# EXAMINING THE IMPORTANCE OF SPATIAL INFLUENCES ON IRRIGATORS' WATER TRADING BEHAVIOUR IN THE SOUTHERN MURRAY-DARLING BASIN

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#### List of Abbreviations

ABARES Australian Bureau of Agricultural and Resource Economics and Sciences

ABS Australian Bureau of Statistics

ACCC Australian Competition and Consumer Commission

ACT Australian Capital Territory

AIC Akaike Information Criterion

ASC Australian Soil Classification

ASDD Australian Spatial Data Directory

ASGS Australian Statistical Geography Standard

ASRIS Australian Soil Resource Information System

ATO Australian Taxation Office

AUD Australian Dollar

AWAP Australian Water Availability Project

BIC Bayesian Information Criterion

BMP Best Management Practices

BoM Bureau of Meteorology

BSMS Basin Salinity Management Strategy

CEWH Commonwealth Environmental Water Holder

CIT Central Irrigation Trust

COAG Council of Australian Governments

CSIRO Commonwealth Scientific and Industrial Research Organisation

CVM Contingent Valuation Method

DoEE Department of the Environment and Energy

DSEWPaC Department of Sustainability, Environment, Water, Population and Communities

EC (μS/cm) Electrical Conductivity (microSiemens per centimetre)

ESLT Environmentally Sustainable Level of Take

GCS-GDA-94 Geographic Coordinate Systems - Geocentric Datum of Australia - 1994

GDP Gross Domestic Product

GIS Geographic Information System

GL Gigalitre (one thousand megalitres (ML); one billion litres). A gigalitre (GL) is

equivalent to 810.71 acre feet.

GMID Goulburn-Murray Irrigation district

GMW Goulburn-Murray Water

G-NAF Geocoded National Address File

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GRP Gross Regional Product

GVAP Gross Value of Agricultural Production

GVIAP Gross Value of Irrigated Agricultural Production

ha Hectare

IIO Irrigation Infrastructure Operator

km<sup>2</sup> Square kilometre

1 Litre

LGA Local Government Area

In Natural Logarithm

LTAAY Long term average annual yield factor

MDB Murray-Darling Basin

MDBA Murray-Darling Basin Authority

MDBC Murray-Darling Basin Commission

MDBMC Murray-Darling Basin Ministerial Council

MIA Murrumbidgee Irrigation Area

MIL Murray Irrigation Limited

ML Megalitre (one million litres)

NA Not applicable

NLWRA National Land and Water Resources Audit

no. Number

NRM Natural Resource Management

NSW New South Wales

NWC National Water Commission

NWI National Water Initiative

Obs. Observations

OLS Ordinary Least Square

PCA Principal Component Analysis

pH Potential of Hydrogen

PP Primary Production

QLD Queensland

RIT Renmark Irrigation Trust

RMB Roadside Mail Box

RSD Roadside Delivery

SA South Australia

SA1 Statistical Area Level 1

SA2 Statistical Area Level 2

SA4 Statistical Area Level 4

SDL Sustainable Diversion Limit

SRWUI Sustainable Rural Water Use and Irrigation Infrastructure

TDS Total Dissolved Solids

TRA Theory of Reasoned Action

TPB Theory of Planned Behaviour

USA United States of America

VIC Victoria

VIF Variance Inflation Factor

WAM Water Audit Monitoring

WTA Willingness to Accept

WTP Willingness to Pay

\$m Million Dollar

# **Glossary of Terms**

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 A change in practice or technology. agriculture) 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). Arrangements which allow water entitlement holders to hold water in storages Carry-over (water allocations not taken in a water accounting period) so that it is available in subsequent years. Catchment (river An area determined by topographic features, within which rainfall contributes to run-off at a particular point. valley) Commonwealth An independent statutory office established by the Water Act 2007 and Environmental responsible for making decisions relating to the management of the Water Holder Commonwealth environmental water aiming to maximise environmental (CEWH) outcomes across the Murray-Darling Basin. Consumptive water The use of water for private benefit (e.g. irrigation, industry, urban, and stock and domestic uses). use Council of Is the peak intergovernmental forum driving and implementing reforms in Australian Australia (members are the Prime Minister, State and Territory Premiers and Governments Chief Ministers and the President of the Australian Local Government (COAG) Association). According to the Basin Plan, include water-dependent ecosystems, ecosystem Environmental asset services and sites with ecological significance. According to the Basin Plan, comprises water provided to wetlands, floodplains Environmental or rivers, to achieve a desired outcome, including benefits to ecosystem water functions, biodiversity, water quality and water resource health. Evapotranspiration Sum of the moisture loss through evaporation and plant transpiration to the atmosphere. Farming water Describes a 12-month period from July 1 to 30 June (similar to the financial season year in Australia). Geocoding The process of assigning coordinates to address data by comparing the input address data to reference address data. 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.

Neighbourhood effect

The impact of neighbourhoods (neighbours' behaviour) on individual behaviour. Also referred to as spill-over effect.

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.

Resilience

The ability of a system to return to its former state following a shock or disturbance. Resilience is a dynamic and systems orientated approach focusing on the adaptive capacity (i.e. the potential or ability of a system to adapt to cope with changes and uncertainties) as a fundamental feature of resilient systems.

Run-off

Excess water (e.g. from precipitation or irrigation) that flows to streams.

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.

Salinity

The salt content in soil or water.

Spatial data

Can be imported into a geographic information system (GIS) and relates to space or a specific location and provide information about the locations and shapes of geographic features as well as the relationships between them. Spatial data is usually stored as coordinates and topology.

Spatial dependence

The tendency of the same variables measured in locations in close proximity to be related (i.e. similar values with similar locations). Spatial dependence may be caused by neighbours' interaction, measurement errors spilling across boundaries, or spatially correlated unobserved latent variables.

Stated preference

A survey-based technique for establishing valuations of people (sometimes referred to as contingent valuation), typically in the form of willingness to

pay/accept (as compared to revealed preference, which focuses on the actual decisions made). The ongoing process of change in the relative size, composition and characteristics of industries and their workforces across all sectors of a national or regional economy in response to a range of environmental and market factors, technological change and government policy reforms. Water that flows over land and in watercourses or artificial channels. 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). A body of water that is shared by or forms the boundary between two or more political jurisdictions. 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. Rivers without major storages or rivers where the storages do not release water downstream. 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. 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). Principal government market-based instrument in Australia to produce environmental benefits in deteriorated sites across the Murray-Darling Basin by

Water buyback program

Structural

adjustment

Surface water

diversion limit

Transboundary

Unregulated river

Water Act 2007

Water allocation

Unbundling

Sustainable

(SDL)

water

system

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 initiative 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. Initially, the budget was set at AUD\$12.9 billion, which allocated AUD\$3.1 billion towards a water buyback program and AUD\$5.8 billion towards Sustainable Rural Water Use and Irrigation Infrastructure (SRWUI) projects. Over the years, the budget was increased, primarily for the purpose of the infrastructure program.

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.

Water trading is increasingly becoming an important farm management tool for irrigators to manage changing environmental conditions. Studies have found that water trading increases farmers' flexibility in water use and moves water from lower value (or less efficient) uses to higher value (or more efficient) uses. Many countries that regularly suffer periods of droughts and have over-allocated water resources face a growing challenge to allocate water to competing water uses. Some of these countries have introduced water markets as a response to help enable an efficient allocation of a scarce resource. This is especially so in Australia's Murray-Darling Basin (MDB), which has had water markets in place for decades. The southern MDB is one of the most active water trading region worldwide, and hence, provides an ideal case study for examining water trading behaviour. The MDB faced the Millennium Drought in the 2000s which caused intensive distress for all alike: irrigators, tourists, rural communities and especially the environment. During the midst of this drought the Federal government introduced a water buyback program that purchased water entitlements from willing irrigators to return to environmental use.

To date, a number of studies have investigated irrigators' determinants to trade water. This literature has primarily focused on farmers' socio-economic and farm specific characteristics. But there is evidence that water trading is also affected by spatial factors, especially water entitlement trading. Thus, this thesis explores the relevance of spatial influences on irrigators' water trade decision-making. Traditional economic models of water trading behaviour are expanded with several spatially explicit variables, such as biophysical and distance factors. The influence of neighbours' water trading decision-making ('neighbourhood effect') is also tested, as anecdotal evidence shows that in the past irrigators experienced considerable social pressure if they sold or were willing to sell water entitlements. Furthermore, this thesis also examines the influence of spatial factors on irrigators' price choices for selling and buying water entitlements.

The results show that a number of spatial influences significantly affect water trading behaviour, especially water entitlement selling behaviour. Irrigators located in poorer resource areas (e.g. regarding soil degradation), in more rural areas and regions that suffer a socioeconomic decline (e.g. population decline) are more likely to sell water entitlements. There is evidence of a substitution effect between surface-water and groundwater (where viable groundwater resources exist). Irrigators in more rural areas tend to sell larger volumes of water entitlements and buy larger volumes of water allocations. Furthermore, a positive neighbourhood effect is confirmed, where irrigators' decisions to sell water entitlements was xviii

influenced by their neighbours. Over time, it became more socially acceptable to sell water entitlements. Finally, spatial influences also affect irrigators' valuation of their water, which is reflected in their price choices for water entitlement selling.

Overall, the results of this thesis support some existing policy measures and programs (e.g. salinity impact zones) and lead to several other policy implications. One such conclusion is the need to focus policy on water entitlement buybacks rather than on water irrigation infrastructure. This thesis concludes that current and future polices (e.g. related to the water buyback) could be more spatially targeted while also considering the externalities and wider irrigator behaviour in policy development. Spatially refined policies have the potential to improve the outcome of water markets (and related environmental programs) and alleviate the pressure on socio-economic and environmental systems.

# **Declaration**

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.

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#### **Journal article (peer-reviewed)**

Haensch, J, Wheeler, SA, Zuo, A & Bjornlund, H 2016, 'The Impact of Water and Soil Salinity on Water Market Trading in the Southern Murray–Darling Basin', *Water Economics and Policy*, vol. 1, no. 4, p. 26.

#### **Book chapter (peer-reviewed)**

Haensch, J, Wheeler, SA & Zuo, A 2016, 'The contribution of spatial analysis to water management: a case study of the Murray-Darling Basin, Australia', *Advances in Environmental Research, Volume 51*, Nova Science Publishers, Inc., Hauppauge, NY, p. 18.

#### **Conference paper (peer-reviewed)**

Haensch, J, Wheeler, SA & Zuo, A 2017, 'The spatial distribution and determinants of stated price choices for water entitlement trading', Contributed paper, 61<sup>th</sup> Australian Agricultural and Resource Economics Society, Brisbane, 8-10 February.

Haensch, J, Wheeler, SA & Zuo, A 2016, 'Location, Location, Location: the spatial influences on water entitlement selling in the southern Murray-Darling Basin', *45<sup>th</sup> Australian Conference of Economists* 2016, Adelaide, 11-13 July.

Haensch, J, Wheeler, SA & Zuo, A 2016, 'The spatial influence of neighbours' water sale behaviour on irrigators' water entitlement selling', Contributed paper, 60<sup>th</sup> Australian Agricultural and Resource Economics Society, Canberra, 2-5 February.

#### Other conference paper/presentations (non peer-reviewed)

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#### 1.1 Problem statement

#### 1.1.1 Water resources and irrigated agriculture in Australia

Water is an indispensable resource to life and comprises a number of values: environmental, economic, cultural and social (e.g. WWAP 2016). Globally, and in Australia, the protection of water resources has become a critical issue as its demand for food production, urban use and industry increases, while climatic changes have placed additional pressure on water and other environmental and social systems (Bowmer 2014).

Australia owns 1% of the global available freshwater resources, and therefore, is recognised and often referred to as the driest inhabited continent (Pigram 2006). Australia's freshwater is a finite and scarce resource in certain regions, due to typically low rainfall and high evaporation rates (BoM 2010). More importantly Australia's run-off is low; on average, less than 10% of rainfall becomes streamflow (Figure A.1) (BoM 2015). In many regions water needs may only be met by available groundwater resources or major water infrastructure (Thomas 1999). This is one of the reasons why irrigation areas in Australia have expanded less compared to other countries (Hallows & Thompson 1995).

Irrigated agriculture covers only about 1% of Australia's agricultural land, but accounts for the majority of the available freshwater in Australia, using approximately 57% of the water in 2013/14 (BoM 2015). Cotton, rice and dairy production consume the largest proportion of Australia's agricultural water (Figure A.2) (ABS 2015d). Given its highly urbanised population, Australia is one of the highest per capita consumers of water in the world (Palutikof 2010). Total water consumption in Australia declined during the Millennium Drought (major drought period from 2001–2009) until 2010/11 and then subsequently increased during higher rainfall years until 2013/14 when drier conditions returned (Figure A.3) (ABS 2016a).

Irrigated agriculture in Australia developed in the 19<sup>th</sup> and 20<sup>th</sup> centuries during European settlement primarily along rivers in the Murray Darling-Basin (MDB) in south-east Australia. The development of irrigation settlements was typically motivated by population growth, recurring periods of droughts, or to support soldiers returning from the war (Hallows & Thompson 1995). The historical developments are detailed in Chapter 2.

The MDB is Australia's most important agricultural production region and is an area of great agricultural, ecological, cultural and recreational significance (MDBA 2009). Irrigated agriculture in the MDB makes a significant contribution to both national and regional economies (Ashton 2014).

Over the years, irrigated agriculture in the MDB has gone through various controversial and extreme events, such as droughts, over-allocation<sup>1</sup> of resources, economic depressions, government subsidies, rising water tables and salinity levels, and increasing water prices (Hallows & Thompson 1995). Particularly, widespread losses in water and land quality in addition to a decreased and more variable water supply threatened irrigated agriculture (Connell 2007; Quiggin 2001). Thus, water resources management in the MDB has regularly been the subject of political controversy and has a long history of water governance producing a myriad of agreements and other initiatives, however, often with little impact (Cummins & Watson 2012; Quiggin 2012). There existed an obvious need for more comprehensive and integrated water management plans in the MDB that sought to sustainably balance competing water demands.

Several international organisations, such as the World Bank and United Nations, promoted water reforms in the second half of the last century, in response to the growing pressure put on water resources worldwide (Bjornlund & McKay 2002). Generally, a number of water resources management instruments exist to combat various water quality and quantity problems (Chartres & Williams 2006). Those instruments are either water supply or water demand management instruments. Supply management comprises, for example, increasing storage capacities, improving conveyance/distribution systems, drilling wells and developing new sources of water supplies, e.g. treated wastewater, desalination plants (Griffin 2006; Pereira et al. 2002). Demand management includes a diverse set of agronomic, economic, and technical instruments with the general objective of reducing irrigation water demand, while increasing yields and income per unit of water used (Pereira et al. 2002). Demand management instruments comprise, for example, water use and behaviour regulation (e.g. metering, quotas, restrictions on fertiliser or chemical use), education on water conservation, and economic instruments, such as water trading/leasing, water pricing, taxes, and subsidies (Griffin 2006; Settre & Wheeler 2016). Water supply and demand management are interdependent as, for example, effective demand management relies on advanced water supply conditions (Pereira et al. 2002). Water demand management instruments were

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<sup>&</sup>lt;sup>1</sup> "Over-allocation exists where the total volume of water permitted to be extracted by entitlement holders exceeds the environmentally sustainable level of extraction [...], the level of water extraction which, if exceeded, would compromise key environmental assets, or ecosystem functions." (NWC 2009, p. 88)

gradually adopted over recent decades in Australia after governments traditionally focused on improving water supply (Settre & Wheeler 2016).

#### 1.1.2 Water markets

Water markets have evolved widely in the world since the 1970s (Chong & Sunding 2006). In the MDB, water markets were endorsed for water reallocation purposes since the 1960s and 1970s, in search of a solution for the emerging water scarcity problem. A wide range of policy and institutional changes were initiated from the 1990s onwards to facilitate water trading and the reallocation from consumptive water uses to environmental needs (e.g. Crase et al. 2004). Major water reforms were driven by the Council of Australian Governments (COAG) and the Murray-Darling Basin Ministerial Council (MDBMC) (MDBMC 1999) producing numerous policies that addressed increasing environmental and regulative problems and inefficiencies within the MDB (Bjornlund 2006c; NWC 2011e). COAG's reforms in 1994 and 2004 arranged for the separation of water rights from land rights and enabled the expansion of water markets across borders of the MDB (COAG 1994). With the introduction of the National Water Initiative (NWI) in 2004 (i.e. Australia's blueprint for water reform), water markets became a central tool for water management and reallocation in the MDB (Bjornlund 2006a; COAG 2004b).

Generally, in Australia, water markets exist for water entitlements and water allocations:

A water (access) entitlement (also known as permanent water) is defined as "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."

A water allocation (also known as temporary water) is defined as "the specific volume of water allocated to water access entitlements in a given season, defined according to rules established in the relevant water plan." (COAG 2004b, p. 30).

Water allocations are seasonally announced as a percentage of their access entitlement depending on the water availability in the specific water resource to prevent over-allocation (NWM 2011).

Over the years, irrigators in the MDB had been adapting to fluctuating seasonal water allocations during droughts and to various changes in their operating environment, as governments introduced additional policies to alleviate the pressure on environmental, economic, and societal systems. Generally, those policy initiatives involved improvements to the water market, changes to pricing for water storage and delivery, funding for modernising irrigation infrastructure, buying back water entitlements, and the development of the Basin

Plan<sup>2</sup> (Ashton 2014). The Millennium Drought had prompted major rethinking in water resources management in Australia as it was clear that water policies at that time were insufficient to combat a declining water resource and increasing water variability (Chiew et al. 2011).

In 2007, a National Plan for Water Security was announced in response to the prolonged Millennium Drought and formalised in the *Water Act 2007*. This program was expanded in 2008 with the new *Water for the Future* program involving a AUD\$12.9 billion budget over a ten-year period (Parliament of Australia 2010). The budget allocated AUD\$3.1 billion towards a water buyback program, which aimed to buy water entitlements from willing irrigators and return these to the environment, and AUD\$5.8 billion towards Sustainable Rural Water Use and Irrigation Infrastructure (SRWUI) projects (DEWHA 2010; Wong 2008).

The water buyback program is the government's principal market-based instrument, deployed to produce environmental benefits in deteriorated sites across the MDB by reallocating water, previously allocated for consumptive uses, back to the environment. The target amount of water to be reallocated was set in the Basin Plan (MDBA 2012a). As at 31 July 2016, through the water buyback program and other water recovery schemes the government had recovered 72% of the total target of 2,750 GL³ per year (DoAWR 2016). Thus, the government still needs to acquire a considerable amount of water to be returned to the environment until the sustainable diversion limits (SDLs) (i.e. the maximum amount of water that can be taken for consumptive use) come into effect on 1 July 2019 (DSEWPaC 2012).

Recent changes in the Australian policy environment and recovery from the Millennium Drought have shifted the focus to recovering water predominantly from infrastructure modernisation projects rather than buying back water entitlements (Loch et al. 2016). While this change is the preferred option for many farmers and rural communities (Loch et al. 2014a), it is not cost-effective, and may not meet long-term sustainability aims of being able to flexibly respond to an uncertain and variable future climate, as put forward by a number of studies (e.g. Adamson & Loch 2014; Crase & O'Keefe 2009; Grafton 2007; Grafton 2010; Lee & Ancey 2009; Productivity Commission 2010; Wittwer & Dixon 2013).

Today Australia's water market is mature and ranks highest in terms of institutional foundations, economic efficiency, and environmental sustainability, when compared with

<sup>&</sup>lt;sup>2</sup> The Basin Plan is a coordinated approach to water management across all states and the territory in the MDB. Most importantly the Basin Plan sets the amount of water that can be extracted annually from the MDB for consumptive use (MDBA 2012a).

<sup>&</sup>lt;sup>3</sup> A gigalitre (GL) is equivalent to 810.71 acre feet.

other water markets in the world (Grafton et al. 2011). Australia's water market guides many other nations in the world that experience similar water scarcity concerns (Wheeler et al. 2015). Water trading has become an important tool to manage water scarcity and is widely adopted by irrigators as an adaptation strategy (Wheeler et al. 2014b). It was estimated that by 2010/11 around 86% of irrigators in New South Wales (NSW), 77% of irrigators in Victoria (VIC) and 63% of irrigators in South Australia (SA) had engaged in at least one water allocation or entitlement trade (Wheeler et al. 2014b). Australia is also known to be at the forefront of the battle for climate change adaptation (e.g. Palutikof 2010), as a highly variable climate has resulted in an uncertain water supply, as well as other environmental and social changes forcing irrigators to adjust and adapt (Beilin et al. 2012; Palutikof 2010). Therefore, Australia and the MDB provide a suitable study area to investigate irrigators' decision-making in water trading and adaptation behaviour in general, and to provide key insights for policy-making in water markets and other related policy areas.

Generally, water trading increases the overall allocation efficiency, as water is moved to higher value and more efficient uses and provides incentives to increase irrigators' water-use efficiency (e.g. Bjornlund & McKay 1995; Young et al. 2000). Thus, understanding irrigator decision-making, specifically regarding water trading, provides insight into the efficient reallocation of water resources between competing uses, and may improve the total allocative efficiency of water markets (Loch 2013).

Moreover, the water buyback program is an important adaptation strategy during a drought. Considering the likelihood of future droughts, understanding irrigators' determinants of participation in this program, and understanding what consequences this program might have, is essential for the overall success of such future environmental programs. Given that the Australian government is spending billions of dollars (AUD\$3.1 billion) on buying back water entitlements, and even more on modernising irrigation infrastructure, it is crucial to have a detailed understanding of what affects water selling decisions. Low participation rates in the water buyback scheme may lead to insufficient water recovery volumes or increased costs (e.g. Wheeler et al. 2012b).

The impact of water entitlement selling on the farm, families, and the wider community is a much discussed topic, but not much research was undertaken to date that could explain this impact. When designing policy programs, such as the buyback program, potential consequences for farmers and communities need to be considered. Farmer support packages can be designed to help farmers adjust to changes or go through a farm exit (Wheeler et al. 2012b).

#### 1.2 Literature Review

# 1.2.1 Water trading behaviour

A range of studies have analysed the determinants of irrigators' water trading decision-making in Australia. It is important to note the difference between water allocation and water entitlement trading behaviour. In general, water allocation trading is associated with short-term considerations in response to seasonal fluctuations of prices or water availability (to manage risk and uncertainty within and between seasons) and personal characteristics (e.g. Loch et al. 2012; Nauges et al. 2016; Wheeler et al. 2010b; Zuo et al. 2014). Water entitlement trading is more likely to be based on long-term considerations largely relating to farm characteristics (e.g. investment in farm technology) (e.g. Bjornlund 2006a; Isé & Sunding 1998; Wheeler et al. 2010b; Wheeler et al. 2012b). This is discussed in Chapter 3.

Previous studies on irrigators' determinants to sell water entitlements to the government for environmental purposes are relatively scarce. Wheeler et al. (2012b) found that, overall, irrigators primarily decided to sell water to the government out of 'last resort' circumstances, i.e. debt, death, and divorce, or for strategic reasons (e.g. following farm investment plans, water surpluses). The study concluded that irrigators' water trading behaviour can be complex, different across regions and dependent on a wide range of different factors, such as financial, farm, institutional, social and regional. Hence, irrigator market behaviour is a multifaceted research question and needs thorough consideration, allowing for an extensive range of potentially influencing factors. Isé and Sunding (1998) studied participation in the USA water buyback program, and similarly found that financial distress was the most important driver for the decision to sell water. In general, irrigators can have distinct reasons for selling their water entitlements to the government, such as farm exit, clearing debt, land use changes or investment opportunities (Wheeler & Cheesman 2013). These distinctive reasons contribute to the complexity of this research area.

