self-reliance through improved risk management (Botterill 2005). However, the NDP also recognised that there are severe events not manageable for many farmers, enabling the affected areas to be declared as experiencing Exceptional Circumstances [EC] (White and Karssies 1999). To be classified as an EC event, which is not limited to drought but includes any type of event outside the capacity of good management (Botterill 2010), the event must be rare (not have happened more than once, on average, every 20 to 25 years) and cover events outside the range of “normal” ones (Aslin and Russell 2008).

The Farm Household Support Scheme links the established drought relief payments with the ‘EC Exit Package’ (Botterill 2005) and is meant to encourage those farmers without a long-term sustainable future in farming to leave the industry (Botterill 2003). Farmers can receive some financial compensation for selling their farms and support in adapting to a new business or different employment (Stehlik 2009). This includes an Exit Grant, offering a taxable payment, an Advice and Retraining Grant, and a Relocation Grant (DAFF 2014). An earlier version of the Exit Package was the MDB Small Block Irrigators Exit Grant Package, implemented in the Millennium Drought to aid the *RtB* efforts until early 2010 (Zuo et al. 2015b).

In 2011, after the Millennium Drought, a new framework to support farmers without the need for EC declarations was agreed, removing the national EC Interest Rate Subsidy because it was determined to neither help farmers to prepare for drought, nor improve risk management (DA 2019). When drought returned to eastern Australia in 2013, there were again calls for financial support for farmers, including interest rate subsidies. Thus, in February 2014, a new drought assistance package, which included subsidising loans, was announced (Peterson 2016). The most recent drought policy package in 2019 includes an additional Farm Household Allowance, which is available for farmers in two instalments. To make it easier for farmers to succeed, it includes a simplified support process and an increased net asset threshold cap of AUD$5.5 million (Lawrence et al. 2019).

Botterill et al. (2017) argue that current attitudes to drought assistance are not reasonable and do not adequately protect farmers from insolvency risks. In particular, taxpayer subsidies can be minimised by delivering default insurance for farmers; the so-called Revenue Contingent Loans. Given that the attitudes of individual farmers to risk have not changed, and that no single drought strategy addresses the needs of all agricultural sectors, farmers decide on their own drought strategies, according to their expectations and financial position (Watson 2019). Moreover, there are some arguments that current drought policy settings are expensive, with spending on the 2001-03 drought amounting to more than AUD$1 billion (Botterill 2005). Botterill (2010) identified that encouraging farmers to build financial reserves, by providing a tax-related savings mechanism in form of the Farm Management Deposit scheme, is an effective risk management approach to drought.

Nauges et al. (2016) suggest that MDB irrigators may be willing to pay for insurance products which protect against the risk of yield or revenue losses. As shown above, Australian drought policy to a large extent encourages farmers to develop their own risk management practices. This is especially relevant because attempts to introduce yield insurance products have failed (Hatt et al. 2012). Despite encouraging farmers’ self-reliance and being unwilling to intervene on the insurance market by subsidising premiums, Australian governments have traditionally provided drought assistance for ‘exceptional’ droughts through the aforementioned income support, interest rate subsidies and exit packages. This may indirectly compromise the establishment of a competitive insurance market, which can pool farmers’ risks through various products. For example, in the Millennium drought of the 2000s, 23% of Australian farms received some drought financial support (Productivity Commission 2009).

Drought and water policy

As another drought and water response policy, the Commonwealth implemented the *Water for Fodder* program in 2019/2020: an agreement to use the Adelaide desalination plant to produce an extra 100 GL of water for SA water consumption in exchange for Commonwealth funds (DAWE 2020a). In turn, 100GL of Murray water (40GL in 2019/20 and 60GL in 2020/21) from the SA state entitlement will be made available to irrigators, in blocks of 50ML for $5,000 per water allocation account, to produce fodder at a discounted price of AUD$100/ML (DAWE 2019d). At the time of writing, of the 40,000 ML available in round one, 14,250 ML were delivered to irrigators in NSW, 25,100 ML to irrigators in VIC, and 650 ML to irrigators in SA (DAWE 2020c). Nauges et al. (2016) criticised Australian drought policy for indirectly compromising irrigators' risk management efforts by providing assistance in exceptional droughts (see later in this section). Crase (2019) criticises the *Water for Fodder* program for its high cost, for not taking the diversity of MDB farmers into account, for a lack of safeguards against arbitraging by buying cheap water from the program and selling one's own allocation for a higher price at the market, and for the difficulties associated with monitoring the program and enforcing compliance with program rules. Arguably, irrigators with appropriate risk management practices would not have to rely on subsidised cheap water allocations for their livelihoods. In essence, the *Water for Fodder* program is a very expensive and blunt instrument (Crase 2019), rewards poor individual risk management and incentivises irrigators' reliance on the government as the insurer of last resort (Watson 2019). The introduction of carryover allowed on this program (Miller 2020), signals the uselessness of this policy and most likely its demise.

Irrigation infrastructure policy

Another aspect is the governments' focus on subsidising irrigation infrastructure efficiencies (and the supply projects) for environmental water recovery, given that there are large questions surrounding the sustainability and effectiveness of the irrigation infrastructure program This focus on recovering water through infrastructure upgrades, needs to be reconsidered as such infrastructure investment policies are found to be not cost effective (e.g. (Grafton 2010; Lee and Ancev 2009; Wittwer and Dixon 2013)) and reduce irrigators' flexibility and adaptive capacity for future droughts (Adamson and Loch 2018; Adamson et al. 2017; Wheeler et al. 2020a). See Wheeler et al. (2020a) for a summary of the criticisms of irrigation infrastructure upgrades. This reconsideration would allow some of the public spending on infrastructure upgrades to be allocated towards restructuring the water buyback scheme and providing farm adjustment programs, in order to achieve better overall environmental and socio-economic outcomes (Wheeler et al. 2013a; Wittwer and Young 2020). Recovering water for the environment can be more appropriately achieved through an optimal mix of flexible water recovery options, including water trading and physical caps/quotas or water pricing increases (Ancev 2015a; Connor et al. 2013; Crase et al. 2015; Loch et al. 2011; Loch et al. 2014b; Wheeler et al. 2013a). MDB policy makers should ultimately concentrate on *"what is sustainable and what is not and how to best balance and optimise the water needs of the environment, agriculture, other non-agricultural industry, and human settlements"* (Kiem 2013, p. 1624).

Summary

This review shows Australian drought and drought adaptation initiatives have strongly focussed on financial capital drivers, such as access to credit and farm income or wealth. The results of this thesis show that although financial capital is an important driver of planned adaptation, financial capital incentives do not work equally well across the full gamut of potential adaptation strategies, and particularly if they are ad hoc responses to crises (Watson 2019), rather than supporting and incentivising irrigators' individual risk management

(Nauges et al. 2016). More emphasis should be given to empower and support irrigators to develop better and more robust risk management strategies. Continuing to restrict the focus to financial incentives that compromise risk management, such as the *Water for Fodder,* or income support measures may lead to expensive policies, failing to incentivise planned adaptation to future drought and climate change. Future policies could also harness the power of non-monetary incentives, such as succession planning and farmer experience with adaptation strategies. Supporting improved succession planning and experience with a range of adaptation strategies, through trials or education, potentially has large positive impacts on future adaptations across all adaptation strategy types, while also encouraging irrigators to manage their own risk. This may also be more effective than focusing on monetary incentives only. To avoid costly, one-size-fits-all and ad hoc approaches, improved adaptation and drought policies need to consider the differences between specific adaptation strategies and the way they are influenced by particular drivers.

8.2.2 MDB water market benefits and market failure

MDB water markets have evolved considerably in the last few years, with both irrigators' entitlement and allocation cumulative trading participation ever increasing (Wheeler and Garrick 2020). Water markets have been shown to provide 1) allocative efficiency; 2) dynamic efficiency; and 3) productive efficiency (Grafton et al. 2016).

Water market efficiency benefits

An extensive literature has shown that short-term adaptation, namely allocative efficiency, to seasonal conditions (e.g. weather, cropping choices) is most often achieved through water allocation trade. Water allocation trading is an important risk management strategy for many irrigators (e.g. (Loch et al. 2012; Nauges et al. 2016; Zuo et al. 2015a)), allowing income creation for annual croppers through selling water allocations to permanent growers to keep their crops alive during droughts (Adamson et al. 2017; Kirby et al. 2014a; Wheeler 2014). Water scarcity plays a major role in water allocation prices and volumes traded on the market (Loch et al. 2012; Wheeler et al. 2008b; Zuo et al. 2015a; Zuo et al. 2016), demonstrating MDB water markets' allocative efficiency.

Voluntary trading of water entitlements allows for new investment opportunities and increased dynamic efficiency, through regulatory shifts in access arrangements (e.g. extraction limits or embargos) or personal strategic choices (e.g. retirement) based on structural or long-term decision making. The two most important motivations for water sales were a) retiring debt and b) generating cash to support farm income and re-investment in the farm (Wheeler and Cheesman 2013). Wheeler and Cheesman (2013) also found that thirty percent of farmers who sold all their entitlement retired, with a number of farmers selling water as part of succession plans. There are two influences from selling water entitlements: a positive (reduction in debt, farm restructure and reinvestment to make it more productive or efficient) and a negative (less water for production and/or higher costs in buying water allocations or bought feed) impact. Wheeler et al. (2014c) found no statistically significant impact on irrigation farms' current financial year from selling water entitlements (but found a negative impact on current year rate of return from buying water entitlements).

Changing water prices (both allocation and entitlement) offer productive efficiency incentives for efficient water resource use, either as an investment or input for productive outcomes (Loch et al. 2013), allowing water to be traded to its highest value use (Grafton and Wheeler 2018). New water market stakeholders also provide benefits by developing new derivative-type temporary trading products, which aid risk management (Seidl et al. 2020b) and provide greater allocative efficiency. The growing value of water entitlements over time provides a benefit for existing farmers in terms of superannuation, as an investment or as mortgage property (Seidl et al. 2020a; Wheeler et al. 2016a). These factors contribute to MDB water markets' productive efficiency.

Water market failure

As highlighted by Wheeler et al. (2017b) and Wheeler and Garrick (2020), water markets only exist within institutions and structures which allow and govern the transfer of water. If these institutions and structures are corrupted or are missing, then this can result in negative impacts for society and market failure. Despite its evolution and maturity, market failure in MDB water markets exists in three areas: 1) imperfect competition; 2) externalities; and 3) information asymmetry.

Imperfect competition occurs when markets are characterised by monopoly, oligopoly, bilateral monopoly or some other market imperfection, potentially leading to an imperfect allocation of resources. In the MDB, there is more evidence of imperfect competition in the nMDB than the sMDB, due to both endowment of resources and unregulated property rights (Wheeler and Garrick 2020). Evidence from the operation of some IVTs is that they do exert material influence on water market prices, and that some brokers have a technical ability and automatically monopolise trade through the choke (Hunt 2020).

Externalities occur when property rights are not clearly defined, and costs and/or benefits can therefore spillovers to others. When discrepancies between private and social benefits and costs occur, then the resource allocation generated by markets will not be efficient because market prices do not reflect the 'full' or social costs involved. In the MDB, there are issues associated with tagging and transmission losses through trading which have potential third party impacts, and impacts of water markets on the environment. However, there is evidence that these environmental impacts are both positive and a negative. For example, positive impacts include allowing the environment to acquire equal water rights (Grafton and Wheeler 2018), decreasing salinity (Lee et al. 2012), and allowing greater movement of water downstream, leading to ecological benefits (NWC 2012). Negative impacts identified are increased salinity in areas where water is traded from (Bjornlund 1999; Khan et al. 2009), increased groundwater substitution and salinity issues (Haensch et al. 2016b; Wheeler et al. 2020a; Wheeler and Cheesman 2013), and activating sleeper and dozer licences (NWC 2012). In order to transfer environmental water between regions, EWHs are required to formally trade water allocations, subject to market trading rules. This has the potential to trigger volumetric trade restrictions, such as IVTs.

Information asymmetry occurs where one party has better information than the other. The information-rich agent can then increase their own benefits at the cost of the information-poor. There are a number of information asymmetries in MDB water markets, hampering decision-making for both irrigators and policy makers. There are ongoing issues with price disclosure in registers, consistency of data information (and timeliness); accuracy of information in registers (especially across states). Water availability and trade data can be fragmented, incomplete or erroneous and weeks out of date (MDBA 2019m; Seidl et al. 2020b). Water valuation and accounting practices are exasperated by poor quality water entitlement ownership data, which sometimes misreports the location and security of stakeholders' water entitlement ownership. There is also information asymmetry through membership of consultation bodies, such as water steering committees, and specific knowledge of water brokers. This can allow for insider trading, and there is quantitative evidence that insider trading may have been present in MDB water markets, especially prior to rules being enforced in 2014 (de Bonviller et al. 2019).

In sum, there is evidence of market failure in MDB water markets. Imperfect competition does seem to exist in some forms, especially in regards to the nMDB, IVT issues and unregulated water broker behaviour. Negative externalities are clearly present, mainly because of the lack of clear property rights and institutional rules. Information asymmetry also clearly exists, again in relation to IVT issues, data and information on prices, water registers and weather, insider trading issues of working groups and water brokers.

To address these issues, this thesis recommends reform in two main areas: 1) water market regulation and policy; and 2) financial water valuation and accounting regulation and policy.

8.2.2.1 Water markets regulation and policy

As highlighted in the previous section, barriers to trade, market failure and the need for further water market regulation and policy reform remain. There is a fundamental need in the MDB for: continued robust accounting of water extraction and use (at both catchment and basin scale); continual monitoring; compliance and enforcement of water use; and water market institutional conditions – in order to ensure transparency and confidence in the market – as well as continual adaptation over time (e.g. (Grafton and Wheeler 2018; Wheeler et al. 2017b)). Additionally, this thesis identifies three areas of further reform: 1) data reform; 2) rules and regulation reform; and 3) new institutional development.

Data Reform

Existing data water registry rules need to be strengthened and better implemented, such as mandatory price reporting for all water trades (MDBA 2019m). In particular, entitlement transactions in conjunction with land must be identified, especially in thin markets and where tax incentives lead to an overreporting of the water entitlement value (i.e. NSW and QLD). There is a pressing need to identify water forward, lease, option, and parking transactions, including counterparty type, within registers in order to support emerging derivative-type water market products. Under current conditions, price discovery is very challenging for these products, likely limiting stakeholders' appetite to utilise them. The spectre of water barons and price gouging by non-landholder investors is front of mind for many irrigators and rural communities. Without reliable water ownership data across all stakeholder types, it is impossible to ascertain whether there may be non-landholder related water market issues. This thesis demonstrates that price-gouging and monopolistic behaviour has little to do with stakeholder type, but rather is based on the concentration of market power within or across particular catchments. Data on entitlement ownership by stakeholder type needs to be transparent and analysed at a catchment level to identify and address concerns about market power and monopolistic behaviour. These issues have also been identified as critical by the ACCC and the Victorian government (ACCC 2019a; DELWP 2019c).

Rules and regulation reform

As argued by Wheeler et al. (2017b), key criteria for robust water markets are strong and transparent institutions and a clear understanding of water rights and trading products, which in turn drive market participation (Wheeler and Garrick 2020). Clear standards and regulation are currently lacking in some areas. Derivative type temporary products are not standardized and are unregulated. Carry-over access and rules are unequal between the states, i.e. SA's access to carry-over is subject to bilateral negotiation between states, whereas NSW and VIC operate their carry-over portion in Dartmouth and Hume differently. As shown in Chapter 3, water market terminology across states is described as confusing to many, IVT rules and announcements lack transparency and are viewed as highly complicated. Improved and more transparent rules and standards for water forwards and options, carry-over access, allocation and IVT determinations would contribute to better decision-making by MDB stakeholders. In the absence of clear standards for water forwards and options, product comparability is problematic, and counterparty risk for forwards is significant. An arguably superior product to forwards is futures, routinely used for many agricultural commodities, such as cotton or corn. Water futures would offer similar risk management benefits for lower counterparty risk, as they are standardised and exchange traded, with a central clearing house that mitigates counterparty risk through daily cash settlement of profits and losses (Pirrong 2011). However, water futures would require a water market central exchange and clearing house, like that of the ASX. With the increasing use of derivative type products and increasing incentives for counterparty default in times of water scarcity and drought, the topic of standardisation and counterparty risk requires urgent attention. Unified water market terminology for comparable water products, such as water entitlements or allocations could improve interstate trading by removing confusion and ambiguity. A review of tagging and transmission losses through trading should identify and quantify corresponding third-party impacts. Conversely, very careful assessment needs to be given to any change in unregulated entitlements to allow trading, such as allowing trading in floodplain water harvesting rights. Legal loopholes enabling stakeholders to bypass trade restrictions and extraction embargoes, for example, as is the case for entitlements tagged prior to 22nd October 2010, need to be closed. Administrative arrangements and structures minimising insider trading and rent-seeking are key to robust water sharing systems (Young 2019). Therefore, membership of consultation bodies which might provide access to sensitive information, such as water steering committees, and standards for water brokers needs to be fully transparent and publicly declared to avoid rent seeking by vested interests.

New institutional development

Finally, the more that stakeholders treat water markets like stock markets, managing water entitlements as financial assets, as opposed to production inputs, and use derivative-type temporary products, the more water markets will require sophisticated institutional development to avoid negative consequences/externalities. A special focus should target codes of conduct and conflict of interest rules for market participants and intermediaries. Australian Securities and Investment Commission market integrity rules (ASIC 2018) could provide guidance for this. Water market institutional development is particularly important for derivative-type temporary products, consideration should therefore be given to additional water market infrastructure, such as creating a central exchange and clearing house. This should be complemented by a well-resourced market regulatory agency with competency in monitoring and enforcing compliance in relation to derivative products. While a central exchange and clearing house provides benefits in regards to counterparty risk and transparency of trades (Duffie and Zhu 2011; Pirrong 2011), it likely will increase the static transaction costs of trade and will require substantial regulatory reform. Arguably, market efficiency gains through derivative products (Bayer and Loch 2017) will make this initial institutional investment worthwhile in the longer term. Sophisticated derivative type products require comprehensive allocation and entitlement data. Providing these data in a timely manner is challenging without a central exchange trading allocation and entitlements. However, this does not necessitate one central exchange for all products; a number of central exchanges, e.g. one for allocation and entitlements and another for derivative products may also be appropriate. Greater water market intermediary regulation is also required; defining, policing and sanctioning conflicts of interests, along with establishing minimal brokerage requirements. Commercial water entitlement ownership by water market intermediaries and principal trading is a point of contention for many water market stakeholders. Regulation may be needed to stop this and thereby avoid conflicts of interest. Strong water market institutions and regulation needs to enforce product standards and codes of conduct, limit rent-seeking based on privileged information, and have appropriate prosecution powers to effectively limit counterparty risk in derivative-type products and unlawful intermediary behaviour. As the water market continues to evolve, institutions and regulation need to keep pace in order to support an effective and fair market for all stakeholders, drawing on best practice from financial and derivative markets.

8.2.2.2 Financial water valuation and accounting policy

With water entitlements widely used as collateral for farm credit and mortgages, appropriate valuation of water assets and their financial accounting is increasingly important.

Water valuation follows similar methods to the valuation of agricultural land (i.e. market value of the asset at valuation date), yet the assets are very different. For one thing, water entitlements are less legally protected than land titles (Fisher 2010); albeit governments and most water market stakeholders ignore this and treat entitlements as a quasi-property right in practice. Water entitlements are also more volatile than land, in many cases extremely liquid, and traded routinely in large volumes in active markets. This arguably makes water a more attractive investment asset than land, given investing and divesting is reasonably quick and uncomplicated. However, a dedicated water valuation methodology has not yet emerged: the current legislative and valuation industry's guidelines are unclear about the treatment of water assets. This leaves much to evaluators' discretion: for example, what period to collect data from, which sources to use, how to clean data, and the general assumptions for valuation calculations. There are a lack of clearly defined methodologies and guidelines in the current practice of water valuation and accounting in the MDB, confirming the findings of other studies (Christ and Burritt 2017b; Tingey-Holyoak 2019). This thesis highlights how the valuation process can be sensitive to bias, because it relies heavily on secondary data that is neither always reported correctly, nor always transparent. This is particularly pronounced in thin markets, where data are scarce and of sometimes dubious quality, which arguably requires the use of longer time-periods and multiple data sources. The use of different data and methods can have a meaningful impact on entitlement values: in the Kia Ora Commonwealth's strategic purchase case study, the same water entitlement could have been valued anywhere between AUD$95-$2,745 per ML. In thin markets and where market concentration and market power are present, various interests may be able to extract unduly high water entitlement prices, particularly where large portions of the *Basin Plan* water recovery targets have yet to be met, such as in northern NSW and southern Queensland. It is standard practice that the seller or mortgagor contracts the services of professional valuation companies and shoulders the cost. As evaluators' method choices and assumptions could drive valuation outcomes, this provides opportunities for deliberate misevaluation, collusion and rent-seeking. Water entitlement valuations are commercial in-confidence, making methodological choices non-transparent and valuations hard to compare. Arguably, valuation methodologies, assumptions, data sources and cleaning methods should be publicly available in order to allow for the reproduction of valuation results, particularly in cases where large public funds are involved, such as strategic purchases. A publicly available database of water valuations, like those available for land valuations may be worth considering.

Financial water accounting in practice follows fair value (AASB 2019a) or historical cost accounting (AASB 2019b) set out by the Australian Accounting Standards Board. With these standards only adhered to by "reporting entities", such as ASX200 listed companies or those with significant external stakeholders, water accounting by smaller businesses is not included. This leads to a wide variety of financial water values being reported, without much transparency about assumptions or the accounting framework used. This is exasperated by the sometimes poor quality of water entitlement ownership data, misreporting the location and the security of stakeholders' water entitlement ownership. This makes comparing different water asset portfolios challenging, at best. Historical cost accounting has been criticised as obscuring real company and farm performance, providing largely irrelevant information, and leading to poorer business decision-making (Argilés Bosch et al. 2012; Barlev and Haddad 2003). As most MDB irrigators use historical cost accounting for water entitlements and revalue infrequently, if they undertake financial accounting at all, there is concern that smaller businesses are disadvantaged in accessing capital since an important part of their asset base, namely water entitlements, are undervalued. EWHs also use historical cost accounting; they undertake yearly impairment testing but generally do not revaluate. While this seems to be a practice stemming from inter-departmental and political reasons, it likely leads to extremely undervalued water portfolios, given that most water entitlement recovery took place at times with lower water entitlement prices. It is therefore extremely challenging to ascertain whether water recovery has provided value for money for the tax-payer. Given the maturity of sMDB water markets, fair value accounting for water assets is possibly more transparent, more reflective of economic realities, and likely simpler than historical cost accounting, particularly with highly probable future improvements in water market data quality from implementing current reviews' recommendations (ACCC 2019a; MDBA 2019m). There is arguably scope for a dedicated financial valuation and accounting framework for water entitlements which reflects the current value of water, because transparent water accounting frameworks provide important information for stakeholders and enable better water management (Chalmers et al. 2012), and they also build trust in the water market system (Wheeler et al. 2017b).

8.3 Limitations and Future research

8.3.1 Limitations

As described within this thesis, the methodologies employed have some weaknesses or limitations. This section briefly summarises the limitations that were encountered, how they were dealt with and their potential effect on the findings.

8.3.1.1 Quantitative irrigators' planned adaptation modelling

Although the irrigator survey data set used for Chapter 5 was rich and comprehensive, a few limitations exist, particularly in relation to different planned adaptation strategies:

- Irrigators were not asked *why* they plan to adopt a certain strategy. Therefore, the planned adoption of a given strategy cannot be definitively attributed to reasons such as climate change or profit maximisation. Given that irrigators will adopt strategies if they perceive a benefit from them (Chavas and Nauges 2020), and perceived benefits will invariably consist of a mix of financial and adaptation considerations (Smit and

Skinner 2002), this thesis argues that modelling planned adaptation at least partially reflects climate change adaptation. It also addresses this limitation by consciously defining planned adaptation strategies as a response to any type of future uncertainty, not just that induced by climate change.

- Irrigators did not provide information on the magnitude of planned adaptation, e.g. increasing the irrigated area by only a small fraction or changing all of a farm area to irrigation, nor whether they intend to undertake certain strategies as one bundle, e.g. increasing the area irrigated and putting the same area under more efficient irrigation infrastructure. As Chapter 5 outlined in more detail, potential dependence of planned adaptation strategies was addressed by utilising seemingly unrelated regression and multivariate probit modelling approaches, as well as using unweighted adaptation indices to reflect the unknown magnitude of adaptations. Sensitivity analysis revealed no material impacts on dependent and independent variable magnitude, direction and significance levels, between models which addressed and ignored potential interdependencies.

8.3.1.2 Qualitative expert interview analysis

There are also some limitations with the expert interviews used in Chapters 6 and 7. Ideally, to analyse all land and non-land stakeholders' water ownership and trading strategies, data would have been available via water registers as either a) a census; or b) representative dataset. As highlighted in Chapter 3, these data are not publicly available for derivative-type temporary water products and ownership/trade information. Interview data represents therefore a second-best solution, but it provided a way to also obtain rich qualitative information on motivations in addition.

- Given the small sample size of 64 total interviews, it cannot be assumed that interview data is statistically representative across all stakeholder types and states, especially as it was first targeted at larger and more sophisticated market participants to supplement the already existing dataset of irrigator trade behaviour.
- It is possible that interview participants may have deliberately misled or engaged in "cheap talk" in due to ulterior motives, such as reviewer bias. Since interviews were anonymised, unincentivised (i.e. unpaid – albeit a Haigh's chocolate frog or chocolate Murray Cod was provided as a thankyou!), and participants did not directly gain from research outcomes, the likelihood of interviewees being deliberately misleading is small. Nevertheless, information volunteered in interviews was fact-checked as much as possible, for example by triangulating stated water portfolio size and entitlement ownership with annual financial reports.
- Initial interview recruitment may have missed key stakeholders. As our target respondent group is highly inter-connected, both professionally and at a personal level, the chain-referral approach employed in this thesis was considered highly appropriate for recruiting important participants. Given recruitment efforts were only terminated if: 1) a relevant person agreed to the interview; 2) directly refused to participate; or 3) no new information was added from more interviews and more data collection subsequently unnecessary, this limitation has no likely material impact on the results.

In addition, data and claims made in the expert interviews were triangulated with other data sources wherever possible, such as water broker forward and parking trading data. This approach ensured maximum caution and research rigour were employed in order to not bias results and derive wrong conclusions.

8.3.2 Future research and Conclusion

Several recommendations for future research can be drawn from this thesis:

Future research

Future research can expand on modelling irrigators' planned behaviour by using data encompassing information on adaptation motivation and magnitude. This analysis requires that future surveys collect in-depth, detailed information on *why* irrigators plan to employ certain adaptation strategies in the future and *how much they intend to do*. Given the importance of water ownership and trading strategies, future quantitative data collection should also explore irrigators' derivative-type, temporary trading behaviour, and ask them to consider and nominate different, alternative ownership philosophies. For example, "*I own all my water needs and do not use leases, forward and futures*", or "*I own less than 50% of my water needs in entitlements and source the rest from the allocation market or through leases, forwards and futures*". Panel data time-series analysis was not possible in this thesis: although a 2010/11 round of the irrigator farm survey was available, it contained a different set of questions, in particular in regards to adaptation strategies and only 338 irrigators participated in both surveys, which is not enough observations for the modelling approaches used in this thesis. Future surveys should be conducted with the aim of establishing a large panel of irrigators, spanning multiple years, in order to analyse how behaviour changed over time. Following Chavas and Nauges (2020), this thesis can be expanded by better incorporating the impacts of planned adaptation on risk and uncertainty. One conceivable way of doing this is grouping planned adaptation strategies around whether they increase, decrease or transform future risk or uncertainty. However, given the inherent complication of assessing multi-dimensional concepts of risk and uncertainty, careful thought needs to be given to how to define the risk-increasing and risk-reducing attributes of planned adaptation strategies.

This thesis found that there are different rules, formal and informal, for EWHs and irrigators when trading on the water market. For one, the good neighbour policy of EWHs may materially impact their ability to deliver environmental outcomes or manage inter-seasonal risk via carry-over. Another aspect is the different treatment of evaporation and delivery losses associated with water trading. EWHs have these attributed to their allocation bank account and irrigators do not. This unequal treatment and the subsequent impact on water markets deserves further investigation, ideally through quantitative data analysis.

The impact of exceptions to water trading rules and restrictions, such as IVTs, through tagged entitlements has also been identified. Given the trend of increasing perennial plantings downstream of the Barmah Choke (Doolan et al. 2019), and a related likely increase in IVT closures, this needs urgent attention. Analysis should quantify how much water bypasses trade restrictions, how this impacts water availability and water prices in different zones and whether this causes environmental damage to the river and its ecosystems. This requires multi-disciplinary research between economists, hydrologists and ecologists.

A quantitative analysis of representative lease, forward and parking data, including a review of water ownership concentration and trading behaviour by different stakeholder types, is of paramount importance. Further research should aim to quantify how much water is held and traded by investors/agri-corporates and non-landholders, and assess whether this has quantifiable impacts for the water market or influences its long-term dynamics (e.g. see (Zuo et al. 2019)). This should include a consideration of concentration of market power, price gouging, or unequal access to carryover and inter-valley transfers. Currently, this analysis is impossible as unit-record water ownership data are not publicly available and derivative-type temporary trading data are not collected. However, given recent debate and the ACCC review currently taking place (ACCC 2019a), the situation may change in the near future, making this type of analysis feasible.

This thesis used a case study to demonstrate potential impacts of valuers' discretion for water entitlement values under Commonwealth strategic purchases. Subject to data availability, a systematic audit of financial water valuations and methodologies used should be undertaken. Valuers' methodological choices could be contrasted to alternative data cleaning and valuation methods, establishing the monetary impact of method choice across different valuations. These differences could then be analysed to quantify whether discretion has a material financial impact in many cases, and the potential for existing patterns to aid deliberate misevaluation for rent-seeking purposes.

Finally, some data collected for this thesis has not yet been analysed. Expert interviews also discussed stakeholders' climate change plans, perceptions, adaptation strategies and future portfolio aspirations. This information will enable an exploration of how non-landholder stakeholders and agri-corporates plan for climate change, and what their likely trading and ownership behaviour may be in the future. Similarly, the data also contain rich information on environmental water management practices and challenges experienced by EWHs. Combined with environmental site case study data, future analysis may yield important insights for environmental watering in practice and identify beneficial rules and policy changes or adjustment. Participants also provided rich data, via comments about non-water-market-related MDB policy improvements and their views and concerns related to compliance issues identified by Four Corners (Four Corners 2017). Triangulating this with quantitative water compliance data and their development over time may enable an analysis of compliance attitudes and perceptions versus the state of compliance in the MDB. This may lead to important insights regarding water market confidence and compliance regulatory adequacy.

Overall, there is a clear need for future studies in water trading and ownership behaviour, quantifying the impact of different rules for consumptive and environmental water users. Special focus needs to be given to derivative-type temporary products trading and non-landholder stakeholders water market activity, quantifying related impacts for third parties, identifying potential market failure, rent-seeking, market power, or monopolistic behaviour.

Conclusion

This thesis is one of the first studies to explore financial valuation and accounting of water entitlements in-depth, and one of only a very few studies analysing derivative-type water market products and non-landholder water market stakeholder behaviour. Further research is warranted to better understand the nature of water entitlements as financial assets, as well as water market evolution towards derivative-type water products and different types of stakeholders. It has also significantly increased our understanding of the drivers of irrigator planned adaptation behaviour.

MDB irrigators will have to adapt to a likely drier and more volatile future, drawing on a range of adaptation strategies, including expansive, accommodating and contractive ones. Drought and climate change adaptation policies need to support irrigators' individual risk management by employing all possible drivers for future adaptation, instead of distributing ad hoc financial support and relying on policies which disincentivise private risk management. Water markets have a large role to play: with increasing diversity of water market stakeholders and tradeable products, including derivative type temporary products, risk management through water trading becomes increasingly powerful and effective. This thesis showed that utilising water entitlement ownership strategies and drawing on the full gamut of new water trading products is currently largely limited to a few agri-corporates and non-landholder financial investors. Water market reform and policy needs to enable and support all water market participants to benefit from these improved risk management options, while also safeguarding against market failure, adverse third-party impacts, conflict of interest, and unethical behaviour. With water entitlements increasingly becoming a valuable financial asset, water accounting and valuation practices need to be transparent and reflect the real value of water, in order to enable equal access to credit and mortgaging for all water holders.

By considering these topics, related policy programmes and future water market trading rules and regulations can achieve more equitable outcomes and contribute to a fair and efficient water market for all stakeholders.

Appendix A Supplementary material for Chapter 3

Table A.1 Allowable direction of water trades in the southern-connected Murray–Darling Basin

MDB Valley	Water Trading Zones	Transfers may be made to these trading zones…	Transfers may be made from these trading zones…
Goulburn	**Trading Zone 1** Greater Goulburn (includes Lake Eildon to Goulburn Weir; Goulburn irrigation areas; and Loddon weir pool)	3, 6, 6B, 7, 10, 11, 12 back trade only: 4A, 4C, 5A, 13, 14*	4A, 4C, 5A back trade only: 3, 6**, 6B, 7, 10**, 11, 12, 13, 14*
Goulburn	**Trading Zone 3** Lower Goulburn (includes Goulburn River below Goulburn Weir)	6, 7, 10, 11, 12 back trade only: 1, 4A, 4C, 5A, 6B, 13, 14*	1, 4A, 4C, 5A back trade only: 6**, 6B, 7, 10**, 11, 12, 13, 14*
Campaspe	**Trading Zone 4A** Campaspe (includes Lake Eppalock to Waranga Western Channel; and Campaspe District)	1, 3, 4C, 6, 6B, 7, 10, 11, 12 back trade only: 5A, 13, 14*	4C back trade only: 1, 3, 5A, 6**, 6B, 7, 10**, 11, 12, 13, 14*
Campaspe	**Trading Zone 4C** Lower Campaspe (includes lower Campaspe River from Waranga Western Channel to Murray River)	1, 3, 4A, 6, 6B, 7, 10, 11, 12 back trade only: 5A, 13, 14*	1, 4A, 5A back trade only: 3, 6**, 6B, 7, 10**, 11, 12, 13, 14*
Loddon	**Trading Zone 5A** Part Loddon (includes Loddon River and Tullaroop Creek; from Cairn Curran and Tullaroop reservoirs to Loddon Weir; and Serpentine Creek system above Bears Lagoon)	(conditional) 1, 3, 6, 6B, 7, 10, 11, 12 back trade only: 13, 14*	back trade only: 1, 3, 6**, 6B, 7, 10**, 11, 12, 13, 14*
Vic Murray	**Trading Zone 6** Vic Murray above Barmah Choke** (includes River Murray from Lake Hume to Barmah Choke; Mitta Mitta River below Lake Dartmouth; and Murray Valley area)	10 back trade only**: 1, 3, 4A, 4C, 5A, 6B, 7, 11, 12, 13, 14*	1, 3, 4A, 4C, 5A, 6B, 7, 10, 11, 12, 13
Vic Murray	**Trading Zone 6B** Lower Broken Creek (includes Broken Creek downstream of Katamatite)	6, 7, 10, 11, 12 back trade only: 1, 3, 4A, 4C, 5A, 13, 14*	1, 4A, 4C, 5A back trade only: 3, 6**, 7, 10**, 11, 12, 13, 14*
Vic Murray	**Trading Zone 7** Vic Murray from Barmah Choke to SA Border (includes Torrumbarry area, Tresco, Nyah, Robinvale, Red Cliffs, Merbein and FMIT irrigation districts)	6, 10, 11, 12 back trade only: 1, 3, 4A, 4C, 5A, 6B, 13, 14*	1, 3, 4A, 4C, 5A, 6B, 11, 12, 13 back trade only**: 6, 10
NSW Murray	**Trading Zone 10** NSW Murray above Barmah Choke (includes River Murray from Lake Hume to Barmah Choke; and Murray Irrigation Ltd areas, including Wakool Irrigation District)	6 back trade only**: 1, 3, 4A, 4C, 5A, 6B, 7, 11, 12, 13, 14*	1, 3, 4A, 4C, 5A, 6, 6B, 7, 11, 12, 13

MDB Valley	Water Trading Zones	Transfers may be made to these trading zones…	Transfers may be made from these trading zones…
NSW Murray	**Trading Zone 11** NSW Murray below Barmah Choke (includes River Murray from Barmah Choke to SA border (including the Edwards / Wakool system and the Western Murray Irrigation District))	6, 7, 10, 12 back trade only: 1, 3, 4A, 4C, 5A, 6B, 13, 14*	1, 3, 4A, 4C, 5A, 6B, 7, 12, 13 back trade only**: 6, 10
SA Murray	**Trading Zone 12** South Australian Murray*** (includes River Murray in SA and Trust districts)	6, 7, 10, 11 back trade only: 1, 3, 4A, 4C, 5A, 6B, 13, 14*	1, 3, 4A, 4C, 5A, 6B, 7, 11, 13 back trade only**: 6, 10
Murrumbidgee	**Trading Zone 13** Murrumbidgee (including Murrumbidgee Irrigation and Colleambally Irrigation areas; Murrumbidgee and Tumut below Burrinjuck and Blowering reservoirs (including Yanko, Colombo and Billabong Creek systems))	6, 7, 10, 11, 12 back trade only: 1, 3, 4A, 4C, 5A, 6B, 14*	back trade only: 1, 3, 4A, 4C, 5A, 6**, 6B, 7, 10**, 11, 12, 14*
Lower Darling	**Trading Zone 14** Lower Darling* (includes Menindee Lakes and the Darling River downstream of the Menindee Lakes)	back trade only: 1, 3, 4A, 4C, 5A, 6B, 13, 4A, 4C, 5A, 6, 7, 10, 11, 12	back trade only: 1, 3, 4A, 4C, 5A, 6**, 6B, 7, 10**, 11, 12, 13

*Note** Trade to and from the Lower Darling is subject to section 11 (of the Permissible Transfer between Trading Zones protocol
*Note*** Trade through the Barmah Choke is subject to sections 7 to 10 (of the Permissible Transfer between Trading Zones protocol
*Note**** South Australia is divided into four 'cap valleys.' The three cap valleys from and to which water entitlements and water allocations may be transferred are:
(a) SA Country Towns
(b) SA Reclaimed Swamps
(c) SA All Other Purposes.

Interstate trade also occurs in the northern Basin between the New South Wales and Queensland Border Rivers. Please click here for more information on trade in this region.

Backtrade:

Section 5 (Definitions) of the Permissible Transfer between Trading Zones Protocol define backtrade as:
'A transfer from one trading zone to another trading zone, being a transfer that is no greater in volume than the net volume of preceding transfers between the same trading in the opposite direction and the volume available in the relevant valley account.'