Other international studies on water trading decision-making are limited. Generally, studies confirm the findings of Australian studies. For example, Canadian studies confirmed that irrigators not participating in water markets were older, had lower education levels and had spent more years in farming (Lafreniere et al. 2012). Water sellers were associated with having a water surplus, and water buying was driven by the aim of increasing long-term water supply security (Nicol et al. 2008). A Spanish study concluded that farmers' ethical views towards water trading (i.e. farmers objected to accept water as a commercial good) were a major barrier to participation in the water market (Giannoccaro et al. 2015).

#### **1.2.2** The gap

While some water trading behaviour studies have tested a limited set of spatial information,<sup>4</sup> the full range of spatial influences,<sup>5</sup> including the influence of neighbours' decision-making (referred to as the 'neighbourhood effect'), have not been accounted for so far. Typically, economic models attempting to explain the drivers of water trading decisions principally focused on farmers' socio-economic and farm specific factors, leaving the incorporation of several other potential determinants for future research (e.g. Wheeler et al. 2012b).

Nevertheless, studies suggested that water entitlement trading in particular is likely to be affected by long-term characteristics, such as spatially explicit biophysical factors, due to the permanent nature of this water right (e.g. Wheeler et al. 2010b). Moreover, studies have called for a more integrated investigation of water trading behaviour that allows for an extensive range of potentially influencing factors to account for the complexity of this research question and the differences across regions (e.g. Wheeler et al. 2012b). Related government programs and policies that ignore this complex nature of irrigator behaviour might not be appropriate in addressing the environmental targets and irrigator preferences.

This thesis attempts to address this gap by combining traditional economic modelling with spatial influences and spatial methods.

### 1.2.3 Spatial analysis

Spatial analysis is generally described as a set of methods that use locational information to analyse underlying processes and relationships while accounting for the special characteristics of spatial data (Anselin et al. 2013; Fotheringham & Rogerson 2009). The three broad categories of spatial methods are spatial exploratory analysis, spatial regression and spatial optimisation (Anselin et al. 2013). Spatial data combine locational information (i.e. based on the coordinates on the surface of the earth or a distance metric) and attribute information (Fotheringham & Rogerson 2009; Nelson 2002). There are two major characteristics that are distinctive for spatial data. Firstly, spatial data are typically not independent of each other which was originally pronounced by Tobler (1970, p. 236): "everything is related to everything else, but near things are more related than distant things". The literature refers to this "value similarity with locational similarity" as spatial dependence or, the weaker term, spatial autocorrelation (Anselin & Bera 1998, p. 241). Secondly, spatial data are often non-stationary in cases when processes vary across space (Fotheringham & Rogerson 2009). Thus,

<sup>&</sup>lt;sup>4</sup> For example, regional rainfall and location (i.e. state) in Wheeler et al. (2012b) and distance to markets in Isé and Sunding (1998).

<sup>&</sup>lt;sup>5</sup> Spatial influences or factors in this thesis are defined as spatially explicit/measured factors, such as distance based factors, regional statistics or neighbourhood interaction.

spatial methods exist to address the distinctive structure of spatial data. Typically, spatial analysis is divided into two phases: First, exploratory spatial data analysis (e.g. cluster analysis) to measure and quantify the spatial structure in the dataset, and second, confirmatory data analysis (i.e. modelling the impact of spatial structure) (e.g. Can 1998). Spatial exploratory analysis consists of methods (e.g. cluster analysis) to explore the dataset which may also involve visualising the data on a map (Fotheringham & Rogerson 2009). Spatial econometrics, as a sub-field of econometrics, provides for techniques (e.g. spatial regression models) to deal with spatial heterogeneity and spatial dependence and to evaluate its magnitude and significance (e.g. Halleck Vega & Elhorst 2015). Spatial regression models relax the assumption, imposed by ordinary least square (OLS) regression, that observations are independent from one another (e.g. Anselin 1988). Spatial econometrics is related to the time-series literature which focuses on the dependence among observations over time using (t-1) lagged variables. Spatial econometrics uses a spatial weights matrix W to describe the relationship and examine the dependence among observations across space (Elhorst 2014). Chapter 4 further describes spatial methods and the underlying spatial theories. The methods used in this thesis are introduced in the analysis Chapters 5 to 7 in the respective methods sections.

# 1.2.4 Spatial economic research in farmers' decision-making

A growing body of literature linking spatial and economic analysis shows that various economic processes are characterised by spatial aspects (Case 1991). In the early stages of spatial economic research, it was argued that economists too often ignore spatial dynamics:

"In fact our treatment of space, in any manner, has been largely superficial. We often use cross-sectional data that are inherently spatial but we rarely exploit the underlying spatial relationships or acknowledge them in our econometrics." (Bockstael 1996, p. 1169).

Empirical studies in agricultural economics incorporating a spatial approach have highlighted the importance of place and space on farmers' decision-making. Datasets in agriculture typically have a spatial pattern in relation to the landscape that is studied. Hence, spatially diverse natural resources, in addition to the interaction between decision-makers, are the driving factors of spatial relationships in agricultural economics (Bell & Dalton 2007). Correspondingly, it has been recognised that the impact and performance of policy instruments vary over both landscape and farmers (i.e. spatial heterogeneity of policy outcomes) (e.g. OECD 2012).

Spatial influences were found to have a major impact on various subjects in agriculture, such as technology adoption (e.g. Case 1992; Genius et al. 2013), land use change (e.g. Holloway

et al. 2002; Li et al. 2013), agricultural land value (indirectly related to farmers' decision-making) (e.g. Benirschka & Binkley 1994; Mukherjee & Schwabe 2015), and other farmer decision areas (see Chapter 6). Commonly assessed spatially explicit determinants involve land/soil quality information, climate data, population growth/density, distance to roads/markets, percentage of urban/rural areas and other regional characteristics. In addition, studies increasingly investigate the impact of neighbourhood effects (also called spill-over effects) on farmers' choices (e.g. Case 1992; Läpple & Kelley 2014). Most studies analyse land use choices, which provide a classic example for analysing spatial dependence because land use is often affected by neighbouring land use or by the same unobserved variables. Neighbouring land use may generate spatial externalities in the form of increased information spill-overs, technology adoption and labour market pooling (e.g. Li et al. 2013).

#### 1.2.5 Contributions of spatial analysis

Adding a spatial perspective to traditional economic research opens up the opportunity to conceptualise spatial relationships and to translate them into spatially targeted policies and spatial planning instruments<sup>6</sup>. For example, spatial analysis can contribute to the understanding of distributional effects of policies or, more specifically, the cost savings of targeted policy action (Bell & Dalton 2007; Newburn et al. 2005). By guiding economic, social and environmental activities, spatial planning has a critical anticipatory role in facilitating and promoting robust adaptation to climate change (e.g. Hurlimann & March 2012; Macintosh et al. 2015; Wilson 2006). It has the capacity to complement local authorities' development plans by emphasising the long-term perspectives of developments and relationships in the biophysical environment (Wilson 2006) and by aligning their activities with the concerns of the wider region, e.g. river basin (Kidd & Shaw 2007). For example, spatial planning instruments were found to be suitable in addressing climate change related coastal and bushfire hazards (Macintosh et al. 2013) or in increasing the effectiveness of reforestation for reducing river salinity levels (van Dijk et al. 2007).

Hurlimann and March (2012, p. 480) provided a useful overview on the abilities and capacities of spatial planning for adapting to climate change: Spatial planning:

- 1. Has the ability to act on and coordinate matters of collective concern or public good;
- 2. Can manage and facilitate the consideration of competing interests;

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<sup>&</sup>lt;sup>6</sup> Spatial planning can be defined as "a broad collection of methods and processes that aim to influence the spatial distribution of economic, social and environmental activities." (Macintosh et al. 2015, p. 1432). Spatial planning instruments range from 'traditional' land use planning techniques, such as zones, overlays and approval conditions, to broader methods, such as information programs, incentives, taxes/charges (Macintosh et al. 2013). As suggested by Hurlimann and March (2012), the term spatial planning is often also referred to as e.g. 'land use planning' or 'urban and regional planning'. In this thesis, the terms spatial analysis or spatial planning highlight the spatially explicit relationships and pattern of observed activities and effects.

- 3. Is a way of thinking and action across various spatial, temporal and governance scales while understanding and acting on local circumstances and particularities;
- 4. Can reduce or modify uncertainty and provide new mechanisms to deal with changing circumstances:
- 5. Has the capacity to be a repository for spatial knowledge sets;
- 6. Is oriented to the future, and has the potential to coordinate the activities of a range of actors to achieve long term benefits.

In the case of water resources management, spatial planning and spatial prioritisation problems arise when deciding on irrigation infrastructure investments, irrigator support programs, water quality improvements, water use/trading regulations and government's water purchases – with the aim to provide the greatest overall outcome for environmental and socioeconomic systems (Crossman et al. 2010a). There has been a call to combine integrated water management plans with spatial planning (e.g. Fidelis & Roebeling 2014), especially in countries where transboundary water management is required and water management has been traditionally based on administrative/political boundaries (Carter 2007). In this case, spatial analysis or spatial planning can put water management plans in the appropriate biophysical context. This approach needs to overcome the typical lack of coordination between planning authorities in shared water resources (Carter 2007).

Examining water trading behaviour spatially in this thesis can provide an understanding of the spatial structure and potential spatial determinants of water trading, to shed light on the complex relationships among water users, the economy and the environment. In doing so, this analysis can reveal important interdependencies in the MDB, such as those between ground and surface water, upstream and downstream use, water/land use and water quality and other important relationships within the system (Connell & Grafton 2008). Furthermore, knowledge of the relationships and spill-over effects in local social structures (communities) can provide policy makers with a more complete understanding to guide public spending. A better understanding of the biophysical and socio-economic structures and the various relationships in the system have the potential to improve the effectiveness of related policies. Generally, new insights into water trading patterns are intended to inform future water and environmental management policies in Australia and other countries. Policy implications may comprise of spatially refined/targeted policies.

Australia's water buyback program and investments in modernising irrigation infrastructure are likely to lead to a reorganisation and reconfiguration of irrigation landscapes (Crossman et al. 2010a). This can occur when large volumes of water entitlements are sold from one area or infrastructure upgrades focus on certain areas, leaving infrastructure in other areas in an aging condition and giving less incentive for local irrigators to stay on their farm. Both policy

programs need to be planned concurrently to avoid, for example, infrastructure investments where water entitlement sales are likely (e.g. Aither 2016; NWC 2009). A spatial analysis of water entitlement selling decisions to the government can lead to spatially refined policy recommendations within the water buyback and infrastructure modernisation program, as well as other government related programs, to alleviate the pressure and adverse effects on environmental and socio-economic systems. For example, results can be used to project water entitlement sales by region along with associated impacts, whilst supporting farmers through change.

# 1.3 Objectives and research questions

The core objective of this thesis is to understand the relevance of spatial influences on irrigator water trading behaviour, taking into account all other variables of importance such as water prices, farm debt, farm income, land use, productivity etc. Specifically, the thesis aims to investigate the impact of spatially explicit biophysical factors associated with poorer resource areas, regional socio-economic considerations, access issues and neighbourhood interaction on irrigators' water trading decisions, at various spatial and temporal scales. Therefore, the intent is to understand the spatial drivers and spatial pattern of water entitlement and allocation trading, and related effects on environmental and socio-economic systems in the southern MDB.

This multi-scale analysis aims to examine differences in the relevance of observed spatial influences on water trading behaviour at the aggregated (regional) and individual (farmer) levels. The aim is to inform policy makers on spatially refined/targeted policies, which improve the overall outcome of water markets.

To meet the outlined objectives, the following research questions will be investigated:

- 1. Is irrigators' water entitlement trading behaviour affected by spatial factors associated with greater resource scarcity and deterioration (regarding soil and water), greater regional socio-economic decline (e.g. regarding population decline) and lower access to markets, infrastructure and other services?
- 2. Is irrigators' water allocation trading behaviour equally impacted by the spatial factors above?
- 3. What is the impact of neighbours' water trading behaviour on irrigators' water trading decision-making?
- 4. Can the incorporation of spatially explicit variables, into a traditional economic model of water entitlement trading behaviour, increase its explanatory power?

5. Which spatial characteristics are associated with irrigators' price choices for selling and purchasing water entitlements (related to irrigators' willingness to accept and willingness to pay for water entitlements)?

#### 1.4 Research design/methodology

This thesis collects and combines a unique set of water market and spatial data to investigate relevant relationships at the regional and farm level. Chapters 5 and 6 address the research questions 1 and 2 using econometric panel models. The final analysis, Chapter 7, combines the collected spatial information with two recent irrigator surveys from 2010 and 2011 (n=1,462) to examine the spatial influences at the individual farmer level (addressing research questions 1 and 3-5). Address information is geocoded<sup>7</sup> and analysed using a Geographic Information System (GIS).<sup>8</sup> The spatial dependence in the dataset is explored using spatial exploratory methods (i.e. Moran's I test and cluster analysis). Relevant relationships are tested using probit models. Figure 1.1 illustrates the research design of the thesis.

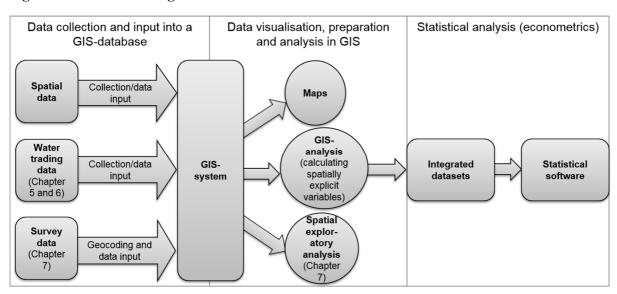


Figure 1.1: Research design

#### 1.5 Thesis structure

This thesis is organised into eight chapters and combines published and unpublished work. Following this introductory chapter, Chapter 2 introduces the study area (the southern MDB) and provides an overview of irrigated agriculture (e.g. key input factors, history of irrigated

<sup>&</sup>lt;sup>7</sup> "Geocoding is the process of assigning an XY coordinate pair to the description of a place by comparing the descriptive location specific elements to those in the reference data." (Zandbergen 2008, p. 215)

<sup>&</sup>lt;sup>8</sup> GIS is a tool to visualise, manipulate and analyse data by combining value information and locational characteristics and using different sets of spatial analysis tools (Anselin 1992; ESRI 2010).

agriculture and water resources management and the current situation), water market reforms and the development of water trading in the southern MDB. Thus, Chapter 2 provides the basis for studying the spatially explicit biophysical factors in relation to irrigators' decision-making, and introduces the institutional setting of the study area.

Chapter 3 comprises the literature review on water trading behaviour as well as an introduction to farmers' decision-making in general, including the influence of different disciplines (i.e. economics, geography, sociology/psychology) with a focus on the role of social capital (e.g. farmer networks) on farmers' decisions. This chapter highlights the complexity of farmers' decision-making and the multi-faceted determinants, as well as the differences in water entitlement and allocation behaviour. This chapter concludes with an overview of the literature gap.

## Chapter 4 presents published work:

Haensch et al. (2016b, 'The contribution of spatial analysis to water management: a case study of the Murray-Darling Basin, Australia', in JA Daniels (ed.), *Advances in Environmental Research*, vol. 51, Nova Science Publishers, Inc., Hauppauge, NY, p. 18.)

This chapter comprises a literature review on the contribution of spatial analysis to water resources management, including an introduction to spatial theories and methods. This chapter concludes by presenting case studies of the MDB, which introduces Chapters 5 and 7. It needs to be noted that some repetition will be encountered (e.g. regarding the study area) due to the format (i.e. publication) of this chapter.

The following three chapters provide the analyses that are summarised in Table 1.1 regarding the type of study, spatial and temporal scales and the methods used.

Table 1.1: Summary of the analysis chapters

Chapter	Water product	Trading decision	Water market/ data source	Spatial scale	Time period	Methods
5	Water entitlements	Selling (volumes)	Private/ revealed	River valley	2000/01 - 2010/11	ANOVA F-test, Bonferroni multiple comparison test, random-effects panel model
6	Water entitlements and allocations	Selling and buying (volumes)	Private/ revealed	Postcode area	2010/11 - 2013/14	Random-effects panel and tobit models
7	Water entitlements	Selling (discrete choice); Selling and buying (price choices)	Government/ revealed; private/ stated	Farm	2009/10 - 2010/11	Probit and tobit models, spatial exploratory methods (global Moran's I test, Cluster-Outlier analysis)

## Chapter 5 presents a published journal article:

Haensch et al. (2016d, 'The Impact of Water and Soil Salinity on Water Market Trading in the Southern Murray–Darling Basin', *Water Economics and Policy*, vol. 1, no. 4, p. 26.)

This chapter studies the influences of various salinity issues on water entitlement selling in the southern MDB at a regional level (i.e. river valley level). Some repetition will be encountered (e.g. regarding the study area and the literature review) due to the format (i.e. publication) of this chapter.

Chapter 6 comprises a literature review of the spatial economic research on various farmer decisions, in order to draw inferences for potential spatial determinants on water trading behaviour. Chapter 6 further complements the regional analysis from Chapter 5, by extending the econometric model with a number of spatial factors, and testing their impact on all water market transactions (i.e. water entitlement and allocation selling and buying) at a more detailed regional spatial scale (i.e. postcode area level).

Chapter 7 is the improved version of two conference publications (Haensch et al. 2016a; Haensch et al. 2016c) and expands on the study in Wheeler et al. (2012b) by including additional data and investigating the spatial influences on water entitlement selling to the government for environmental purposes. This chapter complements the regional analyses within Chapters 5 and 6 by focusing on the individual farmer level, to provide a complete picture of the spatial relationships behind irrigators' water trading behaviour. In addition, this chapter extends its spatial analysis to irrigators' price choices for water entitlement selling (willingness to accept) and buying (willingness to pay).

Chapter 8 summarises the findings of the thesis, discusses its policy implications and limitations, and provides recommendations for future research.

Appendices A to K provide further information that is not covered in the various chapters.

## Chapter 2 The southern Murray-Darling Basin: Irrigated agriculture and water markets

This chapter introduces the study area – the southern Murray-Darling Basin (MDB) in Australia and describes the development of irrigated agriculture in that area. For an understanding of the state of irrigated agriculture in the southern MDB today, it is important to review its beginnings, from European settlement in the 19<sup>th</sup> century, to the rapid developments of the 20<sup>th</sup> century. The final part of this chapter describes the water market in the southern MDB and introduces the major water reforms that have shaped the MDB's water markets, from the late 20<sup>th</sup> century up until today. Each phase of policy development and institutional arrangements has increased irrigators' participation in the water market.

## 2.1 Introduction to the study area

## 2.1.1 The Murray-Darling Basin

Australia's MDB is an area of great agricultural, ecological, cultural and recreational significance. It is often called the 'food bowl' of Australia, as it is Australia's most important agricultural production region, and provides about one third of the nation's food supply (ABS 2012b; MDBA 2009). In 2013/14, the MDB contributed 38% of Australia's gross value of agricultural production (GVAP)<sup>9</sup> (ABS 2015b). MDB's quota of Australia's gross value of irrigated agricultural production (GVIAP)<sup>10</sup> grew from 38% in 2009/10 (at the end of the Millennium Drought) to 49% in 2013/14 (ABS 2012c, 2015b). Cotton, fruit/nuts and dairy produce are the major contributors to MDB's GVIAP, while cereals and livestock products dominate MDB's GVAP (ABS 2015b). The region gained high social and cultural significance during Indigenous and European settlements, and during the more recent development of rural centres and agricultural communities (MDBA 2009, 2010).

<sup>-</sup>

<sup>&</sup>lt;sup>9</sup> GVAP estimates are derived by the multiplication of price and quantity estimates of agricultural commodities (ABS 2015b).

<sup>&</sup>lt;sup>10</sup> GVIAP estimates are derived by the multiplication of price and quantity estimates of agricultural commodities produced on irrigated land (ABS 2015b).

The following facts provide an overview of MDB's key characteristics (MDBA 2009, 2016c). The MDB:

- Covers 14% of Australia (1.06 million square kilometres);
- Comprises around 40% (almost 51,000 farms) of all farms in Australia;
- Is home to over 2 million people (around 10% of Australia's population);
- Provides water to around 3 million people (including the capital city of South Australia);
- Is home to over 40 Aboriginal Nations;
- Is home to 46 species of native fish and 98 species of waterbirds;
- Owns more than 25,000 wetlands and many distinctive species of fauna (e.g. the river red gum forests)
- Produces 50% of Australia's irrigated produce (area of irrigated production is around 1.6 million hectares); and
- Produces around 100% of the rice, 96% of oranges, 94% of cotton, 80% of grapes and 28% of dairy within Australia.

Figure 2.1 shows the MDB's location in south-eastern Australia, across parts of Queensland (QLD), New South Wales (NSW), Victoria (VIC), the Australian Capital Territory (ACT) and South Australia (SA), including the boundaries of the northern and southern MDB.

Cunnamylla

SA

OLD

NORTHERN

BOURKE

Coondiwindi

Nore

Narrabri

Bourke

Forbes Orang

STONEY

Wentworth

Mildura

Wentworth

Mildura

Mildura

Magga

CANBERRA

Bendige

Seymour

MELBOURNE

Figure 2.1: Australia and the Murray-Darling Basin (MDB)

Source: adapted from MDBA (2015a)

The MDB comprises 22 catchments (i.e. river valleys), which are introduced in Section 2.4 for the southern MDB. The Murray-Darling river system is Australia's longest river system and is the fifteenth longest river system in the world. The River Murray (southern MDB) and the Darling River (between southern and northern MDB) form the major streams of the MDB with a vast net of secondary rivers and creeks. MDB's rivers carry one of the smallest volumes of water for their size (annual average: 32,500 GL), which is highly variable and can range from 7,000 GL (in 2006) to almost 118,000 GL (in 1956). About 94% of the rainfall evaporates or is transpired by plants, only 4% flows into the river system (because of a typically flat terrain) and 2% drains to groundwater (MDBA 2016c). Over the years, an extensive network of water storage (e.g. dams, lakes, weirs) has been established, accounting for about 35,000 GL and supporting the MDB during droughts (MDBA 2009).

Water from the MDB's resources is diverted for agricultural, household and urban usage, and irrigated agriculture accounts for the majority of the diversions (between 80-90% depending on the season and water allocations). Groundwater extraction totals an average of about 1,375 GL annually (MDBA 2016c). In general, diversions in the MDB, and thus irrigation water use, respond to a variable climate, which can be observed in Figure 2.2. Diversions significantly declined during the Millennium Drought and increased thereafter, however did not reach the peak diversion levels of the 1990s.