Section 6 (2) (Restrictions on Transfers) of the Permissible Transfer between Trading Zones Protocol specify that if:

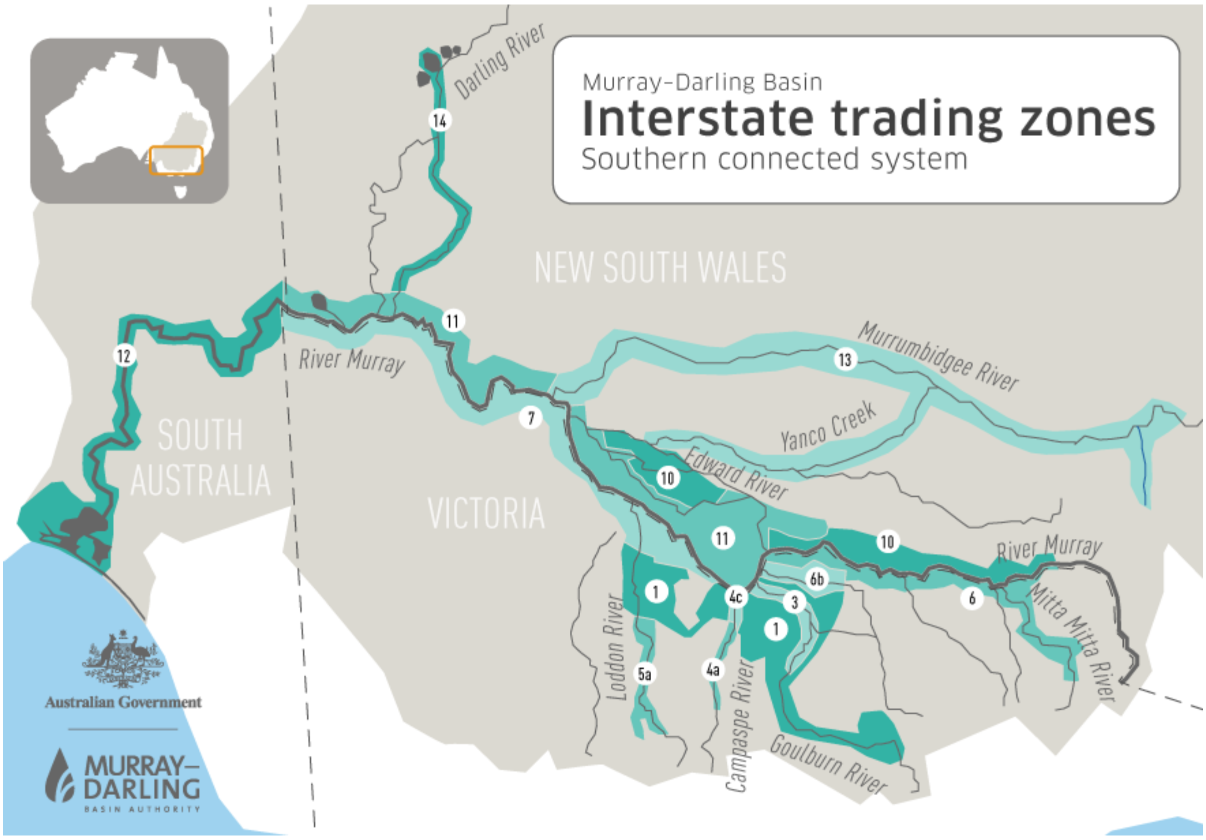
(a) a trading zone specified in column 2 of an item in the table is identified as 'back trade only' then a person may transfer an entitlement (by exchange rate but not by tag trade) or allocation, into the trading zone only from the trading zone described in column 1 of the item by back trade
(b) a trading zone specified in column 3 of an item in the table is identified as 'back trade only' then a person may transfer an entitlement (by exchange rate but not by tag trade) or allocation, only from the trading zone into the trading zone described in column 1 of the item by back trade.

<u>Source:</u> MDBA (2019b)

Figure A.1 Interstate trading zones in the northern MDB

Source: MDBA (2017a)

Figure A.2 Interstate trading zones in the southern-connected MDB



Source: MDBA (2017a)

Figure A.3 Processing time for water allocation trades in VIC

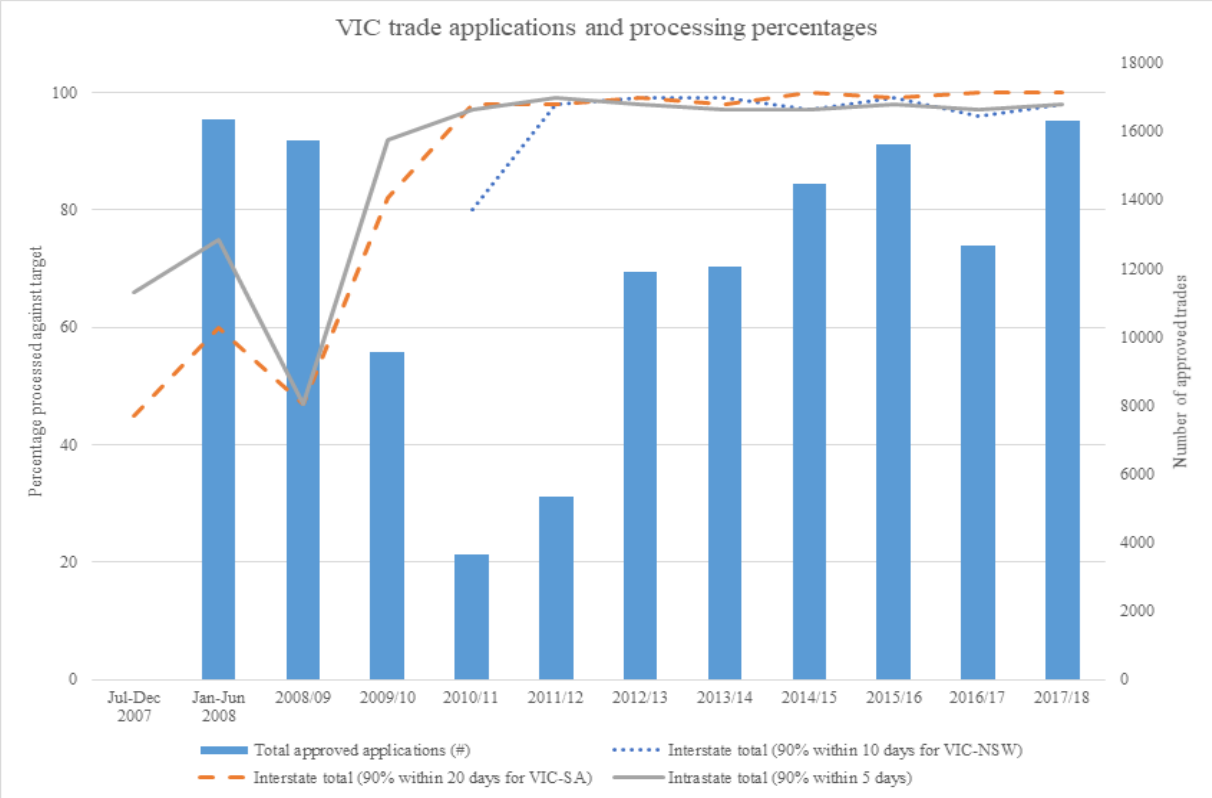


Figure A.4 Processing time for water allocation trades in NSW

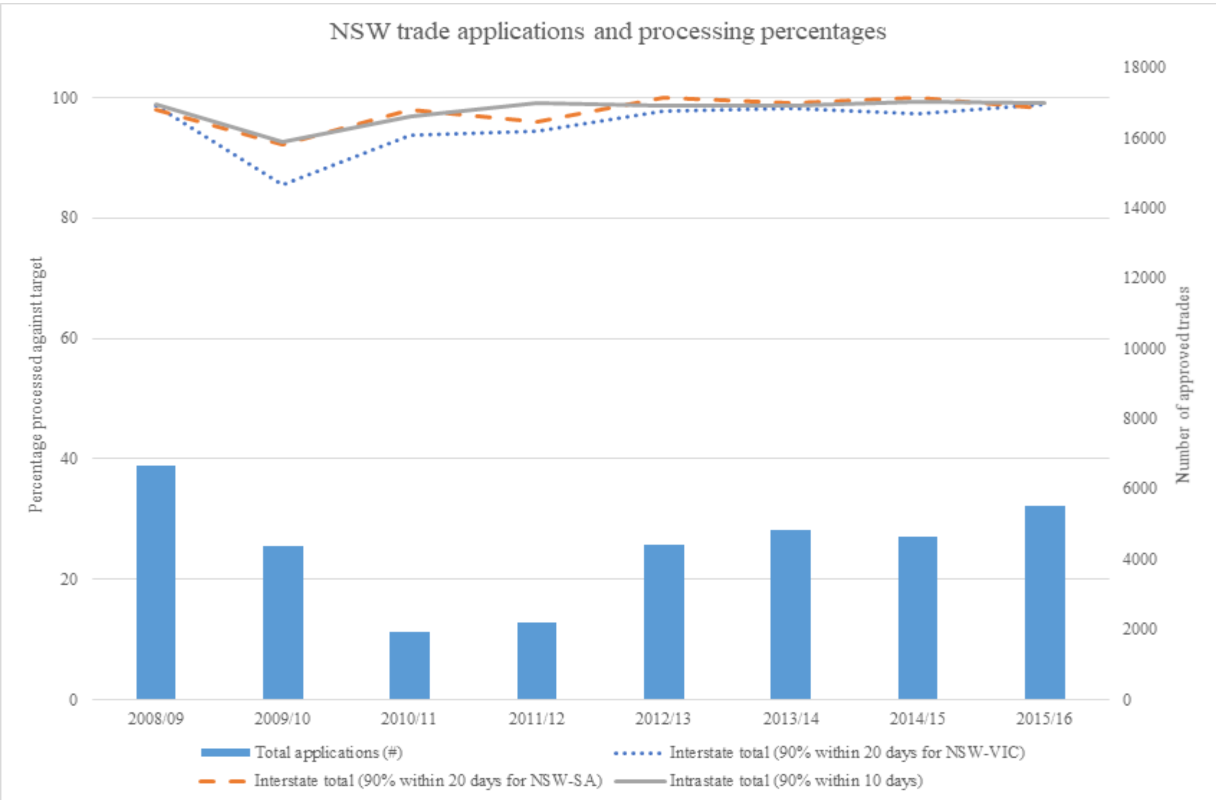
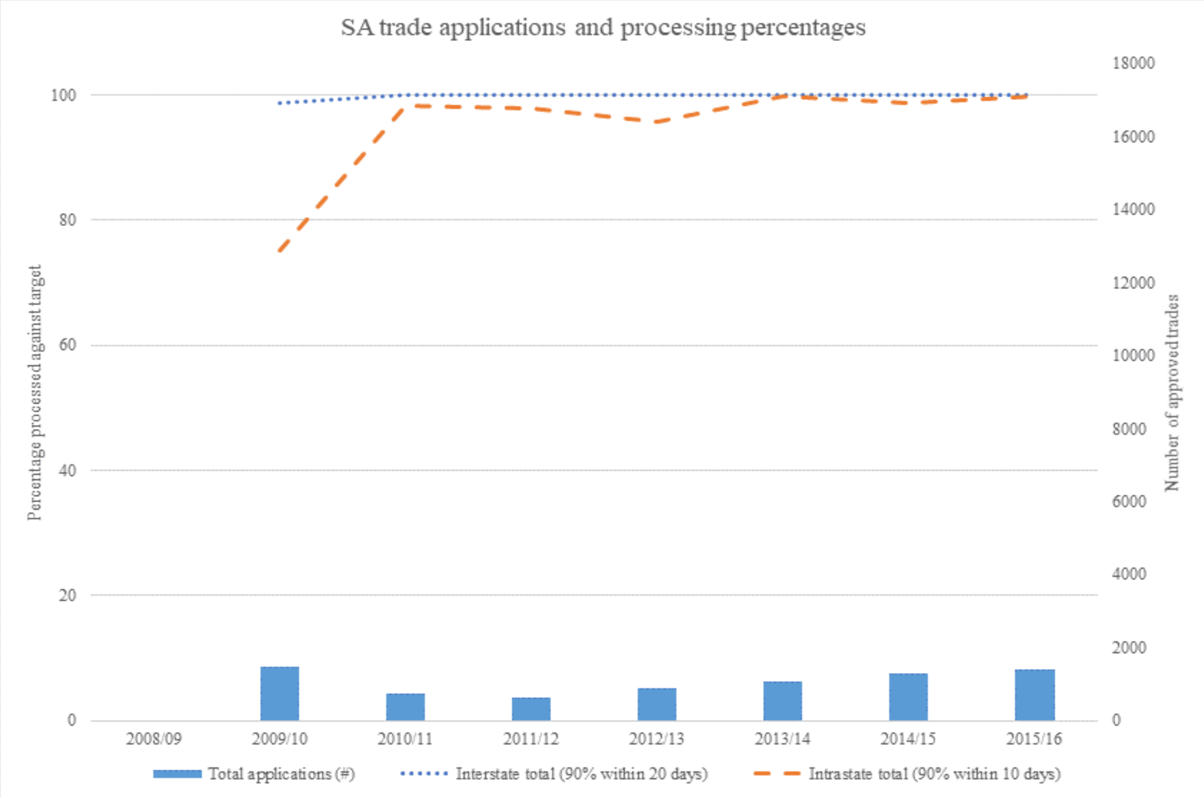


Figure A.5 Processing time for water allocation trades in SA



<u>Source:</u> Loch et al. (2018, p. 569)

Figure A.6 Processing time for water entitlement trades in NSW

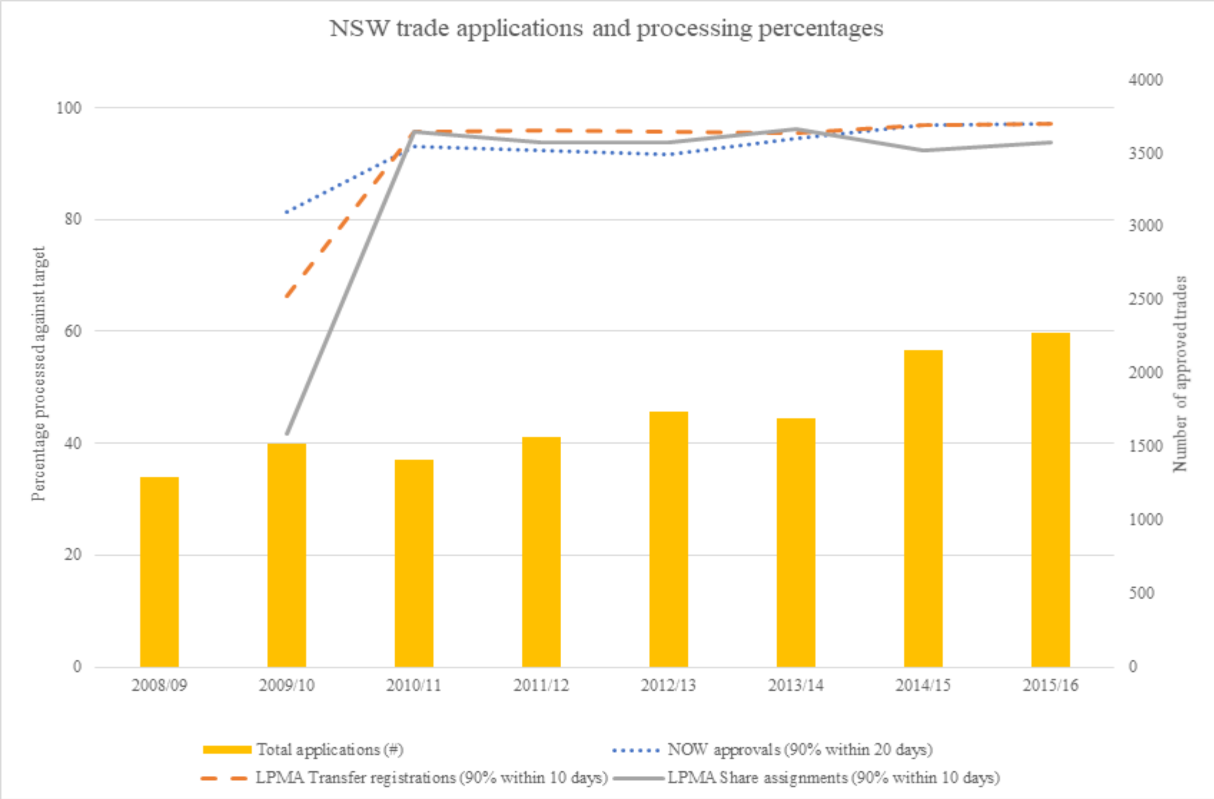


Figure A.7 Processing time for water entitlement trades in VIC

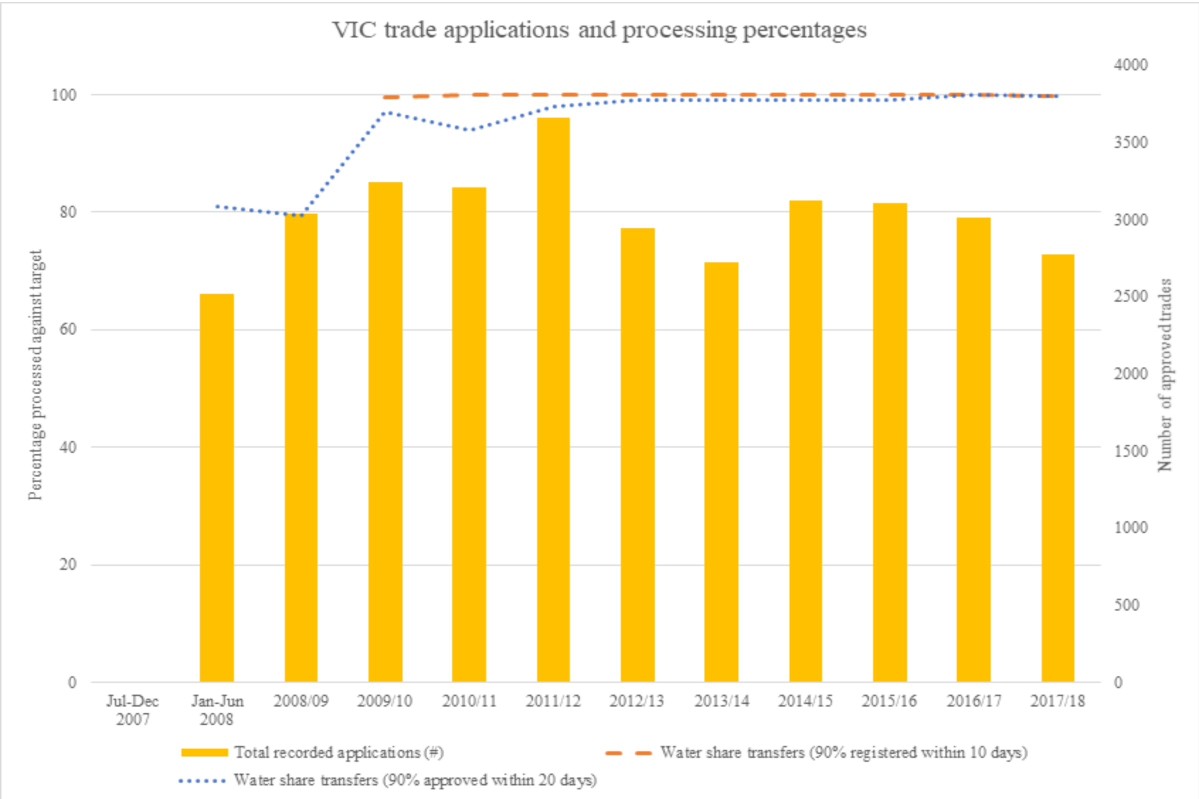
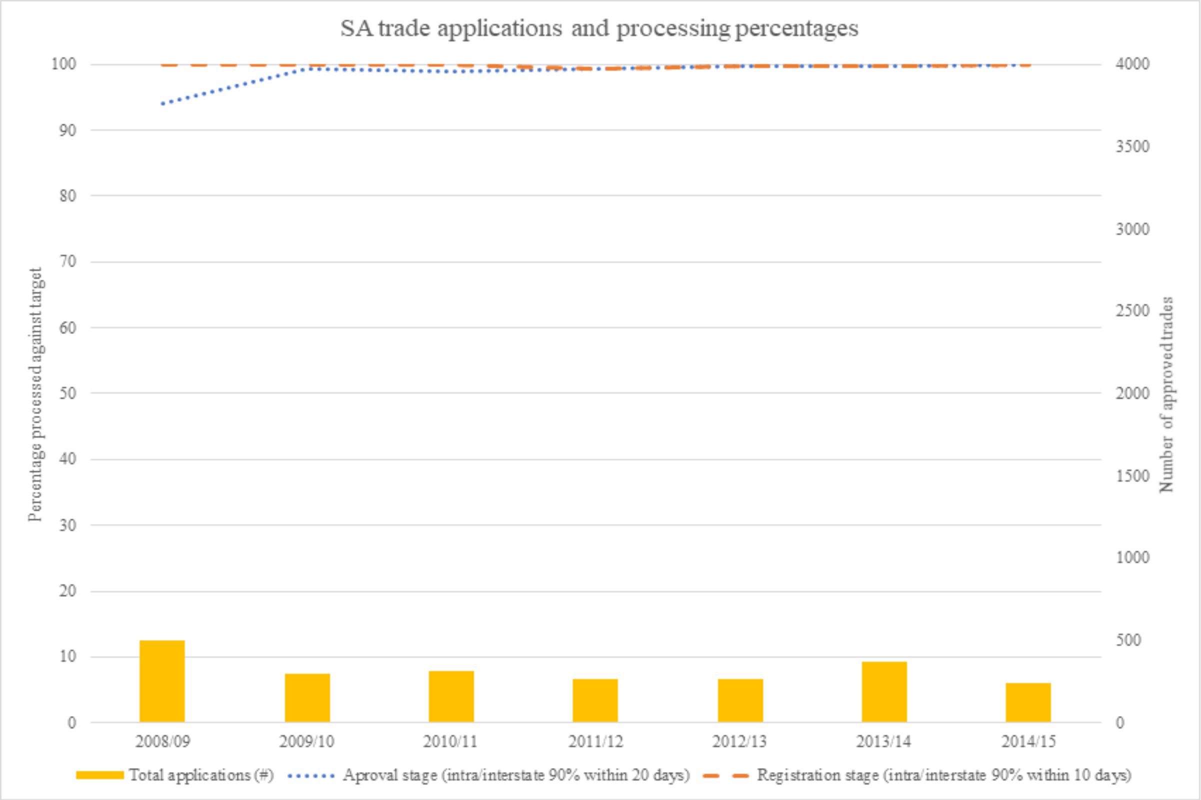
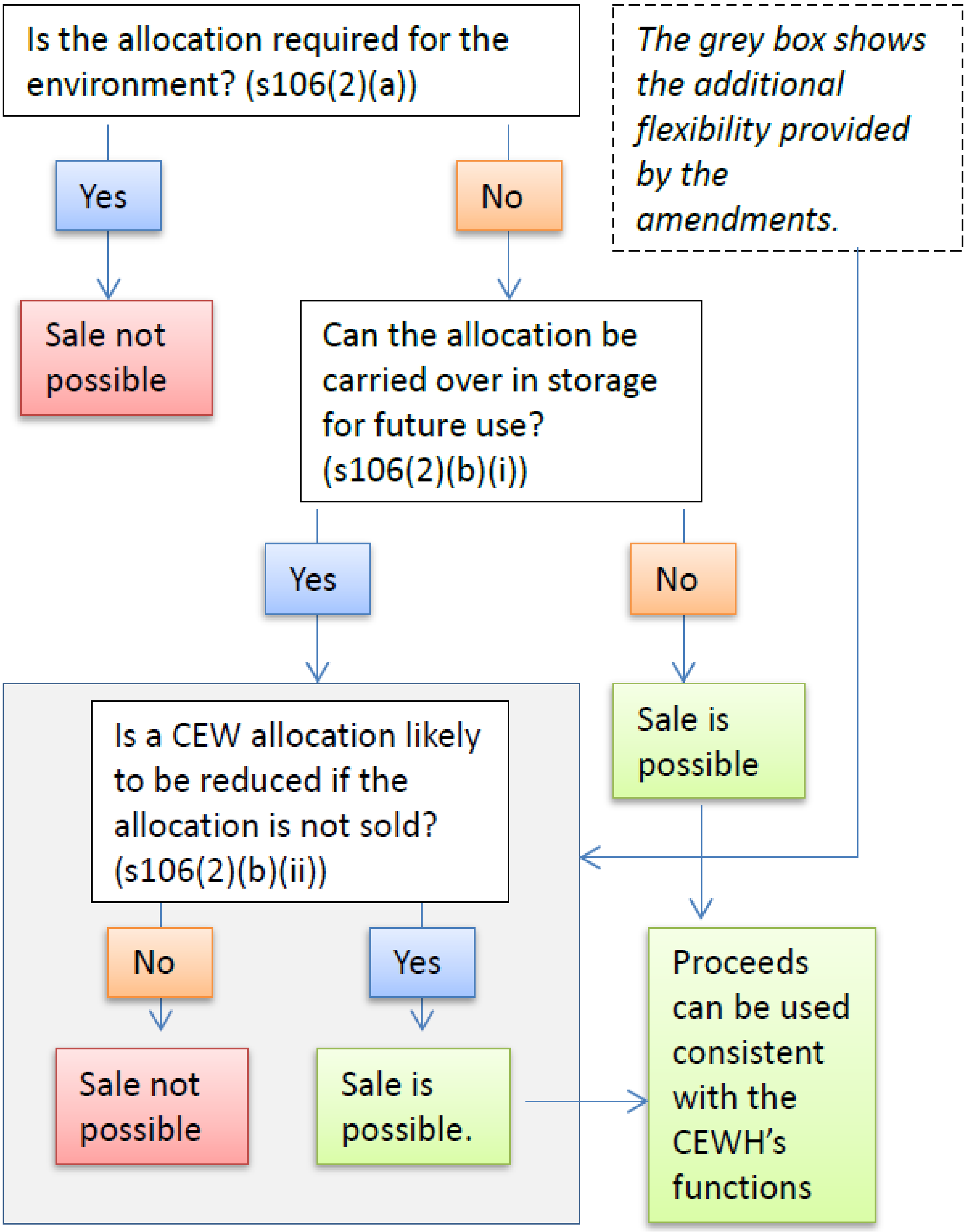


Figure A.8 Processing time for water entitlement trades in SA



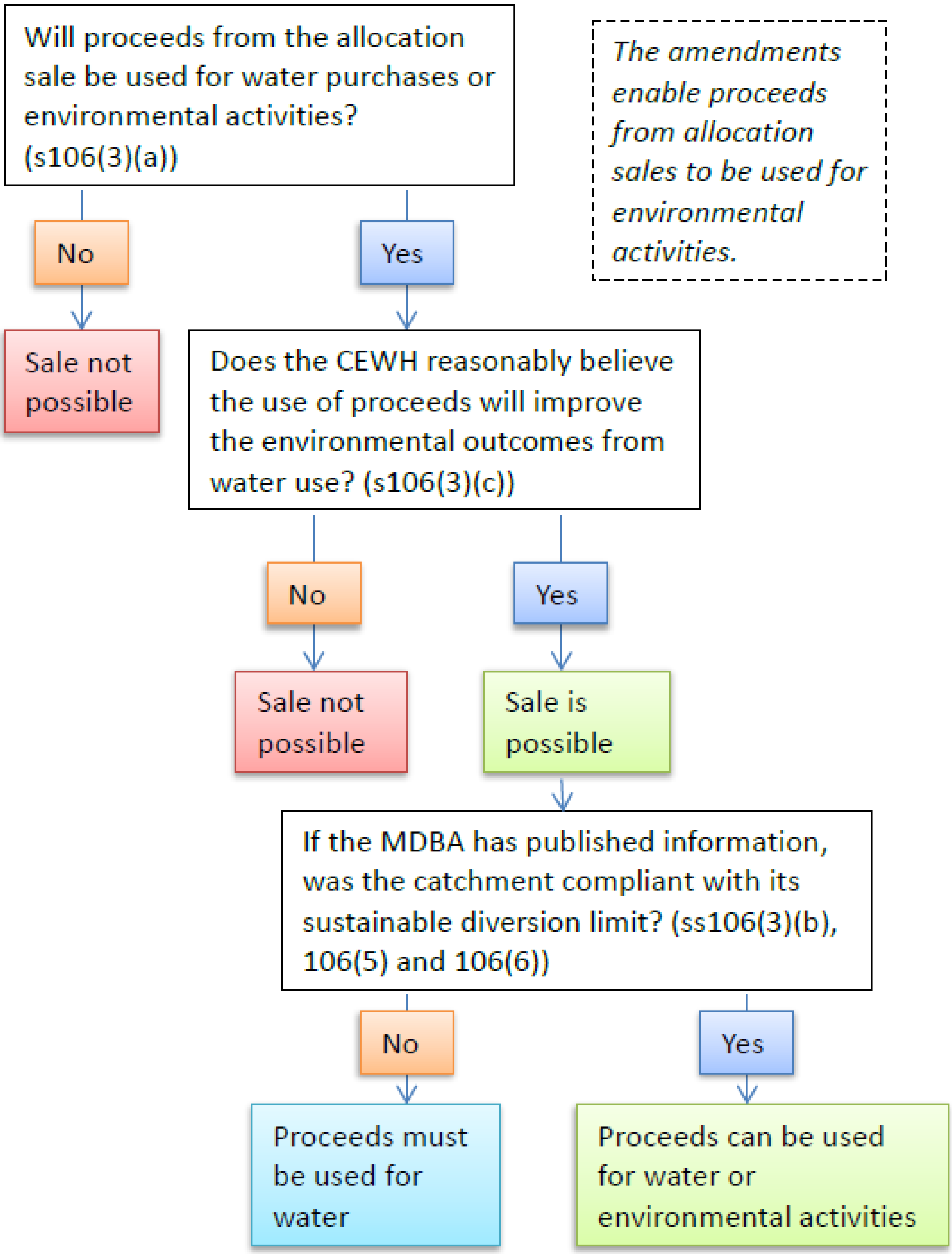
Source: Loch et al. (2018, p. 570)

Figure A.9 CEWH unused water allocation trade under the Water Act



Source: CEWO (2017, p. 20)

Figure A.10 CEWH water allocation trade to fund environmental activities under the Water Act



Source: CEWO (2017, p. 21)

Appendix B Supplementary material for Chapter 4

B.1 Initial recruitment email to known SA participant

Dear Mr/Ms ……..,

My name is Constantin Seidl and I am a PhD student with the Centre for Global Food and Resources at the University of Adelaide. As part of my research, I am looking for a wide range of stakeholders willing to be interviewed about their engagement and experiences with ownership of water entitlements in the Murray-Darling Basin.

This research will explore stakeholders' perceptions and practices around the topics of water risk, water value and water management. It will investigate the motives of Environmental Water Holders and Investors to own and trade water, and their water managing practices. I am also interested in the finance industry's and property valuers' practices around valuing water entitlements. For more detailed information about the research project, please refer to the participant information sheet.

You have been invited to be interviewed based on your position, knowledge and experience in the water sector.

If you are willing to be interviewed, please reply to this email. Interviews will take place at your work at a convenient time and date to yourself within the next few weeks, and take about 30-40 minutes. Further information about the research is attached. If this research is not directly relevant to your current field of work, I would be grateful if you could kindly forward this email to others in your organisation who have relevant expertise and might be interested in participating.

If you have any questions, you are very welcome to contact me or my PhD supervisors Prof Sarah Wheeler (sarah.wheeler@adelaide.edu.au), Dr Adam Loch (adam.loch@adelaide.edu.au) and Dr Alec Zuo (alec.zuo@adelaide.edu.au).

Thank you for your cooperation and support.

Yours sincerely,

Constantin Seidl

B.2 Initial recruitment email to unknown SA participant

To whom it may concern,

My name is Constantin Seidl and I am a PhD student with the Centre for Global Food and Resources at the University of Adelaide. As part of my research, I am looking for a wide range of stakeholders willing to be interviewed about their engagement and experiences with ownership of water entitlements in the Murray-Darling Basin.

This research will explore stakeholders' perceptions and practices around the topics of water risk, water value and water management. It will investigate the motives of Environmental Water Holders and Investors to own and trade water, and their water managing practices. I am also interested in the finance industry's and property valuers' practices around valuing water entitlements. For more detailed information about the research project, please refer to the participant information sheet.

This email is addressed to the person(s) in your organisation directly involved and most familiar with the water sector.

If you would describe yourself with these attributes and are willing to be interviewed, please reply to this email. Interviews will take place at your work at a convenient time and date to yourself within the next few weeks, and take about 30-40 minutes. Further information about the research is attached. If this research is not directly relevant to your current field of work, I would be grateful if you could kindly forward this email to others in your organisation who have relevant expertise and might be interested in participating.

If you have any questions, you are very welcome to contact me or my PhD supervisors Prof Sarah Wheeler (sarah.wheeler@adelaide.edu.au), Dr Adam Loch (adam.loch@adelaide.edu.au) and Dr Alec Zuo (alec.zuo@adelaide.edu.au).

Thank you for your cooperation and support.

Yours sincerely,

Constantin Seidl

B.3 Initial recruitment email to known non-SA participant

Dear Mr/Ms ……..,

My name is Constantin Seidl and I am a PhD student with the Centre for Global Food and Resources at the University of Adelaide. As part of my research, I am looking for a wide range of stakeholders willing to be interviewed about their engagement and experiences with ownership of water entitlements in the Murray-Darling Basin.

This research will explore stakeholders' perceptions and practices around the topics of water risk, water value and water management. It will investigate the motives of Environmental Water Holders, large-scale Irrigators and Investors to own and trade water, and their water managing practices. I am also interested in the finance industry's and property valuers' practices around valuing water entitlements. For more detailed information about the research project, please refer to the participant information sheet.

You have been invited to be interviewed based on your position, knowledge and experience in the water sector.

If you are willing to be interviewed, please reply to this email. Interviews will take place at your work or via telephone at a convenient time and date to yourself from the 28/05/2018 onwards, and take about 30-40 minutes. Further information about the research is are attached. If this research is not directly relevant to your current field of work, I would be grateful if you could kindly forward this email to others in your organisation who have relevant expertise and might be interested in participating.

If you have any questions, you are very welcome to contact me or my PhD supervisors Prof Sarah Wheeler (sarah.wheeler@adelaide.edu.au), Dr Adam Loch (adam.loch@adelaide.edu.au) and Dr Alec Zuo (alec.zuo@adelaide.edu.au).

Thank you for your cooperation and support.

Yours sincerely,

Constantin Seidl

B.4 Initial recruitment email to unknown non-SA participant

To whom it may concern,

My name is Constantin Seidl and I am a PhD student with the Centre for Global Food and Resources at the University of Adelaide. As part of my research, I am looking for a wide range of stakeholders willing to be interviewed about their engagement and experiences with ownership of water entitlements in the Murray-Darling Basin.

This research will explore stakeholders' perceptions and practices around the topics of water risk, water value and water management. It will investigate the motives of Environmental Water Holders and Investors to own and trade water, and their water managing practices. I am also interested in the finance industry's and property valuers' practices around valuing water entitlements. For more detailed information about the research project, please refer to the participant information sheet.

This email is addressed to the person(s) in your organisation directly involved and most familiar with the water sector.

If you would describe yourself with these attributes and are willing to be interviewed, please reply to this email. Interviews will take place at your work or via telephone at a convenient time and date to yourself within the next few weeks, and take about 30-40 minutes. Further information about the research is attached. If this research is not directly relevant to your current field of work, I would be grateful if you could kindly forward this email to others in your organisation who have relevant expertise and might be interested in participating.

If you have any questions, you are very welcome to contact me or my PhD supervisors Prof Sarah Wheeler (sarah.wheeler@adelaide.edu.au), Dr Adam Loch (adam.loch@adelaide.edu.au) and Dr Alec Zuo (alec.zuo@adelaide.edu.au).

Thank you for your cooperation and support.

Yours sincerely,

Constantin Seidl

B.5 Participant information sheet

PARTICIPANT INFORMATION SHEET

PROJECT TITLE:
Investigating different water risk management perspectives in the Murray-Darling Basin: Irrigators, Environmental Water Holders and Investors
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: H-2017-192
PRINCIPAL INVESTIGATOR: Prof. Sarah Ann Wheeler
STUDENT RESEARCHER: Constantin Seidl
STUDENT'S DEGREE: PhD

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
The research will explore Environmental Water Holders' (EWH) and (financial/corporate) investors' water holdings in the southern Murray-Darling Basin (sMDB) under the premise of different water value and water risk perceptions. It will investigate the motives of EWHs and Investors to own water, their water holding management strategies and their water trading goals. It will also explore potential barriers and difficulties faces by EWHs and Investors in managing and using their water holdings. Additionally, this research will investigate different water valuation practices employed by a range of entities, such as banks, and property and land valuers. This study will contribute to a better understanding of water market functionality and could lead to policy recommendations for water market reform to better incorporate non-irrigator stakeholders.

Who is undertaking the project?
This research is part of the degree of Doctor of Philosophy for Constantin Seidl, under the supervision of Prof. Sarah Ann Wheeler, Dr. Adam Loch and Dr. Alec Zuo in the Centre for Global Food and Resources, the University of Adelaide. The PhD research is made possible under the University of Adelaide Wildcard Scholarship, granted by the University of Adelaide.

Why am I being invited to participate?
We are conducting research on non-irrigator water holdings in the sMDB to understand how EWHs and Investors manage their water, the associated risks and contingencies. Additionally, we are investigating the processes and practices commonly used to value water in a financial/accounting context. You have been selected for interview based on your capacity to provide us with better information on strategic goals for water investment, water portfolio management issues, water valuation, and water value and water risk perceptions of non-irrigator stakeholders.

What will I be asked to do?
You are invited to participate in an interview. You will be asked questions about your organisation's water holdings and related (strategic) goals and barriers, your view on risk and value of water as an asset, and rationales for water trading and water investment. This activity will be recorded using an audio recorder for the purpose of confirming the field notes taken

during interview. Your identity will be kept confidential. Any statement you made will not be attributed to you. The interview will be transcribed and sent to you, should you request to see your transcript

How much time will the project take?
Interviews will be about 30-40 minutes. If you want to devote more time, interviews can be extended beyond the 40 minute mark.

Are there any risks associated with participating in this project?
All the information will be kept confidential. The small number of potential respondents means that it may be possible that you could be identified from your answers to our questions. However, we will take all possible care to ensure your confidentiality. The only cost to you will be the time it takes to complete the interview you were asked to participate.

What are the benefits of the research project?
The research might assist MDB policy makers to better understand and subsequently change/reduce water market barriers specific to EWHs and Investors. It could also potentially reduce distrust of other market participants towards EWHs and Investors and therefore lead to a more favourable starting point for potential future interactions with these participants.

Can I withdraw from the project?
Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the interview at any time. You will not be penalised in any way, nor will the choice to withdraw be used against you in any way.

What will happen to my information?
Only the project supervisors and research student associated with this research project will have access to participant data during the collection, recruitment phase and data analysis phase. Only statistics and analytical results will be released publicly. Interview data will be anonymised and only excerpts directly quoted, for illustrative purposes, to provide the highest level of anonymity for participants.

The project outcomes will be made publicly accessible through a PhD thesis and journal articles. All records and materials will be held by principal supervisor (Prof. Sarah Ann Wheeler) at Centre for Global Food and Resources, Faculty of Profession, the University of Adelaide in a password protected computer for at least 5 years, consistent with the Australian code for Responsible Conduct of Research.

Who do I contact if I have questions about the project?

1. Prof. Sarah Ann Wheeler, Centre for Global Food and Resources, the University of Adelaide.
   Phone: +61 8 8313 9130
   e-Mail: sarah.wheeler@adelaide.edu.au
2. Dr. Adam Loch, Centre for Global Food and Resources, the University of Adelaide.
   Phone: +61 8 8313 9131
   e-Mail: adam.loch@adelaide.edu.au
3. Dr. Alec Zuo, Centre for global Food and Resources, The University of Adelaide.
   Phone: +61 8 8313 9133
   e-Mail: alec.zuo@adelaide.edu.au

4. Constantin Seidl, Centre for Global Food and Resources, The University of Adelaide.
   Phone: +61 8 8313 0490
   e-Mail: constantin.seidl@adelaide.edu.au

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2017-192). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding a concern or complaint, the University's policy on research involving human participants, or your rights as a participant, please contact the Human Research Ethics Committee's Secretariat on:

Phone: +61 8 8313 6028
Email: hrec@adelaide.edu.au
Post: Level 4, Rundle Mall Plaza, 50 Rundle Mall, ADELAIDE SA 5000

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?

Please read the participant information sheet and consent form carefully. If you accept the condition defined in these forms, please sign and return the consent form to the student researcher or interviewer, then the research activity will commence. If you participate by phone, the consent form will be read out to you before the interview. You can then verbally give your consent (voice-recorded) to participate. Finally, if you respond to questions asked via email, you give consent to be involved in this research.

Yours sincerely,
Prof. Sarah Ann Wheeler
Dr. Adam Loch
Dr. Alec Zuo
Constantin Seidl

B.6 Follow-up and scheduling email for SA participant

Dear ……..,

Thank you so much for generously volunteering your time to be interviewed.

I would suggest these times in the week starting …………….. for conducting the interview, but I am also flexible if a different arrangement is more suitable.

Could you please mark in the table which slot works the best for you:

	Monday	Tuesday	Wednesday	Thursday	Friday
9.00 -10.00					
11.00 – 12.00					
14.00-15.00					
16.00-17.00					

Could you also kindly fill out the consent form (attached) and have it with you for the interview?

I would be grateful if you could kindly forward the information about this research to members of your professional network in other organisations who have relevant expertise and might be interested in participating.

Thank you again for your support and generosity.

Best wishes,

Constantin Seidl

B.7 Follow-up and scheduling email for non-SA participant

Dear ……..,

Thank you so much for generously volunteering your time to be interviewed.

I would suggest these times in the week starting …………….. for conducting the interview, but I am also flexible if a different arrangement is more suitable.

Could you please mark in the table which slot works the best for you:

	Monday	Tuesday	Wednesday	Thursday	Friday
9.00 -10.00					
11.30 – 12.30					
15.00-16.00					

Could you also kindly fill out the consent form (attached) and have it with you for the interview?

I would be grateful if you could kindly forward the information about this research to members of your professional network in other organisations who have relevant expertise and might be interested in participating.

Thank you again for your support and generosity.

Best wishes,

Constantin Seidl

B.8 Interview participant consent form

Human Research Ethics Committee (HREC)

CONSENT FORM

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	Investigating different water risk management perspectives in the Murray-Darling Basin: Irrigators, Environmental Water Holders and Investors
Ethics Approval Number:	**H-2017-192**

2. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.
3. Although I understand the purpose of the research project it has also been explained that involvement may not be of any benefit to me.
4. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.
5. I understand that I am free to withdraw from the project at any time.
6. I agree to the interview being audio recorded. Yes ☐ No ☐
7. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ______________________Signature: ________________________ Date: __________

Researcher/Witness to complete:

I have described the nature of the research to ____

(print name of participant)

and in my opinion she/he understood the explanation.

Signature: ___________________Position:__________________________ Date: __________

B.9 Research hand-out

Research background

This research will explore stakeholders' perceptions, views and practices around the topics of water risk, water value and water management. It will investigate the motives of EWHs and Investors to own and trade water, and their water managing practices. We are also interested in the finance industry's and property valuers' stance and practices around attaching financial value to water entitlements.

This interview will contain questions around the value of water. In this instance, water value means, but is not limited to mean, financial monetary value. Other questions will explore water valuation practices and methods. These target the processes employed by stakeholders to attribute a financial monetary value to a water entitlement.

This study will contribute to a better understanding of water market functionality and water value for a range of stakeholders. It could lead to policy recommendations for water market reform to better incorporate non-irrigator stakeholders reflecting their particular take on water value.

For more detailed information about the research project, please refer to the participant information sheet.

Could you please answer the questions below? This is completely voluntary.

How long have you been working in your current position for your current organisation?

____________________________years

Have you previously been working in a similar position for a different organisation?

☐ Yes ☐No

For how many years? ____years

B.10 Interview questions for agri-corporates, financial investors and environmental water holders

Interview Questions

1. Do you own any Murray-Darling Basin water entitlements?
    a. Do you own water entitlements outside of the Murray-Darling Basin?
2. **When and why did you first obtain a water entitlement?**
    a. **Do you own water entitlements with different security in different regions?**
    b. **What are the reasons for owning this mix of water entitlements?**
3. In a normal year, how do you use the seasonal allocations associated with your water entitlements?
4. What is the legal structure of the entity that holds your water entitlements?
5. How do you value a specific water entitlement?
6. Do you use carry-over?
7. In your view, what risks are associated with water entitlements?
    a. What benefits are associated with water entitlements?
8. **Do you view water entitlements primarily as an asset?**
    a. **How do water entitlements compare to other assets**?
9. Are there barriers/difficulties you face in trading, using or managing your water?
10. What are the strengths of the water market for you?
    a. What are the weaknesses of the water market for you?
11. **Do you plan to hold more or less water entitlements, or water entitlements with different reliability (ML) in 5 years and why?**
12. **How do you expect climate change to impact your entitlement portfolio?**
13. **Are you aware of the FOUR CORNERS report from July 2017, alleging water theft and Basin plan non-compliance?**
    a. **Did these events influence the way you think about the security of your water/water portfolio?**
14. **If you could change one administrative arrangement or piece of legislation regarding water issues, what would it be?**
    a. **Why would you make those changes?**

B.11 Interview questions for banks, property evaluators and water brokers

Interview response sheet (Valuers)

1. **What method do you use to value water entitlements?**
    a. **Do you value water differently depending on the type and security of the water entitlement (surface, ground, regulated, unregulated, etc.)? Does the method change?**
    b. **Have you ever changed the method you use to value water? When and why?**
2. Do you know any fees associated with water entitlements and their allocations? Which?
    a. Do you use any of these fees in your assessment of water entitlement values? How?
3. How do allocations influence your valuation of a water entitlement?
4. Does carry-over capacity policy factor in your estimation of water entitlement values?
5. In your view, what risks are associated with water entitlements?
    a. What are benefits associated with water entitlements?
6. **Do you view water entitlements primarily as an asset?**
    a. **How do water entitlements compare to other assets**?
7. Did the separation of water from land affected water and farmland value? How?
8. Are there barriers/difficulties you face in trying to value a water entitlement?
9. **Does the risk of climate change affect your valuations of water entitlements?**
    a. **Has climate change changed the way you value water?**
10. Do you expect the practices of valuing water to change in the near to medium future (5-10 years)? Why/how?
11. **Are you aware of the FOUR CORNERS report from July 2017, alleging water theft and Basin plan non-compliance?**
    a. **Did these events effect the value of water entitlements?**
    b. **Has it changed your approach to valuing water?**
12. **If you could change one administrative arrangement or piece of legislation regarding water issues, what would it be?**
    a. **Why would you make those changes?**

Appendix C Supplementary material for Chapter 5

Table C.1 Irrigation adaptation measures in the MDB

Type	Strategy	Specifics
Information	• Utilise a variety of information to predict risk of water scarcity for the season, through a) utilising historic records of inflows and allocations, and b) utilising Southern Oscillation Index data and a range of climate projections for rainfall and evaporation predictions • Utilise water trade information to understand intra-seasonal trade prices & demand	• Provides better predictions about risk of crop failure, whether to plant or trade water for the season • Similarly, use crop insurance/reinsurance options to hedge against climate risk • Can sell/buy water allocations/entitlement at the point in the intra-season where private gains are maximised
Trade	• Utilise alternative water market products such as options, entitlement leasing • Buy (or sell) more water allocations and/or entitlements • Carry-over	• Helps to even out price hikes, provides more certainty about prices and returns over the medium term • Swap lower security entitlements for higher security entitlements. Make greater use of resources not yet fully allocated or subject to restrictions (such as groundwater) • Adopt carry-over techniques (where available) and buy water allocations when cheaper to carry-over
Land	• Buy (or sell more land) • Increase (or decrease) irrigated areas (e.g. irrigate a larger section and improve input efficiency or only irrigate part of an area) • Dry-land practices	• Larger enterprises provide a number of benefits in terms of business scale – can build greater flexibility & capacity to respond more quickly to changed conditions or volatility. Shift growing areas to southern locations (e.g. viticulture to Tasmania) • If production is limited by available water supply, irrigators may need to abandon the idea that production can be maximised on individual paddocks. It is likely that optimal farm performance in irrigated settings will be arrived at by sub-optimal paddock performance & spreading the water where land is abundant • Learn & implement dry-land practices (such as stubble retention and/or supplementary feed for livestock) because future farming with less water is less likely to focus on purely irrigated practices
Farm structure	• Increase off-farm work • Portfolio management • Develop ownership structures to better manage risk	• Reduce risk associated with one source of income • Optimise responsiveness to water availability, such as growing a mix of permanent and annual plantings. Put mechanisms in place to share or transfer risk to others. • Includes further consolidation, possibly at an accelerating rate, to larger, better capitalized family enterprises or corporate structure agricultural enterprises. Establish succession early on for the farm. • Longer-term supply contracts with key purchasers
Agronomy	• Change basic agronomy and management farm practices	• Different crop mixes; precision agriculture; short rotation and pasture-spelling regimes; row configuration; diversify production; varieties, planting dates/times, irrigation, fertilizer regimes; soil management practices, substitute pasture for bought feed; fallow production area; shift timing of livestock reproduction; focus on more water flexible & annual/semi-annual crops; minimum/no-tillage; crop cover; and use deficit irrigation when needed
Infrastructure	• Adopt more efficient irrigation water infrastructure • Improve irrigation management	• Install automatic bay gates, drip irrigation, laser grade paddocks, update reuse system, recycling system, solar energy use, on-farm water storage • Improve irrigation scheduling, soil moisture monitoring, decrease furrow lengths; crop protection treatments (greenhouse, polytunnel, solar radiation shading and evaporative cooling)
Environment	• Employ sustainable practices	• Plant trees, crop cover, improve soil management, adopt conservation tillage, grade banks; improve sediment runoff via grassed waterways and erosion control structures; wetland creation; reduce carrying capacity

Source: Adapted from Wheeler et al. (2014a) and AFI (2019)

Table C.2 Tetrachoric correlations between individual planned adaptation strategies

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**95)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**	**(15)**	**(16)**	**(17)**	**(18)**	**(19)**
(1) purchase water allocations	1.00																		
(2) purchase water entitlements	0.67	1.00																	
(3) purchase any farmland near current properties	0.46	0.52	1.00																
(4) purchase any farmland in different regions	0.39	0.43	0.65	1.00															
(5) improve the efficiency of irrigation infrastructure	0.47	0.42	0.50	0.25	1.00														
(6) increase irrigated area	0.40	0.49	0.51	0.22	0.58	1.00													
(7) change ownership structures	0.11	0.16	0.25	0.22	0.12	0.15	1.00												
(8) changed irrigated production	0.39	0.33	0.36	0.33	0.53	0.47	0.20	1.00											
(9) diversify production	0.27	0.29	0.34	0.41	0.45	0.34	0.24	0.65	1.00										
(10) increase farm insurance	0.31	0.29	0.38	0.27	0.38	0.33	0.18	0.32	0.33	1.00									
(11) decrease area of dryland production	0.02	0.00	-0.04	-0.05	0.11	0.32	0.21	0.20	0.21	0.16	1.00								
(12) increase any collective bargaining with other farmers	0.34	0.34	0.27	0.43	0.26	0.31	0.10	0.38	0.30	0.30	0.17	1.00							
(13) increase area of dryland production	0.26	0.14	0.44	0.53	0.30	0.20	0.17	0.39	0.37	0.30	0.01	0.28	1.00						
(14) utilise solar-power for irrigation	0.28	0.31	0.31	0.22	0.36	0.29	0.08	0.26	0.32	0.22	0.10	0.29	0.10	1.00					
(15) selling the whole farm	-0.09	-0.15	-0.39	-0.10	-0.27	-0.22	0.02	-0.06	-0.10	-0.10	0.13	0.05	-0.16	-0.04	1.00				
(16) decrease irrigated area	-0.07	-0.24	-0.26	0.09	-0.21	-0.45	0.17	0.07	-0.02	-0.10	0.24	-0.16	0.29	-0.16	0.33	1.00			
(17) sell water allocations	-0.41	-0.25	-0.10	0.07	-0.12	-0.15	0.01	0.00	0.06	-0.06	-0.02	-0.01	0.01	-0.06	0.10	0.17	1.00		
(18) sell water entitlements	-0.18	-0.16	-0.11	0.08	-0.21	-0.21	0.19	-0.03	-0.02	-0.11	0.11	-0.06	0.01	-0.11	0.36	0.37	0.40	1.00	
(19) sell any farmland	-0.23	-0.27	-0.30	0.00	-0.28	-0.23	0.31	-0.10	-0.06	-0.17	0.30	-0.04	-0.08	-0.14	0.60	0.46	0.23	0.49	1.00

Table C.3 Planned adaptation indices correlations

Variables	(1)	(2)	(3)
(1) Planned expansive adaptation index	1.00		
(2) Planned accommodating adaptation index	0.53	1.00	
(3) Planned contractive adaptation index	-0.29	-0.02	1.00

Table C.4 Pairwise correlation of full model independent variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Farm debt	1.00										
(2) Farm debt squared	0.97	1.00									
(3) Farmland value	0.61	0.61	1.00								
(4) Farmland value squared	0.60	0.61	0.98	1.00							
(5) Net farm income	0.35	0.36	0.53	0.52	1.00						
(6) Net farm income squared	0.37	0.38	0.51	0.52	0.97	1.00					
(7) Number of insurances	0.32	0.30	0.39	0.38	0.29	0.27	1.00				
(8) Off farm income	-0.25	-0.22	-0.28	-0.23	-0.22	-0.17	-0.11	1.00			
(9) Productivity change	0.14	0.13	0.14	0.12	0.18	0.16	0.11	-0.12	1.00		
(10) Received irrigation grant	0.17	0.17	0.15	0.15	0.11	0.11	0.10	-0.10	0.17	1.00	
(11) Climate change risk perception	0.08	0.07	0.03	0.02	0.14	0.13	0.02	-0.01	0.05	0.08	1.00
(12) Age	-0.30	-0.26	-0.17	-0.16	-0.15	-0.15	-0.23	0.08	-0.09	-0.11	-0.12
(13) Age squared	-0.30	-0.26	-0.17	-0.15	-0.15	-0.15	-0.24	0.08	-0.09	-0.10	-0.12
(14) Low education	-0.07	-0.05	-0.07	-0.05	-0.07	-0.06	-0.12	0.04	-0.12	-0.07	-0.15
(15) Male gender	-0.02	-0.02	0.04	0.04	0.06	0.05	0.01	0.00	-0.01	0.00	-0.01
(16) Marital status	0.11	0.09	0.05	0.06	0.09	0.08	0.17	0.04	0.07	0.02	-0.04
(17) Number of Children	0.05	0.05	0.07	0.06	0.03	0.02	0.06	-0.05	0.05	0.05	-0.04
(18) Succession	0.23	0.21	0.32	0.31	0.22	0.19	0.15	-0.18	0.13	0.09	-0.08
(19) Risk Taker	0.18	0.18	0.14	0.14	0.10	0.10	0.09	-0.09	0.10	0.05	-0.10
(20) Whole of farm plan	0.20	0.18	0.16	0.13	0.13	0.11	0.19	-0.17	0.11	0.11	0.04
(21) Plans for climate change on farm	0.18	0.16	0.12	0.11	0.09	0.08	0.12	-0.09	0.13	0.08	0.50
(22) Average historic pan evaporation	-0.10	-0.10	-0.20	-0.16	-0.11	-0.09	-0.02	0.06	-0.03	-0.04	0.02
(23) Average historic rainfall	0.11	0.10	0.27	0.23	0.13	0.11	0.10	-0.05	0.01	-0.06	0.02
(24) Average historic temperature	-0.07	-0.07	-0.19	-0.14	-0.08	-0.06	0.02	0.05	-0.01	0.03	-0.02
(25) Average historic water allocation factor	-0.16	-0.16	-0.22	-0.21	-0.15	-0.13	-0.11	0.06	0.06	0.00	0.02
(26) Millennium Drought dummy	-0.07	-0.06	-0.09	-0.09	-0.01	-0.03	-0.04	0.02	-0.04	-0.03	-0.04
(27) Historic net rainfall	0.11	0.11	0.24	0.20	0.12	0.10	0.04	-0.06	0.02	0.01	-0.01
(28) State	-0.17	-0.16	-0.24	-0.22	-0.15	-0.13	-0.23	0.13	0.09	0.11	0.01
(29) Historic temperature volatility	0.13	0.13	0.19	0.15	0.12	0.09	0.16	-0.12	-0.09	-0.07	-0.01
(30) Application rate	-0.02	-0.02	-0.04	-0.02	-0.03	-0.02	-0.06	-0.03	-0.05	-0.01	0.04
(31) Broadacre	0.16	0.15	0.23	0.22	0.19	0.16	0.22	-0.06	-0.04	0.08	0.00
(32) Carry-over use between 2014-2016	0.12	0.13	0.20	0.17	0.19	0.17	0.14	-0.09	0.00	0.03	0.04
(33) Dairy	0.23	0.21	0.14	0.10	0.09	0.07	0.01	-0.19	0.07	0.02	0.00
(34) Farm Size	0.19	0.20	0.37	0.39	0.29	0.29	0.23	-0.11	0.00	0.00	0.00
(35) Livestock	-0.20	-0.18	0.00	0.00	-0.09	-0.08	-0.08	0.11	-0.13	-0.13	-0.08
(36) Majority of farm area under drainage	0.22	0.23	0.18	0.15	0.13	0.12	0.10	-0.11	-0.01	0.11	0.02
(37) Majority of farm area under drip irrigation	-0.06	-0.07	-0.17	-0.15	-0.10	-0.08	-0.04	0.05	0.11	0.07	0.06
(38) Number of employees	0.33	0.34	0.37	0.37	0.29	0.30	0.18	-0.12	0.17	0.13	0.03
(39) Excess water	-0.10	-0.10	-0.08	-0.07	-0.05	-0.04	-0.04	0.09	0.03	-0.04	0.04
(40) Water ownership	0.28	0.28	0.36	0.32	0.32	0.29	0.23	-0.24	0.02	0.15	0.04
(41) Social group membership	0.10	0.12	0.17	0.17	0.14	0.12	0.13	-0.05	0.11	0.10	0.12

Variables	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
(1) Farm debt											
(2) Farm debt squared											
(3) Farmland value											
(4) Farmland value squared											
(5) Net farm income											
(6) Net farm income squared											
(7) Number of insurances											
(8) Off farm income											
(9) Productivity change											
(10) Received irrigation grant											
(11) Climate change risk perception											
(12) Age	1.00										
(13) Age squared	0.99	1.00									
(14) Low education	0.29	0.29	1.00								
(15) Male gender	0.05	0.06	0.08	1.00							
(16) Marital status	-0.05	-0.07	0.01	0.06	1.00						
(17) Number of Children	0.20	0.19	0.06	-0.04	0.24	1.00					
(18) Succession	0.08	0.09	0.07	0.00	0.06	0.21	1.00				
(19) Risk Taker	0.06	0.08	0.12	0.06	0.04	0.09	0.13	1.00			
(20) Whole of farm plan	-0.07	-0.08	-0.05	-0.01	0.07	0.07	0.12	0.13	1.00		
(21) Plans for climate change on farm	-0.12	-0.13	-0.12	-0.09	-0.01	-0.02	0.00	-0.03	0.13	1.00	
(22) Average historic pan evaporation	-0.01	-0.01	0.04	0.00	-0.02	-0.03	-0.06	0.00	-0.17	0.00	1.00
(23) Average historic rainfall	-0.02	-0.03	-0.05	-0.02	-0.02	0.02	0.06	0.03	0.15	0.02	-0.60
(24) Average historic temperature	-0.02	-0.02	0.00	0.00	0.02	-0.04	-0.02	-0.05	-0.18	-0.02	0.71
(25) Average historic water allocation factor	0.01	0.01	0.04	0.10	0.03	-0.04	-0.10	-0.08	-0.04	-0.04	0.14
(26) Millennium Drought dummy	0.32	0.27	0.06	0.01	0.08	0.10	0.02	-0.02	0.00	-0.01	0.01
(27) Historic net rainfall	0.00	0.00	-0.05	-0.01	0.01	0.03	0.06	0.01	0.18	0.01	-0.97
(28) State	0.01	0.02	-0.01	0.02	0.03	-0.05	-0.09	-0.06	-0.16	0.01	-0.05
(29) Historic temperature volatility	0.00	0.00	0.00	0.01	-0.04	0.04	0.05	0.05	0.21	0.01	-0.21
(30) Application rate	0.04	0.05	0.07	0.01	0.02	-0.06	-0.03	0.05	-0.05	0.03	0.04
(31) Broadacre	-0.05	-0.05	-0.03	0.03	0.01	0.06	0.17	0.06	0.12	-0.01	-0.04
(32) Carry-over use between 2014-2016	0.02	0.02	-0.06	0.05	0.02	0.04	0.06	0.06	0.14	0.05	-0.28
(33) Dairy	-0.11	-0.11	-0.04	0.05	0.07	0.06	0.05	0.00	0.20	0.06	-0.38
(34) Farm Size	-0.02	-0.02	-0.06	0.01	0.04	0.03	0.16	0.08	-0.01	0.03	0.01
(35) Livestock	0.19	0.20	0.09	-0.10	-0.11	-0.04	-0.06	-0.02	-0.08	-0.06	-0.19
(36) Majority of farm area under drainage	-0.02	-0.02	-0.04	0.07	0.02	0.06	0.09	0.02	0.27	0.04	-0.31
(37) Majority of farm area under drip irrigation	-0.04	-0.04	-0.03	0.02	0.08	-0.07	-0.09	-0.02	-0.13	0.07	0.46
(38) Number of employees	-0.13	-0.12	-0.06	-0.01	0.05	0.00	0.14	0.10	0.06	0.03	-0.03
(39) Excess water	0.01	0.01	-0.03	0.06	0.05	-0.09	-0.11	-0.06	-0.02	-0.01	0.11
(40) Water ownership	-0.07	-0.07	-0.05	0.11	0.02	0.03	0.18	0.05	0.18	0.03	-0.11
(41) Social group membership	0.05	0.05	-0.09	-0.05	0.00	0.08	0.13	-0.03	0.14	0.11	-0.13

Variables	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)
(1) Farm debt											
(2) Farm debt squared											
(3) Farmland value											
(4) Farmland value squared											
(5) Net farm income											
(6) Net farm income squared											
(7) Number of insurances											
(8) Off farm income											
(9) Productivity change											
(10) Received irrigation grant											
(11) Climate change risk perception											
(12) Age											
(13) Age squared											
(14) Low education											
(15) Male gender											
(16) Marital status											
(17) Number of Children											
(18) Succession											
(19) Risk Taker											
(20) Whole of farm plan											
(21) Plans for climate change on farm											
(22) Average historic pan evaporation											
(23) Average historic rainfall	1.00										
(24) Average historic temperature	-0.72	1.00									
(25) Average historic water allocation factor	-0.22	0.12	1.00								
(26) Millennium Drought dummy	-0.02	0.01	0.01	1.00							
(27) Historic net rainfall	0.77	-0.78	-0.18	-0.02	1.00						
(28) State	-0.29	-0.04	0.18	0.04	-0.04	1.00					
(29) Historic temperature volatility	0.41	-0.25	-0.12	-0.05	0.29	-0.78	1.00				
(30) Application rate	-0.04	0.05	-0.02	0.01	-0.05	0.05	-0.05	1.00			
(31) Broadacre	0.13	0.00	-0.23	-0.03	0.07	-0.36	0.27	-0.02	1.00		
(32) Carry-over use between 2014-2016	0.29	-0.31	-0.17	-0.03	0.31	-0.37	0.52	-0.04	0.21	1.00	
(33) Dairy	0.26	-0.44	0.00	-0.03	0.38	0.07	0.18	-0.02	-0.29	0.20	1.00
(34) Farm Size	0.04	0.10	-0.12	0.00	0.00	-0.22	0.09	-0.01	0.14	0.10	-0.09
(35) Livestock	0.22	-0.18	-0.14	0.03	0.22	-0.17	0.19	-0.02	-0.33	0.13	-0.26
(36) Majority of farm area under drainage	0.23	-0.29	-0.15	0.01	0.32	-0.27	0.44	-0.04	0.24	0.36	0.29
(37) Majority of farm area under drip irrigation	-0.45	0.41	0.22	0.01	-0.50	0.41	-0.47	-0.01	-0.27	-0.42	-0.22
(38) Number of employees	0.05	0.03	-0.02	-0.07	0.04	-0.03	0.00	-0.01	0.00	0.03	0.05
(39) Excess water	-0.10	0.12	0.16	0.05	-0.12	0.09	-0.14	-0.02	-0.12	-0.14	-0.15
(40) Water ownership	0.06	-0.02	0.20	-0.04	0.10	-0.28	0.30	0.07	0.22	0.27	0.13
(41) Social group membership	0.10	-0.09	-0.07	0.02	0.13	-0.05	0.08	-0.04	0.12	0.12	-0.01

Variables	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)
(1) Farm debt								
(2) Farm debt squared								
(3) Farmland value								
(4) Farmland value squared								
(5) Net farm income								
(6) Net farm income squared								
(7) Number of insurances								
(8) Off farm income								
(9) Productivity change								
(10) Received irrigation grant								
(11) Climate change risk perception								
(12) Age								
(13) Age squared								
(14) Low education								
(15) Male gender								
(16) Marital status								
(17) Number of Children								
(18) Succession								
(19) Risk Taker								
(20) Whole of farm plan								
(21) Plans for climate change on farm								
(22) Average historic pan evaporation								
(23) Average historic rainfall								
(24) Average historic temperature								
(25) Average historic water allocation factor								
(26) Millennium Drought dummy								
(27) Historic net rainfall								
(28) State								
(29) Historic temperature volatility								
(30) Application rate								
(31) Broadacre								
(32) Carry-over use between 2014-2016								
(33) Dairy								
(34) Farm Size	1.00							
(35) Livestock	0.15	1.00						
(36) Majority of farm area under drainage	0.07	0.00	1.00					
(37) Majority of farm area under drip irrigation	-0.14	-0.24	-0.36	1.00				
(38) Number of employees	0.18	-0.10	0.03	0.04	1.00			
(39) Excess water	-0.03	-0.02	-0.16	0.20	-0.01	1.00		
(40) Water ownership	0.21	-0.10	0.29	-0.15	0.20	-0.01	1.00	
(41) Social group membership	0.08	0.01	0.09	-0.06	0.04	0.00	0.09	1.00

Table C.5 Collinearity diagnostics for the full planned total adaptation index model, clustered and unclustered

Variable	Total planned adaptation index			
	Unclustered	**Cluster 1: Traditional irrigator**	**Cluster 2: Corporate-minded irrigator**	**Cluster 3: Environmentally friendly irrigator**
	VIF			
Age squared	60.77	66.64	65.77	68.19
Age	60.05	66.32	64.22	67.71
Farmland value	31.84	32.39	38.67	33.45
Farmland value squared	29.82	30.5	36.1	30.89
Farm debt	23.04	22.95	27.64	25.77
Farm debt squared	22.06	21.52	25.81	24.89
Net farm income	20.03	19.79	23.62	21.85
Net farm income squared	18.99	18.67	22.17	21.13
Climate change risk perception	4.27	4.23	4.7	4.62
Control function	3.91	3.92	4.27	4.35
Broadacre	3.69	5.43	3.52	3.13
Livestock	3.39	4.62	3.62	3.01
Dairy	3.36	4.7	3.1	2.82
Majority of farm area under drip irrigation	2.08	1.76	2.06	2.51
Historic temperature volatility	1.91	1.8	2.24	2.45
Historic net rainfall	1.92	1.91	2.23	2.18
Water ownership	1.73	1.59	2.02	2.05
Carry-over use between 2014-2016	1.58	1.35	1.94	1.96
Majority of farm area under drainage	1.59	1.5	1.59	1.77
Number of insurances	1.35	1.36	1.49	1.63
Number of employees	1.32	1.59	1.33	1.59
Past index	1.44	1.49	1.68	1.5
Farm Size	1.37	1.45	1.41	1.46
Succession	1.27	1.29	1.3	1.43
Whole of farm plan	1.25	1.28	1.41	1.42
Off farm income	1.26	1.21	1.59	1.4
Average historic water allocation factor	1.44	1.49	1.78	1.39
Low education	1.2	1.3	1.24	1.28
Application rate	1.19	1.25	1.31	1.27
Productivity change	1.18	1.23	1.34	1.25
Excess water	1.13	1.11	1.29	1.24
Irrigation grant	1.19	1.23	1.36	1.24
Male gender	1.07	1.12	1.18	1.22
Mean VIF	9.5	10	10.76	10.43

Table C.6 Collinearity diagnostics for planned individual adaptation strategies index full models

Variable	Buy allocations	Buy entitlements	Buy land in same region	Buy land in different region	More efficiency	More irrigation	Change ownership	Change irrigated production	Diversify production	More insurance
	VIF									
Age squared	60.72	60.7	60.68	60.86	60.71	60.78	61.56	60.68	60.72	60.68
Age	59.86	59.81	59.78	60.02	59.78	59.99	60.8	59.77	59.85	59.77
Farmland value	31.65	31.65	31.65	31.67	31.66	31.7	31.78	31.64	32	31.83
Farmland value squared	29.7	29.69	29.78	29.7	29.71	29.76	29.73	29.7	29.99	29.78
Farm debt	23.13	22.93	23.05	22.88	22.9	22.97	22.88	22.96	22.87	22.88
Farm debt squared	22.1	22.08	22.04	22.03	21.99	22.01	21.98	22.02	21.98	21.98
Net farm income	19.61	19.56	19.58	19.56	19.6	19.58	19.6	19.56	19.6	19.56
Net farm income squared	18.87	18.83	18.84	18.83	18.85	18.83	18.86	18.82	18.85	18.82
Broadacre	3.65	3.65	3.65	3.65	3.67	3.65	3.65	3.65	3.65	3.65
Livestock	3.38	3.37	3.36	3.36	3.38	3.37	3.36	3.36	3.36	3.36
Dairy	3.35	3.32	3.32	3.32	3.33	3.32	3.32	3.32	3.36	3.33
Majority of farm area under drip irrigation	2.08	2.07	2.07	2.07	2.07	2.08	2.07	2.08	2.09	2.07
Historic net rainfall	1.91	1.9	1.89	1.9	1.9	1.89	1.9	1.89	1.9	1.9
Historic temperature volatility	1.9	1.91	1.9	1.91	1.91	1.9	1.9	1.91	1.9	1.9
Water ownership	1.73	1.73	1.73	1.75	1.74	1.73	1.73	1.73	1.73	1.73
Majority of farm area under drainage	1.58	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Carry-over use between 2014-2016	1.57	1.58	1.58	1.58	1.57	1.57	1.57	1.57	1.57	1.57
Average historic water allocation factor	1.44	1.44	1.44	1.45	1.44	1.44	1.44	1.44	1.44	1.44
Past strategy	1.39	1.23	1.34	1.18	1.27	1.27	1.14	1.19	1.16	1.16
Farm Size	1.37	1.37	1.37	1.41	1.37	1.37	1.37	1.37	1.37	1.37
Number of insurances	1.34	1.34	1.33	1.34	1.35	1.33	1.33	1.34	1.34	1.36
Number of employees	1.31	1.32	1.31	1.31	1.3	1.32	1.31	1.31	1.31	1.3
Off farm income	1.26	1.27	1.26	1.26	1.26	1.26	1.26	1.27	1.26	1.26
Succession	1.24	1.24	1.25	1.24	1.24	1.24	1.24	1.24	1.24	1.24
Whole of farm plan	1.21	1.22	1.21	1.21	1.22	1.22	1.21	1.23	1.22	1.21
Application rate	1.19	1.19	1.2	1.2	1.19	1.19	1.19	1.19	1.2	1.19
Productivity change	1.18	1.19	1.19	1.18	1.19	1.22	1.18	1.19	1.19	1.19
Excess water	1.18	1.13	1.13	1.13	1.14	1.13	1.13	1.13	1.13	1.13
Low education	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
Irrigation grant	1.14	1.15	1.14	1.14	1.16	1.15	1.14	1.15	1.14	1.14
Climate change risk perception	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
Male gender	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Mean VIF	9.54	9.52	9.53	9.53	9.52	9.54	9.58	9.52	9.54	9.52

Table C.7 Collinearity diagnostics for planned individual adaptation strategies index full models, table continued

Variable	Less dryland	More collaboration	More dryland	Utilise solar-	Selling the farm	Less irrigation	Sell allocations	Sell entitlements	Sell farmland
	VIF								
Age squared	60.7	60.76	60.68	60.82	60.91	60.8	60.72	60.78	60.88
Age	59.78	59.81	59.77	59.92	59.95	59.89	59.81	59.91	59.99
Farmland value	31.64	31.72	31.7	31.67	31.66	31.67	31.64	31.66	32.3
Farmland value squared	29.69	29.75	29.79	29.71	29.71	29.72	29.7	29.71	30.08
Farm debt	22.95	22.9	23.31	22.87	22.96	22.88	22.89	22.87	22.95
Farm debt squared	22.05	22.02	22.35	21.98	22.02	21.98	21.99	21.98	22.06
Net farm income	19.56	19.52	19.57	19.57	19.57	19.56	19.56	19.73	19.57
Net farm income squared	18.82	18.81	18.82	18.84	18.83	18.83	18.82	18.95	18.82
Broadacre	3.66	3.65	3.69	3.66	3.65	3.65	3.65	3.67	3.65
Livestock	3.37	3.36	3.4	3.37	3.36	3.36	3.4	3.36	3.36
Dairy	3.34	3.32	3.33	3.33	3.32	3.32	3.37	3.33	3.32
Majority of farm area under drip irrigation	2.07	2.07	2.07	2.07	2.07	2.09	2.07	2.08	2.07
Historic net rainfall	1.89	1.9	1.89	1.89	1.9	1.89	1.89	1.89	1.89
Historic temperature volatility	1.9	1.9	1.91	1.91	1.9	1.9	1.91	1.9	1.9
Water ownership	1.73	1.73	1.73	1.73	1.73	1.73	1.74	1.73	1.73
Majority of farm area under drainage	1.57	1.58	1.57	1.57	1.57	1.57	1.58	1.57	1.57
Carry-over use between 2014-2016	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
Average historic water allocation factor	1.44	1.44	1.44	1.45	1.44	1.45	1.44	1.44	1.44
Past strategy	1.05	1.05	1.21	1.06	1.15	1.12	1.19	1.16	1.1
Farm Size	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37
Number of insurances	1.34	1.34	1.34	1.34	1.34	1.33	1.34	1.34	1.34
Number of employees	1.31	1.3	1.31	1.3	1.3	1.3	1.31	1.3	1.3
Off farm income	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Succession	1.24	1.24	1.24	1.24	1.29	1.24	1.24	1.24	1.25
Whole of farm plan	1.21	1.22	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Application rate	1.19	1.19	1.19	1.19	1.19	1.2	1.2	1.19	1.19
Productivity change	1.18	1.18	1.19	1.18	1.21	1.25	1.18	1.18	1.2
Excess water	1.13	1.13	1.13	1.13	1.13	1.13	1.14	1.13	1.13
Low education	1.15	1.15	1.15	1.15	1.16	1.15	1.15	1.15	1.16
Irrigation grant	1.14	1.14	1.14	1.14	1.14	1.14	1.15	1.21	1.14
Climate change risk perception	1.09	1.09	1.09	1.09	1.09	1.1	1.1	1.09	1.09
Male gender	1.07	1.07	1.07	1.08	1.07	1.07	1.07	1.07	1.07
Mean VIF	9.51	9.52	9.55	9.52	9.53	9.52	9.52	9.53	9.56

Table C.8 Collinearity diagnostics for planned expansive adaptation strategies index full models, clustered and unclustered

	Planned expansive adaptation index			
	Unclustered	***Cluster 1: Traditional irrigator***	***Cluster 2: Corporate-minded irrigator***	***Cluster 3: Environmentally friendly irrigator***
Variable	VIF			
Age squared	60.77	66.93	65.31	68.03
Age	60.04	66.9	63.62	67.49
Farmland value	31.67	32.24	38.22	33.66
Farmland value squared	29.74	30.41	35.61	31.19
Farm debt	23.06	23.13	27.64	25.53
Farm debt squared	22.01	21.53	25.74	24.64
Net farm income	20.02	19.4	23.65	21.83
Net farm income squared	18.97	18.44	22	21.14
Climate change risk perception	4.18	4.13	4.48	4.6
Control function	3.86	3.88	4.13	4.34
Broadacre	3.69	5.43	3.52	3.12
Livestock	3.39	4.62	3.62	3.02
Dairy	3.37	4.71	3.13	2.83
Majority of farm area under drip irrigation	2.07	1.76	2.06	2.51
Historic temperature volatility	1.91	1.82	2.27	2.45
Historic net rainfall	1.91	1.9	2.23	2.17
Past index	1.78	1.94	1.89	1.91
Water ownership	1.73	1.59	2.04	2.05
Carry-over use between 2014-2016	1.6	1.37	1.97	1.96
Majority of farm area under drainage	1.58	1.5	1.56	1.78
Average historic water allocation factor	1.44	1.53	1.77	1.38
Farm Size	1.37	1.44	1.41	1.46
Number of insurances	1.35	1.35	1.5	1.64
Number of employees	1.33	1.61	1.35	1.6
Succession	1.27	1.31	1.29	1.4
Off farm income	1.26	1.21	1.59	1.41
Whole of farm plan	1.24	1.33	1.33	1.41
Productivity change	1.2	1.26	1.36	1.27
Application rate	1.19	1.25	1.31	1.27
Low education	1.19	1.3	1.23	1.28
Irrigation grant	1.18	1.23	1.29	1.23
Excess water	1.16	1.09	1.35	1.25
Male gender	1.07	1.12	1.19	1.22
Mean VIF	9.5	10.02	10.69	10.43

Table C.9 Collinearity diagnostics for planned accommodating adaptation strategies index full models, clustered and unclustered