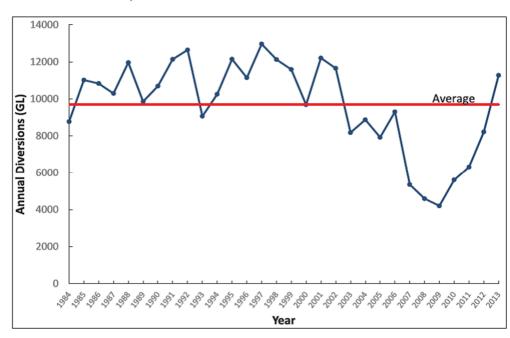


Figure 2.2: MDB diversions, 1983/84 – 2012/13

Source: Neave et al. (2015, p. 105)

## 2.1.2 The southern MDB

The southern part of the MDB covers areas of SA, VIC and NSW, as well as the ACT. Figure 2.3 shows the southern MDB including major rivers and water infrastructure. The southern MDB is a regulated river system which is hydrologically linked and which comprises the majority of the MDB's irrigation farms (NWC 2011e). The region was severely affected by climatic changes (e.g. droughts) and by an historical over-allocation of water resources, and is thus of particular interest for governmental regulations (Thampapillai 2009b). Several areas in the southern MDB suffer from low productivity due to numerous environmental problems, such as rising soil salinity levels caused by inefficient irrigation and high groundwater salinity levels. This was the result of a rather short-term perspective on resources management in the past (e.g. focusing on building large dams, tree depletion, and intensive farming procedures) (Bjornlund 2004), which is further discussed in the following sections.

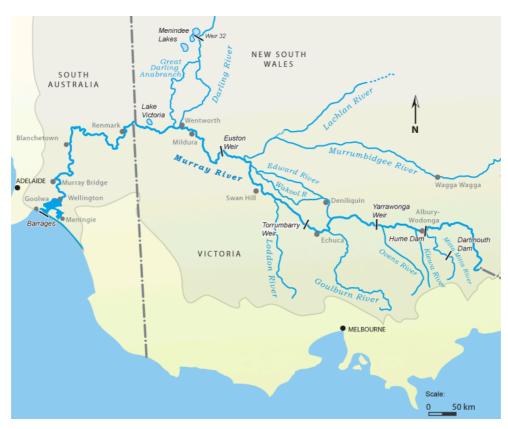


Figure 2.3: The southern MDB

Source: Murray River Guide (2011)

According to Köppen's major climatic zones classes, the southern MDB expands over grassland in the north and temperate zone in the south (BoM 2012b). The grassland zone is classified as warm (with summer drought), whereas the temperate zone is classified as no dry season and hot or warm summer. The main (grain) growing season in the southern MDB is the winter season, starting from April to October. Thus, southern Australia's agriculture

depends heavily on winter-season rainfall (Pook et al. 2006). Most of the southern MDB falls into a wet winter and low summer rainfall zone (BoM 2012b); but rainfall rates are comparatively low and highly variable.

## 2.2 Introduction to irrigated agriculture

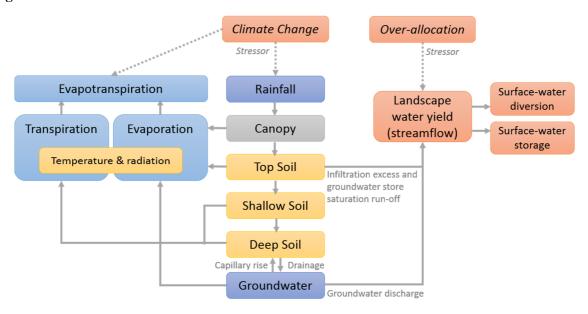
## 2.2.1 Key input factors

Successful irrigated agriculture is dependent on various parameters. Studies advise on systematic land evaluation, including for example soil suitability tests, for irrigated agriculture (e.g. FAO 1985). Table A.1 lists relevant land use requirements and determinants to be evaluated for a given land use, such as irrigated agriculture. Generally, land characteristics that need to be considered include soils, climate, topography, water resources, and vegetation, in addition to socio-economic conditions and infrastructure (FAO 1985).

The most critical factor in deciding on the need for irrigation for a particular crop is rainfall, particularly the amount of rainfall in a growing season and the variability of rainfall within and between growing seasons (Hallows & Thompson 1995). Correspondingly, soil moisture at time of planting and evapotranspiration are additional key factors for crop success (Pook et al. 2006).

Generally, optimal water resources management for irrigated agriculture requires an understanding and quantification of the local and regional water balance/cycle (Bowmer 2014). The water balance, illustrated in Figure 2.4, is typically used to measure water availability. Important variables in the water balance are inflows (e.g. rainfall), outflows (e.g. evaporation, run-off) and change in storage (e.g. soil moisture) (BoM 2012a). Key terms used throughout this thesis are evapotranspiration (i.e. sum of transpiration from vegetation and evaporation from the soil), different soil layers, surface-water run-off (i.e. excess water flows to streams), and groundwater drainage/discharge. Figure 2.4 also shows two major external stressors for the water balance, which are climate change (affecting water availability through changing rainfall and evapotranspiration rates) and over-allocation of water resources (human-induced change in water availability/environmental flows).

Figure 2.4: Water balance and stressors



Own figure (adapted from BoM (2012a, p. 8))

Other important factors for irrigated agriculture and water resources management are off-farm water delivery infrastructure (depending on the region), other water resources such as groundwater, and the level of water quality. Where surface-water resources are scarce, groundwater resources can be a critical factor for irrigation projects (see Chapter 5). There are different types of groundwater resources with different levels of productivity (Harrington & Cook 2014). The interconnectivity of surface-water and groundwater resources is not well understood, which prevents the development of appropriate and integrated surface-water and groundwater management strategies (DPI 2007). Whilst this is a highly researched area, there are major obstacles, such as limited and often unreliable data on surface-water to groundwater interaction. Furthermore, the time lag between groundwater extraction until the impact on surface-water resources is measurable can vary between days, decades and even longer (Harrington & Cook 2014).

Water quality issues, such as the level of nitrogen, turbidity and salinity can also significantly impact irrigated agriculture. For example, modern irrigation infrastructure requires clean water. Furthermore, saline irrigation water can cause soil dispersion and impermeability (e.g. Bowmer 2014) or a decline in crop yield (e.g. Yeo 1998), which is further discussed in Chapter 5. Often downstream irrigators are dependent upon upstream irrigators' effort to maintain water quality levels, e.g. by reducing salt in run-off (Bowmer 2014), which emphasises the importance of considering the interconnectivity of water resources in a river basin.

Soils and topography are also critical parameters that determine the success of irrigation projects (FAO 1985). There are a number of soil characteristics, which need to be taken into consideration when assessing the soil suitability and productivity, <sup>11</sup> depending on land use. Soil characteristics can be classified by chemical (e.g. pH level, organic matter, nutrients, salinity), physical (e.g. bulk density, permeability) and biological (e.g. microorganisms) properties (McKenzie et al. 2004). Furthermore, soil consists of changeable and unchangeable factors. For irrigated agriculture soil suitability assessment should be supplemented by predicting, for example, the change in salinity, water table, subsurface drainage and soil water logging (Crossman et al. 2010b; FAO 1985). Generally, key soil factors for land evaluation are soil structure/texture, soil thickness, pH level, organic matter (carbon) and fertility (DAFWA 2015). Soil texture is the key soil parameter used in this thesis (Chapters 6 and 7). It describes the soil's porosity and the arrangement of soil particles to form aggregates (peds). Large spaces between peds (i.e. macro-pores) are more likely to provide for soil permeability and root growth. A 'good' soil structure is often referred to as having a moderate to strong grade of structure, small-sized peds and abundant macro-pores. <sup>12</sup> Soil permeability can have an effect on local salinity levels as it affects soil leaching processes (McKenzie et al. 2004).

## 2.2.2 Australian and MDB climate

Water availability for irrigated agriculture is, to a great extent, dependent on climate characteristics. As mentioned, rainfall in Australia is characterised as low, seasonal and irregular compared to other countries. This can be observed in Figure A.4 which shows the mean annual rainfall (mm) for Australia between 1900 and 2015. Half of Australia's surface area receives below 300mm and only 20% receives more than 600mm rainfall annually (the long-term average rainfall for 1961–1990 is 465.2mm) (BoM 2016). Around 40% of the continent is naturally too dry for agriculture (Thomas 1999) and SA is the driest state in the country (Pigram 2006).

Several periods of droughts have affected Australia over the previous decades and century. Major drought periods were the 1) Federation Drought, 1896–1905 (on average 5,787 GL annual flow); 2) World War II Drought, 1936–1945 (on average 6,830 GL annual flow); and 3) Millennium Drought, 2001–2009, which is also described as starting as early as 1997 (on average 5,463 GL annual flow) (Neave et al. 2015). Figure 2.5 provides an overview on the long-term average inflows into the River Murray in the southern MDB, and the average

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<sup>&</sup>lt;sup>11</sup> Soil productivity (crop yield per mm of available water) measures the soil's ability to provide water and nutrients for agriculture (DAFWA 2015).

<sup>&</sup>lt;sup>12</sup> Different crops have different resource requirements. Hence, the soil evaluation needs to be undertaken according to the specific land use. For example, rice production requires a massive soil structure without macropores as percolation issues are important (FAO 1985; McKenzie et al. 2004).

inflows during these major drought periods. Each of the droughts has caused major environmental problems and has impacted on regional economies, the development of irrigated agriculture and water resources management (see Section 2.3). The recent Millennium Drought caused an extensive decline in River Red Gum Trees along 1000km of the River Murray (DWLBC 2003) and dried up Ramsar-listed wetlands and lakes (Chiew et al. 2011).

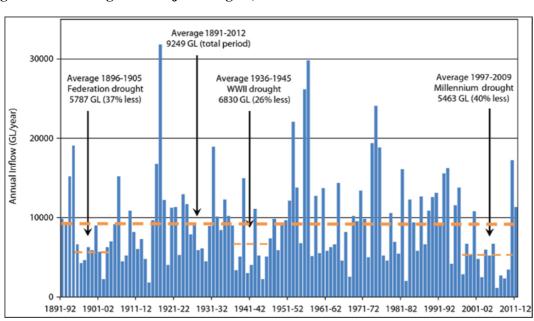


Figure 2.5: Annual total in-flows into the River Murray (including the long-term average and average in-flows during three major droughts)

Source: Neave et al. (2015, p. 102)

Recently, the MDB experienced above average rainfall rates in 2010/11 with widespread flooding. In 2015, Australia again faced below average rainfall (5% below the 1961–1990 average), with a total of 444mm annual rainfall. Generally, in south-eastern Australia a decline in late autumn and early winter rainfall has continued, consistent with longer-term drying trends since the mid-1990s (BoM 2016).

# 2.3 Historical developments of irrigated agriculture and water resources management

Agricultural development in Australia began with the landing of the first European settlers in 1788. Along with agricultural technology, European settlers brought European agricultural experience (especially Irish/British) to the country (Henzell 2007). Prior to the development of irrigation settlements in the southern MDB, a thriving river trade had developed on the River Murray by the 1850s. The potential value of irrigation projects has been promoted by

governments since the end of the 19<sup>th</sup> century, <sup>13</sup> when population increased and droughts emerged (Hallows & Thompson 1995; Loch et al. 2014b). At this time, the main emphasis was on stimulating economic demand and supporting migrants to facilitate population growth (Quiggin 2001). In south-eastern Australia arable land was already scarce and, thus, irrigation seemed to be an ideal opportunity to transfer and also use low quality land (Connell 2007). Overall, the following factors were vital for irrigation development in Australia: closer settlement <sup>14</sup> in rural areas, rainfall deficiency and variability (and the need to overcome it), suitable irrigation water sources, available funds, and nearby markets/centres of population (Hallows & Thompson 1995).

VIC became the pioneering state to develop large irrigation projects from the 1880s, largely thanks to the gold mining boom (Connell 2007). Irrigation areas developed independently depending on various factors, such as the local progress of building water infrastructure, funding opportunities and land suitability. Due to a slower population growth and less water scarcity problems, irrigation development in NSW started comparably late in the early 20<sup>th</sup> century. Irrigated agriculture in NSW was organised in individual river valleys scattered around the state, in contrast to VIC where the majority of irrigation projects took place in one great interconnected system. Thus, the development of irrigated agriculture in NSW was highly dependent on water storage (Hallows & Thompson 1995). SA intended to further continue developing river trade on the River Murray, but eventually followed VIC's and NSW's focus on irrigation development (Crase et al. 2004; Quiggin 2001).

Australia's climate, low surface run-off and highly variable river flow implied a challenge for the European settlers (Crase et al. 2012). As a result, many early agricultural establishments from the late 19<sup>th</sup> century were forced to relocate or shut down during droughts, leaving a degraded landscape behind (Connell 2007; Hallows & Thompson 1995; Musgrave 2008). Droughts typically instigated government involvement in irrigation schemes. For example, Irrigation Trusts took over the control of irrigation settlements in VIC and SA in the late 19<sup>th</sup> century, and water rights were no longer issued according to English common law (i.e. riparian law), which had previously allowed water use from adjacent water resources to a landholder's property (Hallows & Thompson 1995; Musgrave 2008; NWC 2011e).

<sup>&</sup>lt;sup>13</sup> Earliest examples of irrigation were started by private individuals driven by the opportunity to increase production on their farms. The first private irrigators started as early as 1842 in Blanchetown (SA) and in the 1860s at Barmera (SA). The first major irrigation schemes were established in Renmark (SA) and Mildura (VIC) by the 'Chaffey Brothers' in 1887 (Hallows & Thompson 1995).

<sup>&</sup>lt;sup>14</sup> Generally, governments pursued the aim of creating independent small-scale farmer based irrigation settlements, by reducing the land size assigned to farmers with water rights bound to land holdings, to prevent large-scale owners taking over control of resources (Connell 2007).

Furthermore, Australia introduced a system of state control over water resources (Hallows & Thompson 1995; Wheeler et al. 2014a). The states established centralised systems<sup>15</sup> to regulate the allocation of water rights, i.e. creating water entitlements according to seasonal conditions and providing access to a proportion of available water instead of a fixed amount of water, which was an innovative idea worldwide (Connell 2007; NWC 2011e). SA adopted the most conservative water allocation system, due to being located in the downstream area, needing to supply the capital city of SA and the focus on perennial horticulture. NSW developed the least conservative approach, and water management focused on annual water allocation of all available resources, since agriculture concentrated on annual cropping, which can be modified annually. VIC's approach to water allocation was in between SA and NSW in terms of stringency, as farming was dominated by perennial horticulture and the more flexible production of dairy (Bjornlund 2004). Differing water entitlement systems with differing reliabilities led to problems over time (e.g. regarding interstate water trading) (Crase 2008a; Crase et al. 2004; Loch et al. 2014b).

Over time, the southern MDB states realised that the success of their irrigation projects was dependent on the cooperation and compliance of the other relevant states. There exists a long history of disputes between the three states regarding water management along the River Murray, starting in 1850, when VIC was separated from NSW. For example, there was a need for VIC and NSW to cooperate on building water storage and to settle water sharing disputes along the shared border. The Federation Drought in 1902 compelled the states to come together and discuss those water sharing disputes, which led to the first catchment-wide agreement between NSW, VIC and SA; the River Murray Waters Agreement in 1915 (Connell & Grafton 2011; MDBA 2014d; Quiggin 2001). The agreement arranged for the building of a network of dams, weirs, locks and barrages, aiming to increase water supply security. The River Murray Commission was established alongside the agreement in order to assign responsibilities of managing the operation of infrastructure and distributing water to the states (Connell 2007; Hallows & Thompson 1995; NWC 2011e).

Throughout the following decades the focus was on water quantity and expansion of irrigated agriculture, e.g. via subsidies for irrigation industries, price maintenance schemes, and continued investment in infrastructure, which led to a tenfold increase of water storage from 1940 to 1990 (Connell 2007). No limit on total diversions was set. These attitudes are the

<sup>&</sup>lt;sup>15</sup> There is a long history of individual water management systems in the states, as the colonies managed their water resources individually prior to federation in 1901 (i.e. colonies formed the Commonwealth of Australia), and also due to great distances across the country. As a result, irrigation was not a national responsibility in Australia's constitution in 1901 and the states still have individual water rights systems and rules today (Connell 2007; Hallows & Thompson 1995).

reason for over-allocation problems. Between 1918 and 1970 governments also supported irrigation settlements for returned soldiers from both World Wars, in order to provide employment (MDBC 2006; NWC 2011e).<sup>16</sup>

The rapid growth of irrigation schemes was coupled with a number of environmental occurrences (e.g. seepage losses, algal-bloom outbreak, land salinization, water logging, <sup>17</sup> and changes in river channel planform) and other problems (e.g. unsuitable cultivation of crops<sup>18</sup>) (e.g. Crase et al. 2012; Hallows & Thompson 1995; NWC 2011e). Several national subsidy programs were initiated to improve water supply, land conservation and support primary industries. Furthermore, the River Murray Agreement was expanded with water quality responsibilities, following major investigations into salinity concerns (Hallows & Thompson 1995; MDBC 2006).

From the 1970s, public concern about water use and subsidies for irrigated agriculture in the MDB arose due to declined water quality and water availability levels (Crase et al. 2012; NWC 2011e). During this time urban population and agricultural production grew continuously, and the pressure on financial and environmental systems became evident. The trend of urbanisation in Australia, was accompanied by an increased environmental awareness of the wider population (Crase et al. 2012). This stage marked the transition from an expansionary to a mature and more sustainable phase of water management/policies. This phase shifted the emphasis from expanding water storage to conserving water, increasing water use efficiency and managing major environmental problems (e.g. Crase et al. 2012; Hallows & Thompson 1995; Settre & Wheeler 2016). Firstly, regulatory restrictions were introduced to combat the decline of water resources, such as early controls on the issuing of new water entitlements in SA in 1969 (NWC 2011e).

During this stage, some irrigators and policy makers called for the need to transfer water between users to provide for agricultural viability and expansion during times of low water supply. Thus, water trading was largely initiated through "a pragmatic and user-driven response to emerging circumstances, rather than as a comprehensive strategy for introducing

<sup>&</sup>lt;sup>16</sup> After World War I some soldier settlements collapsed as a result of a one-sided expansion strategy and rising competition in global commodity markets (MDBC 2006; NWC 2011e). Soldier schemes after World War II were more advanced as settlers were tested on their suitability and quotas were introduced on irrigated land (Hallows & Thompson 1995).

<sup>&</sup>lt;sup>17</sup> Some soils were not suitable, e.g. for rice cropping, and increased water logging and salinization processes were the consequence (Hallows & Thompson 1995).

<sup>&</sup>lt;sup>18</sup> High water salinity levels limited crop variability in some areas (e.g. citrus was replaced by vines which are more salt tolerant). VIC was particularly affected, in that only shallow rooted crops remained productive under the saline shallow water tables (where water has risen to within 2 metres of the surface) in many areas, which can be counterproductive since shallow rooted crops cannot contribute to decreasing water tables. Thus, dairying and grazing became the sole productive option for a number of VIC farmers, which limited farmers' flexibility to respond to market changes (Hallows & Thompson 1995).

a new market." (NWC 2011e, p. 9). As a result, formal water trading gradually began to develop during the 1980s, which was initially only permitted for water allocations and only between private diverters. The general acceptance of water being treated as an economic commodity was low to begin with, which explains the slow and gradual introduction of formal water trading and water markets (see Section 2.6) (NWC 2011c).

The first Murray-Darling Basin Agreement was put in place in 1992 (initial document signed in 1987) as a result of continuous salinity and land degradation problems in the MDB. <sup>19</sup> The agreement initiated the establishment of the Murray-Darling Basin Ministerial Council (MDBMC) and its executive instrument, the Murray-Darling Basin Commission (MDBC), to expand responsibilities to a Basin-wide management of water and land resources (MDBC 2006; Quiggin 2001). Along with these institutional changes emerged a new perspective of water management, known as integrated catchment management. <sup>20</sup> This more holistic approach aimed to cover all aspects of water management (i.e. water quantity and quality) and considered the interaction across resources and between upstream and downstream users in a river basin (Connell 2007).

## 2.4 Irrigated agriculture today in the southern MDB

This section describes the profiles of the irrigation regions and provides current statistics and information on environmental, economic and social factors of current irrigated agriculture in the southern MDB.

## 2.4.1 River valleys and irrigation districts

Within current statistics, and throughout this thesis, irrigated agriculture in the southern MDB is typically described by river valleys (sometimes also referred to as surface-water systems, catchments or surface-water sustainable diversion limit (SDL) resource units, see below) and in some cases by irrigation districts<sup>21</sup> or by water trading zones.

<sup>. .</sup> 

<sup>&</sup>lt;sup>19</sup> When environmental (e.g. water quality) problems increased, traditional public institutions reached their limits. Managing water quality requires a different set of consultation and communication responsibilities that traditional institutions were not designed for (i.e. regular consultations with farmers, communities, government agencies and researchers). The challenge was to manage increased salinization and nutrient pollution (in addition to low river flow) that resulted from land use changes in the MDB (Connell 2007).

<sup>&</sup>lt;sup>20</sup> The foundation for this new catchment perspective was laid in 1992 at the UN Conference on Environment and Development in Rio de Janeiro, which caused a worldwide shift towards environmental awareness. The conference approved what is commonly known as Agenda 21, which incorporated guidelines for future water management (Connell 2007). It promotes sustainability as a guiding principle for policy development instead of one-sided policies that primarily follow economic interests (George & Kirkpatrick 2006; United Nations 1992). <sup>21</sup> In irrigation districts rural water corporations have rights and responsibilities to supply water by channels and pipelines mainly for irrigation purposes. Some larger irrigation districts can contain several irrigation areas (Victorian Water Register 2015).

River valleys in the southern MDB are shown in Figure 2.6.<sup>22</sup> Each of these river valleys has a water take limit, which is the maximum long-term annual average quantity of water that can be taken on a sustainable basis (SDL) (MDBA 2016f). Figure A.5 illustrates the water trading zones in the southern MDB which correspond to the river valleys, but are divided into subsystems to represent locally specific hydrology aspects. Each water trading zone has its own water trading rules (see Section 2.6.2) (NWC 2013b).

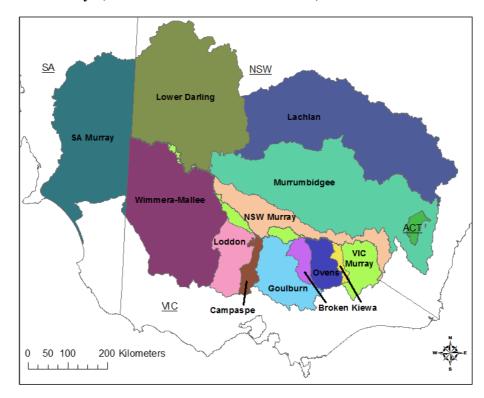


Figure 2.6: River valleys (surface-water SDL resource units) in the southern MDB

Own figure (data sources: Geoscience (2006) and MDBA (2013a))

Major water supply and management responsibilities in the river valleys reside with rural water authorities or Irrigation Infrastructure Operators (IIO) (Table 2.1). IIO provide off-river water infrastructure services (i.e. delivering water through a network of channels or pipes by gravity-fed or pressurised systems) for the main purpose of irrigation. Irrigators not belonging to an IIO are private irrigators (i.e. sourcing water directly from the natural resource) (ACCC 2016).

In recent years, and especially since the end of the Millennium Drought, networks of off-farm water infrastructure, such as channel systems, have been modernised, which has resulted in channel upgrades as well as abandonments. The so called 'Goulburn Murray Water Connection Project' in northern VIC is the largest irrigation modernisation project in

<sup>22</sup> SA Murray comprises other surface-water SDL resource units in SA (SA Non-Prescribed Areas, Marne Saunders and Eastern Mount Lofty Ranges) which are amalgamated in public statistics and in this thesis.