	Planned accommodating adaptation index			
	Unclustered	***Cluster 1: Traditional irrigator***	***Cluster 2: Corporate-minded irrigator***	***Cluster 3: Environmentally friendly irrigator***
Variable	VIF			
Age squared	60.79	66.65	65.71	68.15
Age	60.02	66.29	64.11	67.59
Farmland value	31.89	32.37	38.36	33.49
Farmland value squared	29.84	30.49	35.79	30.88
Farm debt	22.99	22.9	27.71	26.42
Farm debt squared	22.08	21.52	25.84	25.45
Net farm income	20.06	19.67	23.68	21.91
Net farm income squared	19	18.6	22.18	21.18
Climate change risk perception	4.29	4.29	4.72	4.6
Control function	3.93	4.02	4.27	4.33
Broadacre	3.7	5.42	3.51	3.12
Livestock	3.4	4.62	3.63	3.03
Dairy	3.36	4.71	3.1	2.81
Majority of farm area under drip irrigation	2.1	1.76	2.1	2.53
Historic net rainfall	1.91	1.91	2.22	2.17
Historic temperature volatility	1.91	1.79	2.24	2.45
Water ownership	1.73	1.59	2.02	2.07
Majority of farm area under drainage	1.58	1.51	1.57	1.77
Carry-over use between 2014-2016	1.58	1.35	1.94	1.97
Average historic water allocation factor	1.44	1.5	1.77	1.39
Past index	1.38	1.38	1.61	1.57
Farm Size	1.37	1.45	1.44	1.45
Number of insurances	1.37	1.39	1.51	1.64
Number of employees	1.31	1.58	1.32	1.59
Succession	1.27	1.32	1.3	1.4
Off farm income	1.26	1.21	1.61	1.4
Whole of farm plan	1.23	1.26	1.4	1.39
Productivity change	1.19	1.24	1.35	1.27
Application rate	1.19	1.25	1.31	1.27
Low education	1.19	1.3	1.23	1.28
Irrigation grant	1.15	1.21	1.29	1.22
Excess water	1.13	1.1	1.29	1.23
Male gender	1.07	1.12	1.18	1.22
Mean VIF	9.51	9.99	10.74	10.46

Table C.10 Collinearity diagnostics for planned contractive adaptation strategies index full models, clustered and unclustered

	Planned contractive adaptation index			
	Unclustered	***Cluster 1: Traditional irrigator***	***Cluster 2: Corporate-minded irrigator***	***Cluster 3: Environmentally friendly irrigator***
Variable	VIF			
Age squared	61	66.69	65.34	68.51
Age	60.18	66.32	63.68	67.95
Farmland value	31.74	32.24	38.09	33.68
Farmland value squared	29.79	30.41	35.69	31.03
Farm debt	22.95	23.01	27.63	25.17
Farm debt squared	22.02	21.59	25.76	24.53
Net farm income	20.06	19.61	23.74	21.83
Net farm income squared	18.99	18.53	22.11	21.11
Climate change risk perception	4.19	4.11	4.48	4.6
Control function	3.84	3.87	4.1	4.32
Broadacre	3.7	5.39	3.55	3.13
Dairy	3.41	4.73	3.18	2.84
Livestock	3.39	4.62	3.63	3.01
Majority of farm area under drip irrigation	2.07	1.76	2.06	2.51
Historic temperature volatility	1.91	1.79	2.23	2.45
Historic net rainfall	1.89	1.9	2.2	2.15
Water ownership	1.73	1.59	2.02	2.06
Carry-over use between 2014-2016	1.58	1.36	1.94	1.96
Majority of farm area under drainage	1.57	1.49	1.55	1.77
Average historic water allocation factor	1.44	1.5	1.76	1.38
Farm Size	1.37	1.45	1.4	1.46
Number of insurances	1.34	1.35	1.5	1.63
Number of employees	1.31	1.59	1.32	1.57
Succession	1.27	1.29	1.29	1.43
Off farm income	1.26	1.22	1.59	1.4
Whole of farm plan	1.21	1.25	1.32	1.39
Productivity change	1.21	1.28	1.33	1.31
Application rate	1.19	1.25	1.31	1.27
Low education	1.19	1.3	1.23	1.28
Irrigation grant	1.17	1.22	1.33	1.23
Past index	1.16	1.29	1.25	1.17
Excess water	1.13	1.09	1.3	1.23
Male gender	1.07	1.13	1.17	1.22
Mean VIF	9.5	9.98	10.67	10.41

Table C.11 Irrigator attitudinal clusters and numeric attitude values

Cluster description	Cluster 1: Traditional irrigator	Cluster 2: Corporate-minded irrigator	Cluster 3: Environmentally friendly irrigator
Observations	401	283	316
I could never imagine living anywhere other than this area (1 = strongly disagree; 5= strongly agree)	3.8	2.1	3.9
Farming is the only occupation I can imagine doing (1 = strongly disagree; 5= strongly agree)	4.4	2.1	4.3
We would be willing to have our seasonal allocations reduced to ensure sufficient water for the environment (1 = strongly disagree; 5= strongly agree)	1.2	1.6	2.0
It is essential to make allocations to the environment otherwise irrigation will not be long-term sustainable (1 = strongly disagree; 5= strongly agree)	1.8	2.6	3.6
I believe water trading has been a good thing for farming (1 = strongly disagree; 5= strongly agree)	1.5	2.4	3.9

Table C.12 Individual planned adaptation full model regression results

	Planned expansive adaptation index components					
VARIABLES	**Buy allocation**	**Buy entitlement**	**Buy land in same region**	**Buy land in different region**	**More efficiency**	**More irrigation**
Farm debt	-0.027(0.551)	1.294***(0.467)	1.012**(0.472)	1.254**(0.623)	0.635(0.496)	1.003**(0.466)
Farm debt squared	0.044(0.444)	-0.850**(0.365)	-0.595(0.362)	-0.765(0.466)	-0.233(0.396)	-0.707**(0.360)
Farmland value	0.107(0.297)	0.175(0.275)	-0.601**(0.279)	-0.200(0.390)	-0.083(0.274)	-0.261(0.271)
Farmland value squared	-0.029(0.086)	-0.020(0.078)	0.175**(0.078)	0.088(0.107)	0.007(0.081)	0.082(0.077)
Net farm income	1.327(3.063)	3.537(2.518)	2.848(2.529)	-0.929(3.343)	0.825(2.692)	0.048(2.543)
Net farm income squared	-4.019(11.433)	-8.483(9.324)	-9.276(9.370)	3.071(12.492)	-3.499(10.310)	-2.294(9.481)
Number of insurances	0.012(0.045)	0.116***(0.040)	0.027(0.039)	-0.001(0.050)	0.098**(0.040)	0.061(0.040)
Off farm income	-0.002(0.002)	-0.003(0.002)	-0.003(0.002)	-0.004(0.003)	-0.002(0.002)	-0.002(0.002)
Productivity change	0.004(0.049)	0.051(0.045)	0.185***(0.046)	-0.026(0.057)	0.109**(0.046)	0.125***(0.045)
Irrigation grant	0.153(0.156)	0.077(0.121)	-0.170(0.123)	0.267*(0.147)	-0.466***(0.128)	-0.209*(0.122)
Climate change risk perception	0.124(0.199)	0.203(0.191)	0.679***(0.176)	0.414(0.283)	0.610***(0.183)	0.259(0.205)
Age	0.074*(0.045)	0.006(0.032)	-0.024(0.034)	-0.001(0.042)	0.029(0.037)	-0.032(0.032)
Age squared	-0.001**(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.092(0.167)	0.093(0.154)	-0.044(0.156)	0.253(0.189)	-0.057(0.144)	-0.031(0.153)
Male gender	0.164(0.175)	0.343**(0.155)	0.800***(0.173)	0.153(0.191)	0.047(0.155)	0.207(0.150)
Number of employees	0.016(0.018)	0.038*(0.020)	-0.006(0.015)	0.005(0.017)	0.030(0.023)	0.016(0.014)
Whole of farm plan	0.261*(0.140)	0.134(0.122)	-0.111(0.130)	-0.003(0.165)	0.194(0.121)	0.321**(0.127)
Historic net rainfall	-0.000(0.000)	-0.001**(0.000)	-0.000(0.000)	-0.001**(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	-0.469*(0.255)	0.447**(0.226)	-0.089(0.250)	-0.140(0.281)	0.038(0.221)	-0.035(0.223)
Historic temperature volatility	-0.274(1.148)	-1.115(0.939)	-0.798(1.056)	-1.107(1.510)	-1.007(0.951)	-0.311(0.893)
Application rate	-0.003(0.016)	-0.004(0.013)	0.010(0.011)	-0.053**(0.022)	-0.012(0.012)	0.011(0.010)
Broadacre	-0.171(0.249)	-0.263(0.216)	0.394*(0.232)	0.737***(0.273)	0.174(0.220)	-0.065(0.202)
Carry-over use between 2014-2016	0.268*(0.148)	0.140(0.128)	0.059(0.140)	0.162(0.169)	0.296**(0.124)	-0.096(0.127)
Dairy	0.175(0.265)	-0.443*(0.235)	0.038(0.248)	0.579*(0.318)	-0.000(0.242)	-0.046(0.218)
Farm Size	0.001(0.002)	-0.001(0.002)	0.002(0.002)	0.003(0.002)	-0.004**(0.002)	-0.003(0.002)
Livestock	-0.551**(0.253)	-0.133(0.224)	0.280(0.245)	0.501*(0.293)	0.160(0.220)	-0.034(0.212)
Majority of farm area under drainage	0.391***(0.134)	0.227*(0.128)	-0.161(0.123)	0.002(0.160)	0.003(0.128)	-0.149(0.123)
Majority of farm area under drip irrigation	0.142(0.219)	-0.215(0.186)	-0.231(0.200)	0.140(0.296)	-0.478***(0.185)	-0.110(0.175)
Excess water	-0.362**(0.158)	-0.341**(0.146)	0.047(0.138)	-0.165(0.192)	-0.184(0.135)	-0.006(0.130)
Water ownership	-0.031(0.042)	-0.116***(0.037)	0.023(0.040)	-0.037(0.043)	0.062*(0.036)	-0.070*(0.036)
Succession	0.449***(0.138)	0.263**(0.111)	0.612***(0.107)	0.134(0.139)	0.414***(0.116)	0.483***(0.109)
Past index	1.966***(0.121)	1.084***(0.130)	0.613***(0.122)	1.379***(0.212)	1.191***(0.124)	0.898***(0.113)
Constant	-2.769*(1.584)	-1.989(1.238)	-0.847(1.276)	-1.620(1.688)	-2.204*(1.337)	-0.077(1.173)
athrho	-0.036(0.129)	-0.238*(0.134)	-0.395***(0.137)	-0.150(0.202)	-0.305**(0.135)	-0.263*(0.150)
AIC	1643.118	1877.386	1841.471	1512.785	1841.846	1916.178
BIC	1965.176	2199.444	2163.529	1834.843	2163.904	2238.236
Observations	904	904	904	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Individual planned adaptation full model regression results, continued 1

	Planned accommodating adaptation index components							
VARIABLES	**Change ownership**	**Change irrigated production**	**Diversify production**	**More insurance**	**Less dryland**	**More collaboration**	**More dryland**	**Utilise solar**
Farm debt	0.292(0.443)	1.019**(0.480)	0.969**(0.471)	0.002(0.492)	0.112(0.681)	0.323(0.532)	0.541(0.542)	0.963**(0.439)
Farm debt squared	-0.009(0.345)	-0.755**(0.374)	-0.697*(0.370)	-0.151(0.390)	0.186(0.543)	-0.149(0.417)	-0.554(0.417)	-0.689**(0.343)
Farmland value	-0.164(0.256)	-0.397(0.259)	-0.319(0.281)	-0.531*(0.291)	-0.512(0.369)	-0.797**(0.314)	-0.406(0.317)	-0.216(0.258)
Farmland value squared	0.057(0.074)	0.091(0.075)	0.114(0.081)	0.143*(0.082)	0.105(0.109)	0.215**(0.090)	0.127(0.090)	0.071(0.074)
Net farm income	2.712(2.443)	1.720(2.532)	2.238(2.548)	-1.821(2.639)	-0.051(3.518)	2.748(2.937)	-1.284(2.879)	4.061*(2.432)
Net farm income squared	-12.926(9.078)	-6.492(9.432)	-9.543(9.601)	8.083(9.798)	2.551(13.139)	-11.213(10.855)	2.531(10.889)	-20.023**(9.203)
Number of insurances	0.044(0.039)	0.069*(0.040)	0.034(0.039)	0.103**(0.043)	0.056(0.058)	0.081*(0.047)	0.005(0.049)	0.077**(0.039)
Off farm income	0.001(0.002)	-0.002(0.002)	0.000(0.002)	0.001(0.002)	-0.002(0.002)	-0.003*(0.002)	-0.002(0.002)	-0.001(0.002)
Productivity change	0.043(0.040)	-0.071(0.045)	-0.027(0.044)	0.056(0.046)	-0.182***(0.060)	0.062(0.048)	0.008(0.051)	0.051(0.042)
Irrigation grant	-0.143(0.115)	-0.023(0.125)	-0.056(0.130)	-0.069(0.123)	0.225(0.155)	0.047(0.129)	0.016(0.135)	0.121(0.115)
Climate change risk perception	0.358**(0.180)	0.373**(0.172)	0.524***(0.178)	0.209(0.197)	-0.156(0.284)	0.465**(0.208)	0.541**(0.222)	0.679***(0.175)
Age	-0.052(0.033)	0.026(0.036)	-0.003(0.037)	0.006(0.032)	-0.039(0.047)	0.001(0.034)	0.013(0.035)	0.030(0.032)
Age squared	0.001**(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)	0.000(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Low education	0.148(0.129)	0.013(0.144)	-0.124(0.146)	0.023(0.155)	0.357**(0.179)	-0.081(0.160)	0.025(0.173)	0.092(0.140)
Male gender	0.182(0.150)	0.224*(0.132)	0.037(0.156)	0.204(0.158)	0.334(0.288)	0.085(0.167)	0.151(0.165)	-0.188(0.138)
Number of employees	-0.003(0.014)	0.034*(0.020)	0.004(0.021)	-0.000(0.016)	-0.024(0.033)	-0.013(0.017)	0.036**(0.016)	0.026*(0.014)
Whole of farm plan	0.133(0.120)	0.197(0.123)	0.255*(0.135)	0.053(0.137)	0.137(0.198)	0.397***(0.152)	-0.006(0.159)	0.248**(0.119)
Historic net rainfall	0.000(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)	0.000(0.000)	0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Historic allocation factor	-0.104(0.222)	-0.211(0.220)	0.065(0.221)	0.068(0.258)	-0.087(0.302)	-0.287(0.227)	-0.161(0.278)	0.233(0.217)
Historic temperature volatility	-0.393(0.922)	-0.425(0.941)	-0.001(0.968)	1.096(1.004)	1.266(1.272)	-0.320(1.036)	-0.184(1.102)	0.218(0.917)
Application rate	-0.002(0.012)	-0.001(0.012)	-0.008(0.014)	-0.016(0.014)	-0.018(0.020)	-0.010(0.014)	-0.032*(0.019)	-0.005(0.013)
Broadacre	-0.100(0.194)	0.092(0.217)	0.018(0.212)	-0.620***(0.210)	0.037(0.306)	-0.385*(0.226)	0.740**(0.287)	-0.307(0.203)
Carry-over use between 2014-2016	0.087(0.123)	-0.069(0.122)	-0.064(0.128)	0.240*(0.134)	0.216(0.180)	0.239*(0.139)	0.221(0.142)	-0.092(0.122)
Dairy	-0.017(0.209)	-0.097(0.230)	-0.299(0.236)	-0.445**(0.222)	0.164(0.340)	-0.220(0.237)	0.828***(0.308)	-0.266(0.208)
Farm Size	0.000(0.002)	-0.001(0.002)	-0.001(0.002)	0.002(0.002)	-0.001(0.003)	0.003(0.002)	0.001(0.002)	0.001(0.002)
Livestock	-0.210(0.205)	0.124(0.218)	-0.322(0.224)	-0.596***(0.221)	-0.035(0.313)	-0.263(0.229)	0.792***(0.286)	-0.309(0.209)
Majority of farm under drainage	-0.221*(0.117)	0.060(0.121)	0.151(0.126)	0.215*(0.127)	-0.181(0.179)	-0.039(0.136)	0.108(0.140)	0.076(0.121)
Majority of farm under drip irrigation	-0.342*(0.176)	-0.331*(0.195)	-0.367**(0.187)	-0.149(0.189)	0.193(0.245)	-0.194(0.206)	0.033(0.280)	-0.201(0.171)
Excess water	0.189(0.124)	-0.107(0.133)	-0.031(0.140)	-0.039(0.137)	0.164(0.180)	0.003(0.145)	-0.113(0.162)	-0.093(0.125)
Water ownership	0.044(0.035)	0.021(0.036)	-0.031(0.038)	0.015(0.039)	-0.005(0.050)	-0.038(0.041)	-0.010(0.041)	-0.032(0.037)
Succession	0.540***(0.101)	0.301***(0.110)	0.258**(0.110)	0.257**(0.113)	-0.259(0.158)	0.117(0.123)	0.322***(0.121)	0.254**(0.104)
Past index	0.184(0.128)	1.482***(0.103)	1.627***(0.107)	1.641***(0.108)	1.623***(0.169)	2.286***(0.170)	1.455***(0.136)	1.364***(0.169)
Constant	-0.465(1.202)	-1.454(1.291)	-1.222(1.319)	-2.642**(1.227)	-0.825(1.804)	-0.969(1.302)	-2.370*(1.378)	-2.130*(1.191)
athrho	-0.235*(0.128)	-0.165(0.119)	-0.310**(0.130)	-0.090(0.133)	0.173(0.188)	-0.292*(0.153)	-0.357**(0.170)	-0.380***(0.136)
AIC	2031.481	1919.963	1855.112	1826.265	1432.839	1684.78	1658.27	1992.975
BIC	2353.538	2242.021	2177.17	2148.323	1754.897	2006.763	1980.327	2315.033
Observations	904	904	904	904	904	903	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Individual planned adaptation full model regression results, continued 2

	Planned contractive adaptation index components				
VARIABLES	Selling the farm	Less irrigation	Sell allocation	Sell entitlement	Sell land
Farm debt	-0.839(0.541)	0.808(0.569)	-0.943*(0.501)	-0.491(0.517)	-0.115(0.489)
Farm debt squared	0.831*(0.424)	-0.467(0.439)	0.868**(0.392)	0.537(0.399)	0.428(0.384)
Farmland value	0.932***(0.308)	0.012(0.323)	-0.497*(0.278)	-0.441(0.287)	-0.054(0.270)
Farmland value squared	-0.255***(0.088)	-0.022(0.092)	0.170**(0.080)	0.121(0.083)	0.007(0.079)
Net farm income	1.683(2.852)	2.965(3.196)	2.957(2.666)	1.773(2.716)	2.672(2.570)
Net farm income squared	-11.544(10.638)	-7.539(12.030)	-18.517*(9.856)	-7.212(10.252)	-13.548(9.820)
Number of insurances	0.036(0.048)	-0.020(0.049)	-0.087**(0.041)	0.020(0.042)	-0.017(0.041)
Off farm income	-0.001(0.002)	0.001(0.002)	0.001(0.002)	-0.002(0.002)	0.002(0.002)
Productivity change	0.024(0.050)	-0.291***(0.056)	0.002(0.046)	-0.087*(0.046)	-0.108**(0.044)
Irrigation grant	-0.005(0.135)	-0.027(0.147)	-0.299**(0.132)	0.075(0.135)	0.059(0.125)
Climate change risk perception	0.312(0.221)	-0.099(0.263)	0.177(0.200)	-0.292(0.187)	-0.011(0.187)
Age	0.075**(0.037)	-0.075**(0.035)	0.000(0.035)	0.018(0.037)	-0.010(0.036)
Age squared	-0.000(0.000)	0.001**(0.000)	0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.113(0.163)	0.284*(0.164)	0.035(0.152)	-0.068(0.150)	0.334**(0.137)
Male gender	0.362**(0.169)	-0.067(0.175)	-0.134(0.151)	0.012(0.165)	-0.013(0.152)
Number of employees	-0.049**(0.020)	-0.008(0.023)	-0.027**(0.013)	0.021(0.017)	-0.046*(0.027)
Whole of farm plan	-0.031(0.134)	0.189(0.145)	-0.152(0.129)	-0.087(0.132)	0.057(0.124)
Historic net rainfall	-0.000(0.000)	0.000(0.000)	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Average historic water allocation factor	-0.637**(0.255)	0.048(0.284)	-0.359(0.241)	0.577**(0.259)	-0.301(0.228)
Historic temperature volatility	0.968(1.031)	-0.035(1.112)	1.980**(0.986)	0.044(1.010)	2.347**(1.041)
Application rate	0.022(0.015)	-0.008(0.015)	0.002(0.011)	-0.012(0.011)	0.002(0.012)
Broadacre	-0.520**(0.205)	-0.452(0.276)	0.068(0.232)	0.056(0.218)	-0.478**(0.222)
Carry-over use between 2014-2016	0.056(0.139)	0.125(0.154)	-0.116(0.129)	-0.122(0.128)	-0.041(0.126)
Dairy	-0.294(0.227)	-0.143(0.295)	-0.331(0.253)	-0.017(0.237)	-0.306(0.236)
Farm Size	-0.002(0.002)	-0.001(0.002)	0.000(0.002)	0.000(0.002)	0.001(0.002)
Livestock	-0.412*(0.222)	-0.335(0.279)	-0.266(0.234)	-0.142(0.232)	-0.588***(0.224)
Majority of farm area under drainage	0.004(0.141)	0.245*(0.144)	-0.058(0.127)	0.251*(0.128)	0.047(0.121)
Majority of farm area under drip irrigation	-0.016(0.192)	0.226(0.222)	-0.332*(0.195)	-0.201(0.185)	0.027(0.176)
Excess water	0.149(0.154)	0.281*(0.147)	0.473***(0.132)	0.557***(0.126)	0.459***(0.123)
Water ownership	-0.051(0.036)	0.032(0.048)	0.164***(0.040)	-0.027(0.040)	0.074*(0.038)
Succession	-0.703***(0.123)	-0.296**(0.137)	-0.292**(0.119)	-0.391***(0.117)	-0.576***(0.119)
Past index	2.101***(0.120)	1.163***(0.126)	1.630***(0.113)	0.259**(0.114)	0.409***(0.149)
Constant	-4.540***(1.342)	1.487(1.396)	-2.449*(1.321)	-1.517(1.381)	-2.143*(1.297)
athrho	-0.122(0.146)	0.016(0.179)	-0.144(0.138)	0.249*(0.130)	-0.073(0.128)
AIC	1724.867	1624.026	1840.938	1757.289	1904.403
BIC	2046.925	1946.084	2162.995	2079.347	2226.461
Observations	904	904	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.13 Total planned adaptation index full model regression results, clustered and unclustered

	Total planned adaptation index			
	Unclustered	Cluster 1: Traditional irrigator	Cluster 2: Corporate-minded irrigator	Cluster 3: Environmentally friendly irrigator
VARIABLES	**coefficients**			
Farm debt	1.899**(0.742)	1.826(1.192)	1.486(1.206)	1.112(1.589)
Farm debt squared	-0.981*(0.570)	-1.154(0.872)	-0.957(0.955)	0.167(1.262)
Farmland value	-0.965**(0.443)	-0.953(0.752)	-0.930(0.769)	-1.522*(0.780)
Farmland value squared	0.275**(0.125)	0.304(0.209)	0.225(0.214)	0.423*(0.222)
Net farm income	9.759**(4.186)	0.661(6.936)	24.222***(7.407)	10.975(7.672)
Net farm income squared	-40.599**(15.853)	-16.734(26.076)	-78.352***(27.917)	-47.230*(28.502)
Number of insurances	0.155**(0.064)	0.135(0.109)	0.272**(0.111)	0.047(0.113)
Off farm income	-0.006**(0.003)	-0.006(0.005)	-0.010**(0.005)	-0.005(0.005)
Productivity change	0.030(0.072)	0.147(0.115)	-0.398***(0.128)	0.135(0.146)
Irrigation Grant	-0.452**(0.193)	-0.156(0.326)	-0.357(0.347)	-0.605*(0.363)
Climate change risk perception	1.252***(0.319)	2.391***(0.540)	0.128(0.522)	1.179*(0.627)
Age	0.029(0.052)	0.039(0.087)	-0.019(0.089)	0.022(0.100)
Age squared	-0.000(0.000)	-0.000(0.001)	0.000(0.001)	-0.000(0.001)
Low education	0.309(0.228)	0.174(0.354)	0.641(0.501)	0.413(0.399)
Male gender	0.688***(0.232)	0.306(0.436)	0.855*(0.447)	1.015**(0.397)
Number of employees	-0.004(0.024)	-0.113(0.069)	-0.002(0.017)	0.051(0.056)
Whole of farm plan	0.306(0.187)	-0.137(0.328)	0.168(0.343)	0.751**(0.350)
Historic net rainfall	-0.000(0.000)	-0.001(0.001)	-0.001(0.001)	-0.001(0.001)
Average historic water allocation factor	-0.238(0.370)	0.159(0.574)	-0.052(0.724)	-0.725(0.670)
Historic temperature volatility	1.118(1.613)	3.979(4.213)	5.345**(2.470)	-2.166(2.666)
Application rate	-0.014(0.016)	0.004(0.046)	-0.007(0.015)	-0.071**(0.034)
Broadacre	-0.429(0.343)	0.088(0.601)	-1.037*(0.603)	-0.432(0.630)
Carry-over use between 2014-2016	0.200(0.209)	0.045(0.341)	0.471(0.434)	0.233(0.369)
Dairy	-0.509(0.374)	-0.042(0.623)	-0.244(0.615)	-1.099(0.676)
Farm Size	-0.000(0.004)	0.001(0.009)	0.006(0.004)	-0.006(0.005)
Livestock	-0.741**(0.349)	-0.493(0.595)	-1.031*(0.607)	-0.619(0.610)
Majority of farm area under drainage	0.060(0.189)	0.433(0.328)	0.274(0.311)	-0.543(0.353)
Majority of farm area under drip irrigation	-0.792***(0.280)	-0.437(0.586)	-0.521(0.428)	-1.395***(0.480)
Excess water	0.278(0.203)	0.487(0.392)	-0.049(0.346)	0.579*(0.342)
Water ownership	-0.024(0.069)	-0.006(0.109)	-0.100(0.118)	-0.014(0.131)
Succession	0.374**(0.174)	0.834***(0.290)	0.178(0.311)	0.084(0.335)
Past index	0.569***(0.031)	0.514***(0.052)	0.686***(0.052)	0.521***(0.060)
control function	-1.249***(0.368)	-1.791***(0.660)	-0.421(0.674)	-1.804***(0.675)
Constant	-0.399(2.038)	-3.688(4.473)	-2.524(3.147)	3.524(3.698)
AIC	4079.092	1685.384	1113.403	1306.641
BIC	4242.487	1817.793	1234.204	1430.466
Observations	903	363	258	282
R-squared	0.494	0.490	0.652	0.507

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.14 Planned expansive adaptation index full model regression results, clustered and unclustered

	Planned expansive adaptation index			
	Unclustered	Cluster 1: Traditional irrigator	Cluster 2: Corporate-minded irrigator	Cluster 3: Environmentally friendly irrigator
VARIABLES	coefficients			
Farm debt	1.224***(0.374)	1.316**(0.589)	0.287(0.649)	1.534**(0.692)
Farm debt squared	-0.789***(0.293)	-0.832*(0.455)	-0.365(0.497)	-0.786(0.552)
Farmland value	-0.231(0.209)	-0.226(0.336)	-0.085(0.368)	-0.688*(0.370)
Farmland value squared	0.072(0.060)	0.074(0.096)	0.032(0.107)	0.179*(0.107)
Net farm income	1.973(1.993)	-3.387(3.200)	5.646*(3.388)	3.105(3.522)
Net farm income squared	-6.310(7.484)	13.322(12.008)	-18.682(12.748)	-12.588(13.277)
Number of insurances	0.075**(0.031)	0.076(0.051)	0.093*(0.054)	0.027(0.057)
Off farm income	-0.004***(0.001)	-0.003(0.002)	-0.003(0.002)	-0.006**(0.002)
Productivity change	0.092***(0.034)	0.065(0.053)	0.001(0.060)	0.136**(0.064)
Irrigation grant	-0.196**(0.097)	-0.257(0.159)	-0.355**(0.157)	0.160(0.171)
Climate change risk perception	0.543***(0.154)	0.818***(0.253)	0.461*(0.254)	0.416(0.274)
Age	-0.012(0.026)	0.048(0.042)	-0.012(0.046)	-0.069(0.046)
Age squared	-0.000(0.000)	-0.001(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.027(0.111)	-0.198(0.170)	0.093(0.239)	0.183(0.186)
Male gender	0.391***(0.118)	0.583***(0.199)	0.342*(0.196)	0.383*(0.209)
Number of employees	0.015(0.013)	-0.035(0.037)	0.015(0.016)	0.056**(0.024)
Whole of farm plan	0.124(0.097)	-0.093(0.164)	0.103(0.158)	0.234(0.173)
Historic net rainfall	-0.000*(0.000)	-0.001*(0.000)	-0.001**(0.000)	0.000(0.000)
Average historic water allocation factor	-0.007(0.178)	0.416(0.290)	-0.591*(0.313)	-0.285(0.305)
Historic temperature volatility	-0.930(0.748)	1.346(1.933)	1.793(1.337)	-1.996*(1.166)
Application rate	-0.001(0.009)	0.014(0.018)	-0.002(0.011)	-0.011(0.019)
Broadacre	0.167(0.161)	0.409(0.295)	-0.002(0.252)	-0.057(0.274)
Carry-over use between 2014-2016	0.114(0.099)	-0.011(0.161)	0.089(0.175)	0.232(0.180)
Dairy	0.015(0.174)	0.015(0.298)	0.237(0.281)	-0.031(0.308)
Farm Size	-0.001(0.002)	-0.002(0.003)	0.004(0.003)	-0.001(0.002)
Livestock	0.094(0.166)	0.143(0.293)	-0.022(0.283)	0.082(0.280)
Majority of farm area under drainage	0.017(0.096)	0.229(0.159)	0.115(0.153)	-0.282(0.171)
Majority of farm area under drip irrigation	-0.276*(0.142)	0.217(0.312)	-0.122(0.221)	-0.572***(0.221)
Excess water	-0.231**(0.104)	-0.080(0.192)	-0.272(0.173)	-0.140(0.165)
Water ownership	-0.048*(0.028)	-0.069(0.043)	0.006(0.049)	-0.048(0.052)
Succession	0.539***(0.086)	0.856***(0.136)	0.393**(0.153)	0.415***(0.155)
Past index	0.506***(0.031)	0.499***(0.051)	0.598***(0.055)	0.402***(0.056)
control function residual	-0.555***(0.180)	-0.780**(0.304)	-0.346(0.298)	-0.735**(0.306)
Constant	1.041(0.965)	-3.199(2.062)	-1.177(1.669)	4.894***(1.625)
AIC	8562.493	3575.3534	2388.619	2713.134
BIC	9052.676	3972.582	2751.021	3084.609
Observations	903	363	258	282
R-squared	0.543	0.556	0.651	0.573

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.15 Planned accommodating adaptation index full model regression results, clustered and unclustered

	Planned accommodating adaptation index			
	Unclustered	**Cluster 1: Traditional irrigator**	**Cluster 2: Corporate-minded irrigator**	**Cluster 3: Environmentally friendly irrigator**
VARIABLES	**coefficiencts**			
Farm debt	1.091***(0.416)	0.382(0.648)	1.413**(0.719)	1.626**(0.813)
Farm debt squared	-0.742**(0.327)	-0.288(0.503)	-1.012*(0.551)	-1.001(0.648)
Farmland value	-0.807***(0.233)	-0.554(0.372)	-1.066***(0.407)	-1.096**(0.427)
Farmland value squared	0.221***(0.067)	0.162(0.106)	0.282**(0.118)	0.323***(0.123)
Net farm income	3.956*(2.220)	-2.646(3.558)	11.047***(3.749)	4.876(4.082)
Net farm income squared	-16.629**(8.332)	4.057(13.316)	-39.572***(14.118)	-19.435(15.373)
Number of insurances	0.091***(0.035)	0.131**(0.057)	0.051(0.060)	0.044(0.067)
Off farm income	-0.002(0.002)	-0.002(0.003)	-0.006**(0.003)	-0.001(0.003)
Productivity change	-0.004(0.038)	0.056(0.059)	-0.164**(0.066)	0.002(0.074)
Irrigation grant	-0.005(0.106)	0.182(0.174)	-0.079(0.174)	0.011(0.197)
Climate change risk perception	0.681***(0.174)	1.111***(0.284)	0.325(0.289)	0.487(0.317)
Age	0.006(0.029)	0.048(0.046)	0.002(0.051)	0.004(0.053)
Age squared	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Low education	0.092(0.124)	0.110(0.188)	0.046(0.264)	0.124(0.216)
Male gender	0.174(0.131)	-0.136(0.220)	0.359*(0.216)	0.473*(0.242)
Number of employees	0.011(0.015)	-0.037(0.041)	0.026(0.017)	0.011(0.027)
Whole of farm plan	0.303***(0.108)	0.092(0.177)	0.287(0.180)	0.442**(0.199)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	0.000(0.000)	0.000(0.000)
Average historic water allocation factor	-0.004(0.198)	0.084(0.318)	-0.073(0.347)	0.045(0.354)
Historic temperature volatility	0.054(0.830)	0.115(2.121)	1.178(1.467)	-0.777(1.350)
Application rate	-0.015(0.010)	-0.021(0.020)	-0.001(0.012)	-0.053**(0.022)
Broadacre	-0.241(0.179)	-0.004(0.326)	-0.391(0.279)	-0.314(0.317)
Carry-over use between 2014-2016	0.145(0.110)	-0.002(0.177)	0.201(0.192)	0.239(0.208)
Dairy	-0.258(0.193)	0.115(0.329)	-0.010(0.311)	-0.910**(0.355)
Farm Size	0.001(0.002)	-0.000(0.003)	-0.001(0.003)	0.001(0.003)
Livestock	-0.339*(0.185)	-0.251(0.324)	-0.536*(0.314)	-0.230(0.325)
Majority of farm area under drainage	-0.015(0.107)	0.134(0.177)	0.065(0.169)	-0.200(0.198)
Majority of farm area under drip irrigation	-0.339**(0.159)	-0.200(0.344)	-0.077(0.248)	-0.591**(0.257)
Excess water	-0.061(0.114)	0.012(0.213)	-0.186(0.187)	0.022(0.189)
Water ownership	0.000(0.031)	0.021(0.048)	-0.066(0.054)	0.008(0.060)
Social capital				
Succession	0.465***(0.096)	0.648***(0.151)	0.510***(0.169)	0.170(0.180)
Past index	0.609***(0.030)	0.588***(0.047)	0.741***(0.052)	0.512***(0.060)
control function residual	-0.642***(0.202)	-0.847**(0.341)	-0.504(0.335)	-0.625*(0.354)
Constant	0.301(1.071)	-1.949(2.260)	0.254(1.843)	2.106(1.879)
AIC	8562.493	3575.353	2388.619	2713.134
BIC	9052.676	3972.582	2751.021	3084.609
Observations	903	363	258	282
R-squared	0.493	0.494	0.641	0.482

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.16 Planned contractive adaptation index full model regression results, clustered and unclustered

	Planned contractive adaptation index			
	Unclustered	Cluster 1: Traditional irrigator	Cluster 2: Corporate-minded irrigator	Cluster 3: Environmentally friendly irrigator
VARIABLES	**coefficients**			
Farm debt	-0.205(0.365)	0.259(0.585)	-0.183(0.650)	-1.490**(0.638)
Farm debt squared	0.390(0.287)	-0.137(0.453)	0.441(0.499)	1.488***(0.511)
Farmland value	-0.025(0.205)	-0.259(0.335)	0.307(0.369)	0.059(0.343)
Farmland value squared	0.006(0.059)	0.084(0.095)	-0.136(0.107)	-0.002(0.099)
Net farm income	2.441(1.950)	3.288(3.200)	5.350(3.402)	3.456(3.267)
Net farm income squared	-12.421*(7.320)	-20.159*(11.970)	-12.722(12.814)	-16.347(12.307)
Number of insurances	-0.034(0.031)	-0.096*(0.051)	0.048(0.054)	-0.032(0.053)
Off farm income	0.000(0.001)	-0.001(0.002)	-0.000(0.002)	0.002(0.002)
Productivity change	-0.136***(0.033)	-0.071(0.054)	-0.243***(0.059)	-0.071(0.060)
Irrigation grant	-0.050(0.095)	0.049(0.158)	0.368**(0.160)	-0.524***(0.159)
Climate change risk perception	0.090(0.151)	0.377(0.251)	-0.335(0.255)	0.253(0.254)
Age	0.013(0.025)	-0.049(0.042)	-0.042(0.046)	0.060(0.043)
Age squared	-0.000(0.000)	0.000(0.000)	0.001(0.000)	-0.000(0.000)
Low education	0.247**(0.109)	0.305*(0.169)	0.544**(0.239)	0.112(0.173)
Male gender	0.005(0.116)	-0.289(0.198)	0.042(0.196)	0.157(0.194)
Number of employees	-0.019(0.013)	-0.027(0.037)	-0.034**(0.016)	-0.005(0.022)
Whole of farm plan	-0.007(0.094)	-0.166(0.159)	0.015(0.158)	0.232(0.160)
Historic net rainfall	-0.000(0.000)	0.000(0.000)	-0.000(0.000)	-0.001**(0.000)
Average historic water allocation factor	-0.161(0.174)	-0.402(0.286)	0.391(0.313)	-0.067(0.283)
Historic temperature volatility	1.727**(0.730)	1.915(1.910)	2.641**(1.328)	0.294(1.083)
Application rate	0.001(0.009)	0.010(0.018)	-0.005(0.011)	-0.009(0.017)
Broadacre	-0.266*(0.157)	-0.206(0.293)	-0.766***(0.254)	0.097(0.255)
Carry-over use between 2014-2016	-0.096(0.097)	-0.025(0.160)	0.098(0.174)	-0.209(0.166)
Dairy	-0.298*(0.171)	-0.180(0.297)	-0.681**(0.284)	-0.044(0.286)
Farm Size	0.000(0.002)	0.003(0.003)	0.004(0.003)	-0.004*(0.002)
Livestock	-0.446***(0.162)	-0.361(0.292)	-0.666**(0.284)	-0.249(0.260)
Majority of farm area under drainage	0.050(0.094)	0.027(0.158)	0.223(0.153)	-0.073(0.159)
Majority of farm area under drip irrigation	-0.131(0.139)	-0.417(0.310)	-0.085(0.222)	-0.173(0.205)
Excess water	0.615***(0.100)	0.719***(0.192)	0.540***(0.170)	0.558***(0.152)
Water ownership	0.038(0.027)	0.073*(0.043)	-0.038(0.049)	0.028(0.048)
Succession	-0.627***(0.084)	-0.635***(0.135)	-0.688***(0.153)	-0.572***(0.145)
Past index	0.231***(0.038)	0.255***(0.065)	0.169**(0.066)	0.284***(0.061)
control function residual	-0.068(0.175)	-0.039(0.302)	0.146(0.298)	-0.389(0.283)
Constant	-0.089(0.947)	2.440(2.042)	0.544(1.672)	-2.035(1.515)
AIC	8562.493	3575.353	2388.619	2713.134
BIC	9052.676	3972.582	2751.021	3084.609
Observations	903	363	258	282
R-squared	0.239	0.261	0.340	0.354

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.17 Planned compound adaptation strategy water trade 1 full model regression results

	(1)	(2)	(3)
	Compound strategy water trade 1		
VARIABLES	***Buy entitlement***	***Sell allocation***	***Buy allocation***
Farm debt	1.395***(0.458)	-0.966*(0.500)	-0.002(0.553)
Farm debt squared	-0.928***(0.358)	0.872**(0.392)	0.062(0.448)
Farmland value	0.234(0.275)	-0.470*(0.276)	0.072(0.299)
Farmland value squared	-0.036(0.078)	0.164**(0.079)	-0.015(0.086)
Net farm income	3.590(2.497)	2.945(2.666)	1.627(2.992)
Net farm income squared	-8.540(9.209)	-18.822*(9.895)	-4.373(11.052)
Number of insurances	0.123***(0.040)	-0.080**(0.041)	0.016(0.044)
Off farm income	-0.003*(0.002)	0.001(0.002)	-0.002(0.002)
Productivity change	0.057(0.045)	-0.006(0.046)	0.001(0.050)
Irrigation grant	0.072(0.120)	-0.282**(0.130)	0.128(0.147)
Climate change risk perception	0.197(0.203)	0.165(0.176)	0.023(0.186)
Age	0.006(0.032)	-0.005(0.035)	0.087**(0.043)
Age squared	-0.000(0.000)	0.000(0.000)	-0.001***(0.000)
Low education	0.079(0.157)	0.020(0.153)	0.066(0.168)
Male gender	0.348**(0.153)	-0.123(0.150)	0.139(0.168)
Number of employees	0.038*(0.020)	-0.027**(0.013)	0.021(0.021)
Whole of farm plan	0.117(0.123)	-0.153(0.129)	0.256*(0.142)
Historic net rainfall	-0.001**(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	0.417*(0.225)	-0.372(0.241)	-0.416(0.256)
Historic temperature volatility	-0.982(0.942)	1.992**(0.978)	-0.385(1.168)
Application rate	-0.003(0.012)	0.002(0.011)	-0.007(0.014)
Broadacre	-0.265(0.217)	0.018(0.231)	-0.193(0.251)
Carry-over use between 2014-2016	0.151(0.130)	-0.103(0.128)	0.244*(0.146)
Dairy	-0.440*(0.238)	-0.408(0.253)	0.230(0.272)
Farm Size	-0.001(0.002)	0.000(0.002)	-0.000(0.002)
Livestock	-0.115(0.224)	-0.328(0.234)	-0.553**(0.261)
Majority of farm area under drainage	0.205(0.125)	-0.070(0.127)	0.385***(0.133)
Majority of farm area under drip irrigation	-0.221(0.187)	-0.333*(0.194)	0.103(0.219)
Excess water	-0.340**(0.144)	0.482***(0.131)	-0.404***(0.152)
Water ownership	-0.112***(0.037)	0.158***(0.039)	-0.033(0.041)
Succession	0.272**(0.111)	-0.286**(0.117)	0.431***(0.135)
past strategy	1.051***(0.126)	1.581***(0.110)	1.775***(0.120)
correlation between 2 and 1			-0.246***(0.080)
correlation between 3 and 1			0.555***(0.095)
correlation between instrument and 1			-0.217(0.140)
correlation between 3 and 2			-0.348***(0.081)
correlation between instrument and 2			-0.137(0.115)
correlation between instrument and 3			0.041(0.114)
Constant	-2.234*(1.243)	-2.188*(1.300)	-2.928*(1.547)
AIC	3346.085		
BIC	4019.041		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.18 Planned compound adaptation strategy water trade 2 full model regression results

	(1)	(2)	(3)
	Compound strategy water trade 2		
VARIABLES	***Sell entitlement***	***Sell allocation***	***Buy allocation***
Farm debt	-0.514(0.512)	-0.869*(0.512)	-0.030(0.538)
Farm debt squared	0.563(0.396)	0.833**(0.401)	0.060(0.434)
Farmland value	-0.450(0.289)	-0.558**(0.275)	0.121(0.294)
Farmland value squared	0.124(0.083)	0.185**(0.079)	-0.028(0.085)
Net farm income	2.138(2.724)	3.107(2.669)	1.768(3.012)
Net farm income squared	-9.262(10.325)	-18.997*(9.953)	-5.414(11.285)
Number of insurances	0.032(0.042)	-0.082**(0.041)	0.010(0.045)
Off farm income	-0.002(0.002)	0.001(0.002)	-0.002(0.002)
Productivity change	-0.085*(0.046)	0.002(0.045)	-0.001(0.049)
Irrigation grant	0.041(0.136)	-0.269**(0.131)	0.151(0.153)
Climate change risk perception	-0.147(0.182)	0.163(0.180)	-0.044(0.184)
Age	0.027(0.037)	0.003(0.035)	0.074(0.045)
Age squared	-0.000(0.000)	0.000(0.000)	-0.001**(0.000)
Low education	-0.071(0.151)	0.053(0.153)	0.053(0.169)
Male gender	0.005(0.166)	-0.133(0.147)	0.156(0.172)
Number of employees	0.023(0.017)	-0.026*(0.014)	0.016(0.019)
Whole of farm plan	-0.086(0.131)	-0.162(0.129)	0.248*(0.141)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	0.623**(0.262)	-0.434*(0.247)	-0.451*(0.252)
Historic temperature volatility	-0.034(0.999)	2.266**(0.962)	-0.403(1.152)
Application rate	-0.012(0.013)	-0.000(0.011)	-0.003(0.015)
Broadacre	0.098(0.224)	-0.002(0.225)	-0.194(0.250)
Carry-over use between 2014-2016	-0.123(0.127)	-0.113(0.127)	0.282*(0.147)
Dairy	0.017(0.241)	-0.405(0.249)	0.181(0.268)
Farm Size	0.001(0.002)	0.000(0.002)	0.000(0.002)
Livestock	-0.090(0.238)	-0.342(0.227)	-0.551**(0.253)
Majority of farm area under drainage	0.223*(0.129)	-0.076(0.128)	0.388***(0.133)
Majority of farm area under drip irrigation	-0.198(0.185)	-0.351*(0.193)	0.136(0.219)
Excess water	0.555***(0.127)	0.480***(0.132)	-0.368**(0.158)
Water ownership	-0.033(0.039)	0.165***(0.039)	-0.031(0.041)
Succession	-0.389***(0.116)	-0.286**(0.118)	0.425***(0.137)
past strategy	0.354***(0.110)	1.622***(0.107)	1.927***(0.121)
correlation between 2 and 1			0.524***(0.084)
correlation between 3 and 1			-0.101(0.085)
correlation between instrument and 1			0.125(0.119)
correlation between 3 and 2			-0.315***(0.081)
correlation between instrument and 2			-0.136(0.118)
correlation between instrument and 3			0.093(0.111)
Constant	-1.849(1.363)	-2.630**(1.298)	-2.590(1.579)
AIC	3227.67		
BIC	3900.626		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.19 Planned compound adaptation strategy less irrigation full model regression results

	(1)	(2)	(3)
	Compound strategy less irrigation		
VARIABLES	***Less irrigation***	***Sell entitlement***	***More dryland***
Farm debt	0.864(0.564)	-0.512(0.521)	0.570(0.546)
Farm debt squared	-0.518(0.437)	0.558(0.402)	-0.567(0.421)
Farmland value	-0.001(0.322)	-0.452(0.287)	-0.404(0.317)
Farmland value squared	-0.014(0.092)	0.122(0.083)	0.126(0.090)
Net farm income	3.349(3.175)	1.346(2.733)	-0.722(2.920)
Net farm income squared	-8.974(11.969)	-5.425(10.272)	1.404(11.038)
Number of insurances	-0.019(0.049)	0.022(0.042)	0.001(0.050)
Off farm income	0.001(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	-0.298***(0.056)	-0.092**(0.046)	0.006(0.051)
Irrigation grant	-0.047(0.147)	0.065(0.134)	0.012(0.136)
Climate change risk perception	-0.133(0.246)	-0.215(0.169)	0.304(0.198)
Age	-0.075**(0.035)	0.021(0.038)	0.009(0.035)
Age squared	0.001**(0.000)	-0.000(0.000)	-0.000(0.000)
Low education	0.282*(0.164)	-0.067(0.149)	-0.023(0.175)
Male gender	-0.049(0.179)	0.016(0.166)	0.147(0.166)
Number of employees	-0.004(0.021)	0.019(0.016)	0.035**(0.016)
Whole of farm plan	0.191(0.145)	-0.068(0.133)	-0.001(0.159)
Historic net rainfall	0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	0.051(0.278)	0.566**(0.260)	-0.164(0.279)
Historic temperature volatility	-0.200(1.106)	0.133(1.012)	-0.208(1.099)
Application rate	-0.006(0.014)	-0.012(0.011)	-0.035*(0.019)
Broadacre	-0.429(0.273)	0.054(0.215)	0.712**(0.290)
Carry-over use between 2014-2016	0.118(0.156)	-0.128(0.127)	0.258*(0.142)
Dairy	-0.112(0.293)	-0.013(0.236)	0.806***(0.311)
Farm Size	-0.001(0.002)	0.000(0.002)	0.001(0.002)
Livestock	-0.291(0.276)	-0.148(0.229)	0.763***(0.288)
Majority of farm area under drainage	0.249*(0.145)	0.231*(0.130)	0.116(0.141)
Majority of farm area under drip irrigation	0.246(0.221)	-0.196(0.185)	0.058(0.277)
Excess water	0.258*(0.148)	0.543***(0.127)	-0.114(0.165)
Water ownership	0.029(0.047)	-0.024(0.041)	-0.010(0.042)
Succession	-0.295**(0.137)	-0.377***(0.118)	0.296**(0.122)
past strategy	1.130***(0.127)	0.274**(0.111)	1.480***(0.132)
correlation between 2 and 1			0.361***(0.086)
correlation between 3 and 1			0.116(0.088)
correlation between instrument and 1			0.034(0.163)
correlation between 3 and 2			-0.037(0.078)
correlation between instrument and 2			0.183*(0.106)
correlation between instrument and 3			-0.163(0.132)
Constant	1.583(1.398)	-1.666(1.387)	-2.137(1.372)
AIC	3072.948		
BIC	3745.904		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.20 Planned compound adaptation strategy more irrigation 1 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 1		
VARIABLES	***Less dryland***	***Buy entitlement***	***More irrigation***
Farm debt	0.022(0.684)	1.254***(0.468)	1.006**(0.472)
Farm debt squared	0.202(0.547)	-0.823**(0.363)	-0.707*(0.364)
Farmland value	-0.470(0.366)	0.146(0.272)	-0.255(0.271)
Farmland value squared	0.101(0.109)	-0.013(0.077)	0.080(0.077)
Net farm income	-0.473(3.464)	3.393(2.502)	0.095(2.519)
Net farm income squared	3.574(12.972)	-7.903(9.288)	-1.867(9.419)
Number of insurances	0.063(0.057)	0.126***(0.040)	0.067*(0.040)
Off farm income	-0.002(0.002)	-0.003(0.002)	-0.002(0.002)
Productivity change	-0.184***(0.061)	0.060(0.044)	0.132***(0.045)
Irrigation grant	0.213(0.151)	0.077(0.121)	-0.220*(0.124)
Climate change risk perception	-0.041(0.232)	0.200(0.180)	0.232(0.180)
Age	-0.042(0.047)	0.007(0.033)	-0.032(0.033)
Age squared	0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.374**(0.175)	0.122(0.154)	-0.033(0.153)
Male gender	0.359(0.295)	0.320**(0.153)	0.234(0.149)
Number of employees	-0.022(0.033)	0.038*(0.020)	0.014(0.014)
Whole of farm plan	0.170(0.199)	0.144(0.122)	0.333***(0.127)
Historic net rainfall	0.000(0.000)	-0.001**(0.000)	0.000(0.000)
Average historic water allocation factor	-0.110(0.299)	0.428*(0.226)	-0.054(0.223)
Historic temperature volatility	1.096(1.265)	-1.095(0.934)	-0.328(0.903)
Application rate	-0.020(0.021)	-0.005(0.013)	0.010(0.010)
Broadacre	0.036(0.296)	-0.278(0.218)	-0.061(0.204)
Carry-over use between 2014-2016	0.226(0.183)	0.135(0.127)	-0.094(0.128)
Dairy	0.173(0.327)	-0.447*(0.235)	-0.045(0.221)
Farm Size	-0.001(0.003)	-0.001(0.002)	-0.003*(0.002)
Livestock	-0.042(0.302)	-0.137(0.223)	-0.017(0.217)
Majority of farm area under drainage	-0.193(0.179)	0.235*(0.127)	-0.145(0.123)
Majority of farm area under drip irrigation	0.203(0.249)	-0.214(0.186)	-0.103(0.177)
Excess water	0.176(0.178)	-0.365**(0.147)	-0.007(0.132)
Water ownership	-0.000(0.050)	-0.108***(0.037)	-0.074**(0.037)
Succession	-0.233(0.154)	0.265**(0.110)	0.493***(0.109)
past strategy	1.585***(0.170)	1.044***(0.128)	0.838***(0.112)
correlation between 2 and 1			0.043(0.087)
correlation between 3 and 1			0.244***(0.086)
correlation between instrument and 1			0.103(0.144)
correlation between 3 and 2			0.393***(0.071)
correlation between instrument and 2			-0.231*(0.122)
correlation between instrument and 3			-0.234*(0.122)
Constant	-0.767(1.789)	-2.084*(1.245)	-0.072(1.198)
AIC	3236.315		
BIC	3909.271		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.21 Planned compound adaptation strategy more irrigation 2 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 2		
VARIABLES	*Solar*	*More efficiency*	*More irrigation*
Farm debt	1.034**(0.443)	0.611(0.495)	1.043**(0.468)
Farm debt squared	-0.738**(0.345)	-0.207(0.394)	-0.731**(0.361)
Farmland value	-0.199(0.259)	-0.046(0.273)	-0.302(0.273)
Farmland value squared	0.065(0.074)	-0.004(0.080)	0.092(0.077)
Net farm income	4.452*(2.441)	0.846(2.670)	0.433(2.547)
Net farm income squared	-20.983**(9.277)	-3.674(10.218)	-3.089(9.504)
Number of insurances	0.077*(0.039)	0.096**(0.039)	0.066*(0.040)
Off farm income	-0.001(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	0.053(0.043)	0.119***(0.045)	0.132***(0.046)
Irrigation grant	0.130(0.116)	-0.473***(0.127)	-0.205*(0.123)
Climate change risk perception	0.545***(0.166)	0.561***(0.172)	0.235(0.187)
Age	0.032(0.033)	0.031(0.036)	-0.035(0.033)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.066(0.141)	-0.090(0.142)	-0.064(0.150)
Male gender	-0.193(0.138)	0.043(0.154)	0.203(0.150)
Number of employees	0.026*(0.014)	0.033(0.026)	0.016(0.015)
Whole of farm plan	0.233*(0.120)	0.199(0.122)	0.331***(0.126)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	0.259(0.215)	0.036(0.221)	-0.076(0.216)
Historic temperature volatility	0.137(0.909)	-0.827(0.958)	-0.354(0.872)
Application rate	-0.006(0.013)	-0.015(0.013)	0.010(0.010)
Broadacre	-0.323(0.205)	0.141(0.225)	-0.118(0.204)
Carry-over use between 2014-2016	-0.073(0.123)	0.277**(0.124)	-0.094(0.127)
Dairy	-0.292(0.211)	0.030(0.245)	-0.097(0.220)
Farm Size	0.001(0.002)	-0.004**(0.002)	-0.003*(0.002)
Livestock	-0.325(0.211)	0.152(0.226)	-0.061(0.212)
Majority of farm area under drainage	0.086(0.123)	-0.001(0.127)	-0.122(0.125)
Majority of farm area under drip irrigation	-0.207(0.172)	-0.504***(0.186)	-0.141(0.176)
Excess water	-0.089(0.125)	-0.182(0.135)	-0.003(0.131)
Water ownership	-0.032(0.036)	0.070*(0.036)	-0.061*(0.036)
Succession	0.236**(0.105)	0.386***(0.114)	0.463***(0.111)
past strategy	1.418***(0.164)	1.138***(0.115)	0.817***(0.110)
correlation between 2 and 1			0.348***(0.069)
correlation between 3 and 1			0.130**(0.063)
correlation between instrument and 1			-0.263**(0.120)
correlation between 3 and 2			0.548***(0.079)
correlation between instrument and 2			-0.268**(0.117)
correlation between instrument and 3			-0.243*(0.130)
Constant	-2.092*(1.201)	-2.404*(1.306)	0.017(1.172)
AIC	3739.008		
BIC	4411.964		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.22 Planned compound adaptation strategy more irrigation 3 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 3		
VARIABLES	***Sell entitlement***	***More efficiency***	***More irrigation***
Farm debt	-0.484(0.519)	0.659(0.497)	1.023**(0.469)
Farm debt squared	0.526(0.400)	-0.254(0.396)	-0.720**(0.361)
Farmland value	-0.471(0.291)	-0.027(0.271)	-0.298(0.273)
Farmland value squared	0.130(0.084)	-0.007(0.080)	0.092(0.077)
Net farm income	1.391(2.742)	0.915(2.686)	0.612(2.547)
Net farm income squared	-6.642(10.345)	-4.298(10.257)	-3.923(9.487)
Number of insurances	0.022(0.042)	0.099**(0.039)	0.067*(0.039)
Off farm income	-0.002(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	-0.087*(0.046)	0.112**(0.045)	0.129***(0.046)
Irrigation grant	0.069(0.136)	-0.474***(0.127)	-0.192(0.123)
Climate change risk perception	-0.085(0.177)	0.556***(0.171)	0.251(0.188)
Age	0.019(0.037)	0.033(0.036)	-0.037(0.032)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	-0.048(0.151)	-0.062(0.144)	-0.070(0.150)
Male gender	0.023(0.167)	0.053(0.154)	0.200(0.149)
Number of employees	0.023(0.016)	0.033(0.026)	0.017(0.015)
Whole of farm plan	-0.083(0.133)	0.197(0.122)	0.329***(0.127)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	0.571**(0.264)	0.008(0.224)	-0.081(0.217)
Historic temperature volatility	0.016(1.026)	-0.892(0.943)	-0.425(0.869)
Application rate	-0.011(0.011)	-0.014(0.013)	0.011(0.010)
Broadacre	0.084(0.220)	0.132(0.222)	-0.101(0.203)
Carry-over use between 2014-2016	-0.129(0.130)	0.298**(0.123)	-0.095(0.126)
Dairy	0.016(0.239)	-0.008(0.242)	-0.086(0.219)
Farm Size	0.001(0.002)	-0.004**(0.002)	-0.003*(0.002)
Livestock	-0.111(0.235)	0.132(0.222)	-0.044(0.211)
Majority of farm area under drainage	0.245*(0.129)	-0.004(0.127)	-0.114(0.125)
Majority of farm area under drip irrigation	-0.198(0.186)	-0.487***(0.185)	-0.133(0.177)
Excess water	0.550***(0.127)	-0.183(0.136)	-0.017(0.132)
Water ownership	-0.029(0.041)	0.069*(0.036)	-0.063*(0.036)
Succession	-0.377***(0.117)	0.391***(0.115)	0.467***(0.111)
past strategy	0.256**(0.114)	1.150***(0.118)	0.807***(0.110)
correlation between 2 and 1			-0.135*(0.069)
correlation between 3 and 1			-0.181***(0.070)
correlation between instrument and 1			0.076(0.112)
correlation between 3 and 2			0.552***(0.079)
correlation between instrument and 2			-0.263**(0.117)
correlation between instrument and 3			-0.252*(0.131)
Constant	-1.612(1.381)	-2.384*(1.319)	0.120(1.163)
AIC	3517.916		
BIC	4190.872		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.23 Planned compound adaptation strategy more irrigation 4 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 4		
VARIABLES	***Change production***	***More efficiency***	***More irrigation***
Farm debt	1.080**(0.480)	0.659(0.495)	1.105**(0.465)
Farm debt squared	-0.809**(0.371)	-0.249(0.396)	-0.784**(0.358)
Farmland value	-0.389(0.257)	-0.030(0.270)	-0.307(0.271)
Farmland value squared	0.088(0.074)	-0.008(0.079)	0.095(0.077)
Net farm income	1.869(2.523)	0.579(2.680)	0.530(2.543)
Net farm income squared	-7.421(9.395)	-3.237(10.253)	-3.854(9.504)
Number of insurances	0.071*(0.040)	0.098**(0.040)	0.072*(0.039)
Off farm income	-0.003(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	-0.074*(0.044)	0.109**(0.045)	0.127***(0.045)
Irrigation grant	-0.015(0.124)	-0.488***(0.127)	-0.217*(0.123)
Climate change risk perception	0.414**(0.171)	0.637***(0.172)	0.306(0.191)
Age	0.029(0.036)	0.044(0.035)	-0.033(0.032)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	-0.002(0.141)	-0.069(0.144)	-0.091(0.150)
Male gender	0.216*(0.131)	0.037(0.159)	0.218(0.150)
Number of employees	0.039*(0.022)	0.035(0.026)	0.019(0.015)
Whole of farm plan	0.202*(0.122)	0.181(0.122)	0.324**(0.127)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	-0.213(0.216)	0.009(0.226)	-0.064(0.217)
Historic temperature volatility	-0.432(0.921)	-0.822(0.933)	-0.328(0.872)
Application rate	-0.003(0.013)	-0.014(0.013)	0.009(0.010)
Broadacre	0.102(0.215)	0.138(0.220)	-0.116(0.200)
Carry-over use between 2014-2016	-0.081(0.122)	0.298**(0.124)	-0.081(0.124)
Dairy	-0.104(0.227)	0.004(0.241)	-0.089(0.216)
Farm Size	-0.001(0.002)	-0.004**(0.002)	-0.003*(0.002)
Livestock	0.149(0.215)	0.159(0.222)	-0.072(0.209)
Majority of farm area under drainage	0.051(0.119)	0.004(0.127)	-0.112(0.125)
Majority of farm area under drip irrigation	-0.373*(0.195)	-0.460**(0.183)	-0.121(0.176)
Excess water	-0.127(0.133)	-0.179(0.135)	0.002(0.132)
Water ownership	0.029(0.036)	0.067*(0.037)	-0.063*(0.036)
Succession	0.308***(0.109)	0.404***(0.115)	0.474***(0.111)
past strategy	1.395***(0.103)	1.156***(0.118)	0.775***(0.110)
correlation between 2 and 1			0.396***(0.076)
correlation between 3 and 1			0.381***(0.070)
correlation between instrument and 1			-0.194*(0.117)
correlation between 3 and 2			0.545***(0.079)
correlation between instrument and 2			-0.332***(0.121)
correlation between instrument and 3			-0.298**(0.138)
Constant	-1.547(1.300)	-2.772**(1.274)	-0.126(1.164)
AIC	3636.111		
BIC	4309.067		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.24 Planned compound adaptation strategy more irrigation 5 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 5		
VARIABLES	*Buy entitlement*	*More efficiency*	*More irrigation*
Farm debt	1.276***(0.467)	0.675(0.498)	1.046**(0.471)
Farm debt squared	-0.840**(0.363)	-0.254(0.397)	-0.730**(0.361)
Farmland value	0.143(0.272)	-0.046(0.271)	-0.303(0.273)
Farmland value squared	-0.013(0.077)	-0.004(0.080)	0.090(0.077)
Net farm income	3.409(2.519)	0.689(2.693)	0.065(2.546)
Net farm income squared	-7.973(9.350)	-3.118(10.288)	-1.755(9.470)
Number of insurances	0.124***(0.040)	0.098**(0.039)	0.072*(0.040)
Off farm income	-0.003(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	0.058(0.044)	0.113**(0.045)	0.140***(0.045)
Irrigation grant	0.081(0.121)	-0.472***(0.127)	-0.205*(0.123)
Climate change risk perception	0.205(0.194)	0.588***(0.174)	0.289(0.192)
Age	0.008(0.033)	0.035(0.037)	-0.032(0.033)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.120(0.154)	-0.063(0.144)	-0.043(0.151)
Male gender	0.303**(0.151)	0.051(0.155)	0.178(0.149)
Number of employees	0.040**(0.020)	0.033(0.026)	0.016(0.015)
Whole of farm plan	0.133(0.122)	0.197(0.122)	0.328***(0.127)
Historic net rainfall	-0.001**(0.000)	-0.000(0.000)	0.000(0.000)
Average historic water allocation factor	0.425*(0.226)	0.011(0.224)	-0.066(0.217)
Historic temperature volatility	-1.075(0.933)	-0.842(0.942)	-0.383(0.869)
Application rate	-0.005(0.013)	-0.015(0.013)	0.011(0.010)
Broadacre	-0.269(0.220)	0.129(0.222)	-0.099(0.205)
Carry-over use between 2014-2016	0.138(0.128)	0.286**(0.123)	-0.114(0.127)
Dairy	-0.444*(0.237)	-0.003(0.242)	-0.059(0.221)
Farm Size	-0.001(0.002)	-0.004**(0.002)	-0.003**(0.002)
Livestock	-0.132(0.224)	0.141(0.222)	-0.026(0.214)
Majority of farm area under drainage	0.229*(0.127)	-0.004(0.128)	-0.109(0.125)
Majority of farm area under drip irrigation	-0.218(0.186)	-0.482***(0.184)	-0.117(0.176)
Excess water	-0.361**(0.147)	-0.185(0.135)	-0.000(0.130)
Water ownership	-0.108***(0.037)	0.072*(0.037)	-0.059(0.036)
Succession	0.265**(0.111)	0.396***(0.115)	0.482***(0.111)
past strategy	1.042***(0.126)	1.141***(0.118)	0.779***(0.110)
correlation between 2 and 1			0.200***(0.074)
correlation between 3 and 1			0.339***(0.069)
correlation between instrument and 1			-0.231*(0.134)
correlation between 3 and 2			0.539***(0.078)
correlation between instrument and 2			-0.294**(0.122)
correlation between instrument and 3			-0.284**(0.136)
Constant	-2.102*(1.247)	-2.470*(1.319)	-0.053(1.179)
AIC	3616.968		
BIC	4289.925		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.25 Planned compound adaptation strategy more irrigation 6 full model regression results

	(1)	(2)	(3)
	Compound strategy more irrigation 6		
VARIABLES	*Change production*	*More efficiency*	*More irrigation*
Farm debt	1.080**(0.480)	0.659(0.495)	1.105**(0.465)
Farm debt squared	-0.809**(0.371)	-0.249(0.396)	-0.784**(0.358)
Farmland value	-0.389(0.257)	-0.030(0.270)	-0.307(0.271)
Farmland value squared	0.088(0.074)	-0.008(0.079)	0.095(0.077)
Net farm income	1.869(2.523)	0.579(2.680)	0.530(2.543)
Net farm income squared	-7.421(9.395)	-3.237(10.253)	-3.854(9.504)
Number of insurances	0.071*(0.040)	0.098**(0.040)	0.072*(0.039)
Off farm income	-0.003(0.002)	-0.002(0.002)	-0.002(0.002)
Productivity change	-0.074*(0.044)	0.109**(0.045)	0.127***(0.045)
Irrigation grant	-0.015(0.124)	-0.488***(0.127)	-0.217*(0.123)
Climate change risk perception	0.414**(0.171)	0.637***(0.172)	0.306(0.191)
Age	0.029(0.036)	0.044(0.035)	-0.033(0.032)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	-0.002(0.141)	-0.069(0.144)	-0.091(0.150)
Male gender	0.216*(0.131)	0.037(0.159)	0.218(0.150)
Number of employees	0.039*(0.022)	0.035(0.026)	0.019(0.015)
Whole of farm plan	0.202*(0.122)	0.181(0.122)	0.324**(0.127)
Historic net rainfall	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	-0.213(0.216)	0.009(0.226)	-0.064(0.217)
Historic temperature volatility	-0.432(0.921)	-0.822(0.933)	-0.328(0.872)
Application rate	-0.003(0.013)	-0.014(0.013)	0.009(0.010)
Broadacre	0.102(0.215)	0.138(0.220)	-0.116(0.200)
Carry-over use between 2014-2016	-0.081(0.122)	0.298**(0.124)	-0.081(0.124)
Dairy	-0.104(0.227)	0.004(0.241)	-0.089(0.216)
Farm Size	-0.001(0.002)	-0.004**(0.002)	-0.003*(0.002)
Livestock	0.149(0.215)	0.159(0.222)	-0.072(0.209)
Majority of farm area under drainage	0.051(0.119)	0.004(0.127)	-0.112(0.125)
Majority of farm area under drip irrigation	-0.373*(0.195)	-0.460**(0.183)	-0.121(0.176)
Excess water	-0.127(0.133)	-0.179(0.135)	0.002(0.132)
Water ownership	0.029(0.036)	0.067*(0.037)	-0.063*(0.036)
Succession	0.308***(0.109)	0.404***(0.115)	0.474***(0.111)
past strategy	1.395***(0.103)	1.156***(0.118)	0.775***(0.110)
correlation between 2 and 1			0.396***(0.076)
correlation between 3 and 1			0.381***(0.070)
correlation between instrument and 1			-0.194*(0.117)
correlation between 3 and 2			0.545***(0.079)
correlation between instrument and 2			-0.332***(0.121)
correlation between instrument and 3			-0.298**(0.138)
Constant	-1.547(1.300)	-2.772**(1.274)	-0.126(1.164)
AIC	3636.111		
BIC	4309.067		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.26 Planned compound adaptation strategy land ownership 1 full model regression results

	(1)	(2)	(3)
	Compound strategy land 1		
VARIABLES	*Buy land in different region*	*Diversify*	*Sell land*
Farm debt	1.243**(0.622)	0.988**(0.473)	-0.121(0.488)
Farm debt squared	-0.756(0.465)	-0.709*(0.372)	0.435(0.384)
Farmland value	-0.200(0.391)	-0.316(0.283)	-0.060(0.270)
Farmland value squared	0.088(0.107)	0.113(0.082)	0.008(0.079)
Net farm income	-0.915(3.374)	2.405(2.558)	2.658(2.550)
Net farm income squared	3.237(12.581)	-9.877(9.659)	-13.463(9.764)
Number of insurances	-0.002(0.050)	0.033(0.039)	-0.017(0.040)
Off farm income	-0.004(0.003)	0.000(0.002)	0.002(0.002)
Productivity change	-0.026(0.058)	-0.026(0.044)	-0.108**(0.044)
Irrigation grant	0.268*(0.146)	-0.056(0.130)	0.055(0.125)
Climate change risk perception	0.385(0.256)	0.459***(0.175)	0.004(0.177)
Age	-0.000(0.042)	-0.003(0.037)	-0.009(0.036)
Age squared	-0.000(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.245(0.188)	-0.132(0.148)	0.334**(0.137)
Male gender	0.155(0.192)	0.032(0.157)	-0.010(0.152)
Number of employees	0.006(0.016)	0.003(0.021)	-0.046*(0.027)
Whole of farm plan	-0.003(0.165)	0.257*(0.136)	0.056(0.124)
Historic net rainfall	-0.001**(0.000)	-0.000(0.000)	0.000(0.000)
Average historic water allocation factor	-0.130(0.281)	0.070(0.222)	-0.307(0.228)
Historic temperature volatility	-1.115(1.513)	0.004(0.970)	2.343**(1.032)
Application rate	-0.054**(0.022)	-0.009(0.014)	0.002(0.012)
Broadacre	0.732***(0.269)	0.005(0.213)	-0.480**(0.222)
Carry-over use between 2014-2016	0.159(0.169)	-0.058(0.128)	-0.044(0.126)
Dairy	0.574*(0.313)	-0.315(0.235)	-0.302(0.235)
Farm Size	0.003(0.002)	-0.001(0.002)	0.001(0.002)
Livestock	0.497*(0.291)	-0.337(0.225)	-0.587***(0.224)
Majority of farm area under drainage	0.009(0.159)	0.157(0.127)	0.046(0.121)
Majority of farm area under drip irrigation	0.136(0.294)	-0.364*(0.188)	0.024(0.176)
Excess water	-0.158(0.191)	-0.026(0.140)	0.457***(0.123)
Water ownership	-0.037(0.043)	-0.030(0.038)	0.075**(0.038)
Succession	0.133(0.139)	0.254**(0.110)	-0.572***(0.118)
past strategy	1.362***(0.214)	1.630***(0.107)	0.415***(0.149)
correlation between 2 and 1			0.055(0.088)
correlation between 3 and 1			0.072(0.089)
correlation between instrument and 1			-0.126(0.171)
correlation between 3 and 2			0.006(0.075)
correlation between instrument and 2			-0.256**(0.122)
correlation between instrument and 3			-0.086(0.117)
Constant	-1.623(1.692)	-1.180(1.320)	-2.173*(1.292)
AIC	3321.018		
BIC	3993.974		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.27 Planned compound adaptation strategy land ownership 2 full model regression results

	(1)	(2)	(3)
	Compound strategy land 2		
VARIABLES	***Less irrigation***	***Sell entitlement***	***Sell land***
Farm debt	0.899(0.564)	-0.423(0.513)	-0.230(0.491)
Farm debt squared	-0.537(0.434)	0.495(0.397)	0.523(0.387)
Farmland value	-0.034(0.321)	-0.497*(0.288)	-0.043(0.265)
Farmland value squared	-0.005(0.091)	0.137*(0.083)	0.009(0.078)
Net farm income	3.667(3.216)	1.794(2.738)	2.838(2.551)
Net farm income squared	-10.575(12.084)	-7.490(10.230)	-14.308(9.674)
Number of insurances	-0.013(0.048)	0.020(0.041)	-0.017(0.040)
Off farm income	0.001(0.002)	-0.002(0.002)	0.002(0.002)
Productivity change	-0.302***(0.056)	-0.091*(0.047)	-0.110**(0.043)
Irrigation grant	-0.079(0.146)	0.054(0.134)	0.020(0.122)
Climate change risk perception	-0.060(0.249)	-0.221(0.160)	0.014(0.164)
Age	-0.072**(0.035)	0.021(0.037)	-0.011(0.036)
Age squared	0.001**(0.000)	-0.000(0.000)	0.000(0.000)
Low education	0.325**(0.162)	-0.056(0.147)	0.368***(0.135)
Male gender	-0.072(0.175)	0.018(0.166)	-0.015(0.151)
Number of employees	-0.004(0.022)	0.019(0.016)	-0.052**(0.025)
Whole of farm plan	0.179(0.144)	-0.098(0.132)	0.075(0.124)
Historic net rainfall	0.000(0.000)	-0.000(0.000)	0.000(0.000)
Average historic water allocation factor	0.009(0.286)	0.544**(0.264)	-0.322(0.220)
Historic temperature volatility	-0.259(1.081)	0.003(0.988)	2.318**(1.049)
Application rate	-0.004(0.013)	-0.011(0.010)	0.001(0.011)
Broadacre	-0.433(0.272)	0.052(0.214)	-0.516**(0.217)
Carry-over use between 2014-2016	0.124(0.155)	-0.113(0.129)	-0.029(0.124)
Dairy	-0.088(0.291)	-0.009(0.235)	-0.337(0.235)
Farm Size	-0.001(0.002)	0.000(0.002)	0.001(0.002)
Livestock	-0.273(0.275)	-0.135(0.229)	-0.602***(0.220)
Majority of farm area under drainage	0.245*(0.143)	0.244*(0.129)	0.040(0.121)
Majority of farm area under drip irrigation	0.287(0.222)	-0.197(0.185)	0.045(0.175)
Excess water	0.236(0.149)	0.548***(0.128)	0.428***(0.126)
Water ownership	0.028(0.046)	-0.029(0.040)	0.074**(0.037)
Succession	-0.292**(0.137)	-0.383***(0.117)	-0.603***(0.117)
past strategy	1.123***(0.125)	0.282***(0.108)	0.322**(0.140)
correlation between 2 and 1			0.353***(0.082)
correlation between 3 and 1			0.443***(0.083)
correlation between instrument and 1			-0.014(0.165)
correlation between 3 and 2			0.458***(0.074)
correlation between instrument and 2			0.178*(0.097)
correlation between instrument and 3			-0.095(0.107)
Constant	1.564(1.410)	-1.494(1.380)	-2.042(1.325)
AIC	3254.758		
BIC	3927.714		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.28 Planned compound adaptation strategy farm business full model regression results

	(1)	(2)	(3)
	Compound strategy business 1		
VARIABLES	***More collaboration***	***Change production***	***Diversify***
Farm debt	0.361(0.530)	1.053**(0.474)	0.993**(0.464)
Farm debt squared	-0.176(0.416)	-0.779**(0.372)	-0.691*(0.366)
Farmland value	-0.815***(0.312)	-0.337(0.258)	-0.230(0.283)
Farmland value squared	0.219**(0.089)	0.074(0.074)	0.089(0.082)
Net farm income	2.999(2.921)	1.994(2.501)	1.952(2.534)
Net farm income squared	-12.327(10.850)	-6.566(9.345)	-8.106(9.687)
Number of insurances	0.082*(0.047)	0.066(0.040)	0.022(0.039)
Off farm income	-0.003*(0.002)	-0.002(0.002)	-0.000(0.002)
Productivity change	0.060(0.048)	-0.065(0.044)	-0.024(0.045)
Irrigation grant	0.042(0.129)	0.010(0.123)	0.026(0.129)
Climate change risk perception	0.469**(0.208)	0.230(0.187)	0.459***(0.163)
Age	-0.006(0.034)	0.023(0.035)	-0.000(0.036)
Age squared	-0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Low education	-0.110(0.159)	0.012(0.151)	-0.151(0.147)
Male gender	0.107(0.166)	0.208(0.132)	0.016(0.157)
Number of employees	-0.010(0.015)	0.042*(0.021)	0.002(0.019)
Whole of farm plan	0.412***(0.152)	0.188(0.123)	0.262**(0.131)
Historic net rainfall	0.000(0.000)	-0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	-0.297(0.227)	-0.212(0.220)	0.079(0.222)
Historic temperature volatility	-0.252(1.032)	-0.333(0.980)	0.269(0.952)
Application rate	-0.011(0.014)	-0.002(0.012)	-0.011(0.013)
Broadacre	-0.395*(0.223)	0.107(0.222)	-0.014(0.212)
Carry-over use between 2014-2016	0.230*(0.136)	-0.035(0.125)	-0.070(0.128)
Dairy	-0.216(0.234)	-0.085(0.235)	-0.348(0.235)
Farm Size	0.003(0.002)	-0.001(0.002)	-0.001(0.001)
Livestock	-0.274(0.224)	0.131(0.222)	-0.341(0.220)
Majority of farm area under drainage	-0.040(0.137)	0.036(0.121)	0.164(0.124)
Majority of farm area under drip irrigation	-0.190(0.206)	-0.313(0.200)	-0.405**(0.185)
Excess water	-0.004(0.144)	-0.135(0.133)	-0.040(0.139)
Water ownership	-0.038(0.040)	0.012(0.036)	-0.036(0.038)
Succession	0.123(0.122)	0.278**(0.109)	0.228**(0.109)
past strategy	2.236***(0.173)	1.436***(0.100)	1.551***(0.102)
correlation between 2 and 1			0.234***(0.078)
correlation between 3 and 1			0.225***(0.076)
correlation between instrument and 1			-0.300*(0.154)
correlation between 3 and 2			0.598***(0.085)
correlation between instrument and 2			-0.030(0.125)
correlation between instrument and 3			-0.264**(0.114)
Constant	-0.858(1.292)	-1.374(1.274)	-1.421(1.288)
AIC	3419.504		
BIC	4092.305		
Observations	903	903	903

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.29 Planned compound adaptation strategy farm exit full model regression results