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Australia (GMW 2012). The project's aims are (amongst others) upgrading and automating backbone<sup>23</sup> channels and meters, reducing the size of the channel network, and reconnecting properties to the upgraded backbone channel system (GMW 2016b).

The Goulburn-Murray Irrigation district (GMID), managed by Goulburn Murray Water (GMW), is the largest irrigation district with the largest irrigation infrastructure supply network in Australia. GMW comprises customers from several irrigation districts and areas overseeing several supply types, such as gravity irrigation (channels), pumped irrigation, regulated and unregulated surface-water diversions, and groundwater (GMW 2016a). The GMID produces more than one quarter of VIC's agricultural production, which is why the region receives investment priorities to maintain production standards. GMID's irrigation infrastructure is, in places, over 100 years old and in 2008 water 'loss' accounted for 30% (900 GL) per year through leakage, seepage (water seeps through the bed/sides of a channel), evaporation and other infrastructure inefficiencies (Marshall 2008). However, water lost through leakage and seepage is actually not lost in the system, as the water returns to the environment and the river system via closely connected groundwater and surface-water resources (Quiggin 2010). This is further discussed in Section 2.5.2.3.

Other irrigation districts are listed in Table 2.1.<sup>24</sup>

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<sup>&</sup>lt;sup>23</sup> Backbone channels are high capacity (>20 ML/day) water delivery channels and a priority for modernisation (Crossman et al. 2010b). Backbone channels are defined as "larger capacity water supply channels (carriers and trunks) that will form the nucleus of a modernised and automated water supply system to efficiently transport large volumes of water direct to customer service points." (GMW 2009, p. 173)

<sup>&</sup>lt;sup>24</sup> Other major irrigation areas and districts are the Murrumbidgee Irrigation Area (MIA), which also encompasses and manages the water supply of several irrigation districts and areas (MIA 2016), and the Coleambally Irrigation District in Murrumbidgee (NSW). Another major irrigation area is managed by Murray Irrigation Limited (MIL), which is Australia's largest privately owned irrigation company, based in southern NSW, distributing irrigation water by gravity channels (MIL 2012). The Renmark Irrigation Trust (RIT) and Central Irrigation Trust (CIT) manage the irrigation water supply in SA.

Table 2.1: Principal irrigation infrastructure operators (IIO), 2012/13

State	ПО	River valley (water supply system)	Volume of water managed or owned (ML)	Number of irrigation customers (using regulated sources)	
NSW	Murray Irrigation Ltd	NSW Murray	1,054,793	2,043	
	Murrumbidgee Irrigation Ltd	Murrumbidgee	948,182	3,343	
	Coleambally Irrigation Corporation Ltd	Murrumbidgee	402,973	494	
	Jemalong Irrigation Limited	Lachlan	78,382	186	
	Western Murray Irrigation Ltd <sup>a</sup>	NSW Murray	57,743	374	
VIC	Goulburn–Murray Water	Goulburn, Broken, Loddon, Campaspe	2,688,331	20,586	
	Grampians Wimmera Mallee Water	Wimmera, Avoca and Richardson rivers	28,000	320	
	Lower Murray Water	VIC Murray, Goulburn	358,826	5,984	
SA	Central Irrigation Trust	SA Murray	133,681	1,424	
	Renmark Irrigation Trust	SA Murray	42,601	560	

<sup>&</sup>lt;sup>a</sup> Due to a lack of data, figures are as at 30 June 2010.

Source: NWC (2013b)

## 2.4.2 Regional profiles

## 2.4.2.1 Biophysical characteristics

Most of the river valleys in the southern MDB are divided in two major parts, one mountainous region with elevations reaching over 1000m, and a flat river plain region with low elevations on average between 100m and 300m (MDBA 2016a). Correspondingly, the southern MDB can be divided in two major zones according to common soil characteristics and landform development, with the Riverine Plains to the east and the Mallee region to the west. The soils in the Mallee region are based on marine sediments and are generally sandy, well-structured and comparatively fertile. In the Riverine Plains, soils are characterised by sediments that have flowed from the Great Dividing Range (mountain range to the east), then set down and eroded across the Riverine Plains. Sandier sediments accumulated near the rivers and finer sediments set down further away. Thus, the Riverine Plains became characterised by light sandy soils (above old stream courses) as well as clayey soils (further away from old streams) with partially heavy and poorly-structured clays (Hallows & Thompson 1995; McKenzie et al. 2004).

As shown in Section 2.2.1, soil is a complex resource. There are about 500 soil profiles in south-eastern Australia (ASRIS 2013) and many river valleys in the irrigated areas of the southern MDB have a great diversity of soil types, which typically reflects differences in, for example, topography, climate and organic activity. Often those soil types have some chemical

and physical limitations (e.g. acidity, salinity), which need to be addressed by appropriate land management practices to improve land suitability for agriculture (DEDJTR 2015c).

As briefly described in Section 2.1.2, most of the southern MDB's river valleys lie between temperate and grassland climatic zones. Mountainous regions receive on average between 800mm and 1600mm average annual rainfall, and the Riverine Plains receive between 220mm and 400mm of average annual rainfall (MDBA 2016a). Grassland zones (e.g. the semi-arid plains in NSW's west) are typically very dry. In about 60% of NSW, rainfall is on average below 250mm annually and river flows are highly variable (Hallows & Thompson 1995; MDBA 2016a). Figure 2.7 presents average annual rainfall for the most recent farming seasons in the southern MDB. After the Millennium Drought the MDB experienced two above average rainfall years in 2010/11 and 2011/12 followed by a below average rainfall year in 2012/13 (NWC 2013b).

Long-term average (1960–2014)
2013/14
2012/13
2011/12
2010/11
2009/10
2008/09
2007/08

mm 0 100 200 300 400 500 600 700 800 900

Figure 2.7: Average annual rainfall for irrigation farms in the southern MDB, 2007/08 to 2013/14

Own figure (data source: Morey et al. (2015))

The rainfall pattern of the most recent farming seasons is reflected in the southern MDB's water storage levels, displayed in Figure 2.8.<sup>25</sup> During the final drought years, water storages reached less than 30% of their capacity.

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<sup>&</sup>lt;sup>25</sup> Southern MDB storages include: Blowering Dam, Buffalo, Burrinjuck Dam, Cairn Curran, Carcoar Dam, Dartmouth Dam, Eildon, Eppalock, Greens Lake, Hepburn, Hume Dam, Kangaroo, Kow Swamp, Laanecoorie, Lake Brewster, Lake Cargelligo, Lake Victoria, Menindee Lakes, Newlyn, Nillahcootie, Reedy Middle, Third Lake, Tullaroop, Waranga Basin, William Hovell, Yarrawonga Weir (Morey et al. 2015).
30

16000 100 14000 80 12000 10000 60 8000 40 6000 4000 20 2000 n  $\cap$ 2007/08 2008/09 2009/10 2010/11 2011/12 2012/13 2013/14 % GL GL

Figure 2.8: Average water storage levels for the southern MDB, 2007/08 to 2013/14

Own figure (data source: Morey et al. (2015))

In addition, temperatures have been increasing in the southern MDB since recording commenced in 1910 and particularly since 1960. Specifically, between 1910 and 2013 mean surface air temperature increased by 0.8 degree Celsius (Timbal et al. 2015).

Groundwater resources in Australia are broadly classified into sedimentary and fractured rock aquifers. Groundwater extraction is typically concentrated on sedimentary aquifers, which are often located below arable land and have higher groundwater yields. In the southern MDB both sedimentary and fractured rock aquifers can be found; albeit with a low productivity level. Higher productivity sedimentary aquifers are only prevalent in isolated areas, e.g. in the south-west of the southern MDB in VIC (Harrington & Cook 2014).

#### 2.4.2.2 Land use

Table 2.2 lists major irrigated land uses by river valley/water trading zone. The majority of land uses are distributed across most areas of the southern MDB (e.g. fruit, nuts and grapes), whereas cereals and rice are mainly produced in NSW Murray and Murrumbidgee, and dairy is the dominant irrigated industry in VIC Murray and Goulburn. Dryland agriculture is also dominant in most areas of the southern MDB (e.g. in Murrumbidgee, Wimmera and Lower Darling for extensive grazing, cereal-based cropping and livestock). Murrumbidgee makes major contributions to NSW's overall fruit and vegetable production and Australia's overall grape and rice production. Land use in Murrumbidgee is the most diverse, reflecting the region's differences in geography and climate (MDBA 2016a)

Table 2.2: Key irrigated industries in the southern MDB, by river valley/water trading zone

	Cereals for grain and seed	Cotton	Rice	Fruit & nuts	Grapes	Vegetables and seed	Dairy	Meat cattle
Lachlan (NSW)		X		X	X	X		
Lower Darling (NSW)				XX	XX			
NSW Murray	X		XX				X	X
Murrumbidgee (NSW)	X		X	X	X	X		
Goulburn (VIC)				XX			XX	
VIC Murray (below Barmah)				X	X		XX	
VIC Murray (above Barmah)				X	X		XX	X
SA Murray				XX	XX	X		

The number of 'X' reflects the prevalence of the industry in the trading zone (based on GVIAP).

Source: NWC (2014)

Over recent years, there has been a rapid expansion in nut plantings and cotton, due to higher profitability compared to e.g. growing rice, and an overall slow decline in wine grapes (Aither 2016). Rice production, which is flexible and highly dependent upon water availability, significantly dropped during the Millennium Drought and gradually recovered from 2010/11 onwards (NWC 2011g). The development of nut production increased rapidly, e.g. in VIC almond production increased by 852% between 2005/06 and 2013/13 (DEDJTR 2014). In general, perennial production in fruits, nuts and grapes and some high capital annual production (e.g. cotton) were found to return the highest value for water used (Qureshi et al. 2016).

#### 2.4.2.3 Socio-economic characteristics

Many southern MDB river valleys are sparsely populated, such as the Lower Darling, Kiewa and parts of SA Murray/Wimmera-Mallee, with only a few rural centres that provide basic services for rural communities. Other river valleys are more developed with larger population sizes, such as Murrumbidgee (30% of MDB's population) and Goulburn-Broken (7% of MDB's population). In some regions most of the income is derived from agriculture and supporting industries (e.g. in Lachlan, Wimmera-Mallee), however in most of the river valleys tourism is a significant contributor to local economies (mostly through water activities and National Parks) (MDBA 2016a).

Average profitability of irrigated agriculture in the southern MDB has been poor over the last decade, even though some industries were highly profitable (e.g. cotton, nuts). Average farm cash income was around AUD\$75,000 per year and average farm business profit was negative (around AUD\$-10,000 per year) (Aither 2016). The impact of the drought, and financial pressures during and after drought years, is evident when observing the financial performance 32

of farms across major industries (i.e. horticulture, dairy, broadacre<sup>26</sup>) in the southern MDB over time (Figure A.6). The pattern of farm cash income is similar across industries, with the exception of the dairy industry, which experienced another collapse in recent years due to a plunge in milk prices. According to Ashton (2014), the key drivers for changes in farm income included changing commodity prices (Figure A.7), rising farm input costs, varying seasonal conditions and irrigation water availability.

Such major events and trends, are likely to have a significant impact on southern MDB's communities and farmers, particularly in relation to employment, production, investments and wellbeing (Kiem & Austin 2013; MDBA 2015c). For example, extreme events, such as droughts, were found to have a negative effect on farmers' mental health (Berry et al. 2011; Edwards et al. 2015; Polain et al. 2011). Many irrigators who have survived the drought period did so by borrowing money and, thus, by increasing their debt level. Other irrigators, particularly on small farms, substituted low farm income with off-farm work (Aither 2016). Specific farm adaptation strategies involved fallowing, changing crop mix, water trading, technology improvements, input substitution (e.g. purchasing feed in the dairy sector) or raising the overall productivity level (Kirby et al. 2014). Generally, the drought has induced on-farm efficiency improvements and many surviving farms developed business plans based on lower water use. Many dairy farmers, for example, adopted modern irrigation technology (e.g. centre pivot), which was partly subsidised by the government. Other dairy farmers switched to mainly growing and storing winter crops to reduce irrigation water demand during summer (Aither 2016).

Other (social) changes and trends, e.g. intensification/diversification, leasing out or exiting the farm, increased importance of education and trend to seek employment outside of farming, also had an impact on Australia's farms over previous decades, especially on smaller family farms (Barr 2009). Family farms make up a considerable percentage of Australian farms (Muenstermann 2010; Wheeler et al. 2012a). There is a trend towards a higher percentage of farmers having no successor for the farm (Barr 2009), which was shown to be associated with water security issues (Wheeler et al. 2012a). Younger farmers are more likely to pursue a career outside of farming, in order to take advantage of higher income levels (Barr 2014). Overall, between 1971 and 2006, family farming has declined by 46% (Muenstermann 2010) and the number of younger farmers (aged under 35) has fallen by 75% since 1976 (Barr 2014). Typically, small farm enterprises are closing down in favour of larger farms that produce with economies of scale (Barr 2009). Farms need to continuously invest to provide

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<sup>&</sup>lt;sup>26</sup> A term used mainly in Australia describing large-scale cropping production.

long-term viability, growth opportunities and to match rising income levels in other economies, which is difficult to achieve for smaller farms (Barr 2014).

## 2.4.3 Irrigation farms and water use

Consistent with the trend described above, the number of irrigation farms in the southern MDB has been steadily declining over previous years (Aither 2016). Regions in north-east VIC, Mallee and SA Murray, experienced the largest declines in percentage terms (Aither 2016). Figure 2.9 shows the trend of the number of irrigation farms in the southern MDB since 2007/08. Overall, irrigation farms decreased during and after the drought until 2012/13, then increased in 2013/14 and 2014/15, particularly in VIC. The total number of irrigation farms in the southern MDB dropped from 12,305 in 2007/08 to 10,994 in 2014/15. Figure 2.9 also displays the trend for the total irrigated area in the southern MDB by state. Area irrigated remained relatively stable in SA and gradually increased in VIC and NSW during the years after the drought. Thus, a trend of amalgamating irrigation businesses is evident, as fewer businesses operate a similar area of irrigated land (Aither 2016). Overall, irrigated production declined proportionally less than the observed decline in water availability during drought years (Kirby et al. 2014).

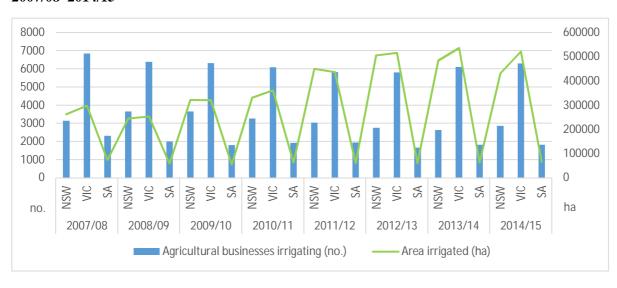


Figure 2.9: Number of irrigation farms and irrigated area (ha) in the southern MDB, by state, 2007/08-2014/15

Own figure (data sources: ABS (2009b, 2010b, 2011c, 2012d, 2013b, 2014, 2015e, 2016d))

<sup>&</sup>lt;sup>27</sup> Figures are based on ABS's statistical local areas 4 (SA4) and Natural Resources Management (NRM) regions. For NSW: Former NRM regions (Lachlan, Lower Murray Darling, Murrumbidgee and Murray) from 2007/08 to 2009/10 and SA4 (Riverina and Murray) from 2010/11 to 2014/15. For VIC and SA: The relevant area in the MDB from 2007/08 to 2009/10 and current NRM regions (VIC: Goulburn Broken, Mallee, North Central, North East and Wimmera; SA: South Australian Murray Darling) from 2010/11 to 2014/15. Some misrepresentation of the southern MDB can be expected for Figures 2.9 and 2.10, e.g. the two SA4 regions in NSW did not cover the total NSW southern MDB area from 2010/11 onwards.

Figure 2.10 shows the total volume of irrigation water applied and the average water application rate per ha in the southern MDB by state since 2007/08.<sup>28</sup> Analogous to the trend of irrigated area in Figure 2.9, Figure 2.10 shows that volume of irrigation water applied was relatively stable in SA over the time period, and increased gradually in VIC and NSW after the drought, but dropped again in 2013/14 and 2014/15. Overall, there were positive trends in water use for cotton and fruits/nuts, and negative trends for dairy and grapes (Aither 2016). Water application rates per ha are generally low in VIC (on average 3.4 ML/ha) and high in SA (on average 5.2 ML/ha), and there is a trend of increasing water application rates over the time period and across the states. At this aggregated level, there is no clear evidence that investments in water infrastructure modernisation have considerably reduced water application rates (Aither 2016). The reduction of water application rates in 2010/11 was caused by widespread flooding in the MDB. The overall upward trend of water application rates can partly be explained by the rise of the almond industry in recent years and its relatively high water application rate (Aither 2016).

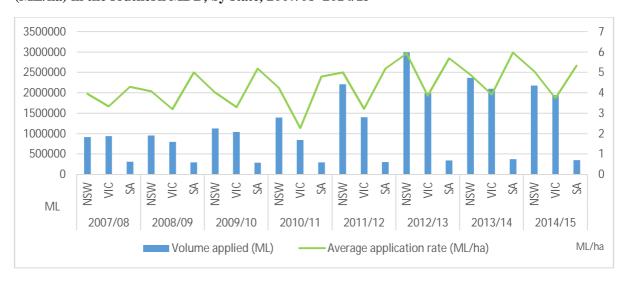


Figure 2.10: Volume of irrigation water applied (ML) and average water application rate (ML/ha) in the southern MDB, by state, 2007/08–2014/15

Own figure (data sources: ABS (2009b, 2010b, 2011c, 2012d, 2013b, 2014, 2015e, 2016d))

The demand for water in the southern MDB's irrigation areas can be very heterogeneous depending on land use and other characteristics (e.g. technical/managerial efficiency) (Figures A.8–A.10). Different land uses are connected with different price elasticities, regional characteristics and other historical factors, which determine the type and size of water rights (Bell et al. 2007; Loch et al. 2012). Specifically, horticultural irrigators cultivating permanent crops have a relatively inelastic water demand in the short-run, as a result of reducing the risk to lose the investment in their permanent produces. In contrast, dairy farmers cultivating annual crops (e.g. pasture) have a relatively elastic water allocation demand, as they may be

able to shift their pasture production according to water availability and the level of water prices compared to feed prices (e.g. Loch et al. 2012). SA predominantly cultivates permanent horticulture, which explains the relatively stable trend for SA in Figures 2.9 and 2.10 compared to VIC and NSW, which adopted more flexible land uses. Figures A.8–A.10 show the differences in water use (volume) and water application rates in major industries for the three states in 2014/15. Cotton and rice have the highest water application rates in NSW, fruit/nuts and rice have the highest water application rates in VIC and fruit/nuts and grapevines have the highest water application rates in SA.

Government subsidies for modernising on-farm irrigation infrastructure were mainly taken up by horticultural farmers. The proportion of horticultural farmers with irrigation infrastructure not older than five years increased from 9% in 2006/07 to 21% in 2010/11 in the MDB. The most commonly used irrigation technologies are flood/furrow (mainly used by broadacre and dairy farmers) and drip/trickle (mainly used by horticultural farmers) irrigation systems in the MDB (Ashton & Oliver 2014).

## 2.4.4 Environmental health

Overall, environmental degradation in Australia at present is widespread, including ecosystem biodiversity losses, soil acidification and erosion, and a decline in water quality and quantity levels, all of which are a consequence of past and current land use along with recent droughts (Ghassemi & White 2007; SoE Committee 2011). The settlement development for agriculture in the southern MDB has transformed the natural state of land and water resources, and placed pressure on environmental systems, as described in Section 2.3. The impact on Australian soils, for example, is sometimes described as 'catastrophic', with 'extremely' severe soil degradation especially during the first 100 years of European settlement after 1850 (McKenzie et al. 2004, p. 112). This was a result of inadequate land use decisions, e.g. landscape clearing, 28 heavy machinery (causing soil compaction), overgrazing (causing soil erosion and nutrient losses) and poorly matched farming systems (e.g. irrigated agriculture) (Ghassemi & White 2007; McKenzie et al. 2004). The recent adoption of more conservative farming practices (e.g. reduced tillage, appropriate crop rotation) reduced the impact on land and soil (McKenzie et al. 2004). However, an over-allocation of water resources, intensive agriculture (including e.g. fertiliser/chemical use) and climatic changes (e.g. droughts) have added to the deterioration of resources.

<sup>28</sup> 

<sup>&</sup>lt;sup>28</sup> Clearing deep-rooted native vegetation for often shallow-rooted annual plantings in agriculture causes nutrient losses, soil erosion, changes to the hydrological cycle (e.g. rising groundwater levels) and biological diversity (McKenzie et al. 2004).

Irrigated agriculture particularly contributes to many environmental problems, especially water logging, salinity and the mobilisation of toxins in the soil (e.g. Perry & Vanderklein 1996). Other environmental problems may arise through decreased levels of sediments/nutrients in water (due to disrupted natural flows), contamination of water supplies (e.g. through animal waste or fertiliser use), habitat destruction (e.g. through large dams), and blocked migration of native species (Quiggin 2001; Schoengold & Zilberman 2007). Salinity in water and soil has been a major problem in the MDB since irrigated agriculture commenced (see Section 2.3). Australia's and MDB's topography (i.e. ancient salty and typically flat continent with low run-off) and climate (i.e. dry and variable with typically low rainfall and high evaporation) are natural causes of higher salinity levels, which is then exacerbated by the intensive land and water use of irrigated agriculture that disturbs water balances (Connell 2007; MDBMC 1999). Chapter 5 further examines the problem of salinity in the southern MDB.

In summary, the Sustainable Rivers Audit 2, which assessed<sup>29</sup> the ecological health of MDB's rivers at the end of the Millennium Drought, concluded that all southern MDB rivers either had 'poor' or 'very poor' overall ecosystem health. In the majority of rivers, drought and river flow regulation had severely affected species abundance and diversity of fish. Additionally, in many catchments, the Audit found widespread changes to river channel form and elevated sediment loads (MDBA 2012d).

## 2.4.5 Future developments

The present environmental state of the MDB is shaped by past environmental influences and land usage. Thus, the future picture of MDB's environment, which will be shaped by land usage over previous decades, is difficult to predict. The toxic algal bloom in the Darling River in 1991/92, the largest toxic algal bloom ever recorded worldwide and still not fully understood, could be one of the worst examples for sudden change to the environmental state (Connell 2007).

Future trends for water availability and water demand are likely to exacerbate water allocation problems. Firstly, Australia's population is projected to grow from 24 million people in 2016 (ABS 2016c) to between 36.8 and 48.3 million people by 2061, and to between 42.4 and 70.1 million people by 2101<sup>30</sup> (ABS 2013a). The predicted population growth is likely to increase water demand for urban and agricultural uses, and to intensify the challenge to allocate water

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<sup>&</sup>lt;sup>29</sup> The Audit assessed the following key biological components and processes: Fish, macroinvertebrates, vegetation, physical forms and hydrology.

<sup>&</sup>lt;sup>30</sup> The projected growth rate depends on the anticipated fertility rate.

between competing users. This may also increase the pressure on other resources, such as groundwater (Barr 2009).