	(1)	(2)	(3)
	Compound strategy farm exit		
VARIABLES	***Farm exit***	***Sell land***	***Sell entitlement***
Farm debt	-0.812(0.535)	-0.210(0.491)	-0.586(0.514)
Farm debt squared	0.820*(0.419)	0.482(0.384)	0.613(0.397)
Farmland value	0.881***(0.305)	-0.039(0.269)	-0.453(0.287)
Farmland value squared	-0.244***(0.087)	0.009(0.078)	0.127(0.082)
Net farm income	1.201(2.798)	2.200(2.603)	1.320(2.741)
Net farm income squared	-9.144(10.485)	-12.174(9.860)	-6.177(10.254)
Number of insurances	0.035(0.048)	-0.016(0.041)	0.022(0.041)
Off farm income	-0.001(0.002)	0.001(0.002)	-0.003(0.002)
Productivity change	0.015(0.050)	-0.105**(0.044)	-0.087*(0.047)
Climate change risk perception	0.299(0.204)	0.074(0.204)	0.074(0.211)
Age	0.073**(0.036)	-0.009(0.036)	-0.009(0.036)
Age squared	-0.000(0.000)	0.000(0.000)	0.000(0.000)
Low education	0.120(0.163)	0.348**(0.163)	0.348**(0.138)
Male gender	0.377**(0.169)	-0.012(0.169)	-0.012(0.151)
Number of employees	-0.053**(0.023)	-0.041*(0.023)	-0.041*(0.023)
Whole of farm plan	-0.007(0.134)	0.057(0.134)	0.057(0.123)
Historic net rainfall	-0.000(0.000)	0.000(0.000)	0.000(0.000)
Average historic water allocation factor	-0.583**(0.250)	-0.292(0.250)	-0.292(0.226)
Historic temperature volatility	1.175(1.021)	2.302**(1.021)	2.302**(1.029)
Application rate	0.022(0.015)	0.004(0.015)	0.004(0.012)
Broadacre	-0.529***(0.205)	-0.462**(0.205)	-0.462**(0.221)
Carry-over use between 2014-2016	0.056(0.137)	-0.025(0.137)	-0.025(0.128)
Dairy	-0.308(0.226)	-0.301(0.226)	-0.301(0.236)
Farm Size	-0.002(0.003)	0.001(0.003)	0.001(0.002)
Livestock	-0.429*(0.220)	-0.582***(0.220)	-0.582***(0.225)
Majority of farm area under drainage	0.005(0.139)	0.041(0.139)	0.041(0.120)
Majority of farm area under drip irrigation	-0.005(0.190)	0.027(0.190)	0.027(0.175)
Excess water	0.160(0.154)	0.455***(0.154)	0.455***(0.125)
Water ownership	-0.053(0.035)	0.065*(0.035)	0.065*(0.036)
Succession	-0.727***(0.120)	-0.563***(0.120)	-0.563***(0.119)
past strategy	1.944***(0.124)	0.444***(0.144)	0.307***(0.106)
correlation between 2 and 1			0.392***(0.088)
correlation between 3 and 1			0.273***(0.082)
correlation between instrument and 1			-0.112(0.127)
correlation between 3 and 2			0.481***(0.078)
correlation between instrument and 2			-0.131(0.143)
correlation between instrument and 3			0.058(0.121)
Constant	-4.480***(1.309)	-2.147*(1.283)	-1.468(1.372)
AIC	3363.393		
BIC	4017.122		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.30 Planned compound adaptation strategy irrigation grant influence 1 full model regression results

	(1)	(2)	(3)
	Compound strategy irrigation grant 1		
VARIABLES	***Buy entitlement***	***Irrigation grant***	***More irrigation***
Farm debt	1.251***(0.466)	-0.618(0.471)	1.075**(0.468)
Farm debt squared	-0.819**(0.362)	0.570(0.365)	-0.766**(0.362)
Farmland value	0.152(0.273)	0.039(0.267)	-0.258(0.273)
Farmland value squared	-0.015(0.077)	0.011(0.075)	0.079(0.077)
Net farm income	3.261(2.511)	-1.740(2.619)	-0.021(2.540)
Net farm income squared	-7.457(9.335)	4.206(9.761)	-1.458(9.470)
Number of insurances	0.124***(0.040)	-0.010(0.038)	0.066*(0.040)
Off farm income	-0.003*(0.002)	-0.003(0.002)	-0.002(0.002)
Productivity change	0.061(0.044)	0.138***(0.047)	0.127***(0.045)
Climate change risk perception	0.209(0.194)	0.034(0.184)	0.224(0.186)
Age	0.007(0.033)	-0.028(0.032)	-0.028(0.032)
Age squared	-0.000(0.000)	0.000(0.000)	0.000(0.000)
Low education	0.117(0.154)	-0.097(0.153)	-0.026(0.153)
Male gender	0.309**(0.152)	-0.139(0.156)	0.197(0.150)
Number of employees	0.039**(0.020)	0.014(0.015)	0.015(0.014)
Whole of farm plan	0.142(0.122)	0.231*(0.125)	0.320**(0.128)
Historic net rainfall	-0.001**(0.000)	0.000(0.000)	0.000(0.000)
Average historic water allocation factor	0.432*(0.226)	-0.109(0.247)	-0.020(0.224)
Historic temperature volatility	-1.197(0.932)	-3.875***(0.897)	-0.162(0.887)
Application rate	-0.005(0.013)	0.001(0.011)	0.011(0.010)
Broadacre	-0.264(0.220)	-0.004(0.210)	-0.058(0.205)
Carry-over use between 2014-2016	0.134(0.128)	0.125(0.130)	-0.112(0.127)
Dairy	-0.447*(0.237)	-0.262(0.216)	-0.007(0.222)
Farm Size	-0.001(0.002)	-0.003(0.002)	-0.003*(0.002)
Livestock	-0.131(0.224)	-0.174(0.220)	-0.001(0.215)
Majority of farm area under drainage	0.243*(0.127)	0.429***(0.126)	-0.161(0.122)
Majority of farm area under drip irrigation	-0.210(0.187)	0.347*(0.189)	-0.110(0.177)
Excess water	-0.364**(0.147)	-0.160(0.135)	-0.007(0.130)
Water ownership	-0.106***(0.037)	0.124***(0.042)	-0.075**(0.036)
Succession	0.266**(0.111)	0.089(0.110)	0.485***(0.109)
past strategy	1.051***(0.127)		0.842***(0.112)
correlation between 2 and 1			0.053(0.070)
correlation between 3 and 1			0.338***(0.069)
correlation between instrument and 1			-0.233*(0.134)
correlation between 3 and 2			-0.100(0.071)
correlation between instrument and 2			0.076(0.122)
correlation between instrument and 3			-0.238*(0.127)
Constant	-1.989(1.253)	2.058*(1.158)	-0.310(1.173)
AIC	3716.53		
BIC	4360.645		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table C.31 Planned compound adaptation strategy irrigation grant influence 2 full model regression results

	(1)	(2)	(3)
	Compound strategy irrigation grant 2		
VARIABLES	***Change production***	***Irrigation grant***	***More irrigation***
Farm debt	1.045**(0.478)	-0.611(0.472)	1.151**(0.464)
Farm debt squared	-0.793**(0.371)	0.566(0.365)	-0.836**(0.358)
Farmland value	-0.399(0.258)	0.041(0.268)	-0.260(0.271)
Farmland value squared	0.092(0.074)	0.011(0.075)	0.082(0.077)
Net farm income	1.741(2.541)	-1.657(2.618)	0.521(2.550)
Net farm income squared	-6.799(9.461)	3.911(9.752)	-3.913(9.528)
Number of insurances	0.071*(0.040)	-0.009(0.038)	0.066*(0.039)
Off farm income	-0.003(0.002)	-0.003*(0.002)	-0.002(0.002)
Productivity change	-0.071(0.044)	0.138***(0.047)	0.116***(0.045)
Climate change risk perception	0.373**(0.180)	0.020(0.188)	0.229(0.196)
Age	0.028(0.036)	-0.029(0.032)	-0.033(0.031)
Age squared	-0.000(0.000)	0.000(0.000)	0.000(0.000)
Low education	0.001(0.143)	-0.100(0.152)	-0.064(0.152)
Male gender	0.223*(0.132)	-0.137(0.156)	0.226(0.152)
Number of employees	0.036*(0.021)	0.014(0.015)	0.018(0.015)
Whole of farm plan	0.198(0.122)	0.229*(0.125)	0.321**(0.128)
Historic net rainfall	-0.000(0.000)	0.000(0.000)	-0.000(0.000)
Average historic water allocation factor	-0.216(0.218)	-0.104(0.247)	-0.029(0.224)
Historic temperature volatility	-0.406(0.915)	-3.870***(0.895)	-0.078(0.887)
Application rate	-0.001(0.013)	0.001(0.011)	0.009(0.010)
Broadacre	0.112(0.216)	-0.009(0.210)	-0.093(0.202)
Carry-over use between 2014-2016	-0.082(0.123)	0.130(0.130)	-0.088(0.124)
Dairy	-0.083(0.229)	-0.270(0.217)	-0.048(0.219)
Farm Size	-0.001(0.002)	-0.003(0.002)	-0.003(0.002)
Livestock	0.154(0.218)	-0.179(0.220)	-0.066(0.212)
Majority of farm area under drainage	0.057(0.120)	0.428***(0.126)	-0.155(0.123)
Majority of farm area under drip irrigation	-0.349*(0.193)	0.339*(0.189)	-0.121(0.176)
Excess water	-0.119(0.133)	-0.155(0.135)	0.006(0.131)
Water ownership	0.027(0.036)	0.123***(0.042)	-0.075**(0.035)
Succession	0.298***(0.109)	0.085(0.110)	0.473***(0.110)
past strategy	1.428***(0.103)		0.831***(0.112)
correlation between 2 and 1			0.005(0.071)
correlation between 3 and 1			0.376***(0.071)
correlation between instrument and 1			-0.164(0.122)
correlation between 3 and 2			-0.110(0.072)
correlation between instrument and 2			0.089(0.126)
correlation between instrument and 3			-0.241*(0.138)
Constant	-1.542(1.281)	2.083*(1.157)	-0.303(1.156)
AIC	3754.728		
BIC	4398.843		
Observations	904	904	904

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix D Supplementary material for Chapter 6

Table D.1 Glossary of key terms for chapter 6

Term	***Explanation***
Barmah Choke trade restriction	Due to a geo-hydrological phenomenon near the town of Barmah (Barmah Choke), only around 7,000 ML/day can be transferred from the important upstream storages Dartmouth and Hume dam to the lower Murray catchment in New South Wales and Victoria (Zone 10 to 11, and Zone 6 to 7) and the significant horticultural planting areas of Sunraysia and Riverland downstream (MDBA 2019c)
Carry-over	Arrangements which allow water entitlement holders to hold water in storages (water allocations not taken in a water accounting period) so that it is available in subsequent years (ACCC 2010)
Counterparty risk	The risk that a counterparty defaults on a contractual agreement (Pirrong 2011)
Delivery share	The legal, and tradeable, right to have water delivered within an irrigation system, region or trust run by an irrigation infrastructure operator (Wheeler et al. 2014a)
Financial investors	Financial investors are individuals or businesses without land ownership who generate their income through trading or leasing water to other parties. Although most financial investors own large portfolios of water entitlements, some generate their income purely through water trading without owning entitlements.
Inter-valley trade restriction (IVT)	The maximum amount of water transferrable between two catchments, either due to hydrological or legal considerations (MDBA 2010c)
Investors/agri-corporates	Investors/agri-corporates are individuals or businesses with large water entitlement and/or land ownership, generating their main income (in a normal year) through primary production
Long-term average annual yield factor (LTAAY)	LTAAY is the long-term annual average volume of water permitted to be taken for consumptive use under a water access entitlement. Currently all LTAAY figures are calculated using the long-term diversion limit equivalent factors, with these factors to be accredited in finalised state water resource plans (Cheesman and Wheeler 2012)
Parking	A contractual arrangement permitting the buyer to store their water allocation on the carry-over of the seller, usually from one water accounting period to the next (ABARES 2018)
Risk premium	The monetary premium a forward/option seller charges above the spot price to compensate for the extra risk they bear through the contractual arrangement (Gaydon et al. 2012)
Spill risk	The risk of losing carried over water in the event that a water storage is full and needs to release water for storage security purposes (Productivity Commission 2010)
Spot price	The market price of a given good/commodity on the day. This usually refers to the allocation price in the water market (Bayer and Loch 2017)
Supply risk	The risk associated with uncertainty in future water supply (Bjornlund 2006)
Tagged Trading	Water entitlement holders can establish a “tag”, changing the extraction location of allocations associated with an entitlement to a different region/zone than the zone of the entitlement (system of origin). Water extracted under a tag can only be used, not sold, and gets delivered through a “tagged trade”. This delivery can be exempt from inter-valley trade restrictions (MDBA 2010d)

Unbundling	The legal separation of rights to land and rights to access water, have water delivered, use water on land or operate water infrastructure, all of which can be traded separately (ACCC 2010)
Unregulated river system	Rivers without major storages or rivers where the storages do not release water downstream (Wheeler et al. 2014a)
Water allocation	Also called temporary water, the seasonal allocation received by a given water entitlement (Wheeler et al. 2014a)
Water entitlement	Also called permanent water, a right to extract water from a watercourse/body every year, subject to climatic conditions. Some water entitlements provide access to carry-over. Water entitlements come in different securities, with high security yielding a full allocation in 90-95 of 100 years, general security 42-81 of 100 years, and low security 20-35 of 100 years. Supplementary and conveyance entitlements only yield water in flood years. Unregulated entitlements are in unregulated river systems (Cheesman and Wheeler 2012)
Water forward	A contractual arrangement whereby the seller guarantees to deliver a defined volume of allocation, for a predetermined price, at a predetermined point in time in the future to the buyer. The buyer guarantees to honour the contract (Bayer and Loch 2017)
Water future	Water futures currently do not exist in the MDB. Futures are similar to forwards in that the seller guarantees to deliver a defined volume of allocation, for a predetermined price, at a predetermined point in time in the future to the buyer. The difference is that futures are exchange traded: the central clearing house collects collateral deposits from the counterparties and guarantees contract delivery in case of counterparty default. For most futures, the difference between the spot price and price agreed in the future contract is credited/debited daily to the counterparties' accounts (daily cash settlement) (Pirrong 2011)
Water lease	A contractual arrangement whereby the lease taker (lessee) receives all allocation attributed to a leased water entitlement. The entitlement remains property of the lease giver (lessor) (ABARES 2018)
Water option	A contractual arrangement whereby the buyer has the option, but not obligation, to deliver/have delivered a defined volume of allocation, for a predetermined price, at a predetermined point in time the future to/by the seller (Wheeler et al. 2013a)

Table D.2 Data sources and corresponding analyses

Data source	***Year***	***Observations***	***Analysis***	***Figures/Tables***
Irrigator telephone survey	2015-16	1,000 irrigators	Entitlement ownership, entitlement ownership diversification, carry-over, allocation and entitlement trading	Figure 2 Table 2
Semi-structured qualitative expert interviews	2018-19	63 expert interviews (with mainly 38 of them used in this paper)	Water ownership motivation and strategies, water trading strategies, water market design improvements	Figure 2 Table 2 Table 3 Table 4 Table 5
Water market transaction data	2018-19	BOM trade data (Murrumbidgee allocations and entitlements) Victorian Water Register trade data (Goulburn allocations and entitlements) H2Ox: private register data (forwards and parking)	Water forward and parking trade	Table 1

Appendix E Supplementary material for Chapter 7

Table E.1 Glossary of key terms for chapter 7

Term	***Explanation***
“Dry” water entitlement sale	Transfer of a water entitlement without any water allocation or carry-over volume as part of the transaction. The price reported to the water register only refers to the water entitlement itself.
“Thin” market/ Illiquid market	A market with only a few sellers and buyers, and a limited number of transactions. Water markets are often thin due to hydrological constraints to trade (Tisdell 2011)
“Wet” water entitlement sale	Transfer of a water entitlement which includes some volume of water allocation or carry-over. The price reported to the water register may contain the price of allocation (Deloitte 2019).
Bona fide/non-anxious/genuine seller/buyer and reasonable terms/ordinary circumstances and arm’s length transaction	These expressions mean largely the same. A bona fide transaction is between willing but not anxious buyer/seller, who have a reasonable period to negotiate the transaction with the property reasonably exposed to the market (*Land Valuation Bill 2010* (QLD)). Forced transactions, e.g. from mortgagor default, or transactions between businesses under the same ownership are not bona fide or at arm’s length.
Carry-over	Arrangements which allow water entitlement holders to hold water in storages (water allocations not taken in a water accounting period) so that it is available in subsequent years (ACCC 2010)
Impairment of an intangible asset and impairment testing	If the market value of an intangible asset is lower than its book value, this gets accounted for as an impairment loss equalling the difference between the values. If the market value of an intangible asset is higher than the book value, no impairment or adjustment is made (AASB 2019b). Intangible assets get tested for impairment annually, or when there is indication that the asset may be impaired
Long-term average annual yield factor (LTAAY)	LTAAY is the long-term annual average volume of water permitted to be taken for consumptive use under a water access entitlement. Currently all LTAAY figures are calculated using the long-term diversion limit equivalent factors, with these factors to be accredited in finalised state water resource plans (Cheesman and Wheeler 2012)
Overland flow entitlements	Allows water extraction only when there is a flood that goes over the banks of the rivers and brings water onto the properties where the entitlements are held (Grafton and Williams 2019)
Supplementary water entitlement	Supplementary water, formerly known as off-allocation water, is surplus flow that cannot be captured, or ‘re-regulated’, into storages. When storm events result in flows that cannot be captured in storages, and the water is not needed to meet current demands or commitments, then regulated rivers become unregulated for a period of time. Supplementary water entitlement holders can only pump water against these licences during these periods (DPIE 2019)

Supplemented water entitlement	An entitlement to water from major infrastructure that is owned and operated by a Water Supply Provider. Supplemented entitlements have a higher reliability than unsupplemented entitlements (Hargraves et al. 2013)
Unbundling	The legal separation of rights to land and rights to access water, have water delivered, use water on land or operate water infrastructure, all of which can be traded separately (ACCC 2010)
Unregulated river system	Rivers without major storages or rivers where the storages do not release water downstream (Wheeler et al. 2014a)
Unsupplemented water entitlement	An entitlement to take water from higher level river flows (i.e. in excess of supplemented water allocation requirements) that is managed by the resource manager (Hargraves et al. 2013)
Water allocation	Also called temporary water, the seasonal allocation received by a given water entitlement (Cheesman and Wheeler 2012)
Water entitlement	Also called permanent water, a right to extract water from a watercourse/body every year, subject to climatic conditions. Some water entitlements provide access to carry-over. Water entitlements come in different securities, with high security yielding a full allocation in 90-95 of 100 years, general security 42-81 of 100 years, and low security 20-35 of 100 years. Supplementary and conveyance entitlements only yield water in flood years. Unregulated entitlements are in unregulated river systems (Cheesman and Wheeler 2012)
Zero price trade	Trades submitted to the water register with a AUD$0 price. While there are legitimate instances of zero price trades (for example, the transfer of an entitlement between trading zones by the same owner), it seems common practice for sellers to deliberately misreport the price of trades as zero dollars (MDBA 2019m)

Table E.2 Land and water entitlement valuation legislation

Act/Bill	State(s) and relevance for water entitlement valuation
Land Valuation Bill 2010	QLD: value of rural land is the unimproved value of the land in a "bona fide" transaction, water allocation (entitlement) value is part of the land value.
Natural Resources Management Act 2004	SA: amended in 2009 for unbundling of water from land, makes no provisions for water entitlement valuation, allows for a caveat to be put on a water entitlement, makes no provisions for forced water entitlement sales.
Rates Act 2004	ACT: value of rural land is the unimproved value of land in a transaction at "reasonable terms", no separate provision for water entitlements.
Valuation of Land Act 1916	NSW: value of rural land is the unimproved value from a transaction at "reasonable terms" by "bona fide" seller/buyer, value of water access licence (entitlement) included in land value (not used since unbundling), water access licence value assessed excluding allocation (not used since unbundling).
Valuation of Land Act 1960	VIC: value of rural land is value of sale by "genuine seller" in "ordinary circumstances" of comparable properties, valuation can include every information the valuer deems relevant to take into account.
Valuation of Land Act 1971	SA: value of rural land is the unimproved value realised by "reasonable" sale for comparable properties, no separate provision for water, land valuation necessary every five years.
Water Act 1989	VIC: introduced water trade, determines valuation of water shares (entitlement) needs to be done by a valuer, dictates the order of distributing the proceeds of a forced water share sale between the interest holders, determines the method to calculate and exit fee in an irrigation district, enables mortgages on water shares and defines the rights of the mortgagee.
Water Act 2000	QLD: mentions market value of water allocation (entitlement) for compensation purposes, makes no provisions for water allocation valuation, allows for a caveat to be put on water allocation, makes no provisions for forced water entitlement sales.
Water Act 2007	Commonwealth: unbundled water from land, mentions "market value" of water entitlements, method to determine change in "market value" subject to "regulations".
Water Management Act 2000	NSW: developed water access licences (entitlements), makes no provision for the valuation of water access licences, allows for a

	caveat to be put on an access licence, determines the order of distributing the proceeds of a forced water access licence sale between the interest holders.
Water Resources Act 2007	ACT: makes no provisions for water entitlement valuation or security interests in water entitlements.

References

AAS (2019), *Investigation of the causes of mass fish kills in the Menindee Region NSW over the summer of 2018-2019*, Australian Academy of Science, Canberra, pp. 1-162.

AASB (1995), *Definition and Recognition of the Elements of Financial Statements,* Australian Accounting Standards Board, Melbourne.

AASB (2019a), *Fair Value Measurement*, (AASB 13), Australian Accounting Standards Board, Melbourne.

AASB (2019b), *Intangible Assets,* (AASB 138), Australian Accounting Standards Board, Melbourne.

AASB (2019c), *Presentation of Financial Statements,* (AASB 101), Australian Accounting Standards Board, Melbourne.

ABA (2019), *Almond Insights 2018-19*, Almond Board of Australia, Loxton, pp. 1-20.

ABARES (2011), *Modelling the economic effects of the Murray-Darling Basin Plan*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, pp. 1-109.

ABARES (2014), *Irrigated agriculture in the southern Murray–Darling Basin - Murrumbidgee, Murray and Goulburn–Broken regions 2006–07 to 2012–13,* Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, pp. 1-35.

ABARES (2017), *Irrigated agriculture in the Murray-Darling Basin: an economic survey of irrigators, 2013-14 to 2015-16*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, pp. 1-20.

ABARES (2018), *Australian Water Markets Report 2016-17*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, pp. 1-44.

ABARES (2019a), *About the Australian water markets report 2015-16*, Australian Bureau of Agricultural and Resource Economics and Sciences, accessed 10/03/2020, <https://www.agriculture.gov.au/abares/research-topics/water/aust-water-markets-reports/awmr-2015-16/about>.

ABARES (2019b), *Southern Murray–Darling Basin*, Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra, pp. 1-26.

Abid, M, Schneider, UA and Scheffran, J (2016), 'Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan', *Journal of Rural Studies*, 47, pp. 254-266.

ABS (2016), *Water Use on Australian Farms 2015-16*, Australian Bureau of Statistics, Canberra, pp. 1-2.

ABS (2019a), *Australian Environmental-Economic Accounts, 2019*, Australian Bureau of Statistics, Canberra.

ABS (2019b), *Gross Value of Irrigated Agricultural Production, 2017-18,* Australian Bureau of Statistics, Canberra, pp. 1-10.

ABS (2019c), *Water Use on Australian Farms, 2017-18,* Australian Bureau of Statistics, Canberra, pp. 1-8.

ACCC (2010), *Water trading rules - final advice*, Australian Competition & Consumer Commission, Canberra, pp. 1-325.

ACCC (2011), *ACCC Water Monitoring Report 2009-10,* Australian Competition & Consumer Commission, Canberra, pp. 1-178.

ACCC (2016), *Review of the Water Charge Rules: Final Advice*, Australian Competition & Consumer Commission, Canberra, pp. 1-403.

ACCC (2017), *ACCC Water Monitoring Report 2015-2016,* Australian Competition & Consumer Commission, Canberra, pp. 1-201.

ACCC (2019a), *ACCC inquiry into water markets in the Murray-Darling Basin - Issues Paper*, Australian Competition & Consumer Commission, Canberra, pp. 1-21.

ACCC (2019b), *Water Monitoring Report 2017-18,* Australian Competition & Consumer Commission, Canberra, pp. 1-165.

Adamson, D and Loch, A (2014), 'Possible negative feedbacks from ‘gold-plating’ irrigation infrastructure', *Agricultural Water Management*, 145, pp. 134-144.

Adamson, D and Loch, A (2018), 'Achieving environmental flows where buyback is constrained', *Australian Journal of Agricultural and Resource Economics,* 62 (1), pp. 83-102.

Adamson, D, Loch, A and Schwabe, K (2017), 'Adaptation responses to increasing drought frequency', *Australian Journal of Agricultural and Resource Economics*, 61 (3), pp. 385-403.

Adamson, D, Mallawaarachchi, T and Quiggin, J (2009), 'Declining inflows and more frequent droughts in the Murray–Darling Basin: climate change, impacts and adaptation', *Australian Journal of Agricultural and Resource Economics,* 53 (3), pp. 345-366.

Adamson, D, Quiggin, J and Quiggin, D (2011), *Water Supply Variability & Sustainable Diversions Limits: Issues to Consider in Developing the Murray-Darling Basin Plan*, Australian Bureau of Agricultural and Resource Economics and Sciences, Brisbane, pp. 1-60.

Adger, NW, Agrawala, S, Mirza, MMQ, Conde, C, O’Brien, K, Pulhin, J, Pulwarty, R, Smit, B and Takahashi, K (2007), 'Assessment of adaptation practices, options, constraints and capacity', in ML Parry, OF Canziani, JP Palutikof, CE Hanson and PJ van der Linden (eds), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, pp. 717-743.

Adger, NW, Arnell, NW and Tompkins, EL (2005), 'Successful adaptation to climate change across scales', *Global Environmental Change*, 15 (2), pp. 77-86.

AFI (2019), *Change in the air: defining the need for an Australian agricultural climate change strategy*, Australian Farm Institute, Surry Hills, pp. 1-78.

Aither (2016), *Supply-side drivers of water allocation prices: Identifying and modelling supply-side drivers of water allocation prices in the southern Murray-Darling Basin*, Aither, Canberra, pp. 1-52.

Ajzen, I (1991), 'The theory of planned behavior', *Organizational Behavior and Human Decision Processes*, 50 (2), pp. 179-211.

Ajzen, I (2012), 'Martin Fishbein's Legacy: The Reasoned Action Approach', *The ANNALS of the American Academy of Political and Social Science*, 640 (1), pp. 11-27.

Alam, K (2015), 'Farmers' adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh', *Agricultural Water Management*, 148, pp. 196-206.

Aldenderfer, MS and Blashfield, RK (1984), *Cluster Analysis*, Quantitative Applications in the Social Sciences, SAGE, Thousand Oaks, California.

Alston, M and Kent, J (2004), *Social impacts of drought*, Centre for Rural Social Research, Charles Sturt University, Wagga Wagga, pp. 1-147.

Ancev, T (2015a), 'The role of the commonwealth environmental water holder in annual water allocation markets', *Australian Journal of Agricultural and Resource Economics*, 59 (1), pp. 133-153.

Ancev, T (2015b), 'Water Markets, Environmental Flows, and Adaptation to Climate Change', *Water Economics and Policy*, 01 (03), p. 1550016.

Arbuckle, JG, Morton, LW and Hobbs, J (2013), 'Farmer beliefs and concerns about climate change and attitudes toward adaptation and mitigation: Evidence from Iowa', *Climatic Change*, 118 (3), pp. 551-563.

Argilés Bosch, JM, Aliberch, AS and Blandón, JG (2012), 'A Comparative Study of Difficulties in Accounting Preparation and Judgement in Agriculture Using Fair Value and Historical Cost for Biological Assets Valuation', *Revista de Contabilidad*, 15 (1), pp. 109-142.

ASIC (2018), *ASIC Market Integrity Rules (Security Markets) 2017*, Australian Securities & Investment Commission, Brisbane.

Aslin, H and Russell, J (2008), *Social impact of drought: Review of literature,* Bureau of Rural Sciences, Canberra, pp. 1-100.

ATO (2019), *Register of foreign Ownership of Water Entitlements: Report of registrations as at 30 June 2018*, Australian Taxation Office, Canberra, pp. 1-22.

Australian Property Institute (2016), *Mortgage Valuations which include a water component – NSW Member reminder*, Australian Property Institute, accessed 15/07/2019, <https://www.api.org.au/news/mortgage-valuations-which-include-a-water-component-nsw-member-reminder>.

Australian Property Institute (2017), 'Technical Information Paper - Market Value of Rural and Agribusiness Properties'), Australian Property Institute, Deakin, pp. 1-21, viewed 06/05/2019.

AWBA (2019a), *AWBA response to Almond Board of Australia's allegations of price fixing*, Australian Water Brokers Association, 10/09/2019, Shepparton.

AWBA (2019b), *Code of Conduct*, Australian Water Brokers Association, Shepparton, pp. 1-5.

Awotide, BA, Alene, AD, Abdoulaye, T and Manyong, VM (2015), 'Impact of agricultural technology adoption on asset ownership: the case of improved cassava varieties in Nigeria', *Food Security*, 7 (6), pp. 1239-1258.

Azad, MAS and Ancev, T (2020), 'Assessing the dynamics of natural capital on farms: A soil natural capital indicator', *Ecological Economics*, 168, p. 106500.

Baines, P (1998), 'Australia's Climate Cerberus: The puzzle of three oceans', *ECOS*, 97, pp. 22-25.

Baker, D, Dunn, A, Doucouliagos, A, Olszak, C and Gormly, R (2017), *Water Markets Report: 2016-17 review and 2017-18 outlook*, Aither, Melbourne, pp. 1-41.

Bark, R, MacDonald, DH, Connor, J, Crossman, N and Jackson, S (2011), 'Water values', in I Prosser (ed.), *Water: science and solutions for Australia*, CSIRO Publishing, Collingwood, pp. 17-27.

Barlev, B and Haddad, JR (2003), 'Fair Value Accounting and the management of the firm', *Critical Perspectives on Accounting*, 14 (4), pp. 383-415.

Bayer, RC and Loch, A (2017), 'Experimental evidence on the relative efficiency of forward contracting and tradable entitlements in water markets', *Water Resources and Economics*, 20, pp. 1-15.

Bazeley, P (2013), *Qualitative data analysis with NVivo*, Second edition / Pat Bazeley and Kristi Jackson. edn, ed. K Jackson, SAGE, London.

Beal, GM, Rogers, EM and Bohlen, JM (1957), 'Validity of the Concept of Stages in the Adoption Process', *Rural Sociology*, 22 (2), pp. 166-168.

Beare, S and Heaney, A 2002, 'Climate change and water resources in the Murray Darling Basin, Australia', in *Conference paper*, Citeseer, vol. 2.

Begley, P (2017), 'Top water bureaucrat Gavin Hanlon resigns after corruption allegations', *The Sydney Morning Herald*, 16/09/2017.

Below, TB, Mutabazi, KD, Kirschke, D, Franke, C, Sieber, S, Siebert, R and Tscherning, K (2012), 'Can farmers' adaptation to climate change be explained by socio-economic household-level variables?', *Global Environmental Change,* 22 (1), pp. 223-235.

Bichler, M, Fux, V and Goeree, JK (2019), 'Designing combinatorial exchanges for the reallocation of resource rights', *Proceedings of the National Academy of Sciences*, 116 (3), pp. 786-791.

Biernacki, P and Waldorf, D (1981), 'Snowball sampling: Problems and techniques of chain referral sampling', *Sociological Methods & Research*, 10 (2), pp. 141-163.

Bjornlund, H 1999, 'Water trade policies as a component of environmentally, socially and economically sustainable water use in rural Southeastern Australia', PhD thesis, University of South Australia, Adelaide.

Bjornlund, H (2002), 'The Socio-economic structure of Irrigation Communities – water markets and the structural adjustment process', *Rural Society*, 12 (2), pp. 123-147.

Bjornlund, H (2004), 'Formal and informal water markets: Drivers of sustainable rural communities?', *Water Resources Research*, 40 (9), pp. 1-12.

Bjornlund, H (2006), 'Can water markets assist irrigators Managing Increased Supply Risk? Some Australian experiences', *Water International,* 31 (2), pp. 221-232.

Bjornlund, H (2007), 'Do markets promote more efficient and higher value water use? Tracing evidence over time in an Australian water market', in *Water resources management IV*, 103, WIT Press, pp. 477-489.

Bjornlund, H and McKay, J (2002), 'Aspects of water markets for developing countries: experiences from Australia, Chile, and the US', *Environment and Development Economics*, 7 (4), pp. 769-795.

Bjornlund, H and Rossini, P (2007), 'An Analysis of the Returns from an Investment in Water Entitlements in Australia', *Pacific Rim Property Research Journal*, 13 (3), pp. 344-360.

Bjornlund, H, Wheeler, S and Cheesman, J (2011), 'Irrigators, water trading, the environment and debt: Buying water entitlements for the environment', in D Connell and QR Grafton (eds), *Basin Futures: Water reform in the Murray-Darling Basin*, ANU Press, Canberra, pp. 291-302.

Bjornlund, H, Wheeler, SA and Rossini, P (2012), 'Water markets and their environmental, social and economic impacts in Australia', in J Maestu (ed.), *Water Trading and Global Water Scarcity*, Routledge, pp. 88-113.

BOM (2019a), *Entitlement Trade History - Murray-Darling Basin 2015-2017*, Bureau of Meteorology, accessed 22/05/2019, <http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/et>.

BOM (2019b), *National Water Account 2018 - Murray-Darling Basin*, Australian Bureau of Meteorology, accessed 09/08/2019, <http://www.bom.gov.au/water/nwa/2018/mdb/climateandwater/climateandwater.shtml#About_the_region>.

BOM (2019c), *Trade History - Murray-Darling Basin 2018-2019*, Bureau of Meteorology, accessed 27/08/2019, <http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/et>.

BOM (2019d), *Trade History - southern Murray-Darling Basin*, Bureau of Meteorology, accessed 12/11/2019, <http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/et>.

BOM (2020a), *About water markets*, Bureau of Meteorology, accessed 10/03/2020, <http://www.bom.gov.au/water/market/about.shtml>.

BOM (2020b), *Climate change and extremes*, Bureau of Meteorology, accessed 03/03/2020, <http://www.bom.gov.au/climate/change/#tabs=Tracker&tracker=timeseries&tQ=graph%3Drranom%26area%3Dmdb%26season%3D0706%26ave_yr%3D0>.

BOM (2020c), *Drought: Rainfall deficiencies and water availability*, Bureau of Meteorology, accessed 07/04/2020, <http://www.bom.gov.au/climate/drought/>.

BOM (2020d), *National Water Account*, Bureau of Meteorology, accessed 26/02/2020, <http://www.bom.gov.au/water/nwa/about.shtml>.

BOM (2020e), *National Water Account 2018 - Murray–Darling Basin: Geographic information*, Bureau of Meteorology, accessed 23/03/2020, <http://www.bom.gov.au/water/nwa/2018//mdb/regiondescription/geographicinformation.shtml>.

BOM (2020f), *National Water Account 2018: Murray–Darling Basin*, Bureau of Meteorology, Canberra.

BOM (2020g), *Water Markets Dashboard*, Bureau of Meteorology, accessed 10/03/2020, <http://www.bom.gov.au/water/dashboards/#/water-markets/mdb/et>.

Botterill, LC (2003), 'Uncertain Climate: The Recent History of Drought Policy in Australia', *Australian Journal of Politics & History*, 49 (1), pp. 61-74.

Botterill, LC (2005), 'Late twentieth century approaches to living with uncertainty: the national drought policy', in *From Disaster Response to Risk Management*, Springer, Dodrecht, pp. 51-64.

Botterill, LC (2010), 'Risk management as policy. The experience of Australia's National Drought Policy', in A López-Francos (ed.), *Economics of Drought and Drought Preparedness in Climate Change Context*, Zaragoza, pp. 241-248.

Botterill, LC and Chapman, B (2002), 'Developing equitable and affordable government responses to drought in Australia', *Centre for Economic Policy Research Discussion Paper*, 455).

Botterill, LC, Chapman, B and Kelly, S (2017), 'Revisiting revenue contingent loans for drought relief: government as risk manager', *Australian Journal of Agricultural and Resource Economics*, 61 (3), pp. 367-384.

Bowmer, K (2014), 'Water resources in Australia: deliberation on options for protection and management', *Australasian Journal of Environmental Management*, 21 (3), pp. 228-240.

Bradshaw, B, Dolan, H and Smit, B (2004), 'Farm-level adaptation to climatic variability and change: crop diversification in the Canadian prairies', *Climatic Change*, 67 (1), pp. 119-141.

Brennan, D (2008), 'Missing markets for storage and the potential economic cost of expanding the spatial scope of water trade', *Australian Journal of Agricultural and Resource Economics*, 52 (4), pp. 471-485.

Briers, M, Luckett, P and Chow, C (1997), 'Data Fixation and the Use of Traditional Versus Activity-Based Costing Systems', *Abacus*, 33 (1), pp. 49-68.

Brooks, N and Adger, NW (2005), 'Assessing and enhancing adaptive capacity', in B Lim, I Burton, E Malone and S Huq (eds), *Adaptation policy frameworks for climate change: Developing strategies, policies and measures*, Cambridge University Press, New York, pp. 165-181.

Bryan, E, Deressa, TT, Gbetibouo, GA and Ringler, C (2009), 'Adaptation to climate change in Ethiopia and South Africa: options and constraints', *Environmental Science & Policy*, 12 (4), pp. 413-426.

Bryan, E, Ringler, C, Okoba, B, Roncoli, C, Silvestri, S and Herrero, M (2013), 'Adapting agriculture to climate change in Kenya: Household strategies and determinants', *Journal of Environmental Management*, 114, pp. 26-35.

Burritt, RL and Christ, KL (2017), 'The need for monetary information within corporate water accounting', *Journal of Environmental Management*, 201, pp. 72-81.

Business.gov.au (2019), *Technology helping farmers - new web and mobile based app launched*, Commonwealth of Australia, accessed 22/10/2019, <https://www.business.gov.au/news/technology-helping-farmers-new-web-and-mobile-based-app-launched>.

Caliński, T and Harabasz, J (1974), 'A dendrite method for cluster analysis', *Communications in Statistics-theory and Methods*, 3 (1), pp. 1-27.

Carey, JM and Sunding, DL (2001), 'Emerging markets in water: a comparative institutional analysis of the Central Valley and Colorado-Big Thompson Projects', *Natural Resources Journal*), pp. 283-328.

Carmody, E (2018), 'Managing our scarce water resources: recent developments in the Murray-Darling Basin', *Law Society Journal*, 51), pp. 75-77.

Carr, B, Nias, D, Fitzsimons, J and Gilmore, R 2016, 'The Murray-Darling Basin Balanced Water Fund and the Environmental Water Trust–using markets and innovative financing to restore wetlands and floodplains in the Murray-Darling Basin for financial, social and environmental outcomes', in *Proceedings of the 8th Australian Stream Management Conference, edited by GJ Vietz, AJ Flatley and I. D. Rutherford. Leura*, vol. 31.

CEWH (2018), *Submission to the Productivity Commission's Murray-Darling Basin Plan: Five-year assessment*, Commonwealth Environmental Water Holder, Canberra, pp. 1-13.