Secondly, the effect of population growth may impact water allocation further due to predicted climate changes. Climate change predictions for the southern MDB for the near (2020–2039) and later future (2080–2099) are the following (Timbal et al. 2015):

- Higher temperatures
- Hotter, more frequent hot days and less frost
- Less rainfall (cool season)
- Increased intensity of heavy rainfall
- Longer (meteorological) drought periods

The impact of climate change on agriculture is far-reaching, ranging from the aforementioned water allocation issues to negative crop yield effects (e.g. Challinor et al. 2014; Yeo 1998), lower agricultural return and value (e.g. Mendelsohn et al. 1994; Xu et al. 2014), and increased environmental deterioration (e.g. water and soil quality) (e.g. Hopmans & Maurer 2008). As a result, farmers' need to continually adjust and adapt to a highly variable and uncertain water supply (Palutikof 2010). Typical adaptation strategies for the southern MDB are predicted to be reducing irrigated area, increasing irrigation efficiency and shifting from perennial to annual cropping in more severe climate change scenarios (Connor et al. 2009). Quiggin et al. (2010) showed that in absence of an appropriate mix of mitigation and adaptation strategies, many catchment areas in the southern MDB would be forced out of irrigated agriculture. Coping with unpredictable water availability may pose a challenge to some farmers, as more 'conservative' farm management plans might need to be replaced with a more adaptive (and in some cases more risky) approach, which may however maximise the farm income in the long-term (Thomas 1999).

Finally, a recent study (Aither 2016) predicted a substantial expansion in cotton and a small reduction in grapes production in the southern MDB over the next five years. Furthermore, a significant expansion in nuts can be expected, despite the recent decline in almond prices. Correspondingly, water use was projected to increase by around 65% for cotton and around 18% for fruits/nuts. However, water use was estimated to decrease by between 8 to 16% for dairy, rice and grapes production. The expansion in nuts, and to some extent cotton, is projected to increase water allocation prices by between 7 to 10% (depending on the level of water availability) between 2015/16 and 2020/21, which may threaten the viability of lower value permanent plantings (Aither 2016). This study raised concerns about the implications of the projected large movement of water to cotton and nut production, given many of these areas are located outside of irrigation districts. This may put pressure on irrigation

infrastructure systems and could result in the underutilisation of recently modernised water infrastructure through government subsidies and the risk of delivery congestion in some parts of the region.

## 2.5 Water market reforms and water trading in the southern MDB

## 2.5.1 Theoretical background

#### 2.5.1.1 Water economics

"The economics of water concerns the measurement and effective management of the tradeoffs across its many competing uses (and non-uses) over time and in different locations"
(Grafton 2014, p. 7). Measuring trade-offs implies estimating costs, benefits and risks
associated with alternative water uses (e.g. environmental, agricultural or urban uses).

Effective management is concerned with meeting society's objectives for water use (e.g.
environmental sustainability, food production) by facilitating the allocation of water to higher
value uses and by ensuring basic water needs (Grafton 2014). In doing so, economic
instruments in water management aim to address the key global challenges in water: Water
scarcity, water quality deterioration, conflict across competing users and over-allocation of
water resources. Economic analysis can improve decision-making and the overall outcomes
concerning the challenges in water (Grafton & Wheeler 2015).

Water has several characteristics which make it unique and which are also likely to require government intervention in water management and allocation mechanisms (Dinar et al. 1997). Water can be classified as either a private (e.g. household water use) or public (e.g. recreational and environmental water use) good, depending on the type of water use. Water as a private good implies that water users compete with each other and that water use is excludable. Water as a public good involves a non-rival (i.e. water consumption of an individual does not reduce the amount of the other individual's water consumption) and nonexclusive (i.e. excluding individuals from using water is not possible or is excessively expensive) water use (e.g. Grafton & Wheeler 2015; Griffin 2006). The water's public good characteristic may encourage 'free-riders' and complicates the estimation of the correct value of the water (e.g. Grafton & Wheeler 2015; Young & Haveman 1985). The lack of beneficiary identification may lead to under-investment, over-allocation and negative externalities among users. Furthermore, economies of scale may result in monopoles and socially inefficient allocation (Dinar et al. 1997). Non-market valuation techniques, e.g. the contingent valuation method (CVM) (see Chapter 7), are typically applied to value such public goods (Griffin 2006). Moreover, water infrastructure typically involves large capital

investment and the physical nature of water may challenge the process of transporting and allocating water (Dinar et al. 1997).

Furthermore, water resources inherit a diverse set of public values, including social, cultural, environmental, recreational and ecosystem values. Public values are often unnoticed, e.g. in a water market which mainly addresses private values of buyers/sellers. Other effects, such as unrecognised opportunity costs (i.e. downstream benefits) and positive or negative externalities of water markets further complicate the issue (Howe 2000). Generally, in order to let water markets achieve their full potential in reallocating scare water resources, governments need to be involved in the water market, e.g. by creating effective institutions for water management and by minimising transaction costs (Easter et al. 1999).

#### 2.5.1.2 Water markets: economic instruments to allocate a scarce resource

Previous sections of this chapter have described the increasingly deteriorated and scarce water resources in the southern MDB and the importance of healthy water resources for irrigators, local communities and the environment. Section 2.3 described how water management in the MDB developed from largely supply management approaches focusing on expansion, to more sustainable practices that seek to balance competing water demands. Accordingly, water demand management strategies (see Chapter 1) were increasingly developed and implemented to manage water allocation issues and are expected to be progressively adopted as a result of projected increases in future water demand (Grafton et al. 2016).

Economic instruments can be one water demand management strategy to tackle declining water resources. Water markets are a common example for economic instruments to provide a flexible, voluntary and efficient allocation of a scarce resource (e.g. Howe et al. 1986; Randall 1981). For that reason, water markets have been widely advocated for many decades (Gardner & Fullerton 1968; Howe 2000). Many studies have proven the public gains derived from the reallocation of water resources through water markets (e.g. Easter et al. 1999; Knapp et al. 2003; Vaux & Howitt 1984).

Water markets can be established formally (i.e. through government legislation) or informally, and typically involve water users located in a specific region or sharing a water resource. A key criterion for establishing water markets are well defined, enforced, and transferable water use rights (Grafton et al. 2004).

Water markets allocate water to its highest value user by establishing a price signal for the value of that water. Thus, optimal water allocation requires the assessment of the value of water in various uses (Grafton & Wheeler 2015). The total economic value of water

comprises direct (i.e. benefits for individuals or agricultural businesses from using the water) and indirect (i.e. non-use water values, such as aesthetic values) use values (e.g. Grafton & Wheeler 2015; Rolfe 2008).

There are several key advantages of water markets over other water allocation schemes:<sup>31</sup> (1) flexible reallocation over time in response to economic, demographic, and social-value changes; (2) involving only willing sellers and buyers; (3) willing seller/buyers provide security of tenure of property rights; (4) by providing the value of water, water users are confronted with the real opportunity cost of their water; and (5) measures can be put in place to keep transaction costs low (Howe 2000).

Water allocation regimes, such as water markets, typically aim to comply with economic efficiency terms (focusing on wealth creation by a resource) and social equity considerations (focusing on the wealth distribution among sectors and individuals) (Dinar et al. 1997). To achieve optimal resource allocation, water allocation schemes can be evaluated according to several criteria: flexibility, security, real opportunity cost, predictability, equity, political and public acceptability (Howe et al. 1986) as well as efficacy and administrative feasibility/sustainability (Winpenny 1994).

Water markets exist in many other countries in the world (with differing development stages), for example in the USA, Spain and Chile (e.g. Grafton et al. 2011; Hearne & Easter 1997; Howitt 1994; Palomo-Hierro et al. 2015). Formal water markets can be slow to develop in some regions due to a number of reasons, such as local political circumstances and the interrelated nature of water use (e.g. return flows) (Vaux & Howitt 1984; Young 1986).

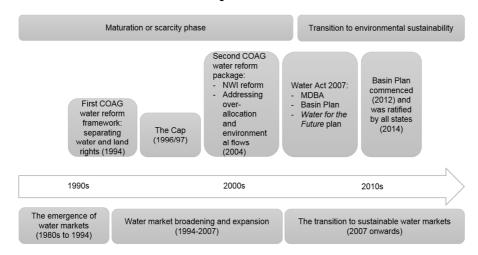
#### 2.5.2 Water market reforms in the MDB between 1990 and 2016

Following on from Section 2.3, which described the evolution of irrigated agriculture and water resources management and the beginning of water trading in the southern MDB, this section introduces water market development and associated major water reforms from the 1990s. The evolution of water markets in the MDB is typically divided into the exploratory and expansionary phases (prior to the 1980s demonstrating the origins of water markets), the maturation/scarcity phase (until 2007) and, most recently, the transition to sustainability phase (Cummins & Watson 2012; NWC 2011e; Randall 1981). This section concerns the latter two phases. Figure 2.11 provides an overview of these two phases and major water market reforms.

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<sup>&</sup>lt;sup>31</sup> Other water allocation mechanisms involve for example marginal cost pricing, public/administrative water allocation (to address market failure), and user-based allocation (e.g. farmer-managed irrigation systems) (Dinar et al. 1997).

Figure 2.11: Phases of water market development



Own figure (adapted from NWC (2011e, p. 4))

It is typically emphasised that droughts or other crises have been the major catalyst for water policy changes in the MDB (see Section 2.3) (e.g. Grafton & Horne 2014; Wheeler 2014). The previous sections have described a number of drought periods and environmental crises over the past century, however it was not until the 1990s that water markets were recognised in policy-making processes in Australia. As mentioned in Section 2.3, water policy reform was promoted by the Earth Summit in Rio de Janeiro in 1992 which ultimately put Australia at the forefront of instigating new guidelines (Bjornlund 2006b).

## 2.5.2.1 COAG's reforms, the Cap and NWI (1990-2004)

As shown in Figure 2.11, major water reforms in Australia were driven by the Council of Australian Governments (COAG) from the 1990s. In 1994, the COAG agreed to an initial water resource policy framework arranging for the separation of water entitlements from land rights (COAG 1994). This reform initiated the formal shift to a market-based approach in water resource management and facilitated the transfer of water property rights (Lee & Ancev 2009). Key elements of this reform comprised, amongst others, of a cost-recovery pricing framework, the development of tradable water rights separated from land ('unbundling' of water rights), recognising environmental needs and requiring infrastructure investments to address economic and environmental criteria (Crase et al. 2012; Quiggin 2001). The COAG emphasised the need for reallocating water supplies and establishing formal water entitlements, while recognising the environment as a legitimate water user (Loch et al. 2011). This reform also emphasised the need for a shift towards integrated catchment management, which involved the devolution of existing water authorities and the reorganisation of responsibilities, including a shift of operational function to local irrigation bodies (Bjornlund 2006a).

The results of a water use audit in 1995, undertaken by the MDBC, led to the introduction of a Cap on further water extractions in 1996/97, due to the predicted severe environmental consequences of forecasted increased levels of water extraction rates for consumptive use (Crase et al. 2004; Parliament of Australia 2010; Quiggin 2001). The Cap restricted water extractions to the 1993/94 level, resulting in lower water allocation levels, which coincided with the beginning of the Millennium Drought (Bjornlund 2006b). It was the first significant step towards balancing the economic, social and environmental benefits of water use (MDBA 2011b). However, such decisions of the MDBMC were often compromised by the challenge in gaining approval from all involved governments (Connell & Grafton 2008). The relevant states and the ACT were responsible for implementing the Cap, however they had complete autonomy in how they installed and achieved it. Consequently, the Cap and other water trading regulations in the states generally resulted in varying impacts on water use and management across the states (Bjornlund & McKay 2002).

As the Cap was not designed to reduce existing consumptive water entitlements to improve environmental flows, consumptive uses were still prioritised over environmental uses (Loch et al. 2011). This was especially evident during periods of drought, and after water markets had activated previously unused/underused water entitlements (so called sleeper/dozer water entitlements), which were bought by active water users (Bjornlund 2007; Loch et al. 2011). At the same time, other activities, such as groundwater use, water storage construction, and plantation forestry continued to expand, which additionally reduced run-off and inflows to water resources (Kendall 2013). As a result, ten years after the first COAG reform, a second reform package was signed comprising an agreement on a National Water Initiative (NWI) (COAG 2004a) and an "Intergovernmental Agreement on Addressing Water Over-allocation and Achieving Environmental Objectives in the Murray-Darling Basin" (COAG 2004c).

The first agreement on the NWI emphasised water allocation processes that were environmentally sustainable while maximising social and economic outcomes. This was achieved based on statutory water sharing plans providing consumptive users to a fixed share of a consumptive pool (after defining environmental flow requirements) with initially no compensation for reduced water entitlements (Loch et al. 2011). The NWI is Australia's blueprint for water reform in which the states have agreed to a more cohesive and cooperative national approach to water management (NWC 2007). The NWI put forward several key objectives: Effective water planning; clear, nationally compatible and secure water access entitlements; conjunctive management of surface-water and groundwater resources; resolution of over-allocation and over-use; clear assignment of the risks associated with changes in

future water availability; effective water accounting; open water markets; and effective structural adjustment (NWC 2011d).

Following the NWI the states complied to remove water entitlement trading limits out of irrigation districts, which often caused distortions in the water market and raised costs for buyers and sellers. However, for example, in VIC water entitlement trading was still limited to 4% of the total water entitlements for many years (NWC 2013b).

The second agreement specifically addressed the problem of over-allocation and the need for additional environmental flows to secure a sustainable river system in the MDB. Thereby, this agreement resulted in the first water entitlement buyback program in VIC, the *Living Murray* program. The program was based on a AUD\$500 million budget to buy water entitlements from irrigators in order to secure additional environmental flows (approximately 500 GL per year) by recovering certain key sites along the River Murray until 2009 (Parliament of Australia 2010). The agreement also allocated AUD\$150 million for building the required water delivery infrastructure. In 2006, the funding commitment was increased to AUD\$700 million for purchasing water entitlements and AUD\$270 million for the infrastructure program (MDBA 2011b).

Generally, this period saw the development of market-based water demand management instruments (e.g. pricing tools for cost recovery) as well as a fundamental change of priority towards the provision of environmental water beside consumptive water use (Lee & Ancev 2009).

The record low rainfall year in 2006 during the Millennium Drought threatened the collapse of these objectives, when NSW suspended the plans of above described policy programs. This caused the Federal Government to design a new policy program to progress the uncompleted objective of providing water for the environment, in order to rebalance historic overallocation (Loch et al. 2011).

## 2.5.2.2 The Water Act 2007 and the Water for the Future program

The *Water Act* 2007 formed new administrative procedures and water market institutions, such as the Murray-Darling Basin Authority (MDBA – former MDBC).<sup>32</sup>

<sup>&</sup>lt;sup>32</sup> The Act further established the Commonwealth Environmental Water Holder (CEWH) to manage the government's environmental water and provided the Australian Competition and Consumer Commission (ACCC) and Bureau of Meteorology (BoM) with key roles and functions (Kendall 2013).

The MDBA was created to overcome legislative barriers and to manage water resources across states (MDBA 2010). Furthermore, the MDBA's responsibility was to develop a strategic plan on integrated and sustainable water management in the MDB. The commonly known Basin Plan was designed to comply with international agreements and optimise outcomes for the society, environment and economy. The following points represent the key parts of the Basin Plan: defining the SDLs for surface-water and groundwater systems, identifying and managing risks to water resources, and developing an environmental watering plan and water trading rules for the MDB (Kendall 2013; NWC 2013b). The Basin Plan was adopted and commenced operation in 2012 (NWC 2013b).<sup>33</sup> The proposal and implementation phase of the Basin Plan was a contentious procedure. For example, the Guide to the proposed Basin Plan, which was released in 2010, was met with a strong and hostile reaction in irrigation communities and was publicly burned by farmers (Bowmer 2014; Quiggin 2012). This was attributed to a failure to balance the various social and environmental needs ('people and place') associated with water (Loch et al. 2014b) and a lack of consultation with stakeholder groups during the development phase of the Basin Plan (Crase 2011).

The Basin Plan limits surface water use to 10,873 GL/year (long-term average) which means a reduction of 2,750 GL/year in consumptive water use compared to 2009 baseline diversions (NWC 2013b). This reduction in surface-water use is required based on the Environmentally Sustainable Level of Take (ESLT)<sup>34</sup> to achieve sustainable diversion limits (SDL) for the MDB and restore<sup>35</sup> its water resources (MDBA 2012a). This reduction in consumptive use ultimately aims to balance historical over-allocation of water resources and offset associated negative externalities (e.g. salinity and other environmental problems) (e.g. Adamson 2013). The long-term average SDLs are scheduled to be effective from 01 July 2019. Appendix B

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<sup>&</sup>lt;sup>33</sup> The Basin Plan was prepared over a series of steps, from a concept statement in June 2009 to a Guide to the proposed Basin Plan in October 2010 and to a study on the social and economic impacts of reduced water allocations in May 2011 as well as a House of Representative Standing Committee report (Windsor inquiry) on alternatives to recover environmental water in June 2011. The Draft Basin Plan was published in November 2011 followed by the Proposed Basin Plan in May 2012 and the Altered Proposed Basin Plan in August 2012 (NWC 2013b).

<sup>&</sup>lt;sup>34</sup> Environmentally sustainable level of take are defined as the level at which water can be extracted from a water resource "which, if exceeded, would compromise: (a) key environmental assets of the water resource; or (b) key ecosystem functions of the water resource; or (c) the productive base of the water resource; or (d) key environmental outcomes for the water resource." (OLDP 2012, p. 8)

<sup>&</sup>lt;sup>35</sup> "In the context of the Basin Plan, 'protect and restore' refers to retaining or improving the ecological character and ecosystem functions of a site, such as connections along rivers and between rivers and wetlands, end-of-system water quality and flow, habitat diversity and food webs." (MDBA 2011c, p. 18)

provides criteria for selecting environmental assets and ecosystem functions that require watering.

*Water for the Future Program (2008/09–2018/19)* 

In response to record low water-flows in 2006, a National Plan for Water Security was announced in 2007 and formalised in the Water Act 2007. The government intended to invest AUD\$10 billion over ten years to meet the Basin Plan's objectives (e.g. improving water infrastructure, buying back water entitlements), which was expanded in 2008 with the new Water for the Future program, involving a AUD\$12.9 billion budget over a ten-year period (Parliament of Australia 2010). The budget allocated AUD\$3.1 billion towards a water buyback program ('Restoring the balance'), aiming to buy water entitlements from willing irrigators to return water to the environment, and AUD\$5.8 billion to Sustainable Rural Water Use and Irrigation Infrastructure (SRWUI) projects (DEWHA 2010; Wong 2008). Water recovery projects were initially working towards recovering 2,750 GL as announced in the Basin Plan. After a re-assessment the government committed a further AUD\$1.77 billion in 2014 to increase the target to 3,200 GL (e.g. Loch et al. 2016). The additional 450 GL is planned to be recovered via water savings from water infrastructure upgrades (Gillard & Burke 2012; McCormick & Powe 2015). Furthermore, in 2015, the government increased the investment for the infrastructure program by AUD\$3.9 billion until the end of the Water for the Future program in 2019 (Baldwin 2015; Loch et al. forthcoming). This reflects the government's recent shift to prioritise water recovery via infrastructure and efficiency measures, rather than the market based approach through water buybacks, which is discussed further in the following section.

The water that is recovered through both programs is managed by the Commonwealth Environmental Water Holder (CEWH) and is held in storages across the MDB (NWC 2013b). As at 31 July 2016, the government had recovered 72% of the total target of 2,750 GL with 766 GL remaining<sup>36</sup> to be recovered (DoAWR 2016). The water buyback program contributed 59% of the amount recovered. Table A.2 details the recovery process per river valley and recovery scheme up until July 2016. Figure A.11 shows the environmental water secured by source between 2007/08 and 2013/14. In 2013/14, around 87% of the environmental water was secured through infrastructure improvements (compared to 37% in 2011/12) (Morey et al. 2015).

<sup>36</sup> 

<sup>&</sup>lt;sup>36</sup> Exclusive of the additional 450 GL, which are planned to be recovered through savings from infrastructure efficiency improvements, as mentioned above (McCormick & Powe 2015).

The buyback program is carried out as a multistage tendering system (i.e. the government announces the funding for the tender round in a specific region and irrigators interested in selling submit a non-binding expression of interest specifying the desired price). The government assesses the offers according to several criteria, such as the price, the capacity to deliver the water to targeted environmental assets, the priority of these assets and their water requirements. Not all offers are finalised, since irrigators may pull back or the purchase is not possible due to other reasons, e.g. legal (Hone et al. 2010). Since 2012, the government has also used 'Strategic Water Purchase Initiatives', primarily in VIC, aiming to buyback water from willing irrigators affected by the decommissioning of channels and not currently connected to a backbone channel as a result of the GMW Connections Project (see Section 2.4) (Burke 2012; GMW 2013).

#### 2.5.2.3 Debates on water recovery programs

Water reallocation from consumptive to environmental uses has been widely discussed in the literature and is becoming more common worldwide (e.g. Ansink & Marchiori 2015; Bennett 2008; Knapp et al. 2003; Turner & Perry 1997). Within this context, purchasing or leasing water by governments is gradually becoming more popular, not only in Australia but in several other countries (e.g. Gomez et al. 2014; Landry 1998; Marchiori et al. 2012). In Australia, the water buyback program is the government's principal market-based instrument deployed to address the needs of deteriorated environmental sites in the MDB (e.g. rivers, streams, wetlands, forests, floodplains and billabongs) (MDBA 2012a; Wheeler et al. 2012b). In contrast to previous policy measures, this program compensates irrigators for their reduction in water entitlements.

The literature however has discussed numerous concerns and obstacles in relation to the performance and success of the program, particularly during its initial stages. For example: the risk of not purchasing an optimal portfolio of water products (e.g. primarily low security water) that meet future environmental water demands (e.g. Adamson 2012; Adamson et al. 2011; Thampapillai 2009b); a decrease in rural community viability and severe structural changes as a result of large water purchases which may lead to widespread farmland abandonment<sup>37</sup> (e.g. Isé & Sunding 1998; Wittwer 2011); and general resistance from irrigators due to future uncertainty and the prospect for speculative gain that may impede participation in the entitlement market (Crase et al. 2000). Irrigators' main concerns about the program relate to its transparency, rising costs of irrigation and other infrastructure, and the management of environmental water by the CEWH (Thampapillai 2009a). Thus, the success

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<sup>&</sup>lt;sup>37</sup> Often referred to as the 'swiss-cheese effect' where areas are left with geographically-dispersed farms (Productivity Commission 2010).

of the reforms has been contested, as general distrust and concerns prevailed amongst irrigators throughout the years, enforcing the need to address those concerns to secure a successful outcome of the program (e.g. Thampapillai 2009a; Wheeler et al. 2012b). Nevertheless, a higher than expected participation rate of irrigators in the buyback program was found, i.e. by 2012 up to 20% of irrigators in the MDB had sold water to the government, and at least 10% more irrigators were trying to sell (Wheeler & Cheesman 2013; Wheeler et al. 2014c). Participation in the buyback program may be driven by taking advantage of higher prices offered by the program, when compared to the private market, or not being able to find a buyer on the private market (Adamson 2013; Wheeler & Cheesman 2013).

Recent changes in the Australian policy environment and recovery from the Millennium Drought have prompted a change in priorities to address the concerns of irrigation communities (Loch et al. 2016). It is planned to recover the remaining gap of 766 GL primarily through infrastructure upgrades. Water purchases are currently capped at 1,500 GL and the focus of the water buyback program is only on high priority and strategically important purchases, e.g. in regions where a gap to the SDL remains (DoE 2014; McCormick & Powe 2015). The government will review this strategy in 2016 to find out if the sustainable targets can be met, after the SDL have been adjusted and the returns of infrastructure investments are clear (DoE 2014; Hart 2016). This 'SDL Adjustment Mechanism' may result in the SDL increasing or decreasing by no more than 5% and early results indicate that water recovery could be reduced by 200 GL (MDBA 2016e). As a result, the government is currently considering to discontinue water purchases in the southern MDB (Joyce 2016). The opposition and other stakeholders question this approach as being inefficient and undermining the Basin Plan's targets (e.g. Rhiannon 2014).

Prioritising infrastructure upgrades over water buybacks contradicts a number of studies that have found water buybacks to be more cost effective than infrastructure upgrades (e.g. Crase & O'Keefe 2009; Grafton 2007; Grafton 2010; Lee & Ancey 2009; Loch et al. 2014a; Productivity Commission 2010; Wittwer & Dixon 2013). Furthermore, the buyback program was found to improve rural economic activity (Dixon et al. 2011) and enable farmers to reduce debt, besides facilitating efficient water reallocation to critical environmental sites (e.g. Isé & Sunding 1998). Generally, infrastructure modernisation programs provide no adequate, flexible and long-term response to an uncertain and variable future climate (Adamson & Loch 2014). Investments in infrastructure address short-term political risk measures (e.g. improving efficiency levels, facilitating structural adjustment through providing jobs in the region) but lead to increased farm debt levels and reduce farmers' flexibility in responding to long-term water availability changes. Such investments also do not 48

increase the security of water held by farmers or districts (Adamson & Loch 2014). It was further found that infrastructure modernisation may not improve environmental flow outcomes due to increased consumptive water usage (Loch & Adamson 2015) and may produce adverse effects, given that technical efficiency can lead to reduced return flows (Adamson & Loch 2014).

The water buyback and the infrastructure modernisation programs are inherently linked and impact on each other's effectiveness. If the government invests in infrastructure upgrades within a particular area, without considering the water buyback program's current and future local activities, over-investments and ineffective investments are the result (Aither 2016; Cooper & Crase 2013; Crossman et al. 2010b). Thus, it is important to predict government's water purchases and likely structural adjustments first, before viable investment decisions can be made<sup>38</sup> (NWC 2009; Productivity Commission 2010). The challenge is to incorporate possible future trends in water use when investing in infrastructure modernisation (Aither 2016).

Furthermore, a restructuring of the water buyback program has been suggested by incorporating alternative water products (e.g. water allocations, water entitlement leasing and options) leading to more flexibility in recovering water, higher participation rates by irrigators and providing farmers and communities more time to adjust (e.g. Loch et al. 2010; Wheeler et al. 2013a). Increasing the flexibility of the program was also recently advocated by Owens (2016), proposing a shift from the government-led process to a mixed approach of competition and collaboration between government and non-government actors (e.g. water trusts). Non-government actors have the potential to facilitate strategic partnerships and to enable a more innovative approach to recovering water for the environment. For example, the 'Murray-Darling Basin Balanced Water Fund' was recently launched<sup>39</sup>, which will buy water entitlements in the southern MDB to support farmers and the environment according to their water demands and current environmental flows.

<sup>&</sup>lt;sup>38</sup> A regional example is the GMW Connection Project that is confronted with concurrent investments by both programs. This project implemented two strategies to overcome the risk of overinvestment. Firstly, by primarily modernising 'backbone' infrastructure. And secondly, by determining cap exempt zones (typically characterised by low productivity soils and no proximity to main backbone infrastructure) where irrigators were allowed to trade all of their water entitlement holdings (Crossman et al. 2010b).

<sup>&</sup>lt;sup>39</sup> Launched by the Nature Conservancy, the Kilter Group and the Murray-Darling Wetlands Working Group Ltd.

# 2.6 Development of water trading in the southern MDB

#### 2.6.1 Introduction

Australia's water market was estimated at AUD\$1.4 billion in 2012/13 (NWC 2013b).

"Water markets have facilitated increased productivity, improved flexibility for individuals and businesses, and resulted in positive economic gains at the community, regional and national levels. Irrigators are increasingly sophisticated in their use of water trading as a business tool." (NWC 2011d, p. 71).

Water markets also enable the reallocation of water from consumptive to environmental uses, and thus, deliver environmental benefits.

Irrigators dominate participation in the water market, despite the water purchases by the government (NWC 2014). That is why, this thesis concentrates on irrigators' water trading behaviour.

Over recent years, water trading processes were restructured and became more efficient as a result of removing artificial trading barriers, allowing interstate water trading and creating better service standards and transaction systems. However, today's mature water market for surface-water can still be improved by additional reforms in order to increase efficiency and access to information. Additional regulations and reforms are also needed so that water trading outside of the MDB and in groundwater systems can mature (NWC 2013c).

This section provides an overview of the water market in the southern MDB, its overall structure, and the developments and impacts of water trading.

### 2.6.2 Terminology, structure and rules

The southern connected MDB is the largest water market in Australia in terms of the geographic area and volumes/numbers of water entitlements (NWC 2013b). In 2012/13, around 78% of Australia's water entitlement trading and around 98% of Australia's water allocation trading occurred in the southern MDB (NWC 2013b).

Water users in the MDB can own various types of water property rights. After water reforms initiated the unbundling of historical water rights, which were tied to land, several individual rights for different purposes were created: 1) water access rights (i.e. right to take/hold water from a water resource); 2) water delivery rights (i.e. right to have water delivered, e.g. by an IIO); and 3) irrigation rights (i.e. right to receive water from an IIO). There are two broad types of water access rights: water access entitlements and water allocations (as defined in Chapter 1). Water markets in the MDB facilitate the trading of water access, delivery and irrigation rights (i.e. tradeable water rights). However, there remains a lack of clarity about

the rights, the available options to manage them (e.g. trading, transforming<sup>40</sup> or terminating<sup>41</sup>) and the charges payable for each right (ACCC 2016).

As discussed in previous sections, each state in the southern MDB introduced individual legislative and administrative processes (water trading regulations) depending on the individual historical developments in water resources management, as well as the characteristics of the water resources and water demand. For example, each state has developed water sharing plans for each catchment (river valley) (ACCC 2016), and adopted their own terms to describe water access entitlements, which are listed in Table 2.3 (this table does not represent an exhaustive list of water access entitlements on issue in the southern MDB). The main difference between water entitlements is the reliability, i.e. the frequency of water being fully supplied (high reliability water entitlements receive larger water allocation volumes and therefore higher prices). In general, water is first supplied to high reliability water entitlements and then to lower reliabilities in the event of water scarcity (Morey et al. 2015). Thus, water rights in the MDB were designed to represent the uncertainty in water supply due to climatic changes (Adamson 2012).

Table 2.3: Water entitlement terminology and types, by state

State	Water access entitlement	Types of water access entitlement
NSW	Water access licence	Conveyance, general security, high security, local water utility, major utility, stock and domestic, and supplementary water (Lowbidgee)
VIC	Water share	High reliability, low reliability, spill and Wimmera-Mallee pipeline
SA	Water licence (bundled) and water access entitlement (unbundled)	Class 1 (stock, domestic and stock and domestic purposes), class 2 (urban water use), class 3a (irrigation excluding Qualco Sunlands Groundwater Control area), class 3b (irrigation in Qualco Sunlands Groundwater Control area), class 4 (recreation), class 5 (industrial and industrial dairy), class 7 (environment) and class 9 (wetlands)

Source: adapted from NWC (2013b) and Morey et al. (2015)

This thesis uses the generic terms 'water entitlements' and 'water allocations' and refers to either 'high security' (i.e. high security water entitlements in NSW, high reliability water entitlements in VIC and water access entitlements in SA) or 'low security' (i.e. general security water entitlements in NSW and low reliability water entitlements in VIC) water entitlements.

In general, water entitlements are not comparable across water systems and reliability classes, as water allocation depends on local hydrology and water sharing plan rules. In particular, there exist significant differences in the long-term allocation levels or yields of water

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<sup>&</sup>lt;sup>40</sup> Transforming an irrigation right against an IIO into a water access entitlement held by the irrigator. This decreases the share component of the IIO's water access entitlement (ACCC 2016).

<sup>&</sup>lt;sup>41</sup> Typically terminating a water delivery right (fully or partly) (ACCC 2016).

entitlements. Public statistics (also used in this thesis) typically use nominal water entitlement volumes, representing the maximum volume of water allocation per water entitlement, and often refer to long-term average annual yield (LTAAY) volumes, which accounts for the security class (Morey et al. 2015).

The states had implemented restrictions on water trading in the past, however these were gradually eased or removed. For example, restrictions in 2009/10 comprised of a 4% annual limit on the total water entitlement volume able to be traded out of VIC irrigation districts, a 10% limit on ownership of water entitlements by non-water users in VIC, an embargo to sell water entitlements to the government in NSW, and a temporary embargo on water allocation trading from Murrumbidgee (NSW) into NSW Murray (NWC 2010a). The states also have differing carry-over policies (the amount of water that can be carried over to the next farming season), which affects irrigators' water demand (NWC 2013c), and have implemented other water trading restrictions, e.g. in high salinity impact zones (NWC 2012). Furthermore, water entitlement trading between and within water systems (river valleys) can be restricted by physical or environmental constraints, hydrologic connections and water supply considerations, or low hydraulic connectivity (BoM 2011).

Water trading rules also vary across the states and river valleys. In general, water entitlement and allocation trading in the southern MDB occurs between and within river valleys, and across state borders. Table A.3 shows the broad processes involved in water entitlement and allocation trading. Within valley water trading rules are defined at the regional (i.e. water resource plans, IIO rules) and state (i.e. state legislation) level, whereas inter-valley water trading rules also refer to the basin level (i.e. Basin Plan). Interstate water trading rules refer to the *Water Act* 2007 and the Basin Plan (BoM 2011). Interstate water trading is a complex process due to varying water entitlement systems across the states, as outlined above. In addition, there are differing systems for fees and charges, as well as individual policies for environmental management (Young et al. 2000).

The MDBA announced new Basin Plan water trading rules in 2014, which operate alongside existing state legislation and IIO rules, and aim to reduce water trading restrictions, improve transparency/access to information as well as the market's effectiveness (MDBA 2014b). Each IIO may impose several charges and fees on their water users, such as a fee on the termination of a water right, or services provided in relation to that right (MDBA 2014c). Water charges vary greatly amongst the IIO (e.g. volumetric or non-volumetric) depending on the type of infrastructure and other factors (e.g. water charges are generally lower for gravity-fed than pressurised networks) (ACCC 2016). The natural monopoly characteristics of IIO

may result in charges/fees and services at a non-competitive level, which might discriminate customers and prevent the efficient use of water resources. Furthermore, the IIO have an incentive to prevent customers trading water out of their network area. Thus, the Australian Competition and Consumer Commission (ACCC) monitors the rural water sector and enforces water market/charge rules (e.g. ACCC 2016).

## 2.6.3 Water trading in the southern MDB over time

#### 2.6.3.1 Water entitlements on issue

In 2013/14, around 35,150 GL of water entitlements (28,023 GL surface-water and 7,127 GL groundwater) were issued across Australia. The MDB accounted for 57% of the total volume of water entitlements on issue (62% surface-water and 36% groundwater entitlements). Figure 2.12 provides an overview of water entitlements on issue by river valley in the southern MDB in 2014. Typically, Murrumbidgee (NSW) owns the largest amount of water entitlement volumes, whereas VIC (Goulburn and VIC Murray) owns the highest number of water entitlements.

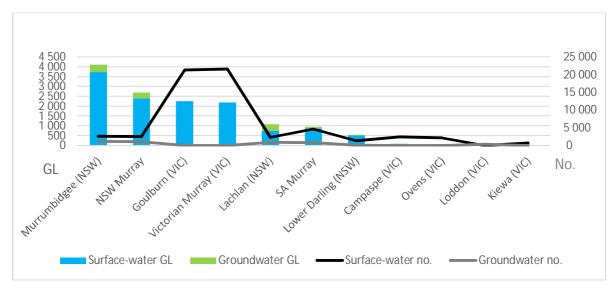


Figure 2.12: Water entitlements on issue by resource and river valley, as at 30 June 2014

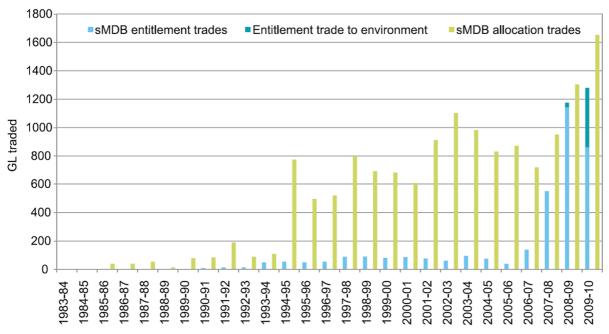
Own figure (data source: Morey et al. (2015))

### 2.6.3.2 Water entitlement and allocation trading activity

Water entitlement trading and related reforms undertook a slower development than water allocation trading (Brennan 2006). Due to the more complex process of transferring water entitlements and the subsequent administrative duties needed, irrigators are generally less likely to participate in water entitlement markets (Bjornlund 2004). Figure 2.13 presents the adoption of water trading in the southern MDB since the 1980s. Water allocation trading significantly increased from 1994/95 as a result of a first fall in seasonal water allocation levels. A second spike in water allocation trading occurred in 2002/03 at the beginning of the

Millennium Drought (NWC 2011e). In contrast, water entitlement trading did not significantly increase until the record low flow year in 2006. Generally, the drought and the water buyback program (i.e. from 2008/09 onwards) caused widespread adoption of water entitlement trading (NWC 2013b).

Figure 2.13: Volumes of water entitlement (private and governmental market) and allocation trading in the southern MDB, 1983/84-2009/10



Notes: sMDB: southern Murray-Darling Basin

Source: NWC (2011e, p. 99)

The following Figures 2.14 to 2.17, illustrate water entitlement and allocation trading by state<sup>42</sup> and river valleys in the southern MDB for the period 2007/08 to 2013/14. The figures highlight volumes and numbers of trade, and allow for the comparison of water rights. NSW is the most active water entitlement trader by volumes (Murrumbidgee) and VIC (VIC Murray and Goulburn) by numbers of transactions, which reflects the water entitlements on issue observed in the previous Figure 2.12. SA held its water entitlement trading (volumes and numbers) at a constant and lower level over time. Overall, higher levels of water entitlement trading can be observed during the drought years until 2009/10, and then again in 2013/14 after the below long-term average rainfall year in 2012/13 (see Figure 2.14). The large amount of water entitlement trade in NSW in 2013/14 is due to the government purchasing over one-third of the water entitlement volume traded in Murrumbidgee within a single trade (Morey et al. 2015).

<sup>&</sup>lt;sup>42</sup> Parts of NSW belong to the northern MDB, but were not excluded in this figure.

2 500 2 000 1 500 1 000 5 000 1 000 1 000 0

2010/11

2011/12

SA GL

2012/13

■ MDB GL

MDB no.

Figure 2.14: Water entitlement trade (volumes and numbers) by state, 2007/08 to 2013/14

Own figure (data source: Morey et al. (2015))

2008/09

2009/10

NSW GL VIC GL

2007/08

GL

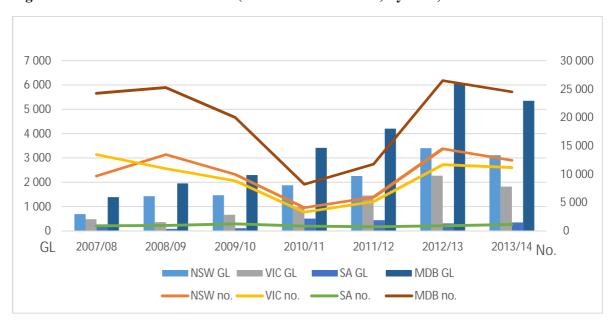


Figure 2.15: Water allocation trade (volumes and numbers) by state, 2007/08 to 2013/14

NSW no. VIC no. SA no.

Own figure (data source: Morey et al. (2015))

<sup>2013/14</sup> No.

1 200 1 400 1 200 1 000 1 000 800 800 600 600 400 400 200 200 0 No. Surface-water GL Groundwater GL Groundwater no. Surface-water no.

Figure 2.16: Water entitlement trade by resource and river valley, 2013/14

Own figure (data source: Morey et al. (2015))

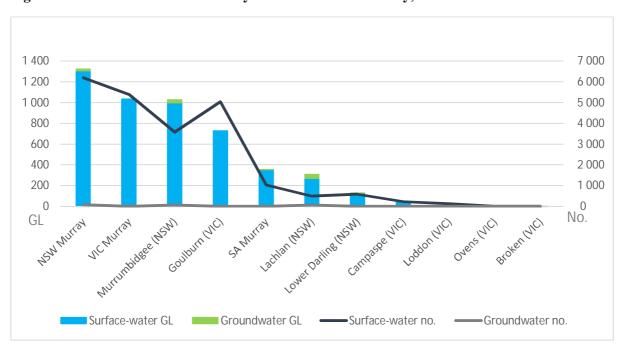


Figure 2.17: Water allocation trade by resource and river valley, 2013/14

Own figure (data source: Morey et al. (2015))

NSW, particularly NSW Murray, is the most active water allocation trader by volume and number of transactions, similar to the water entitlement trading scenario. SA held its water allocation trading (volumes and numbers) at a constant and lower level over time. Overall, water allocation trading increased rapidly in the years after the drought, for example between 2011/12 and 2012/13 there was an overall increase in water allocation trading of 44% in the

MDB, mainly driven by the southern MDB (NWC 2013b). In 2013/14, around 46% of total water allocations traded were environmental water trades in the southern MDB. These transactions have no direct effect on water market prices (no financial component) but are included in water trading statistics (Morey et al. 2015).

Overall, in 2013/14, the MDB accounted for 88% (93% surface-water and 56% groundwater) of the national water entitlement trade (2,421 GL) and 96% (southern MDB: 84%) of the national water allocation trade (5,554 GL) (Morey et al. 2015).

Figures 2.18 and 2.19 display water trading prices by river valley in 2013/14. Prices for water entitlements vary considerably between reliability classes<sup>43</sup> and river valleys. Water allocation prices are less variable across river valleys and highest in VIC. Differences in the long-term average volume of water allocated to water entitlements and water flow constraints have a major impact on the price differentials (Morey et al. 2015). MDBA (2013b) described a number of water flow constraints (i.e. physical, operational and management flow constraints) in the individual river valleys. For example, Barmah Choke (between Yarrawonga Weir and Echuca) is a major constraint with a channel capacity of 10 GL a day. Thus far, Barmah Choke did not constitute a major impediment to water allocation trade and did not affect water allocation prices below or above Barmah Choke but it is likely to constrain water allocation trade in the future (Morey et al. 2015).

Lower Darling (NSW) SA Murray Murrumbidgee (NSW) VIC Murray Goulburn (VIC) Campaspe (VIC, seasonal) Loddon (VIC) **NSW Murray** Lachlan (NSW) Ovens (VIC) \$/ML 0.0 200.0 800.0 1000.0 1200.0 1400.0 1600.0 1800.0 400.0 600.0 ■ High reliability ■ Low reliability

Figure 2.18: Water entitlement trade prices (weighted average) by reliability and river valley, 2013/14

Own figure (data source: Morey et al. (2015))

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<sup>&</sup>lt;sup>43</sup> Lower reliability levels include NSW general security water entitlements.

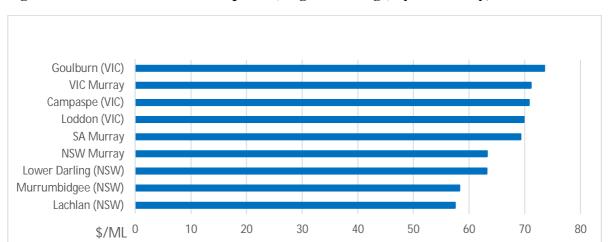


Figure 2.19: Water allocation trade prices (weighted average) by river valley, 2013/14

Own figure (data source: Morey et al. (2015))

The development of water allocation prices is closely connected to water storage volumes and seasonal water allocation levels. Figure A.12 shows water allocation price levels over time with record high price levels during the Millennium Drought (above AUD\$1,000/ML).

Water allocation trading is highly dependent on the announcement of water allocation levels at the beginning and during the season. Water allocation levels determine how much water is available from water entitlements and reflect the current and local level of water availability. Water allocation levels may vary during the season, which is shown in Figure 2.20 for the 2013/14 season. Often water allocation levels are low at the beginning of the season (very often starting at 0%) and increase during the season when water availability for the season is more observable and predictable. Figure A.13 shows a more detailed development of water allocation levels per river valley in the southern MDB for 2013/14.

120
100
80
60
40
20
0
NSW - General
NSW - High
SA - High
VIC - Low
VIC - High

Figure 2.20: Intra-seasonal average water allocation announcements for high and low security water entitlements, 2013/14 per state

Own figure (data source: Morey et al. (2015))

#### 2.6.3.3 Groundwater trading

As discussed earlier in this section, groundwater trading accounts for a small percentage of overall water trading in Australia and the MDB. The MDB's groundwater resources are, along with surface-water, managed by the Basin Plan, which means that groundwater will also be subject to SDL from 2019, in order to increase groundwater use control and establish consistent groundwater management across the MDB (MDBA 2016b). The Basin Plan generally prohibits groundwater trading (unless certain circumstances are met). Groundwater entitlement and allocation trading averaged 5% and 1% respectively, of total water trade between 2007/08 and 2013/14. In 2013/14, the majority of groundwater trading occurred in NSW (especially in Murrumbidgee and Lachlan), due to larger volumes of groundwater resources and the full unbundling of water rights (Morey et al. 2015). NWC (2011c) identified several impediments to groundwater trading, such as limited connectivity of aquifers and groundwater areas (trading is limited to within aquifers), bundled groundwater entitlements in some states, and demand/markets for groundwater are not fully established (especially where surface-water is abundant).

### 2.6.3.4 Interstate trading

Interstate water entitlement trading is allowed in the southern connected MDB across the borders of NSW, VIC and SA (as discussed in previous sections). Thereby, water entitlements are tagged to retain their original characteristics, e.g. the nominal volume and allocation of the

water entitlement, while water is extracted in a different state. However, water tagging is only slowly being adopted and not commonly used (Morey et al. 2015).

In NSW and VIC most of the water allocation trading took place internally, whereas in SA the majority of water allocation transactions were traded into the state during 2013/14 (Table 2.4).

Table 2.4: Water allocation traded internally, into and out of the state/river valley, 2013/14

Water system	Internal	Trade In	Trade Out	
NSW Total	85%	1%	15%	
NSW Murray	62%	9%	29%	
Murrumbidgee	78%	6%	17%	
Lower Darling	11%	45%	44%	
Lachlan	100%	0%	0%	
VIC Total	68%	13%	19%	
VIC Murray	37%	26%	37%	
Loddon	38%	16%	46%	
Broken	100%	0%	0%	
Campaspe	22%	8%	70%	
Goulburn	60%	23%	17%	
Ovens	100%	0%	0%	
SA Total	25%	64%	10%	

Own table (data source: Morey et al. (2015))

In 2013/14, NSW Murray and VIC Murray were the major net exporter and net importer respectively in (non-environmental) water allocation trading. When focusing on environmental water allocation transfers by environmental water holders, Goulburn and NSW Murray were the largest net exporters, moving water downstream to SA Murray as the largest net importer (Morey et al. 2015).