CEWO (2013), *Framework for Determining Commonwealth Environmental Water Use*, Commonwealth Environmental Water Office, Canberra, pp. 1-26.

CEWO (2014), *Commonwealth environmental water Trading Framework*, Commonwealth Environmental Water Office, Canberra, pp. 1-20.

CEWO (2017), *Development of a Framework for Investing in Environmental Activities*, Commonwealth Environmental Water Office, Canberra, pp. 1-22.

CEWO (2019), *Commonwealth Environmental Water Portfolio Management Planning: Approach to planning for the use, carryover and trade of Commonwealth environmental water*, Commonwealth Environmental Water Office, Canberra, pp. 1-25.

CEWO (2020a), *About Commonwealth environmental water*, Commonwealth Environmental Water Office, accessed 14/03/2020, <https://www.environment.gov.au/water/cewo/about-commonwealth-environmental-water>.

CEWO (2020b), *Past trades*, Commonwealth Environmental Water Office, accessed 01/04/2020, <https://www.environment.gov.au/water/cewo/trade/trading-outcomes>.

Chalmers, K, Godfrey, J and Potter, B (2012), 'Discipline-Informed Approaches to Water Accounting', *Australian Accounting Review*, 22 (3), pp. 275-285.

Chavas, J-P and Nauges, C (2020), 'Uncertainty, Learning, and Technology Adoption in Agriculture', *Applied Economic Perspectives and Policy*, 42 (1), pp. 42-53.

Cheesman, J and Wheeler, SA (2012), *Survey of water entitlement sellers under the Restoring The Balance in the Murray-Darling Basin Program*, Department of Sustainability Environment, Water, Population and Comunities, Canberra, pp. 1-85.

Chiew, F, Young, W, Cai, W and Teng, J (2011), 'Current drought and future hydroclimate projections in southeast Australia and implications for water resources management', *Stochastic Environmental Research and Risk Assessment*, 25 (4), pp. 601-612.

Christ, KL (2014), 'Water management accounting and the wine supply chain: Empirical evidence from Australia', *The British Accounting Review*, 46 (4), pp. 379-396.

Christ, KL and Burritt, RL (2017a), 'Water management accounting: A framework for corporate practice', *Journal of Cleaner Production*, 152, pp. 379-386.

Christ, KL and Burritt, RL (2017b), 'What Constitutes Contemporary Corporate Water Accounting? A Review from a Management Perspective', *Sustainable Development*, 25 (2), pp. 138-149.

COAG (1994), *The Council of Australian Governments' Water Reform Framework*, Hobart.

COAG (2004a), *Intergovernmental Agreement on a National Water Initiative*, Canberra.

COAG (2004b), *Intergovernmental Agreement on Addressing Water over-allocation and Achieving Environmental Objectives in the Murray-Darling Basin*, Council of Australian Governments, Canberra, pp. 1-12.

Coase, RH (1960), 'The Problem of Social Cost', *The Journal of Law and Economics*, 3, pp. 1-44.

Connell, D (2007), *Water politics in the Murray-Darling Basin*, Federation Press, Alexandria, NSW.

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

Connor, JD, Franklin, B, Loch, A, Mirby, M and Wheeler, SA (2013), 'Trading water to improve environmental flow outcomes', *Water Resources Research*, 49 (7), pp. 4265-4276.

Connor, JD, Kandulu, JM and Bark, RH (2014), 'Irrigation revenue loss in Murray–Darling Basin drought: An econometric assessment', *Agricultural Water Management*, 145, pp. 163-170.

Connor, JD, Schwabe, K, King, D and Knapp, K (2012), 'Irrigated agriculture and climate change: The influence of water supply variability and salinity on adaptation', *Ecological Economics*, 77, pp. 149-157.

Cooper, B, Crase, L and Pawsey, N (2014), 'Water tariffs and farmer adaptation: The case of Goulburn-Murray Water, Victoria, Australia', in JP Palutikof, SL Boulter, J Barnett and D Rissik (eds), *Applied Studies in climate Adaptation*, John Wiley & Sons, Chichester, pp. 156-165.

Corbin, J and Strauss, A (2015), *Basics of qualitative research : techniques and procedures for developing grounded theory*, 4 edn, SAGE Publications, Thousand Oaks.

Cosier, P, Flannery, T, Hillman, T, Hughes, L, Lindenmayer, D, Karoly, D, Pittock, J, Possingham, H, Purves, R, Saunders, D, Thom, B and Wilder, M (2017), *Review of water reform in the Murray-Darling Basin*, Wentworth Group of Concerned Scientists, Sydney, pp. 1-318.

Crase, L (2011), 'The fallout to the guide to the proposed basin plan', *Australian Journal of Public Administration*, 70 (1), pp. 84-93.

Crase, L (2019), 'Up the creek: the $85 million plan to desalinate water for drought relief', *The Conversation*, 14/11/2019, pp. 1-5.

Crase, L and Cooper, B (2015), 'Politics, socio-economics and water allocations: a note on the limits of Integrated Water Resources Management', *Australasian Journal of Environmental Management*, 22 (4), pp. 388-399.

Crase, L and O'Keefe, S (2009), 'The paradox of national water savings: a critique of'Water for the Future'', *Agenda: A Journal of Policy Analysis and Reform*), pp. 45-60.

Crase, L, O’Keefe, S, Wheeler, S and Kinoshita, Y (2014), 'Water trading in Australia: understanding the role of policy and serendipity', in *Routledge Handbook of Water Economics and Institutions*, Routledge, pp. 312-329.

Crase, L, Pawsey, N and Cooper, B (2015), 'Water Pricing in Australia: Unbundled Politics, Accounting, and Water Pricing', in A Dinar, V Pochat and J Albiac-Murillo (eds), *Water Pricing Experiences and Innovations*, Springer International Publishing, Cham, pp. 15-39.

Creswell, J (1998), *Qualitative inquiry and research design: Choosing among five traditions*, SAGE Publications, Thousand Oaks.

Creswell, J (2003), *Research Design: Qualitative, quantitative, and mixed methods approaches*, 2nd edn, SAGE Publications, London.

Creswell, J and Plano Clark, VL (2011), *Designing and conducting mixed method research.*, 2nd edn, SAGE Publishing, Thousand Oaks, CA.

CSIRO (2008), *Water Availability in the Murray-Darling Basin. A report from CSIRO to the Australian Government*, Commonwealth Scientific and Industrial Research Organisation, Canberra, pp. 1-68.

CSIRO (2012), *Climate and water availability in south-eastern Australia: A synthesis of findings from Phase 2 of the South-Eastern Australian Climate initiative (SEACI)*, Commonwealth Scientific and Industrial Research Organisation, Caberra, pp. 1-44.

D'Emden, FH, Llewellyn, RS and Burton, MP (2006), 'Adoption of conservation tillage in Australian cropping regions: An application of duration analysis', *Technological Forecasting and Social Change*, 73 (6), pp. 630-647.

DA (2019), *Exceptional Circumstances Programs*, Department of Agriculture, accessed 27/03/2020, <https://www.agriculture.gov.au/ag-farm-food/drought/drought-policy/history/business-support>.

DAFF (2014), *The Evolution of drought policy in Western Australia*, Department of Agriculture and Food, Perth, pp. 1-52.

Daghagh Yazd, S, Wheeler, SA and Zuo, A (2019), 'Exploring the Drivers of Irrigator Mental Health in the Murray–Darling Basin, Australia', *Sustainability*, 11 (21), p. 6097.

Damodaran, A (2012a), 'Understanding Financial Statements', in A Damodaran (ed.), *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, 3 edn, John Wiley & Sons, New York, pp. 27-57.

Damodaran, A (2012b), 'Valuing Other Assets', in A Damodaran (ed.), *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, 3 edn, John Wiley & Sons, New York, pp. 766-780.

Damodaran, A (2012c), 'Valuing Real Estate', in A Damodaran (ed.), *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, 3 edn, John Wiley & Sons, New York, pp. 739-765.

Dang, HL, Li, E, Bruwer, J and Nuberg, I (2014), 'Farmers' perceptions of climate variability and barriers to adaptation: lessons learned from an exploratory study in Vietnam', *Mitigation and Adaptation Strategies for Global Change*, 19 (5), pp. 531-548.

Davies, A (2019a), 'Murray-Darling basin plan given reprieve by states but NSW says it will miss deadline', *The Guardian Australia*, 17/12/2019.

Davies, A (2019b), 'New questions raised over calculations behind $80m water buyback', *The Guardian*, 25/04/2019, pp. 1-3.

Davies, A (2020), 'Government to spend millions buying water from company it already paid $80m', *The Guardian*, 26/02/2020.

Davies, J and Burns, A (2019), 'As rivers and dams dry up, groundwater emerges as new battleground in fight for water', *ABC News*, 13/10/2019, pp. 1-6.

Davis, RJ and Koop, K (2006), 'Eutrophication in Australian Rivers, Reservoirs and Estuaries – A Southern Hemisphere Perspective on the Science and its Implications', *Hydrobiologia*, 559, pp. 23-76.

DAWE (2019a), *Commonwealth water purchasing in Murray-Darling Basin*, Department of Agriculture, Water and the Environment, accessed 02/03/2020, <https://www.agriculture.gov.au/water/markets/commonwealth-water-mdb>.

DAWE (2019b), *Environmental Works and Measures Feasibility Program*, Department of Agriculture, Water and the Environment, accessed 01/03/2020, <https://www.agriculture.gov.au/water/mdb/programs/basin-wide/environmental-works-measures>.

DAWE (2019c), *Sustainable Diversion Limit (SDL) adjustment mechanism and its implementation*, Department of Agriculture, Water and the Environment, accessed 02/03/2020, <https://www.agriculture.gov.au/water/mdb/policy/sdl-adjustment-mechanism>.

DAWE (2019d), *Water for Fodder - Program Guidelines*, Department for Agriculture, Water and the Environment, Canberra, pp. 1-19.

DAWE (2020a), *Project Agreement to produce water from the Adelaide Desalination Plant to support the Water for Fodder Program*, Department of Agriculture, Water and the Environment, Canberra, pp. 1-8.

DAWE (2020b), *Surface water recovery under the Basin Plan as at 31 December 2019*, Department of Agriculture, Water and the Environment, accessed 14/04/2020, <https://www.agriculture.gov.au/water/mdb/progress-recovery/progress-of-water-recovery>.

DAWE (2020c), *Water for Fodder*, Department of Agriculture, Water and the Environment, accessed 10/04/2020, <https://www.agriculture.gov.au/water/mdb/programs/basin-wide/water-for-fodder>.

DAWR (2018), *Background information on significant Commonwealth strategic water purchases in 2017*, Department of Agriculture and Water Resources, accessed 20/09/2018, <http://www.agriculture.gov.au/about/media-centre/on-the-record/background-significant-commonwealth-strategic-water-purchases-2017>.

DAWR (2019), *Media statement on Eastern Australian Agriculture water purchase*, Department of Agriculture and Water Resources, 19/04/2019, Canberra.

de Bonviller, S, Zuo, A and Wheeler, SA (2019), 'Is there evidence of insider trading in Australian water markets?', *Australian Journal of Agricultural and Resource Economics*, 63 (2), pp. 307-327.

de Roest, K, Ferrari, P and Knickel, K (2018), 'Specialisation and economies of scale or diversification and economies of scope? Assessing different agricultural development pathways', *Journal of Rural Studies*, 59, pp. 222-231.

de Sousa, W, Ducrot, R, Munguambe, P, Bjornlund, H, Machava, A, Cheveia, E and Faduco, J (2017), 'Irrigation and crop diversification in the 25 de Setembro irrigation scheme, Mozambique', *International Journal of Water Resources Development*, 33 (5), pp. 705-724.

Deloitte (2019), *Independent Assurance Report to the Members of Murray-Darling Basin Authority: Part 2*, Deloitte, Sydney, pp. 1-9.

DELWP (2014), *Understanding the Goulburn to Murray trade limit*, Department of Environment, Land, Water and Planning, accessed 12/03/2020, <https://waterregister.vic.gov.au/about/news/171-understanding-the-goulburn-to-murray-trade-limit>.

DELWP (2018), *Opportunities to trade from the Goulburn to the Murray, including use of tagged accounts*, Department of Environment, Land, Water and Planning, 20/02/2018, Melbourne.

DELWP (2019a), *Updated trends in the Northern Victorian water trade 2001-2018*, Department of Environment, Land, Water and Planning, Melbourne, pp. 1-40.

DELWP (2019b), *Victorian Water Register*, Department of the Environment, Land, Water and Planning, accessed 16/10/2019, <https://waterregister.vic.gov.au/water-trading/water-share-trading>.

DELWP (2019c), *Water market transparency: Options paper*, Department of Environment, Land, Water and Planning, Melbourne, pp. 1-38.

DELWP (2020a), *Changes to the Goulburn to Murray trade rule - Consultation Paper*, Department of Environment, Land, Water and Planning, Melbourne, pp. 1-20.

DELWP (2020b), *Victorian Water Register - Water share trading*, Department of Environment, Land, Water and Planning, accessed 26/02/2020, <https://waterregister.vic.gov.au/water-trading/water-share-trading>.

Deressa, TT, Hassan, RM, Ringler, C, Alemu, T and Yesuf, M (2009), 'Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia', *Global Environmental Change*, 19 (2), pp. 248-255.

DEWHA (2010), *Securing our Water Future*, Department for the Environment, Water, Heritage and the Arts, Canberra, pp. 1-24.

Dinar, A, Rosegrant, MW and Meinzen-Dick, R (1997), *Water allocation mechanisms: principles and examples*, The World Bank, New York.

Dinh, H, Daly, A and Freyens, B (2017), 'Farm adjustment strategies to water-related challenges in the Murray-Darling Basin', *Policy Studies*, 38 (5), pp. 482-501.

Dixon, PB, Rimmer, MT and Wittwer, G (2011), 'Saving the Southern Murray-Darling Basin: The Economic Effects of a Buyback of Irrigation Water', *Economic Record*, 87 (276), pp. 153-168.

Doolan, J, Davidson, D, Harriss, D, Hillman, T, Simpson, P and Turner, G (2019), *Independent Panel for Capacity Project Review: Report to Murray Darling Basin Ministerial Council*, Murray-Darling Basin Ministerial Council, Canberra, pp. 1-27.

Douglas, EM, Wheeler, SA, Smith, DJ, Overton, IC, Gray, SA, Doody, TM and Crossman, ND (2016), 'Using mental-modelling to explore how irrigators in the Murray–Darling Basin make water-use decisions', *Journal of Hydrology: Regional Studies*, 6, pp. 1-12.

Doyle, K (2019), 'Murray-Darling Basin in 'most severe' two-to-three year drought conditions in 120 years of records, BOM says', *ABC News*, 19/07/2019, Weather, pp. 1-4.

DPI (2016), *Broken Hill Long-Term Water Supply Solution: Final Business Case*, NSW Department of Primary Industries, Sydney, pp. 1-178.

DPI (2018), *Murrumbidgee Inter-Valley Trade account (IVT)*, Department of Industry NSW, accessed 29/07/2019, <https://www.industry.nsw.gov.au/__data/assets/pdf_file/0018/209412/murrumbidgee-ivt-fact-sheet.pdf>.

DPIE (2019), *Water in New South Wales: Supplementary water*, Department of Planning, Industry and Environment, accessed 11/11/2019, <https://www.industry.nsw.gov.au/water/allocations-availability/allocations/how-water-is-allocated/supplementary-water>.

DPIE (2020), *Menindee Lakes Water Saving Project*, NSW Department of Planning, Industry and Environment, accessed 02/03/2020, <https://www.industry.nsw.gov.au/water/plans-programs/water-recovery-programs/sustainable-diversion-limits/menindee-lakes>.

Duda, RO, Hart, PE and Stork, DG (2012), *Pattern classification*, John Wiley & Sons.

Duffie, D and Zhu, H (2011), 'Does a Central Clearing Counterparty Reduce Counterparty Risk?', *The Review of Asset Pricing Studies*, 1 (1), pp. 74-95.

Easter, KW, Rosegrant, MW and Dinar, A (1999), 'Formal and informal markets for water: institutions, performance, and constraints', *The World Bank Research Observer*, 14 (1), pp. 99-116.

Elders (2019), 'Water trading terms and conditions'), Elders, Adelaide, pp. 1-6.

Ellis, F (2000), *Rural livelihoods and diversity in developing countries*, 1 edn, Oxford University Press, New York.

Ellsberg, D (1961), 'Risk, Ambiguity, and the Savage Axioms', *The Quarterly Journal of Economics*, 75 (4), pp. 643-669.

Fankhauser, S, Smith, JB and Tol, RS (1999), 'Weathering climate change: some simple rules to guide adaptation decisions', *Ecological Economics*, 30 (1), pp. 67-78.

Feder, G, Just, RE and Zilberman, D (1985), 'Adoption of agricultural innovations in developing countries: A survey', *Economic Development and Cultural Change*, 33 (2), pp. 255-298.

Feder, G and Slade, R (1984), 'The Acquisition of Information and the Adoption of New Technology', *American Journal of Agricultural Economics*, 66 (3), pp. 312-320.

Feola, G, Lerner, AM, Jain, M, Montefrio, MJF and Nicholas, KA (2015), 'Researching farmer behaviour in climate change adaptation and sustainable agriculture: Lessons learned from five case studies', *Journal of Rural Studies*, 39, pp. 74-84.

Fielding, KS, Terry, DJ, Masser, BM and Hogg, MA (2008), 'Integrating social identity theory and the theory of planned behaviour to explain decisions to engage in sustainable agricultural practices', *British Journal of Social Psychology*, 47 (1), pp. 23-48.

Fischer, AJ, Arnold, AJ and Gibbs, M (1996), 'Information and the Speed of Innovation Adoption', *American Journal of Agricultural Economics*, 78 (4), pp. 1073-1081.

Fisher, DE (2010), 'Water law, the High Court and techniques of judicial reasoning', *Environmental and Planning Law Journal*, 27 (2), pp. 85-97.

Foerster, A (2011), 'Developing Purposeful and Adaptive Institutions for Effective Environmental Water Governance', *Water Resources Management*, 25 (15), pp. 4005-4018.

Four Corners 2017, *Pumped: Who's benefitting from the billions spent on the Murray-Darling?*, Television, 24/07/2017, Australian Broadcasting Corporation, <http://www.abc.net.au/4corners/pumped/8727826>.

Four Corners 2019, *Cash Splash*, Television, 08/07/2019, Australian Broadcasting Corporation, <https://www.abc.net.au/4corners/cash-splash/11289412>.

Frontier Economics (2009), *Changing extraction location between water systems - 'tagging' and alternatives*, Frontier Economics, Melbourne, pp. 1-82.

Frydenberg, J (2019), *Competition and Consumer (Price Inquiry— Water Markets in the Murray-Darling Basin) Direction 2019*, Canberra.

Fuessel, H-M and Klein, RJT (2006), 'Climate change vulnerability assessments: an evolution of conceptual thinking', *Climatic Change*, 75, pp. 301-329.

Fuglie, KO and Kascak, CA (2001), 'Adoption and Diffusion of Natural-Resource-Conserving Agricultural Technology', *Applied Economic Perspectives and Policy*, 23 (2), pp. 386-403.

Fulton, J, Norton, M and Shilling, F (2019), 'Water-indexed benefits and impacts of California almonds', *Ecological Indicators*, 96, pp. 711-717.

Gadédjisso-Tossou, A (2015), 'Understanding Farmers’ Perceptions of and Adaptations to Climate Change and Variability: The Case of the Maritime, Plateau and Savannah Regions of Togo', *Agricultural Sciences*, 06 (12), pp. 1441-1454.

Gandure, S, Walker, S and Botha, JJ (2013), 'Farmers' perceptions of adaptation to climate change and water stress in a South African rural community', *Environmental Development*, 5, pp. 39-53.

García de Jalón, S, Silvestri, S and Barnes, AP (2017), 'The potential for adoption of climate smart agricultural practices in Sub-Saharan livestock systems', *Regional Environmental Change*, 17 (2), pp. 399-410.

Gardner, DB and Fullerton, HH (1968), 'Transfer restrictions and misallocations of irrigation water', *American Journal of Agricultural Economics*, 50 (3), pp. 556-571.

Garrick, D, Whitten, SM and Coggan, A (2013), 'Understanding the evolution and performance of water markets and allocation policy: A transaction costs analysis framework', *Ecological Economics*, 88, pp. 195-205.

Gaydon, DS, Meinke, H, Rodriguez, D and McGrath, DJ (2012), 'Comparing water options for irrigation farmers using Modern Portfolio Theory', *Agricultural Water Management*, 115, pp. 1-9.

Gbetibouo, GA, Hassan, RM and Ringler, C (2010), 'Modelling farmers' adaptation strategies for climate change and variability: The case of the Limpopo Basin, South Africa', *Agrekon*, 49 (2), pp. 217-234.

Ghadim, AKA and Pannell, D (1999), 'A conceptual framework of adoption of an agricultural innovation', *Agricultural Economics*, 21 (2), pp. 145-154.

Ghadim, AKA, Pannell, D and Burton, MP (2005), 'Risk, uncertainty, and learning in adoption of a crop innovation', *Agricultural Economics*, 33 (1), pp. 1-9.

GMW (2018), *2018/19 Prices: Annual Fees and Charges*, Goulburn-Murray Water, Tatura, pp. 1-4.

GMW (2019), *Yarrawonga Weir*, Goulburn-Murray Water, accessed 17/10/2019, <https://www.g-mwater.com.au/water-resources/catchments/storages/murray/yarrawongaweir>.

Godfrey, JM and Chalmers, K (eds) 2012, *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK.

Goesch, T, Donoghoe, M and Hughes, N (2019), *Snapshot of Australian Water Markets*, ABARES, Canberra, pp. 1-9.

Gooch, D, Ball, G and Roberts, G (2020), 'Murray-Darling Basin war of words over northern irrigators extracting water from potential river flows', *ABC Broken Hill*, 07/02/2020.

Grafton, QR (2010), 'How to increase the cost-effectiveness of water reform and environmental flows in the Murray-Darling Basin', *Agenda: A Journal of Policy Analysis and Reform*), pp. 17-40.

Grafton, QR (2019), 'Policy review of water reform in the Murray–Darling Basin, Australia: the “do's” and “do'nots”', *Australian Journal of Agricultural and Resource Economics*, 63 (1), pp. 116-141.

Grafton, QR (2020), 'While towns run dry, cotton extracts 5 Sydney Harbours' worth of Murray Darling water a year. It's time to reset the balance', *The Conversation*, 14/04/2020, pp. 1-5.

Grafton, QR, Chu, L and Wyrwoll, P (2020a), 'The paradox of water pricing: dichotomies, dilemmas, and decisions', *Oxford Review of Economic Policy*, 36 (1), pp. 86-107.

Grafton, QR, Colloff, MJ, Marshall, V and Williams, J (2020b), 'Confronting a 'Post-Truth Water World' in the Murray-Darling Basin, Australia', *Water Alternatives*, 13 (1), pp. 1-28.

Grafton, QR and Horne, J (2014a), '8. Water markets in the Murray-Darling Basin', in RQ Grafton, P Wyrwoll, W Chris and D Allendes (eds), *Global Water: Issues and Insights*, Australian National university Press.

Grafton, QR and Horne, J (2014b), 'Water markets in the Murray-Darling Basin', *Agricultural Water Management*, 145, pp. 61-71.

Grafton, QR, Horne, J and Wheeler, SA (2016), 'On the Marketisation of Water: Evidence from the Murray-Darling Basin, Australia', *Water Resources Management*, 30 (3), pp. 913-926.

Grafton, QR and Jiang, Q (2009), *Economics of drought, water diversions, water recovery and climate change in the Murray–Darling Basin*, pp. 10-01.

Grafton, QR, Libecap, G, McGlennon, S, Landry, C and O'Brien, B (2011), 'An Integrated Assessment of Water Markets: A Cross-Country Comparison', *Review of Environmental Economics and Policy*, 5 (2), pp. 219-239.

Grafton, QR, Pittock, J, Williams, J, Jiang, Q, Possingham, H and Quiggin, J (2014a), 'Water planning and hydro-climatic change in the Murray-Darling Basin, Australia', *Ambio*, 43 (8), p. 1082.

Grafton, QR and Wheeler, SA (2015), 'Water economics', in R Halvorsen and DF Layton (eds), *Handbook on the Economics of Natural Resources*, Edward Elgar, Cheltenham, pp. 401-420.

Grafton, QR and Wheeler, SA (2018), 'Economics of Water Recovery in the Murray-Darling Basin, Australia', *Annual Review of Resource Economics*, 10 (1), pp. 487-510.

Grafton, QR and Williams, J (2019), 'Rent-seeking behaviour and regulatory capture in the Murray-Darling Basin, Australia', *International Journal of Water Resources Development*), pp. 1-21.

Grafton, QR, Williams, J, Perry, C, Molle, F, Ringler, C, Steduto, P, Udall, B, Wheeler, SA, Wang, Y, Garrick, D and Allen, G (2018), 'The paradox of irrigation efficiency', *Science*, 361 (6404), pp. 748-750.

Grafton, QR, Wyrwoll, P, White, C and Allendes, D (2014b), *Global water: issues and insights*, ANU E Press.

Greene, WH (2008), *Econometric analysis*, 6th (International) ed. edn, Pearson/Prentice Hall, Upper Saddle River, N.J.

Griffin, RC (2016), *Water resource economics : the analysis of scarcity, policies, and projects*, Analysis of scarcity, policies, and projects, 2 edn, MIT Press, Cambridge, Massachusetts.

Griliches, Z (1957), 'Hybrid Corn: An Exploration in the Economics of Technological Change', *Econometrica*, 25 (4), pp. 501-522.

Guest, C (2016), *Sharing the water : one hundred years of River Murray politics*, MDBA publication ; no: 43/16, Murray-Darling Basin Authority, Canberra, Australian Capital Territory.

H2OX (2019a), *Fees*, H2OX, accessed 25/07/2019, <https://h2ox.com/fees/>.

H2OX (2019b), *Parking*, H2OX, accessed 23/10/2019, <https://h2ox.com/water-products/parking/>.

Haensch, J, Wheeler, SA and Zuo, A (2016a), 'The Contribution of Spacial Analysis to Water Management: A Case Study of the Murray-Darling Basin, Australia', in JA Daniels (ed.), *Advances in Environmental Research*, 51, Nova Science Publishers, New York.

Haensch, J, Wheeler, SA and Zuo, A (2019), 'Do neighbors influence irrigators' permanent water selling decisions in Australia?', *Journal of Hydrology*, 572, pp. 732-744.

Haensch, J, Wheeler, SA, Zuo, A and Bjornlund, H (2016b), 'The Impact of Water and Soil Salinity on Water Market Trading in the Southern Murray–Darling Basin', *Water Economics and Policy*, 2 (1), pp. 1-26.

Hallows, PJ and Thompson, DG (1995), *history of irrigation in Australia*, ANCID.

Hanemann, WM (2006), 'The economic conception of water', in P Rogers and R Llamas (eds), *Water Crisis: myth or reality*, Taylor & Francis, New York, pp. 61-92.

Hannam, P (2019), ''Disdain': Anger as Broken Hill pipe business case finally released', *The Sydney Morning Herald*, 15/08/2019.

Hardaker, JB (2015), *Coping with Risk in Agriculture: Applied Decision Analysis*, Coping with Risk in Agriculture, 3 edn, eds G Lien, JR Anderson and RBM Huirne, CABI, Wallingford.

Hardin, G (1968), 'The Tragedy of the Commons', *Science*, 162 (3859), pp. 1243-1248.

Hargraves, C, Goudie, S and Farrington, O (2013), *Queensland Murray Darling Basin Environmental Works and Measures Feasibility Program: Summary Report for Milestones 3 and 6 - Delivery of feasibility and pre-feasibility investigations.*, Department of Natural Resources and Mines, Brisbane, pp. 1-41.

Harrison, PA, Holman, IP, Cojocaru, G, Kok, K, Kontogianni, A, Metzger, MJ and Gramberger, M (2013), 'Combining qualitative and quantitative understanding for exploring cross-sectoral climate change impacts, adaptation and vulnerability in Europe', *Regional Environmental Change*, 13 (4), pp. 761-780.

Hart, BT (2016), 'The Australian Murray–Darling Basin Plan: challenges in its implementation (Part 2)', *International Journal of Water Resources Development*, 32 (6), pp. 835-852.

Harvey, CA, Rakotobe, ZL, Rao, NS, Dave, R, Razafimahatratra, H, Rabarijohn, RH, Rajaofara, H and MacKinnon, JL (2014), 'Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369 (1639).

Hatt, M, Heyhoe, E and Whittle, L (2012), *Options for insuring Australian agriculture*, Australian Bureau of Agricultural and Resource Economics and Sciences Canberra, pp. 1-38.

Hayne, KM (2019), *Royal Commission into Misconduct in the Banking, Superannuation and Financial Services Industry - Final Report*, Royal Commission into Misconduct in the Banking, Superannuation and Financial Services Industry, Canberra, pp. 1-530.

Hoekstra, AY (2012), 'Water Footprint Accounting', in J Godfrey and K Chalmers (eds), *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK, pp. 58-75.

Hoepfl, MC (1997), 'Choosing qualitative research: A primer for technology education researchers', *Journal of Technology Education*, 9 (1), pp. 47-63.

Hogan, A, Berry, HL, Ng Peng, S and Bode, A (2011), *Decisions Made by Farmers that Relate to Climate Change*, Rural Industries Research and Development Corporation, Canberra, pp. 1-78.

Horne, A, O'Donnell, EL, Loch, A, Adamson, D, Hart, B and Freebairn, J (2018), 'Environmental water efficiency: Maximizing benefits and minimizing costs of environmental water use and management', *Wiley Interdisciplinary Reviews: Water*, 5 (4), p. e1285.

Howe, CW (1999), 'Protecting public values in a water market setting: improving water markets to increase economic efficiency and equity', *University of Denver Water Law Review*, 3, p. 357.

Howe, CW, Schurmeier, DR and Shaw Jr, WD (1986), 'Innovative approaches to water allocation: the potential for water markets', *Water Resources Research*, 22 (4), pp. 439-445.

Huffman, WE (2020), 'Human Capital and Adoption of Innovations: Policy Implications', *Applied Economic Perspectives and Policy*, 42 (1), pp. 92-99.

Hunt, P (2017), 'Water gushes through Olam 'tag' loophole', *Weekly Times*, 15/03/2017, Water, pp. 1-3.

Hunt, P (2019a), 'Investors 'stay out'', *The Weekly Times*, 01/05/2019, p. 4.

Hunt, P (2019b), 'Murray water surges to $700/ML as irrigators' rush to secure water', *The Weekly Times*, 22/08/2019, Water, pp. 1-2.

Hunt, P (2020), 'Choke on water sales', *The Weekly Times*, 18/03/2020, pp. 1-2.

Iftekhar, MS, Tisdell, JG and Connor, J (2013), 'Effects of competition on environmental water buyback auctions', *Agricultural Water Management*, 127, pp. 59-73.

IIGMDBWR (2020), *Current Inquiry*, Interim Inspector-General Murray-Darling Basin Water Resources, accessed 02/03/2020, <https://www.igmdb.gov.au/reviews>.

IPCC (2014), *Climate Change 2014: Synthesis Report*, Intergovernmental Panel on Climate Change, Geneva, pp. 1-169.

IPCC (2019), *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, Intergovernmental Panel on Climate Change, Geneva, pp. 1-1542.

ISA (2017), *Driving super fund investment in agriculture: discussion paper*, Industry Super Australia, Canberra, pp. 1-71.

Jackson, S (2011), 'Aboriginal access to water in Australia: opportunities and constraints', in RQ Grafton (ed.), *Water Resources, Planning and Management, Cambridge University Press, Cambridge*, Cambridge University, Cambridge, pp. 601-628.

Jäger, J, Rounsevell, MDA, Harrison, PA, Omann, I, Dunford, R, Kammerlander, M and Pataki, G (2015), 'Assessing policy robustness of climate change adaptation measures across sectors and scenarios', *Climatic Change*, 128 (3), pp. 395-407.

Jiang, Q and Grafton, QR (2012), 'Economic effects of climate change in the Murray–Darling Basin, Australia', *Agricultural Systems*, 110, pp. 10-16.

Jianjun, J, Wang, X and Yiwei, G (2015), 'Gender differences in farmers' responses to climate change adaptation in Yongqiao District, China', *Science of the Total Environment*, 538, pp. 942-948.

Karimi, P, Molden, D, Bastiaanssen, W and Cai, X (2012), 'Water accounting to assess use and productivity of water: evolution of a concept and new frontiers', in J Godfrey and K Chalmers (eds), *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK, pp. 76-90.

Kariuki, M and Schwartz, J (2005), *Small-Scale Private Service Providers Of Water Supply And Electricity : A Review Of Incidence, Structure, Pricing, And Operating Characteristics*, Policy Research Working Paper No. 3727, World Bank, Washington, DC.

Karp, P (2020), 'Coalition's axing of funding to climate change adaptation body condemned', *The Guardian Australia*, 16/01/2020, Environment.

Kassie, M, Teklewold, H, Jaleta, M, Marenya, P and Erenstein, O (2015), 'Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa', *Land Use Policy*, 42, pp. 400-411.

Kendall, M (2013), 'Drought and its role in shaping water policy in Australia', in *Drought in Arid and Semi-Arid Regions*, Springer, pp. 451-467.

Khan, S, Rana, T, Hanjra, MA and Zirilli, J (2009), 'Water markets and soil salinity nexus: Can minimum irrigation intensities address the issue?', *Agricultural Water Management*, 96 (3), pp. 493-503.

Kiem, AS (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 (6), pp. 1615-1626.

Kingsford, RT (2000), 'Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia', *Austral Ecology*, 25 (2), pp. 109-127.

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

Kirby, M, Connor, J, Ahmad, M-uD, Gao, L and Mainuddin, M (2015), 'Irrigator and Environmental Water Management Adaptation to Climate Change and Water Reallocation in the Murray–Darling Basin', *Water Economics and Policy*, 1 (3), pp. 1-31.

Kirby, M, Connor, J, Ahmad, M, Gao, L and Mainuddin, M (2014b), 'Climate change and environmental water reallocation in the Murray–Darling Basin: Impacts on flows, diversions and economic returns to irrigation', *Journal of Hydrology*, 518, pp. 120-129.

Knapp, KC, Weinberg, M, Howitt, R and Posnikoff, JF (2003), 'Water transfers, agriculture, and groundwater management: a dynamic economic analysis', *Journal of Environmental Management*, 67 (4), pp. 291-301.

Knight, FH (1933), *Risk, uncertainty and profit*, Houghton Mifflin Co., Boston.

Knudson, MK (1991), 'Incorporating Technological Change in Diffusion Models', *American Journal of Agricultural Economics*, 73 (3), pp. 724-733.

Kuehne, G, Bjornlund, H and Cheers, B (2008), 'Identifying common traits among Australian irrigators using cluster analysis', *Water Science and Technology*, 58 (3), pp. 587-595.

Lawrence, M, Somerset, G and Slonim, R (2019), *Rebuilding the FHA: a better way forward for supporting farmers in financial hardship, an independent review of the Farm Household Allowance*, Canberra, pp. 1-86.

Lee, L and Ancev, T (2009), 'Two Decades of Murray-Darling Water Management: A River of Funding, a Trickle of Achievement', *Agenda: A Journal of Policy Analysis and Reform*, 16 (1), pp. 5-23.

Lee, L, Ancev, T and Vervoort, W (2012), 'Evaluation of environmental policies targeting irrigated agriculture: The case of the Mooki catchment, Australia', *Agricultural Water Management*, 109, pp. 107-116.

Leiserowitz, A (2005), 'American Risk Perceptions: Is Climate Change Dangerous?', *Risk Analysis*, 25 (6), pp. 1433-1442.

Leonard, B, Costello, C and Libecap, GD (2019), 'Expanding Water Markets in the Western United States: Barriers and Lessons from Other Natural Resource Markets', *Review of Environmental Economics and Policy*, 13 (1), pp. 43-61.

Leroux, AD and Martin, VL (2016), 'Hedging Supply Risks: An Optimal Water Portfolio', *American Journal of Agricultural Economics*, 98 (1), pp. 276-296.

Leviston, Z and Walker, I (2011), *Second Annual Survey of Australian attitudes to climate change: Interim Report*, Commonwealth Scientific and Industrial Research Organisation, Canberra, pp. 1-38.

Li, C, Poskitt, DS and Zhao, X (2019), 'The bivariate probit model, maximum likelihood estimation, pseudo true parameters and partial identification', *Journal of Econometrics*, 209 (1), pp. 94-113.

Li, S, Juhász-Horváth, L, Harrison, PA, Pintér, L and Rounsevell, MDA (2017), 'Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary', *Journal of Environmental Management*, 185, pp. 21-30.

Lindner, RK, Pardey, PG and Jarrett, FG (1982), 'Distance to information source and the time lag to early adoption of trace element fertilisers', *Australian Journal of Agricultural Economics*, 26 (2), pp. 98-113.

Llewellyn, RS and Brown, B (2020), 'Predicting Adoption of Innovations by Farmers: What is Different in Smallholder Agriculture?', *Applied Economic Perspectives and Policy*, 42 (1), pp. 100-112.

Loch, A and Adamson, D (2015), 'Drought and the rebound effect: a Murray–Darling Basin example', *Natural hazards*, 79 (3), pp. 1429-1449.

Loch, A, Adamson, D and Auricht, C (2019), '(g)etting to the point: The problem with water risk and uncertainty', *Water Resources and Economics*), p. 100154.

Loch, A, Bjornlund, H and McIver, R (2011), 'Achieving Targeted Environmental Flows: Alternative Allocation and Trading Models under Scarce Supply—Lessons from the Australian Reform Process', *Environment and Planning C: Government and Policy*, 29 (4), pp. 745-760.

Loch, A, Bjornlund, H, Wheeler, SA and Connor, J (2012), 'Allocation trade in Australia: a qualitative understanding of irrigator motives and behaviour', *Australian Journal of Agricultural and Resource Economics*, 56, pp. 42-60.

Loch, A, Wheeler, S and Adamson, D (2014a), 'People Versus Place in Australia's Murray-Darling Basin: balancing economic, social ecosystem and community outcomes', in VR Squires, HM Milner and KA Daniell (eds), *River basin management in the twenty-first century : understanding people and place*, CRC Press, Boca Raton, FL, pp. 275-303.

Loch, A, Wheeler, SA, Bjornlund, H, Beecham, S, Edwards, J, Zuo, A and Shanahan, M (2013), *The role of water markets in climate change adaptation*, National Climate Change Adaptation Research Facility, Gold Coast, pp. 1-144.

Loch, A, Wheeler, SA, Boxall, P, Hatton-Macdonald, D, Adamowicz, WL and Bjornlund, H (2014b), 'Irrigator preferences for water recovery budget expenditure in the Murray-Darling Basin, Australia', *Land Use Policy*, 36, pp. 396-404.

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

MacLennan, L (2019), 'The Murray-Darling Basin Royal Commission has handed down its findings. Here's how we got here', *ABC News*, 29/01/2019.

Manda, J, Alene, AD, Gardebroek, C, Kassie, M and Tembo, G (2016), 'Adoption and Impacts of Sustainable Agricultural Practices on Maize Yields and Incomes: Evidence from Rural Zambia', *Journal of Agricultural Economics*, 67 (1), pp. 130-153.

Marshall, V (2016), 'Deconstructing Aqua Nullius: Reclaiming Aboriginal Water Rights and Communal Identity in Australia', *Indigenous Law Bulletin*, 8 (26), pp. 9 - 14.