### 2.6.4 Impact of water trading

### 2.6.4.1 Aggregated economic impact

Various economic modelling has shown that water trading increased Australia's gross domestic product (GDP) and the southern MDB's gross regional product (GRP). For example, water trading reduced the impact of the Millennium Drought on the southern MDB's GRP from AUD\$11.3 billion to AUD\$7 billion between 2006/07 and 2010/11 (NWC 2012).

During the drought, profit reductions in irrigated agriculture were much lower than the reductions in surface-water diversions, which can mostly be attributed to water markets moving water from lower to higher value water users (Jiang & Grafton 2012). In general, water trading facilitated adjustment and recovery, as investment and employment did not decline as much as it would have been the case in a non-water trading scenario. Water

purchases by the government up until 2010/11 led to a small decline in agricultural production in the southern MDB (AUD\$14 million in 2010/11) and a small consumption increase (AUD\$55 million in 2010/11). A decline in irrigated agricultural production was partly offset by increased production in other sectors, such as dryland agriculture (NWC 2012).

Specifically, water trading has supported the survival of many agricultural industries during the drought in the southern MDB, such as dairy and rice, by providing flexibility and an income from water allocation sales. Water trading has further facilitated the expansion of some horticultural production areas (e.g. almond production) on new areas of irrigation land (NWC 2012).

## 2.6.4.2 Socio-economic impact on irrigators and communities

Studies that have conducted interviews and surveys with irrigators in the southern MDB typically report concerns that irrigators raise about the impact of water trading, especially selling water out of a region. Particularly, irrigators worry about the ongoing maintenance and costs of irrigation infrastructure in their area, an erosion of the local tax base, and other negative externalities for farm properties remaining in the irrigation community<sup>44</sup> as water is traded out (e.g. Bjornlund et al. 2011; Edwards et al. 2008; Thampapillai 2009a; Wheeler & Cheesman 2013; Young et al. 2000). Additionally, many irrigators felt forced to sell through the water buyback program due to the financial distress they experienced at the time of selling (e.g. Bjornlund et al. 2011; Wheeler et al. 2014b).

The overall impact of the water buyback program has not been fully assessed, but interim reports show that the government's water entitlement purchases resulted in reduced farm debt levels, and many irrigators have used the proceeds from water sales to stay in business and improve on-farm efficiency or prepare for retirement (e.g. Wheeler & Cheesman 2013; Wheeler et al. 2014c). Irrigators' concerns about the water buyback program associated with selling large volumes of water entitlements out of a region have not been verified thus far. Studies show that the majority of irrigators did not terminate their water delivery rights when selling water entitlements to the government (ACCC 2013; Wheeler & Cheesman 2013), which means irrigators continued to make contributions to the infrastructure system and may have plans to continue farming in the long-term. Furthermore, the IIO's termination fees are set to fully offset the terminating irrigator's share of the infrastructure costs (being around two-thirds of the infrastructure asset's average life) (NWC 2012).

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<sup>&</sup>lt;sup>44</sup> For example, regarding the thread of weeds and pests and potentially decreasing land values on remaining farmland and overall less social cohesion in the communities (Bjornlund et al. 2011).

The impact of water reforms and water trading on rural communities is widely discussed in the literature (e.g. Alston & Whittenbury 2014; EBC et al. 2011; MDBA 2012c; Wheeler et al. 2014b). Outward water trading is generally associated with reduced agricultural production, economic activity and employment in some regions, causing pressure and stress for some farmers. However, as drought conditions had often led to this scenario, it is difficult to discern which negative change was caused by water trading (NWC 2012). EBC et al. (2011) identified towns in the MDB that are likely to be more sensitive to changes in water availability, which were typically small, highly dependent on irrigated agriculture and often geographically isolated. A recent study on the effects of water recovery on communities in the northern MDB concluded that impacts vary according to the local socio-economic characteristics and structure, as well as the form of water recovery and the volume, location and type of water entitlements recovered. For example, large volumes of water sales over very short time periods resulted in significant long-term effects since local economies typically need time (i.e. 2-5 years) to adjust to changes (MDBA 2016d). However, generally it is suggested that the overall effect of water markets on rural communities is minimal and current socio-economic trends in those communities do not vary much under a non-water trading scenario (e.g. NWC 2012).

Overall, many irrigators perceive water trading as an important farm management tool (e.g. regarding climatic changes, land use change, farm expansion and farm exit), despite initial concerns and distrust from irrigators regarding water trading (NWC 2010b; Wheeler 2014). Water trading is suggested to produce net benefits for irrigators and provide a useful adaptation strategy to future climate change related impacts (e.g. Loch et al. 2013; Wheeler et al. 2014b). Wheeler et al. (2014d) found that selling water allocations can be associated with higher farm net income and rate of return; and selling water entitlements can result in positive (e.g. reducing debt) and negative (e.g. reducing farm production) impacts. Wheeler and Cheesman (2013) showed that almost 80% of irrigators who participated in the water buyback program up until 2011 believed their decision to sell water had been an overall positive decision.

#### 2.6.4.3 Environmental impact

Water trading can have a number of positive and negative impacts on the environment. For example, water trading improved the flow stress ranking (i.e. indicator of stress in the river system) during summers and resulted in water moving downstream during the drought. Water trading may also reduce overall environmental impacts, as water buyers are generally found to be more efficient (e.g. use better technology which may reduce waterlogging) and grow on better soils (fewer soil degradation problems, such as dryland salinity) (NWC 2012). Better

efficiency levels amongst buyers can result in reduced return flows (which can have positive and negative impacts on the environment). Furthermore, water trading can highly interfere natural flow regimes, as water buyers tend to grow high value crops which may concentrate water demand on some crops and locations during particular months (NWC 2012). Alternatively, water trading by a CEWH can increase environmental outcomes in the form of environmental flows, especially during drought periods (Connor et al. 2013).

Furthermore, studies have found that water may not always move to the most efficient user, and salinity problems could increase if water is moved to areas with high water tables, which would exacerbate local groundwater recharge problems (e.g. Bjornlund & McKay 1995; NWC 2010b). It was also found that water trading to upstream areas increases surface-water salinity due to reduced dilution flows (Bjornlund & McKay 2002). Such negative impacts have been addressed by several strategies, for example by defining high salinity impact zones, regulating water trading in those areas (NWC 2012), and implementing exchange rates for water entitlements traded to other water trading zones (Wheeler et al. 2014b). The relationship between salinity issues and water trading is further discussed in Chapter 5. Moreover, studies show that surface-water is substituted with groundwater in some areas where viable groundwater sources exist and surface-water is of lower quality (Haensch et al. 2016d; Wheeler & Cheesman 2013; Wheeler et al. 2016). Many of the impacts described above require further investigation given, for example, the interconnectivity between surface-water and groundwater is not fully understood, and the magnitude of potential impacts and differences between water buyers and sellers have not been fully assessed and quantified (Haensch et al. 2016d; NWC 2012).

The environmental impact of water purchases by the government has not been fully quantified at this stage, however it can be assumed that environmental watering has resulted in overall positive outcomes for the environment, although there are concerns about a negative impact on surface-water salinity levels (NWC 2012).

To summarise, despite some of the questions raised around water trading to meet social, environmental and economic goals (e.g. Kiem 2013) and, as described above, instances of negative socio-economic and environmental impacts; over time, water markets have proven to be beneficial in many ways. "If water markets are embedded within fair and effective metagovernance and property right structures, the potential exists for marketisation to increase efficiency, promote fairness in terms of initial water allocations, and to improve environmental outcomes" (Grafton et al. 2016, p. 913).

## 2.7 Summary

This chapter has provided a comprehensive introduction to the geographical/biophysical, socio-economic, historical and institutional background to the overall thesis. In particular, this chapter introduced to the study area (the southern MDB in Australia), historical and current developments in irrigated agriculture in the southern MDB, along with relevant major agricultural inputs. In doing so, this chapter has provided an overview on some of the spatial/biophysical characteristics that are studied in the following chapters, in the context of irrigators' water trading behaviour.

Furthermore, this chapter summarised recent water market reforms, developments in water trading, the structure of the water market, and the impacts of water trading. The water market reforms of previous decades, served as a means to reallocate water during a time when Australia was hit by a major drought. The social, economic and environmental implications of water trading indicate the many interrelationships and the wide-reaching impacts of water resource variability and water trading.

The southern MDB provides an ideal study area for water trading behaviour, as it has been shown that farmers increasingly use water trading as a farm management tool to adapt to variable water resources and other changes. Due to the southern MDB's geographical location, with a major part of its area undergoing hot and dry summers, the region is susceptible to climate changes. Water trading contributed to upholding irrigated agriculture during the previous Millennium Drought. Water markets in Australia are mature and provide a leading example for other countries in a world that faces water scarcity issues (Wheeler et al. 2015)

The next chapter studies in detail the determinants of irrigators' water entitlement and allocation trading, after initially providing an overview of farmers' decision-making.

Irrigators' water trading behaviour is introduced and explored in this chapter. Prior to that, this chapter describes ground-laying theoretical and empirical research on farmers' decision-making emphasising the various influences of economists, sociologists/psychologists and geographers. The chapter introduces the behavioural settings within this thesis, with a focus on behavioural and economic models of agricultural decision-making. The chapter's literature review culminates in highlighting gaps within the literature, which are later explored in this thesis.

## 3.1 Farmer adoption and adaptation strategies

Farmers' decision-making is often studied by analysing their behaviour towards two distinct but linked processes of change: adoption and adaptation. Adoption is defined as a change in practice or technology, whereas adaptation is defined as the response to "[...] major environment change (e.g. global warming) and/or political and economic shocks (e.g. famine or war)" (Zilberman et al. 2012, p. 28). Hence, adaptation is often imposed on individuals and societies by external undesirable changes. "Efforts to respond to these changes frequently entail reducing vulnerability and enhancing the capacity to adapt, in effect, to enhance the resilience of people and places, localities, and ways of life." (Nelson et al. 2007, p. 396).

According to the definitions above, the motive for change, and more specifically the response to major external changes in the case of adaptation, is the primary difference between the two concepts. Consequently, traditional adoption strategies (e.g. modern technologies) can also be used as an adaptation strategy to climatic changes. In the case of water trading both concepts may be relevant, depending on the motive behind the decision to trade water. Hence, the following section focuses on farmers' decision-making regarding adoption and adaptation strategies, since external changes are likely to be not the only reasons for water trading (as discussed in Section 3.3).

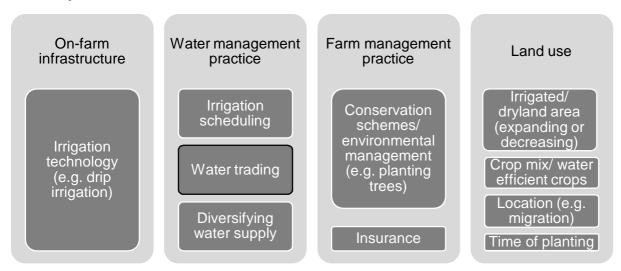
The emerging farmer adaptation literature is based on, and builds upon, the well-developed research on adoption in agricultural economics. Although the definition of adaptation implies a generic term, much of the recent adaptation literature concentrates on environmental changes in view of global concerns of climate change (Hansen et al. 2011; Zilberman et al. 2012). As a resource-dependent industry, agriculture is particularly vulnerable to climatic

change (Marshall 2010), and thus, understanding adaptation processes in agriculture has become vital (e.g. Meinke et al. 2009). Additionally, agriculture faces a 'double exposure' to the effects of climate change and economic globalisation (O'Brien & Leichenko 2000), which may aggravate the pressure on environmental, social and economic systems, threatening rural community resilience.

Farmers' adoption and adaptation behaviour affects the success of environmental policies. Research in farmer behaviour can identify the need for policy interventions (e.g. incentives, regulations), or the need for non-interventions where bottom-up adaptation is in progress. Hence, a better understanding of farmers' decision-making can ultimately improve environmental/agricultural problems and the adaptive capacity in general (Feola et al. 2015).

Given Australia's variable and, at times, extreme climate, as well as predicted population increases (see Chapter 2), irrigators in the MDB needed, and will continuously need, to adjust and adapt to a changing environment, especially to variable water supply. Farmers can choose to take on several strategies in response to water supply variability, which may result in various changes on or for the farm (Figure 3.1).

Figure 3.1: Examples for farmer adoption and adaptation strategies in response to water supply variability



Own figure (adapted from Hansen et al. (2011); Smit and Skinner (2002); Wheeler et al. (2013b); Zilberman et al. (2012); Mukherjee and Schwabe (2015))

The literature has suggested several typologies of adoption strategies, such as differentiating between the adoption of technologies and institutional innovations (Zilberman et al. 2012), the adoption of innovations that are embodied in capital goods or products (e.g. machinery,

seeds) or disembodied (e.g. integrated pest management) (Sunding & Zilberman 2001)<sup>45</sup> or the adoption of hard and soft technologies (Wheeler et al. 2010a). Hence, innovations are commonly distinguished according to their form (i.e. solid farm equipment versus farm management/know-how). Categorising according to form is useful as these categories may raise different policy questions (e.g. chemical innovations can be associated with environmental concerns).

Adaptation strategies are typically classified into incremental and transformational strategies. Incremental adaptation is limited in spatial and temporal scales using existing technologies or institutional structures (e.g. Nelson et al. 2007). Incremental adaptation strategies can be categorised into expansive, accommodating and contractive strategies (Wheeler et al. 2013b). Transformative adaptation is large in scale; involving major decisions and a fundamental change "in the biophysical, social, or economic components of a system from one form, function or location (state) to another" (Park et al. 2012, p. 119). In the future, system transformation in agriculture is likely to become more common in light of the projected climatic changes that may result in land areas becoming unviable (Nelson et al. 2007).

Wheeler et al. (2013b) classified water trading as an incremental adaptation strategy, which can either be expansive (buying water entitlements) or contractive (selling water entitlements). In some cases, selling all water entitlements from an irrigation farm, as well as selling all delivery entitlements associated with that farm, can be classified as a transformational adaptation strategy. Further, water trading can be regarded as the adoption of an institutional innovation (Garrick et al. 2011; Zilberman et al. 2012) or the adoption of a soft technology, i.e. adopting a water management practice in contrast to a hard technology, such as irrigation technology (Wheeler et al. 2010a).

## 3.2 Farmers' decision-making behaviour

#### 3.2.1 Introduction

Decision theory aims to explain factors that influence the decision-making process (Edwards & Tversky 1967) by using either empirical/descriptive or normative decision-making models. <sup>46</sup> Farmer decision-making has been highly researched by agricultural economists

<sup>45</sup> Sunding and Zilberman (2001) list further categories of innovations according to their form: mechanical (e.g. tractors), biological (e.g. seeds), chemical (e.g. fertilisers), agronomic (e.g. management practices), biotechnological, and informational (e.g. computer technologies).

<sup>&</sup>lt;sup>46</sup> An empirical model explores "patterns, regularities, or principles in the way people make decisions in given situations" and a normative theory describes; "how a rational decision maker would act in a given situation. It seeks to discover rules for making decisions which are 'best'." (Ilbery 1978, p. 451)

starting in the 1960s (Griliches 1960; Jones 1963) with earlier ground-laying work from rural sociologists (Rogers 1958; Ryan & Gross 1943; Wilkening 1950) and geographers (Hagerstrand 1967; Wolpert 1964). Those pioneering studies focused on the diffusion and adoption of innovations in agriculture and indicate the inter-disciplinary nature of this research area. The importance of studying farmers' decision-making, and adoption processes specifically, is reflected in its significant role in informing policy makers and the importance of e.g. technological change for economic growth, social development and environmental management at large.

### 3.2.2 Ground-laying theories

In agricultural economics, examining farmers' decision-making typically involves the profit-maximising approach originating from the neo-classical concept of the firm, i.e. decisions are made according to profit maximising goals (e.g. David 1975; Feder et al. 1985). It was rapidly realised that basing decision-making purely on the economic rationale does not adequately describe actual (farmer) decision-making. Critiques came from geographers and sociologists, who developed their own theories with references to normative economic theory. It was argued that the term of profit maximisation should be replaced by the maximisation of personal satisfaction (Garrison & Marble 1957). Decisions in agriculture are typically the result of a number of individual decisions made at different times for different reasons, which may not be simply economic ones: "A farmer may wish to optimise in several different directions at the same time (income, comfort, pleasure, leisure, and so on), and it is difficult to find some common scale of measurement for such disparate items." (Harvey 1966, p. 370).

Social-psychological theories (e.g. Lewin 1951)<sup>47</sup> and the work of rural sociologists (e.g. Wilkening 1950) triggered the so called 'behavioural revolution' (Ilbery 1978) of farmers' decision behaviour. Generally, sociologists emphasised the role of farmers' ideas, values, and sentiments as well as social relations in their decision-making (Wilkening 1950). Foremost in agricultural economics was Gasson (1969, 1971, 1973) who examined the relevance of sociological principles.

A number of ground-laying theories in farmers' adoption and adaptation behaviour were introduced by sociologists over the years. For example, Rogers (2003) described an S-shape curve of a technology adoption pattern, indicating a slow rise in adoption during the early stage of the technologies' introduction followed by an accelerated adoption and slowdown in the last stage of the diffusion process. This indicates that there are a few farmers who actively

<sup>&</sup>lt;sup>47</sup> Lewin (1951) proposed that "behaviour is a function of the person in his environment", i.e. behaviour is a result of a person's aspirations and the perceived environment of resources and constraints to accomplish a preferred goal (Gasson 1973).

seek information on innovations and adopt early, in contrast to most farmers who show a conservative approach and adopt innovations after observing adoption in their environment. This S-shaped distribution is divided into five categories, which provides a widely accepted classification of adopters: innovators, early adopters, early majority, late majority and laggards.

Another significant theory was developed by Fishbein and Ajzen (1975) called the 'Theory of Reasoned Action' (TRA). The TRA was the first model to prove the relationship between attitudes and behaviour. Further, the model described the role of 'subjective norm'48 (normative influence) which can have a large impact on farmers' choices as subjective norms may dominate attitudes towards behaviour (Burton 2004a). Studies ignoring this potential social influence may be "effectively removing the individual from any social context" (Burton 2004a, p. 363). Over time, the TRA was transformed to the 'Theory of Planned Behaviour' (TPB) by including 'perceived behavioural control' (perceived self-efficacy) in the model (Ajzen 1985). Subsequently, studies discussed several other additions to the TPB, such as the concept of 'self-identity', given farmers often face 'contemporary challenges' to their selfidentity (Burton 2004a). Self-identity (which is referred to as internalised social norms<sup>49</sup>) could play a significant role in cases where communities fear a change in their values. It has been shown that including concepts of farmer-identity<sup>50</sup>, may improve the overall understanding of farmers' decision-making, e.g. farmers' support for conservation polices (McGuire et al. 2015; Seabrook & Higgins 1988). Section 3.2.5 discusses the effect of social pressure within agriculture.

Over the years, it has become widely accepted that farmers' decision behaviour is far more complex than a purely economic rationale, and is substantially influenced by social and psychological factors in addition to other external determinants (e.g. Burton 2004a; Ilbery 1978; Morris & Potter 1995; Willock et al. 1999). Simultaneously, the field of behavioural economics was formed and evolved rapidly (Kao & Velupillai 2015). Farmers' social and psychological attributes were increasingly incorporated into agricultural decision-making studies by numerous agricultural economists (e.g. Hansson et al. 2012; Hatch et al. 1974; Läpple & Kelley 2013; Wheeler et al. 2012b; Willock et al. 1999). Generally, the importance of such attributes increases when information for farmers is not fully available or difficult to obtain (Ilbery 1978). However, incorporating intrinsic values and measuring satisfaction in empirical models introduces new problems of extreme complexity (Garrison & Marble 1957).

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<sup>&</sup>lt;sup>48</sup> Subjective norms can be described as "the perceived evaluations of behaviour" (Burton 2004a, p. 363).

<sup>&</sup>lt;sup>49</sup> Social norms are defined as "the behavioural acts approved of by significant others" (Burton 2004a, p. 363).

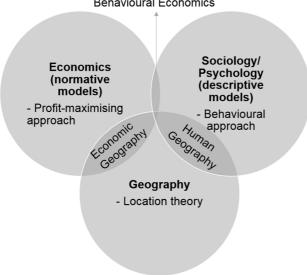
<sup>&</sup>lt;sup>50</sup> Understanding how farmers view themselves in their role as a farmer.

At the same time, geographers introduced a second approach to decision-making in agriculture that recognised the spatial dimension, i.e. some factors influencing decision-making vary spatially (Gould 1969; Wolpert 1964). In fact, geographers created location theories using examples from agricultural economics (Nelson 2002). The 'classical' descriptive model of an agricultural location theory proposed by von Thuenen (1826), which is described in Chapter 4, is still relevant at present. The spatial diffusion of agricultural innovations has been of particular interest since many decades (e.g. Griliches 1960; Hagerstrand 1967).<sup>51</sup>

Figure 3.2 provides an overview of the various disciplines and theories that have contributed to research in agricultural decision-making. It is clear that disciplines, theories and models are diverse and complex, as is the decision-making behaviour of a farmer (Ilbery 1978). None of these disciplines can explain decision-making alone, thus various sub-disciplines developed, such as human or economic geography. It is obvious that the researcher needs to take on an integrated approach to fully understand farmers' decision-making: "If the gap between spatial models, developed by geographers and economists, and behavioural models, developed by sociologists and psychologists, can be bridged then one crucial step forward will have been taken" (Ilbery 1978, p. 461).

Figure 3.2: Different disciplines in agricultural decision-making and their interaction

Behavioural Economics



Source: Own figure

<sup>&</sup>lt;sup>51</sup> Wolpert (1964), Harvey (1966), Hagerstrand (1967), Symons (1967) and Gould (1969) and others laid the foundation for further discussion and theory development in geography and agriculture throughout the 20<sup>th</sup> century and indicate the historical relevance of spatial analysis in agricultural production and decision-making since many decades.

As this thesis is concerned with the spatial factors influencing irrigators' water trading decisions, the focus of the following chapters is on the nexus areas of 'Economic Geography' and 'Human Geography'.

## 3.2.3 Adaptation theories

The more recent adaptation literature has focused on theories from the resilience and vulnerability research, as well as other theories, such as the TPB. In contrast to adaptation, the resilience approach is more dynamic, systems orientated, and focuses on the adaptive capacity <sup>52</sup> as a fundamental feature of resilient systems (Nelson et al. 2007). The adaptive capacity is generally dependent on three essential factors: susceptibility to change, capability of self-organisation, and the capacity for learning (Walker et al. 2006). The resilience approach implies change to be the natural state of a system rather than equilibrium (Holling 1973), aiming for flexibility rather than stability and accepting vulnerability as a core feature of a system that needs to be managed according to acceptable levels (Nelson et al. 2007). When identifying appropriate policy implications, adaptation research can learn from the resilience framework and its dynamic perspective on adaptation processes at different spatial and temporal scales (Nelson et al. 2007). Park et al. (2012) introduced the concept of 'Adaptation Action Cycles', developed on the basis of the resilience and vulnerability literature, which describes the difference and the link between incremental and transformative adaptation as a continuous process.