Matthews, K (2017), *Independent investigation into NSW water management and compliance: interim report*, Department of Industry, Sydney, pp. 1-78.

MDB Socio-economic Panel (2020), *Panel report: Independent assessment of social and economic conditions in the Basin - Draft Report*, Murray-Darling Basin Socio-Economic Panel, Canberra, pp. 1-101.

MDBA (2010a), *Murray-Darling Basin Agreement (Schedule D - Calculating Cap Adjustments) Protocol 2010*, Canberra.

MDBA (2010b), *Murray-Darling Basin Agreement (Schedule D - Conversion Factors and Exchange Rates) Protocol 2010*, Canberra.

MDBA (2010c), *Murray-Darling Basin Agreement (Schedule D - Permissible Transfers between Trading Zones) Protocol 2010*, Canberra.

MDBA (2010d), *Murray-Darling Basin Agreement (Schedule D - Tagging Entitlements for Extraction in another State) Protocol 2010*, Canberra.

MDBA (2011a), *Guide to the proposed Basin Plan*, Murray-Darling Basin Authority, Canberra, pp. 1-262.

MDBA (2011b), *The Living Murray story - one of Australia's largest river restoration projects*, Murray-Darling Basin Authority, Canberra, pp. 1-108.

MDBA (2014a), *Basin-wide environmental watering strategy*, Murray-Darling Basin Authority, Canberra.

MDBA (2014b), *Restrictions on the delivery of water under a tagged water access entitlement established on or after 22 October 2010*, Murray-Darling Basin Authority, accessed 29/07/2019, <https://www.mdba.gov.au/sites/default/files/pubs/09_WTG-RESTRICTIONSONDELIVERY_final.pdf>.

MDBA (2016a), *Murray–Darling Basin Boundary map*, Murray-Darling Basin Authority, Canberra.

MDBA (2016b), *The Northern Basin Review - Understanding the economic, social and environmental outcomes from water recovery in the northern basin*, Murray-Darling Basin Authority, Canberra, pp. 1-57.

MDBA (2017a), *Interstate water trade*, Murray-Darling Basin Authority, accessed 11/03/2020, <https://www.mdba.gov.au/managing-water/water-markets-trade/interstate-water-trade>.

MDBA (2017b), *The Murray-Darling Basin Water Compliance Review*, Murray-Darling Basin Authority, Canberra, pp. 1-148.

MDBA (2017c), *Sustainable Diversion Limit Adjustment Mechanism: Draft Determination Report*, Murray-Darling Basin Authority, Canberra, pp. 1-70.

MDBA (2017d), *Water Markets Product Information*, Murray-Darling Basin Authority, accessed 10/03/2020, <https://www.mdba.gov.au/managing-water/water-markets-trade/water-markets-product-information>.

MDBA (2018), *Climate*, Murray-Darling Basin Authority, accessed 22/02/2020, <https://www.mdba.gov.au/discover-basin/landscape/climate>.

MDBA (2019a), *2017–18 groundwater trial SDL water take account*, Murray-Darling Basin Authority, Canberra.

MDBA (2019b), *Allowable direction of water trades in the southern-connected Murray-Darling Basin*, Murray-Darling Basin Authority, accessed 11/03/2020, <https://www.mdba.gov.au/publications/products/allowable-direction-water-trades-southern-connected-basin>.

MDBA (2019c), *Barmah Choke trade balance and restriction*, Murray-Darling Basin Authority, accessed 17/10/2019, <https://www.mdba.gov.au/managing-water/water-markets-trade/interstate-water-trade/barmah-choke-trade-balance>.

MDBA (2019d), *Basin environmental watering priorities 2019-20*, Murray-Darling Basin Authority, Canberra, pp. 1-64.

MDBA (2019e), *Basin Plan Report Card - December 2019*, Murray-Darling Basin Authority, Canberra, pp. 1-16.

MDBA (2019f), *Basin Plan water trading rules*, Murray-Darling Basin Authority, accessed 02/03/2020, <https://www.mdba.gov.au/managing-water/water-markets-trade/basin-plan-water-trading-rules>.

MDBA (2019g), *Climate change, science and evaluation*, Murray-Darling Basin Authority, accessed 24/02/2020, <https://www.mdba.gov.au/basin-plan-roll-out/climate-change>.

MDBA (2019h), *Losses in the River Murray System 2018-19*, Murray-Darling Basin Authority, Canberra, pp. 1-46.

MDBA (2019i), *MDBA response to the South Australian Royal Commission*, Murray-Darling Basin Authority, Canberra, pp. 1-76.

MDBA (2019j), *Transition Period Water Take Report 2017-18*, Murray-Darling Basin Authority, Canberra, pp. 1-239.

MDBA (2019k), *Values of the Basin*, Murray-Darling Basin Authority, accessed 16/05/2019, <https://www.mdba.gov.au/discover-basin/rivers-worth-it/values-basin>.

MDBA (2019l), *Water markets and trade*, Murray-Darling Basin Authority, accessed 16/05/2019, <https://www.mdba.gov.au/managing-water/water-markets-and-trade>.

MDBA (2019m), *Water Trade Price Reporting under the Basin Plan: Part 1*, Murray-Darling Basin Authority, Canberra, pp. 1-22.

MDBA (2020a), *Water in storages as at 12 Feb 2020*, accessed 22/02/2020, <https://www.mdba.gov.au/managing-water/water-storage>.

MDBA (2020b), *Water quality*, Murray-Darling Basin Authority, accessed 23/03/2020, <https://www.mdba.gov.au/basin-plan-roll-out/water-quality-and-salinity>.

MDBBOC (2019), *Objectives and outcomes for river operations in the River Murray System*, Murray-Darling Basin Basin Officials Committee, Canberra, pp. 1-102.

MDBC (2000), *Overview report - Review of the Operation of the Cap*, Murray-Darling Basin Commission, Canberra, pp. 1-60.

MDBMC (1995), *An audit of water use in the Murray-Darling Basin*, Murray-Darling Basin Ministerial Council, Canberra, pp. 1-43.

MI (2015), *Glossary Water Trade - Permanent and temporary*, Murray Irrigation, Deniliquin, pp. 1-9.

Miller, A (2019), 'AWBA in discussions with state water registers on transparency', *Stock & Land*, 24/09/2019, Water, pp. 1-4.

Miller, A (2020), 'The federal government is allowing unused Water for Fodder to be carried over', *Stock&Land*, 13/04/2020, pp. 1-5.

Mishra, AK and Goodwin, BK (2006), 'Revenue insurance purchase decisions of farmers', *Applied Economics*, 38 (2), pp. 149-159.

MJA (2020), *Murray-Darling Basin Water Markets 2019-20 Update and 2018-19 Review*, Marsden Jacobs Associates, Sydney, pp. 1-20.

Moniruzzaman, S (2015), 'Crop choice as climate change adaptation: Evidence from Bangladesh', *Ecological Economics*, 118, pp. 90-98.

Montes de Oca Munguia, O and Llewellyn, R (2020), 'The Adopters versus the Technology: Which Matters More when Predicting or Explaining Adoption?', *Applied Economic Perspectives and Policy*, 42 (1), pp. 80-91.

Morey, E, Thacher, J and Breffle, W (2006), 'Using angler characteristics and attitudinal data to identify environmental preference classes: a latent-class model', *Environmental and Resource Economics*, 34 (1), pp. 91-115.

Morrison, M (2005), 'Identifying Market Segments for Technology Adoption', paper presented at Australian Agricultural and Resource Economics Society Conference, Coffs Harbour, 2005.

Mukherji, A (2008), 'Spatio-temporal analysis of markets for groundwater irrigation services in India: 1976–1977 to 1997–1998', *Hydrogeology Journal*, 16 (6), pp. 1077-1087.

Mumuni, E and Oladele, OI (2016), 'Access to livelihood capitals and propensity for entrepreneurship amongst rice farmers in Ghana', *Agriculture & Food Security*, 5 (1), pp. 1-11.

Mungatana, E and Hassan, R (2012), 'Two perspectives of water resource accounting: comparing the Australian and the United Nations approaches', in J Godfrey and K Chalmers (eds), *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK, pp. 162-188.

Mushtaq, S, Maraseni, TN and ReardonSmith, K (2015), 'Trade-offs and synergies between water and energy use in rural Australia', in J Pittock, K Hussey and S Dovers (eds), *Climate, Energy and Water: Managing Trade-offs, Seizing Opportunities*, Cambridge University Press, New York, pp. 123-140.

Natural Resources Commission (2019), *Draft Water Sharing Plan Review - Barwon-Darling Unregulated & Alluvial Water Sources 2012*, NSW Government, Sydney, pp. 1-181.

Nauges, C and Wheeler, SA (2017), 'The Complex Relationship Between Households' Climate Change Concerns and Their Water and Energy Mitigation Behaviour', *Ecological Economics*, 141, pp. 87-94.

Nauges, C, Wheeler, SA and Zuo, A (2016), 'Elicitation of irrigators' risk preferences from observed behaviour', *Australian Journal of Agricultural and Resource Economics*, 60, pp. 442-458.

Neave, I, McLeod, A, Raisin, G and Swirepik, J (2015), 'Managing water in the Murray-Darling Basin under a variable and changing climate', *Water: Journal of the Australian Water Association*, 42 (2), p. 102.

Neville, L (2019a), *Inter Valley Trade Changes To Protect Our Waterways*, Minister for Water, 20/08/2019, Melbourne.

Neville, L (2019b), *Minister takes control of Lower Murray water extraction*, 10/07/2019, Melbourne.

Ng'ang'a, SK, Van Wijk, MT, Rufino, MC and Giller, KE (2016), 'Adaptation of agriculture to climate change in semi-arid Borena, Ethiopia', *Regional Environmental Change*, 16 (8), pp. 2317-2330.

Nicholas, KA and Durham, WH (2012), 'Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in Northern California', *Global Environmental Change*, 22 (2), pp. 483-494.

Nielsen, DL and Brock, MA (2009), 'Modified water regime and salinity as a consequence of climate change: prospects for wetlands of Southern Australia', *Climatic Change*, 95 (3-4), pp. 523-533.

NWC (2011a), *Australian water markets: trends and drivers 2007-08 to 2009-10*, National Water Commission, Canberra, pp. 1-78.

NWC (2011b), *Water markets in Australia: A short history*, National Water Commission, Canberra, pp. 1-155.

NWC (2012), *Impacts of Water Trading in the Southern Murray-Darling Basin between 2006-07 and 2010-11*, National Water Commission, Canberra, pp. 1-254.

O'Bryan, K (2016), 'Victoria's traditional owner settlement act and indigenous management of water resources: an improvement on the nativ title act or more of the same?', *Indigenous Law Bulletin*, 8 (26).

O'Donnell, E (2012), 'Institutional Reform in Environmental Water Management: The new Victorian Environmental Water Holder', *The Journal of Water Law*, 22 (2/3), pp. 73-84.

O'Donnell, E (2013), 'Australia's environmental water holders: Who is managing our environmental water?', *Australian Environment Review*, 28 (3), pp. 508-513.

O'Donnell, E (2018), *Legal Rights for Rivers: Competition, Collaboration and Water Governance*, Routledge, New York, USA.

O'Donnell, E and Garrick, D (2019), 'The diversity of water markets: Prospects and perils for the SDG agenda', *Wiley Interdisciplinary Reviews: Water*, 6, pp. e1368-1391.

Oliveira, R and Teixeira-Pinto, A (2015), 'Analyzing Multiple Outcomes: Is it Really Worth the use of Multivariate Linear Regression?', *Journal of Biometrics & Biostatistics*, 06 (04), pp. 1-6.

Ostrom, E (2008), 'Tragedy of the Commons', in SN Durlauf and LE Blume (eds), *The New Palgrave Dictionary of Economics*, 2 edn, Palgrave Macmillan, New York.

Palinkas, LA, Aarons, GA, Horwitz, S, Chamberlain, P, Hurlburt, M and Landsverk, J (2011), 'Mixed Method Designs in Implementation Research', *Administration and Policy in Mental Health and Mental Health Services Research*, 38 (1), pp. 44-53.

Palinkas, LA, Horwitz, SM, Green, CA, Wisdom, JP, Duan, N and Hoagwood, K (2015), 'Purposeful Sampling for Qualitative Data Collection and Analysis in Mixed Method Implementation Research', *Administration and Policy in Mental Health and Mental Health Services Research*, 42 (5), pp. 533-544.

Palomo-Hierro, S, Gómez-Limón, JA and Riesgo, L (2015), 'Water Markets in Spain: Performance and Challenges', *Water*, 7 (2), pp. 652-678.

Pannell, D (1999), 'Economics, extension and the adoption of land conservation innovations in agriculture', *International Journal of Social Economics*, 26 (7/8/9), pp. 999-1014.

Pannell, D, Marshall, GR, Barr, N, Curtis, A, Vanclay, F and Wilkinson, R (2006), 'Understanding and promoting adoption of conservation practices by rural landholders', *Australian Journal of Experimental Agriculture*, 46 (11), pp. 1407-1424.

Pannell, D and Zilberman, D (2020), 'Understanding Adoption of Innovations and Behavior Change to Improve Agricultural Policy', *Applied Economic Perspectives and Policy,* 42 (1), pp. 3-7.

Park, SE, Marshall, NA, Jakku, E, Dowd, AM, Howden, SM, Mendham, E and Fleming, A (2012), 'Informing adaptation responses to climate change through theories of transformation', *Global Environmental Change*, 22 (1), pp. 115-126.

Parliament of Australia (2007), *Water Act,* Canberra.

Parliament of Australia (2010), *Sustainable management by the Commonwealth of water resources,* Canberra.

Parliament of Australia (2012), *Basin Plan 2012,* Canberra.

Parliament of Australia (2015), *Water Amendment Act 2015*, Canberra.

Parliament of Australia (2018), *Report on the inquiry into the management and use of Commonwealth environmental water*, House of Representatives, Canberra, pp. 1-118.

Parliament of NSW (2017), *Natural Resources Access Regulator Act 2017,* Sydney.

Perry, C, Steduto, P and Karajeh, F (2017), *Does improved irrigation technology save water? A review of the evidence*, Food and Agriculture Organisation of the United Nations (FAO), Cairo, pp. 1-57.

Peterson, DC (2016), 'Drought policy: lessons and strategies to change the transformational game', in M Young and C Esau (eds), *Transformational Change in Environmental and Natural Resource Management*, Routledge, London, pp. 134-149.

Pirrong, C (2011), *The economics of central clearing: theory and practice*, International Swaps and Derivatives Association, pp. 1-44.

Pittock, J (2013), 'Lessons from adaptation to sustain freshwater environments in the Murray–Darling Basin, Australia', *Wiley Interdisciplinary Reviews: Climate Change*, 4 (5), pp. 429-438.

Pittock, J and Finlayson, CM (2011), 'Australia's Murray–Darling Basin: freshwater ecosystem conservation options in an era of climate change', *Marine and Freshwater Research*, 62 (3), pp. 232-243.

Pittock, J and Finlayson, CM (2013), 'Climate change adaptation in the Murray-Darling Basin: Reducing resilience of wetlands with engineering', *Australasian Journal of Water Resources,* 17 (2), pp. 161-169.

Pittock, J, Williams, J and Grafton, QR (2015), 'The Murray-Darling Basin plan fails to deal adequately with climate change', *Water: Journal of the Australian Water Association*, 42 (6), pp. 28-32.

Productivity Commission (2009), *Government Drought Support*, Productivity Commission, Canberra, pp. 1-486.

Productivity Commission (2010), *Market Mechanisms for Recovering Water in the Murray-Darling Basin*, Productivity Commission, Canberra, pp. 1-420.

Productivity Commission (2018), *Murray-Darling Basin Plan: Five-year assessment, Inquiry Report*, Productivity Commission, Canberra, pp. 1-430.

Prokopy, LS, Floress, K, Klotthor-Weinkauf, D and Baumgart-Getz, A (2008), 'Determinants of agricultural best management practice adoption: Evidence from the literature', *Journal of Soil and Water Conservation*, 63 (5), pp. 300-311.

Prosser, I (2011), *Water : science and solutions for Australia*, ed. CSIRO, CSIRO Publishing, Collingwood.

Pujol, J, Raggi, M and Viaggi, D (2006), 'The potential impact of markets for irrigation water in Italy and Spain: a comparison of two study areas', *Australian Journal of Agricultural and Resource Economics*, 50 (3), pp. 361-380.

Quiggin, J (2001), 'Environmental economics and the Murray–Darling river system', *Australian Journal of Agricultural and Resource Economics*, 45 (1), pp. 67-94.

Quiggin, J (2010), *Water Policy after the Drought*, University of Queensland, Brisbane, pp. 1-13.

Quiggin, J (2012), 'Why the guide to the proposed basin plan failed, and what can be done to fix it', in J Quiggin, T Mallawaarachchi and S Chambers (eds), *Water Policy Reform Lessons in Sustainability from the Murray-Darling Basin. Cheltenham: Edward Elgar*, Edward Elgar, Cheltenham, pp. 49-62.

Quiggin, J, Adamson, D, Chambers, S and Schrobback, P (2010), 'Climate change, uncertainty, and adaptation: the case of irrigated agriculture in the Murray–Darling Basin in Australia', *Canadian Journal of Agricultural Economics*, 58 (4), pp. 531-554.

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

Reeson, A and Whitten, S (2015), *Motivating the Market: A brief review of options for improving water purchases*, Commonwealth Scientific and Industrial Research Organisation, Canberra, pp. 1-26.

Reisman, E (2019), 'The great almond debate: A subtle double movement in California water', *Geoforum*, 104, pp. 137-146.

Rencher, AC and Christensen, WF (2012), *Methods of multivariate analysis*, Wiley series in probability and statistics, 3 edn, Wiley, Hoboken, N.J.

Rey, D, Pérez-Blanco, CD, Escriva-Bou, A, Girard, C and Veldkamp, TIE (2019), 'Role of economic instruments in water allocation reform: lessons from Europe', *International Journal of Water Resources Development*, 35 (2), pp. 206-239.

RMCG (2016), *Basin Plan - GMID socio-economic impact assessment*, GMID Water Leadership Forum, Bendigo, pp. 1-98.

Roca, E, Jin, Y, Li, B and Wong, V (2015), 'Sprinkle your investment portfolio with water!', *International Journal of Water*, 9 (1), pp. 43 - 59.

Roco, L, Engler, A, Bravo-Ureta, B and Jara-Rojas, R (2014), 'Farm level adaptation decisions to face climatic change and variability: Evidence from Central Chile', *Environmental Science & Policy*, 44, pp. 86-96.

Rogers, EM (2003), *Diffusion of innovations*, 5th edn, Free Press, New York.

Ruml, CC (2005), 'The Coase theorem and western US appropriative water rights', *Natural Resources Journal*), pp. 169-200.

Russek, BE and Weinberg, SL (1993), 'Mixed methods in a study of implementation of technology-based materials in the elementary classroom', *Evaluation and Program Planning*, 16 (2), pp. 131-142.

Ryan, B and Gross, NC (1943), 'The Diffusion of Hybrid Seed Corn in Two Iowa Communities', *Rural Sociology*, 8 (1), p. 15.

Seidl, C, Wheeler, SA and Zuo, A (2020a), 'High turbidity: water valuation and accounting in the Murray-Darling Basin', *Agricultural Water Management*, 230, p. 105929.

Seidl, C, Wheeler, SA and Zuo, A (2020b), 'Treating water markets like stock markets: Key water market reform lessons in the Murray-Darling Basin', *Journal of Hydrology*, 581, p. 124399.

Settre, CM and Wheeler, SA (2017), 'A century of intervention in a Ramsar wetland – the case of the Coorong, Lower Lakes and Murray Mouth', *Australasian Journal of Environmental Management*, 24 (2), pp. 163-183.

Shaik, S, Coble, KH, Knight, TO, Baquet, AE and Patrick, GF (2008), 'Crop revenue and yield insurance demand: a subjective probability approach', *Journal of Agricultural and Applied Economics*, 40 (1379-2016-112787), pp. 757-766.

Shampine, A (1998), 'Compensating for Information Externalities in Technology Diffusion Models', *American Journal of Agricultural Economics*, 80 (2), pp. 337-346.

Sheldon, F (2019), *Technical Review of the Water Sharing Plan for the Barwon-Darling Unregulated and Alluvial Water Sources 2012*, NSW Natural Resources Commission, Brisbane, pp. 1-53.

Sherrick, BJ, Barry, PJ, Ellinger, PN and Schnitkey, GD (2004), 'Factors Influencing Farmers' Crop Insurance Decisions', *American Journal of Agricultural Economics*, 86 (1), pp. 103-114.

Siepmann, L and Nicholas, KA (2018), 'German Winegrowers' Motives and Barriers to Convert to Organic Farming', *Sustainability*, 10 (11), p. 4215.

Slattery, M and Campbell, R (2018a), *Moving Targets*, The Australia Institute, Canberra, pp. 1-19.

Slattery, M and Campbell, R (2018b), *That's not how you haggle*, The Australia Institute, Canberra, pp. 1-22.

Slattery, M and Campbell, R (2019), *Strategic Failure*, The Australia Institute, Canberra, pp. 1-21.

Slattery, M and Campbell, R (2020), *Rough Estimates*, The Australia Institute, Canberra, pp. 1-9.

Slattery, M, Campbell, R and Quicke, A (2019), *Dam shame: The hidden new dams in Australia*, Australia Institute, Canberra, pp. 1-26.

Slattery, M, Chalmers, K and Godfrey, J (2012), 'Beyond the hydrographer's legacy: water accounting in Australia', in J Godfrey and K Chalmers (eds), *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK, pp. 17-31.

Smit, B and Skinner, MW (2002), 'Adaptation options in agriculture to climate change: a typology', *Mitigation and Adaptation Strategies for Global Change*, 7 (1), pp. 85-114.

Stehlik, D (2009), 'Intergenerational transitions in rural Western Australia: an issue for sustainability?', in F Merlan and D Raftery (eds), *Tracking Rural Change: Community, Policy and Technology in Australia, New Zealand and Europe*, ANU Press, Canberra, pp. 135-150.

Stephenson, G (2003), 'The somewhat flawed theoretical foundation of the extension service', *Journal of Extension*, 41 (4), pp. 1-10.

Stoler, J (2017), 'From curiosity to commodity: a review of the evolution of sachet drinking water in West Africa', *WIREs Water*, 4 (3), p. e1206.

Sullivan, K (2019), 'ACCC to study Murray-Darling Basin's $2 billion water market to see who owns what', *ABC News*, 07/08/2019, Politics, pp. 1-2.

Sullivan, K and Jasper, C (2019), ''Can the Plan' protesters say they've brokered a deal with Federal Water Minister and Mick Keelty', *ABC Rural*, 03/12/2019.

Tambo, JA (2016), 'Adaptation and resilience to climate change and variability in north-east Ghana', *International Journal of Disaster Risk Reduction*, 17, pp. 85-94.

Tashakkori, A, Teddlie, C and Johnson, B (2015), 'Mixed Methods', in *International Encyclopedia of the Social & Behavioral Sciences*, Second Edition edn, Elsevier Ltd, pp. 618-623.

Tello, E and Hazelton, J (2018), 'The challenges and opportunities of implementing general purpose groundwater accounting in Australia', *Australasian Journal of Environmental Management*, 25 (3), pp. 285-301.

Testa, C (2019), 'Warning of 'dire consequences' for some Murray-Darling irrigators if water trade restricted', *ABC News*, 14/10/2019, ABC Rural, pp. 1-4.

Thampapillai, V (2009), 'Limits to government water buy-backs for environmental flows in the Murray-Darling Basin (Part 1)', *Envtl. Pol'y & L.*, 39, p. 247.

The Senate (2018), *Order for the Production of Documents 579*, Canberra.

Timbal, B, Abbs, D, Bhend, J, Chiew, F, Church, J, Ekström, M, Kirono, D, Lenton, A, Lucas, C, McInnes, K, Moise, A, Monselesan, D, Mpelasoka, F, Webb, L and Whetton, P (2015), *Murray Basin Cluster Report*, CSIRO and Bureu of Meteorology, Canberra, pp. 1-59.

Tingey-Holyoak, J (2019), 'Water accounting knowledge pathways', *Pacific Accounting Review*, 31 (2), pp. 258-274.

Tisdell, JG (2010), 'Impact of environmental traders on water markets: An experimental analysis', *Water Resources Research*, 46 (3).

Tisdell, JG (2011), 'Water markets in Australia: an experimental analysis of alternative market mechanisms', *Australian Journal of Agricultural and Resource Economics*, 55 (4), pp. 500-517.

Touch, V, Martin, RJ, Scott, JF, Cowie, A and Liu, DL (2016), 'Climate change adaptation options in rainfed upland cropping systems in the wet tropics: A case study of smallholder farms in North-West Cambodia', *Journal of Environmental Management*, 182, pp. 238-246.

Turral, H, Svendsen, M and Faures, JM (2010), 'Investing in irrigation: Reviewing the past and looking to the future', *Agricultural Water Management*, 97 (4), pp. 551-560.

United Nations (2012), *System of Environmental-Economic Accounting for Water (SEEA-Water)*, Department of Economic and Social Affairs, New York, pp. 1-216.

van der Linden, S (2017), *Determinants and Measurement of Climate Change Risk Perception, Worry, and Concern*, Oxford Research Encyclopedia of Climate Science, Oxford University Press, New York.

Vardon, M, Martinez-Lagunes, R, Gan, H and Nagy, M (2012), 'The System of Environmental-Economic Accounting for Water: development, implementation and use', in J Godfrey and K Chalmers (eds), *Water Accounting: International approaches to policy and decision-making*, Edward Elgar, Cheltenham, UK, pp. 32-57.

Väre, M, Pietola, K and Weiss, CR (2010), 'The irrelevance of stated plans in predicting farm successions in Finland', *Agricultural and Food Science*, 19 (1), pp. 81-95.

Vaux, HJ and Howitt, RE (1984), 'Managing Water Scarcity: An Evaluation of Interregional Transfers', *Water Resources Research*, 20 (7), pp. 785-792.

Venkatachalam, L (2015), 'Informal water markets and willingness to pay for water: a case study of the urban poor in Chennai City, India', *International Journal of Water Resources Development*, 31 (1), pp. 134-145.

Vertessy, R, Barma, D, Baumgartner, L, Mitrovic, S, Sheldon, F and Bond, N (2019), *Final report of the Independent Assessment of the 2018-19 fish deaths in the lower Darling*, Canberra, pp. 1-99.

VEWH (2018a), *Annual Report 2017-18*, Victorian Environmental Water Holder, Melbourne, pp. 1-84.

VEWH (2018b), *Water allocation trading strategy 2018-19*, Victorian Environmental Water Holder, Melbourne, pp. 1-20.

VEWH (2018c), *Water sale in northern Victoria*, Victorian Environmental Water Holder, 12/02/2018, Melbourne.

Victorian Ombudsman (2011), *Investigation into the Foodbowl Modernisation Project and related matters*, Victorian Ombudsman, Melbourne, pp. 1-216.

Vigani, M and Kathage, J (2019), 'To Risk or Not to Risk? Risk Management and Farm Productivity', *American Journal of Agricultural Economics*, 101 (5), pp. 1432-1454.

Vincent, M (2018), 'Walgett has two rivers but no water left to drink', *ABC News*, 19/12/2018.

Wainaina, P, Tongruksawattana, S and Qaim, M (2016), 'Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya', *Agricultural Economics*, 47 (3), pp. 351-362.

Wakerman Powell, K, Smith, E, Delves, E and Olszak, C (2019), *Water Markets Report: 2018-19 Review and 2019-20 Outlook*, AITHER, Melbourne, pp. 1-45.

Walker, B (2019), *Murray-Darling Basin Royal Commission Report*, Murray-Darling Basin Royal Commission, Adelaide, pp. 1-756.

Wang, J, Klein, KK, Bjornlund, H, Zhang, L and Zhang, W (2015a), 'Adoption of improved irrigation scheduling methods in Alberta: An empirical analysis', *Canadian Water Resources Journal*, 40 (1), pp. 47-61.

Wang, J, Klein, KK, Bjornlund, H, Zhang, L and Zhang, W (2015b), 'Changing to more efficient irrigation technologies in southern Alberta (Canada): an empirical analysis', *Water International*, 40 (7), pp. 1040-1058.

Water Accounting Standards Board (2012a), *Australian Water Accounting Standard 1: Preparation and Presentation of General Purpose Water Accounting Reports*, (AWAS 1), Bureau of Meteorology, Canberra.

Water Accounting Standards Board (2012b), *Illustrative Water Accounting Reports for Australian Water Accounting Standard 1*, Bureau of Meteorology, Canberra, pp. 1-212.

Water NSW v Barlow (2019), Land and Environment Court New South Wales, 22/03/2019.

Water NSW v Harris (No 3) (2020), NSW Land and Environment Court, 19/03/2020, pp. 1-71.

Waterexchange (2019), 'Rules and Brokerage Agreement'), Wentworth, pp. 1-11.

Waterfind (2019a), *Australian Water Markets Annual Report 2018-19*, Waterfind, Adelaide, pp. 1-86.

Waterfind (2019b), *Water trade terms and conditions*, personal communication on 07/08/2019 with C Seidl.

Watson, A (2019), 'Australian drought policy: Notes on collateral damage and other issues', paper presented at 63rd Australasian Agricultural and Resource Economics Society Annual Conference, Melbounre.

WEF (2019), *The Global Risks Report 2019*, World Economic Forum, Geneva, pp. 1-114.

West, M (2019), 'Barnaby Joyce, Angus Taylor, Australia and the Caribbean', *michaelwest.com*, 21/04/2019, pp. 1-11.

Wheeler, SA (2014), 'Insights, lessons and benefits from improved regional water security and integration in Australia', *Water Resources and Economics*, 8, pp. 57-78.

Wheeler, SA, Bjornlund, H, Shanahan, M and Zuo, A (2008a), 'Factors influencing water allocation and entitlement prices in the Greater Goulburn area of Australia', *WIT Transactions on Ecology and the Environment*, 112, pp. 63-71.

Wheeler, SA, Bjornlund, H, Shanahan, M and Zuo, A (2008b), 'Price elasticity of water allocations demand in the Goulburn-Murray Irrigation District', *The Australian Journal of Agricultural and Resource Economics*, 52, pp. 37-55.

Wheeler, SA, Bjornlund, H, Shanahan, M and Zuo, A (2009), 'Who trades water allocations? Evidence of the characteristics of early adopters in the Goulburn–Murray Irrigation District, Australia 1998–1999', *Agricultural Economics*, 40 (6), pp. 631-643.

Wheeler, SA, Bjornlund, H, Zuo, A and Edwards, J (2012a), 'Handing down the farm? The increasing uncertainty of irrigated farm succession in Australia', *Journal of Rural Studies*, 28 (3), pp. 266-275.

Wheeler, SA, Bjornlund, H, Zuo, A and Shanahan, M (2010), 'The changing profile of water traders in the Goulburn-Murray Irrigation District, Australia ', *Agricultural Water Management*, 97 (9), p. 10.

Wheeler, SA, Carmody, E, Grafton, QR, Kingsford, RT and Zuo, A (2020a), 'The rebound effect on water extraction from subsidising irrigation infrastructure in Australia', *Resources, Conservation & Recycling*, 159, p. 104755.

Wheeler, SA and Cheesman, J (2013), 'Key findings from a survey of sellers to the restoring the balance programme', *Economic Papers*, 32 (3), pp. 340-352.

Wheeler, SA and Garrick, D (2020), 'A Tale of Two Water Markets in Australia: Lessons for Understanding Participation in Formal Water Markets', *Oxford Review of Economic Policy*, 36 (1), pp. 132-153.

Wheeler, SA, Garrick, D, Loch, A and Bjornlund, H (2013a), 'Evaluating water market products to acquire water for the environment in Australia', *Land Use Policy*, 30 (1), pp. 427-436.

Wheeler, SA, Hatton MacDonald, D and Boxall, P (2017a), 'Water policy debate in Australia: Understanding the tenets of stakeholders' social trust', *Land Use Policy*, 63, pp. 246-254.

Wheeler, SA, Loch, A, Crase, L, Young, M and Grafton, RQ (2017b), 'Developing a water market readiness assessment framework', *Journal of Hydrology*, 552, pp. 807-820.

Wheeler, SA, Loch, A, Zuo, A and Bjornlund, H (2014a), 'Reviewing the adoption and impact of water markets in the Murray–Darling Basin, Australia', *Journal of Hydrology*, 518, pp. 28-41.

Wheeler, SA and Marning, A (2019), 'Turning water into wine: Exploring water security perceptions and adaptation behaviour amongst conventional, organic and biodynamic grape growers', *Land Use Policy*, 82, pp. 528-537.

Wheeler, SA, Rossini, P, Bjornlund, H and Spagnoletti, B (2016a), 'The Returns from Investing in Water Markets in Australia', in V Ramiah and GN Gregoriou (eds), *Handbook of Environmental and Sustainable Finance*, first edn, Academic Press, San Diego, pp. 371-385.

Wheeler, SA, Schoengold, K and Bjornlund, H (2016b), 'Lessons to Be Learned from Groundwater Trading in Australia and the United States', in AJ Jakeman, O Barreteau, RJ Hunt, J-D Rinaudo and A Ross (eds), *Integrated Groundwater Management: Concepts, Approaches and Challenges*, Springer International Publishing, Cham, pp. 493-517.

Wheeler, SA, Xu, Y and Zuo, A (2020b), 'Modelling the climate, water and socio-economic drivers of farmer exit in the Murray-Darling Basin', *Climatic Change*, 158, pp. 551-574.

Wheeler, SA and Zuo, A (2017), 'The impact of drought and water scarcity on irrigator farm exit intentions in the Murray–Darling Basin', *Australian Journal of Agricultural and Resource Economics*, 61 (3), pp. 404-421.

Wheeler, SA, Zuo, A and Bjornlund, H (2013b), 'Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia', *Global Environmental Change*, 23 (2), pp. 537-547.

Wheeler, SA, Zuo, A and Bjornlund, H (2014b), 'Australian irrigators' recognition of the need for more environmental water flows and intentions to donate water allocations', *Journal of Environmental Planning and Management*, 57 (1), pp. 104-122.

Wheeler, SA, Zuo, A and Bjornlund, H (2014c), 'Investigating the delayed on-farm consequences of selling water entitlements in the Murray-Darling Basin', *Agricultural Water Management*, 145, pp. 72-82.

Wheeler, SA, Zuo, A, Bjornlund, H and Lane-Miller, C (2012b), 'Selling the Farm Silver? Understanding Water Sales to the Australian Government', *Environmental Resource Economics*, 52, pp. 133-154.

Wheeler, SA, Zuo, A, Bjornlund, H, Mdemu, MV, van Rooyen, A and Munguambe, P (2017c), 'An overview of extension use in irrigated agriculture and case studies in south-eastern Africa', *International Journal of Water Resources Development*, 33 (5), pp. 755-769.

Wheeler, SA, Zuo, A and Hughes, N (2014d), 'The impact of water ownership and water market trade strategy on Australian irrigators' farm viability', *Agricultural Systems*, 129, pp. 81-92.

Wheeler, SA, Zuo, A and Loch, A (2018), 'Water torture: Unravelling the psychological distress of irrigators in Australia', *Journal of Rural Studies*, 62, pp. 183-194.

White, DH and Karssies, L (1999), 'Australia's National Drought Policy', *Water International*, 24 (1), pp. 2-9.

Wilks, T (2019), *Buyer listing - Purchaser Details*, Wilks Water, Wagga Wagga, p. 1.

Williams, J and Grafton, QR (2019), 'Missing in action: possible effects of water recovery on stream and river flows in the Murray–Darling Basin, Australia', *Australasian Journal of Water Resources*), pp. 1-10.

Winpenny, J (2005), *Managing water as an economic resource*, Routledge, New York.

Wittwer, G (2011), 'Confusing Policy and Catastrophe: Buybacks and Drought in the Murray–Darling Basin', *Economic Papers*, 30 (3), pp. 289-295.

Wittwer, G and Dixon, J (2013), 'Effective use of public funding in the Murray-Darling Basin: a comparison of buybacks and infrastructure upgrades', *Australian Journal of Agricultural and Resource Economics*, 57 (3), pp. 399-421.

Wittwer, G and Griffith, M (2011), 'Modelling drought and recovery in the southern Murray-Darling basin*', *Australian Journal of Agricultural and Resource Economics*, 55 (3), pp. 342-359.

Wittwer, G and Young, MD (2020), 'Distinguishing Between Policy, Drought and International Events in the Context of the Murray Darling Basin Plan', *CoPS Working Paper*, G-295, pp. 1-23.

Wooldridge, JM (2010), *Econometric analysis of cross section and panel data*, MIT press, London.

Wooldridge, JM (2015), 'Control function methods in applied econometrics', *Journal of Human Resources*, 50 (2), pp. 420-445.

Wroe, D (2019), 'Taxpayers dudded in water deal, experts say', *The Sydney Morning Herald*, 21/04/2019, p. 5.

Young, MD (2014), 'Designing water abstraction regimes for an ever-changing and ever-varying future', *Agricultural Water Management*, 145, pp. 32-38.

Young, MD (2019), *Sharing Water: The role of robust water-sharing arrangements in integrated water resources management*, Global Water Partnership, Stockholm, pp. 1-32.

Young, MD and McColl, JC (2009), 'Double trouble: the importance of accounting for and defining water entitlements consistent with hydrological realities*', *Australian Journal of Agricultural and Resource Economics*, 53 (1), pp. 19-35.

Young, RA (1986), 'Why Are There so Few Transactions among Water Users?', *American Journal of Agricultural Economics*, 68 (5), pp. 1143-1151.

Zampaligré, N, Dossa, LH and Schlecht, E (2014), 'Climate change and variability: perception and adaptation strategies of pastoralists and agro-pastoralists across different zones of Burkina Faso', *Regional Environmental Change*, 14 (2), pp. 769-783.

Zellner, A (1962), 'An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias', *Journal of the American Statistical Association,* 57 (298), pp. 348-368.

Zellner, A (1963), 'Estimators for seemingly unrelated regression equations: Some exact finite sample results', *Journal of the American Statistical Association*, 58 (304), pp. 977-992.

Zilberman, D, Zhao, J and Heiman, A (2012), 'Adoption versus adaptation, with emphasis on climate change', *Annual Review of Resource Economics*, 4 (1), pp. 27-53.

Zuo, A, Nauges, C and Wheeler, SA (2015a), 'Farmers' exposure to risk and their temporary water trading', *European Review of Agricultural Economics*, 42 (1), pp. 1-24.

Zuo, A, Qiu, F and Wheeler, SA (2019), 'Examining volatility dynamics, spillovers and government water recovery in Murray-Darling Basin water markets', *Resource and Energy Economics*, 58, p. 101113.

Zuo, A, Wheeler, SA, Adamowicz, WL, Boxall, PC and Hatton-MacDonald, D (2016), 'Measuring Price Elasticities of Demand and Supply of Water Entitlements Based on Stated and Revealed Preference Data', *American Journal of Agricultural Economics,* 98 (1), pp. 314-332.

Zuo, A, Wheeler, SA, Boxall, P, Adamowicz, WL and Hatton MacDonald, D (2015b), 'Identifying Water Prices at which Australian Farmers Will Exit Irrigation: Results of a Stated Preference Survey', *Economic Record*, 91, pp. 109-123.