Studies have emphasised the importance of bringing in line endogenous (e.g. local customs, community-level actors) and exogenous (e.g. external guidance, regulations) processes for creating strong community resilience (e.g. Wilson 2013). Further, it may be beneficial not to focus on the potential negative impacts of external changes, but to highlight likely positive outcomes of system 'disturbances', as they may lead to innovation and development (Folke 2006). Subsequent adaptation processes can be advantageous for the system by creating prospects, maintaining quality of life or even enabling the system to flourish and survive external changes (Gallopín 2006; Smit & Wandel 2006).

This chapter concentrates on the actor-focused adaptation rather than the system-focused resilience approach. It should be noted however that the water buyback program follows some characteristics of a 'system transformation' strategy in response to environmental changes following the examples provided by Nelson et al. (2007). But the 'system' (irrigated

<sup>52</sup> Adaptive capacity describes the potential or ability of a system to adapt to cope with changes and uncertainties (including variability and extremes). Thus, improving adaptive capacity decreases system vulnerability and supports sustainability (Smit & Pilifosova 2001).

agriculture) in the MDB is not planned to transform as a whole, rather it is aimed to shift water away from some low value users, or to recover unused water, for the environment.

### 3.2.4 Empirical analysis and findings

Numerous empirical studies have examined the factors promoting various farmer adoption strategies; such as conservation tillage (e.g. Knowler & Bradshaw 2007), land management practices in general (Pannell & Vanclay 2011b), changing land use e.g. to high-yielding crops (e.g. Bera & Kelley 1990; Holloway et al. 2002) and modern irrigation technologies (e.g. Genius et al. 2013).

The comprehensive irrigation technology adoption literature, for example, commonly identified age, education level, debt level or access to credit, access to extension/information or farm organisation/cooperatives memberships as significant determinants (e.g. Alcon et al. 2011; He et al. 2007; Koundouri et al. 2006). Other typical influences are soil productivity or soil water holding capacity, farm/field size, water prices and access to surface-water (e.g. Dinar & Yaron 1990; Green et al. 1996; Negri & Brooks 1990). Most of the studies include biophysical data at the farm-level, but some also test spatially observed data, such as distance to urban area or to irrigation water source (e.g. Abdulai et al. 2011; He et al. 2007), number of adopters in the neighbourhood or distance to extension outlets (e.g. Genius et al. 2013) and location (region or state dummies). Case (1992) found that neighbours have an important influence on farmers' decision to adopt a new technology, and that ignoring this interaction may lead to misleading results that overemphasise household factors. Additionally, studies confirm the influence of farmer attitudes (e.g. Skaggs 2001) and subjective/social norms on irrigation technology adoption (e.g. Lynne et al. 1995).

Wheeler et al. (2010b) observed that the adoption of water allocation trading showed some consistencies with the technology adoption literature. Thus, above mentioned factors contributing to irrigators' adoption of modern irrigation technology are likely to also influence the uptake of water trading. The same may apply for the determinants of changing land use, since water trading may result in, or may be the result of, land use changes.<sup>53</sup>

Feder and Umali (1993) reviewed the technology adoption literature and highlighted that different factors affect different stages in a diffusion cycle, which needs to be considered by policy makers. Studies also need to take into account the different stages of the diffusion process when deciding on the form of analysis (e.g. cross-sectional or panel-data analysis).

<sup>&</sup>lt;sup>53</sup> A number of land use change studies are reviewed in Chapter 6.

The empirical literature on farmers' adaptation behaviour includes a diverse range of approaches. Primarily, studies focus on biophysical or economic modelling, thereby emphasising the role of farmer socio-economic factors (e.g. Below et al. 2012; Wheeler et al. 2013b) or climate variables, e.g. regarding crop switching behaviour (e.g. Seo & Mendelsohn 2007). For example, Wheeler et al. (2013b) found that succession, farm productivity, and farmers' values of innovation, tradition and the environment have a positive effect on irrigators' incremental adaptation, whereas age showed a negative impact. Further, climate change beliefs and attitudes were found to be highly relevant in a number of studies (Kuehne 2014; Loch et al. 2013; e.g. Niles et al. 2016; Wheeler et al. 2013b). Climate change beliefs were also found to differ according to farmers' personal and environmental characteristics (e.g. location, irrigation infrastructure) (Golding et al. 2009; Niles & Mueller 2016). Other studies focus on a more socially driven framework in the context of the vulnerability or resilience concepts emphasising the influence of networks on adaptation (e.g. Adger et al. 2009; Nelson et al. 2007). It was found that complicated multijurisdictional structures and a lack of information may constrain adaptation processes (Few et al. 2007; Loch et al. 2013; Risbey et al. 1999). Below et al. (2012) concluded that farmers' adaptation can be improved by various investments, e.g. in rural infrastructure, education/extension systems, or financial and social capital.

As research finds significant differences among adapting and non-adapting farmers, some studies have grouped farmers into several farming types/clusters in relation to adaptation. For example, Hogan et al. (2011) identified three major types of farmers in the order of occurrence: 'Cash poor long-term adaptors' (younger, healthy, resource-poor, socially well-connected, information-seeking, believed in climate change, and strived to be sustainable in the long-term), 'Comfortable non-adaptors' (older, socially well-connected, resource-rich (financially and biophysically), and not believing in climate change), and 'Transitioners' (under farm-related pressures, low income, worst health, isolated from information and other support services, and considered leaving farming).

The results of farmers' decision-making studies can contribute to the work of many stakeholders in agriculture: such as policy makers (regarding farmers' potential response to policy changes), agricultural scientists (regarding the potential adoption of their research results by farmers), environmental managers (regarding farmers' potential response to environmental projects), and extension agents/agricultural consultants (regarding farmers' motivations and the potential limits of their extensions) (Pannell & Vanclay 2011a). Many of those stakeholders' interests also apply in a water-trading scenario.

Overall, the adoption of modern technologies/crops and other farm management practices as adaptation strategies has found much attention in the literature. Water trading as an adaptation strategy has had less attention. While there are some common determinants of adoption decisions (e.g. financial factors), studies often identified different factors depending on the type of adoption strategy. In the case of hard technology, farm and spatial characteristics seem to play a larger role than in the case of soft technology (i.e. farm management practices), where information factors are crucial. Likewise information was a critical factor in adaptation studies, in addition to farmers' climate change beliefs and attitudes.

### 3.2.5 Focus: Role of social capital

Section 3.2.2 has underscored the influence of social and psychological aspects in decision-making behaviour. This includes the effect of social influences, which describes the process of social learning<sup>54</sup> (i.e. adult and community learning) and the impact of social capital<sup>55</sup> (Brown & Schulz 2009; Wagemakers & Röling 2000). Possible sources of social capital may include family, neighbourhood, workplace, ongoing education, or voluntary organisations (Field et al. 2000). While there exist many forms and definitions of social capital (Bjørnskov & Sønderskov 2013), in general, social capital is defined by networks, norms and values, as well as the relationship between actors, social ties and connectedness (Coleman 1988; Ostrom 2000b; Pretty & Ward 2001; Putnam 1995). In agriculture, social capital can be built by farmers exchanging favours/information (Palis et al. 2005), farmer-organised resource governance systems<sup>56</sup> (Ostrom 2000b), farmer associations e.g. farmer unions (Vera-Toscano et al. 2013) or other local farmer groups, e.g. in catchment management (Pretty & Ward 2001). The influence of farmers' neighbours in a neighbourhood or community area (neighbourhood effect) is of particular interest in Chapter 7.

Generally, sociologists increased the awareness of the interdependence between farmers by arguing that during the decision process farmers seek to verify and confirm their own decision with peers using informal/interpersonal communication channels (Rogers & Shoemaker 1971). Approximately 50% of the information used for farmers' economic decision-making is gained through informal information channels, a ratio which increases when formal information sources (e.g. extension) are not well developed (Just et al. 2002). Analogous, salesmen were identified as the distributor of knowledge and neighbours' as the facilitator of

<sup>&</sup>lt;sup>54</sup> Social learning theory proposes that most human behaviour is formed by observing other individuals to learn from their behaviour, which may serve as a guide for own behaviour (Bandura 1977).

<sup>&</sup>lt;sup>55</sup> Social capital has increasingly been the focus in social sciences with regard to lifelong/adult learning (e.g. Field 2005; Field et al. 2000) as well as in other disciplines, e.g. in the knowledge spill-over literature (e.g. Krugman 1991).

<sup>&</sup>lt;sup>56</sup> For example, self-organised irrigation systems that aim to overcome collective-action problems (Ostrom 2000b).

'conviction' (Ryan & Gross 1943). The concept of social learning was also emphasised for successful and meaningful adaptation to climate changes in the southern MDB (e.g. Brown & Schulz 2009; Golding & Campbell 2009). Brown and Schulz (2009) identified six different forms of social learning for climate change adaptation: learning to produce, to be efficient, to survive, to live with uncertainty, to be sustainable and to share.

Traditional farmer information channels (e.g. extension services, magazines, government farm agencies, cooperatives or local farm suppliers) may not satisfactorily transfer relevant information, particularly regarding specialised farming skills, such as intensive grazing (CIAS 1996; Paine et al. 2000). Localised and specific networks in agriculture provide an additional information platform (Paine et al. 2000). Traditionally, the role of farmers' social capital and the various information sources were often neglected in environmental management by development policies (e.g. Wilson 1997); however, gradually the formation of groups to support collective action<sup>58</sup> was enforced (Pretty & Ward 2001). An Australian example is the 'Landcare' program, which established the Landcare group networks in rural areas and showed that top-down government initiatives can activate bottom-up community development (Sobels et al. 2001). Other Natural Resources Management (NRM)<sup>59</sup> programs and groups were established over time to foster farmers' self-reliance in conservation adoption decisions (Marshall 2011) and to facilitate a link to local communities e.g. by organising NRM forums (DEWNR 2015). Generally, it is shown that social capital promotes economic development in regional Australia (e.g. Woodhouse 2006).

Manski (1993) studied three different types of network influences: firstly, *endogenous* impacts, i.e. individual behaviour affects average group behaviour and vice versa. Secondly, *correlated* impacts, which occur when similar behaviour of individuals within one group is observed due to potential similar characteristics (e.g. similar political, institutional or environmental influences). Finally, *contextual* impacts, which state that individual behaviour is affected by the exogenous factors of the individual's group. Furthermore, Rogers (2003) described certain characteristics of the local social structure that affect information diffusion: *group homogeneity* (farmers with similar attributes/beliefs are more likely to share information effectively, which is related to the aforementioned *correlated* effects), *participatory norms* (the degree to which local customs and social norms promote interaction

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<sup>&</sup>lt;sup>57</sup> Examples for Australia: 'Dairy Australia', 'Future Farmers' (young farmers aged 18 to 35 years) or more local farming networks such as the 'Evergreen Farming' group in Western Australia.

<sup>&</sup>lt;sup>58</sup> Can also be described as community, participatory or joint management (Pretty & Ward 2001).

<sup>&</sup>lt;sup>59</sup> NRM regions were defined by the Australian Government, in association with state and territory governments, in order to facilitate the integrated delivery of NRM priority issues (ABS 2008).

and information exchange) and *leadership heterogeneity* (effects of leaders' differing socioeconomic attributes in a social structure).

Numerous studies confirm the relevance of aforementioned concepts. For example, sharing beliefs and values in a farmer organisation (e.g. Vera-Toscano et al. 2013) or within the family (e.g. Battershill & Gilg 1997) increased the likelihood of social learning and thereby influenced farmers' decision-making (*group homogeneity*), e.g. regarding conservation behaviour. Further, network effectiveness might be higher amongst highly educated and younger farmers due to a higher social participation rate, being more active when seeking information, and thus potentially being an early adopter (Ilbery 1978). Granovetter (1973) found that leaders with a higher social status or different career than other community members may be able to serve as an inter-mediator between formal information sources and other community members (*leadership heterogeneity*). Similarly, Palis et al. (2005) identified a positive effect on the adoption process if the pioneering adopter has a higher social status than the observer and is perceived as a leader in the community.

As indicated in Section 3.2.2, not all social capital is likely to equally result in adoption or adaptation, e.g. by imposing constraints, in the form of social norms, that can ultimately reduce the local adaptive capacity (e.g. Bodin et al. 2006; Newman & Dale 2005). Specifically, a high dependence (strong ties) upon primary groups (e.g. neighbours, kinship) can decrease the acceptance rate of innovations, as a result of the individual's strong dependence on the primary group's thinking (e.g. Wilkening 1950). This study also concluded that the strongest ties are associated with communities that have the greatest cultural isolation. Further, transformational adaptation was associated with weak social ties and extensive network connections as compared to incremental adaptation (Dowd et al. 2014). The influence of social norms has long been the focus of behavioural studies (e.g. Ostrom 2000a). Individuals' behaviour tends to be reflected by cultural and social influences, according to an individual's central reference group. Social norms can cause social pressure, which may ultimately prevent farmers to act according to their attitudes (Burton 2004a). Several empirical studies confirmed the impact of social pressure amongst farmers, e.g. in the case of adopting habitat conservation schemes (Ducros & Watson 2002), farmers' technology adoption (Lynne 1995; Lynne & Casey 1998) or other conservation strategies (Carr & Tait 1990). In rural farming communities there is often a tendency to conform to behavioural norms (i.e. social conformity), which can affect farmers' decision-making (e.g. Läpple & Kelley 2013; Platteau 2000; Wollni & Andersson 2014). The utility derived from social conformity may direct farmers' decision as much as or even more than profit considerations (e.g. Akerlof 1980; Moser & Barrett 2006).

Farming communities tend to be susceptible to the influence of social pressure, due to several specific characteristics that are likely to contribute to the manifestation of local norms and the development of social pressure. For example, the literature often described the closed (Carr & Tait 1990) and conservative (Burton 2004a; Jones 1963) nature of farming communities, and a high relevance of status symbols (Burton 2004b; Rogers 2003). According to Carr and Tait (1990, p. 228) the 'closed nature' of the farming community reinforces dominant farming values and "a feeling of powerlessness and fear of being ridiculed" amongst some farmers. As a result, farmers may be highly susceptible to neighbours' decisions and views (Burton 2004a). The intensity of social norms and social pressure may vary with farmers' socioeconomic characteristics. For example, 'new' farmers are less likely to 'judge' neighbours' behaviour in contrast to 'traditional' farmers (Battershill & Gilg 1997). Younger farmers may have a more outward-looking approach due to wider social networks, which exposes them to the views of a wider society (e.g. regarding environmental problems). This may encourage younger farmers to reflect on those views and to see the farming community not as a special group set apart from the wider society (Ward & Lowe 1994).

In the southern MDB, anecdotal evidence suggested considerable social pressure in irrigation communities against those who were willing to sell or had sold their water entitlements (e.g. Fenton 2006). This was largely the result of farmers' concerns that water entitlement sales, possibly leading to farmer exits, may threaten the viability and survival of the local farming community and may lead to increased infrastructure costs for the remaining irrigators. Irrigators were ostracised from the local pub if they had sold their water in the early stages of the water market. Similar responses to changes in farming communities were found in previous adoption studies, e.g. Jones (1963, p. 403) concluded; "technological change [...] is usually accompanied by social tension and conflict as old customs, traditions and values have to be cast aside." Chapter 7 empirically analyses a neighbourhood influence effect on the decision to sell water entitlements.

Farmer networks and their impact on adoption and adaptation behaviour is a challenging research field due to their often intangible nature, e.g. when determining the network's physical boundaries and the effectiveness of the network. Defining the (farmer) neighbourhood/network area is a common challenge and is dependent on many national and

local physical, as well as cultural characteristics.<sup>60</sup> A potential definition of a farmer network area in the southern MDB is discussed in Chapter 7.

# 3.3 Influences on water trading decision-making

This section reviews the literature that has studied influences on irrigators' water trading decision-making. As the analysis chapters in this thesis explore the determinants of participating in the government as well as the private market, the following sections review studies on both markets separately.

## 3.3.1 Selling water entitlements to the government

The literature on irrigator participation in government water entitlement markets is limited. Studies focus on the programs in Australia and USA using either a quantitative/econometric approach (Isé & Sunding 1998; Wheeler et al. 2012b) or a qualitative methodology (e.g. Thampapillai 2009a). As Chapter 7 expands the model in Wheeler et al. (2012b), this study will be reviewed first.

Wheeler et al. (2012b) observed actual sales and the willingness of irrigators to participate in the buyback program for the southern MDB, based on two datasets from 2008/09 and 2010/11. The 2008/09 survey included Riverland (SA) and GMID (VIC) areas, whereas the 2010/11 survey comprised the connected irrigation regions in the southern MDB. Overall, irrigators primarily decided to sell water to the government due to 'last resort' circumstances, i.e. debt, death, divorce, or for strategic reasons (e.g. following farm investment plans, water surpluses). More specifically, the following factors predicted actual water entitlement sales most successfully: age, education, attitude<sup>61</sup> (tradition), number of children, information source, past water allocation sales, whole farm plan, water entitlement holdings, land use (percentage of annual and permanent crops), operating surplus, debt, allocation level, and the location (VIC or SA) (Table 3.1 lists the direction of the variables' influence).

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<sup>&</sup>lt;sup>60</sup> The rise of online networks may transform farmer networks in the future. It is however unknown how relevant online platforms are for farmers today. In 2007/08, 66% of Australian farmers used the internet for business operations (ABS 2009a). A more recent survey of internet access in Australian households indicated a higher use rate with 82% of rural households having internet access (ABS 2016b). There is great potential in online extension services and online groups for farmers regarding skill development and for complementing face-to-face interaction, which may ultimately support the adaptive capacity (e.g. Easdown & Starasts 2004). If online networking between farmers becomes more common in the future, modelling the influence of farmer-to-farmer networks based on distance or number of neighbours may not capture real networking effects in future studies. <sup>61</sup> Using factor analysis the study identified attitudinal constructs from value and attitude statements used in a survey: *Tradition, Commerce, Succession, Environment* and *Technology*. The higher the factor score, the more the farmers associated themselves with the construct's value.

A slight difference between 2008/09 and 2010/11 sellers was identified: age, education, number of children, information source, having a whole farm plan, farm operating surplus and the location only had an influence on sales in 2010/11 and percentage of the farm area under horticulture and the level of debt only had an influence on sales in 2008/09. Contradictory results were found for the ownership of high security entitlements. Water sales were more likely if the seller held a small volume of high security water entitlements in 2008/09 and a higher volume of high/general security water entitlements in 2010/11. This is because in 2008/09 most of the sellers were from the Riverland, where irrigators generally own smaller holdings of water entitlements. Different regional results are caused by specific magnitudes of the drought (Riverland irrigators tended to be more affected by the then recent drought) and other issues, such as institutional and historical factors, permanent crop characteristics and commodity prices.

The models predicting the willingness to sell water entitlements disclosed further relationships. In contrast to the actual sales models, irrigators' willingness to sell was influenced by gender, number of years farmed, other attitudes (succession, commercial and environment), past water entitlement sales experience, whether the cap had prevented previous water entitlement trade, number of full-time equivalent employees, and farm size. Permanent crop irrigators were less willing to sell water entitlements in 2008/09 since permanent cropping allows less flexibility and a higher reliance on secure resources. But in 2010/11 permanent crop irrigators were more willing to sell potentially due to decreasing prices for wine grape (and citrus).

Overall, the following variables explain both willingness to sell and actual sales, and thus appear to be the most relevant variables: traditional attitude, government agencies as information source, number of allocation sales in the past, number of high security water entitlements owned, percentage of land under horticulture, farm operating surplus and the mean season end water allocation level in the previous five years. Generally, financial factors played a more important role in the actual sales models, whereas attitudinal and regional/institutional factors had a higher influence in willingness to sell models. The difference between 2008/09 and 2010/11 models can largely be explained by the effect that drought and non-drought years can have on the decision to sell water entitlements, as well as by the different characteristics of the survey regions.

The study tested some regional (spatial) data such as state location dummies (VIC, SA and NSW) and regional net rainfall (rainfall take evaporation). The location by state was highly significant for actual sales in 2010/11. Net rainfall was not found to have a significant impact

on the models, possibly due to its regional dimension (calculated on a broad district level) and the importance of the water allocation level variable.

The study also suggested that strategic water sales (e.g. following farm investment plans) were dependent on the water price level at the time. Hence, in years of low water prices, water sales as a 'last resort' decision may dominate. Also, irrigators' strategic water sales might fall over time as their water surplus diminishes. Overall, irrigators' preferences changed between the years, with more irrigators seriously considering selling in 2010/11.

Isé and Sunding (1998) studied the determinants of farmers' participation in the first stage of Nevada's (USA) water buyback program. In contrast to Australia's program, irrigators were not allowed to sell parts of their water entitlements, subsequently irrigators were more likely to exit farming if they decided to sell water entitlements to the government. The study estimated that financial distress was the most important driver for the decision to sell water. Additional results suggested that farmers were more likely to sell if they grew on poor soil quality, 62 were located further away from the city and off-farm employment was available.

Poor soil quality might indicate lower yields and thus lower profits, which in turn denotes less profitable agricultural land. It could also be expected that farmers closer to the city are more likely to sell due to a greater land development potential and more off-farm employment opportunities. But there is the danger of crop damages, due to wildlife and weeds, if the farm property is located on the periphery. Furthermore, being a full-time farmer increases the reliance on agricultural income and the owned water, which in turn decreases the likelihood of selling. In addition, the farmer could be more attached to the farm and the rural lifestyle, and thus, wish to continue their way of farming. It is important to note that the study worked with a relatively small sample size (n=65).

Table 3.1: Significant variables explaining water entitlement sales to the government in Wheeler et al. (2012) and Isé and Sunding (1998) and their direction

Human & social cap	ital	Physical/farm capital		Financial capital		Regional capital	
Age	(-)	Net seller of water allocations	(+)	Operating surplus	(-)	Allocation level	(-)
Low education	(+)	Whole farm plan	(+)	Debt	(+)	State location (VIC, SA)	(+)
Attitude (tradition)	(-)	High security entitlements owned	(+)/ (-)	Off-farm employment	(+)	Distance to city	(+)
Number of children	(+)	Annual crops (cereal)	(-)				
Information source (agency)	(-)	Horticulture	(-)				
-		Soil quality	(-)				

<sup>&</sup>lt;sup>62</sup> Defined good soil quality if more than 50% of the soil was defined as one of the upper three soil classes.

Loch et al. (2016) studied irrigators' stated preferences for a market-based reallocation approach, which includes purchasing water entitlements and/or trade in temporary water, including leasing and option contracts, for environmental purposes in Australia. The study identified the following determinants that increase engagement with market-based programs: state regional influences, type of farm production and recent stress related to debt, low income and low water allocations received. Price variables were found to be less relevant.

Other qualitative studies found similar influences. For example, Thampapillai (2009a) found comparable results after conducting in-person interviews (n=41) in the MDB: irrigators in financial hardship, close to retiring, with off-farm income availability, and having no successor were more likely to sell water entitlements to the government. Murrumbidgee (NSW) irrigators, who faced greater farm regulations, showed reluctance to sell water separate to the land because water entitlements were still considered as being part of the land and an integral farm asset. Irrigators from the Goulburn-Broken (VIC) region expressed concern about the future and security of food production. In general, irrigators not willing to sell revealed concerns about the rural viability, rising costs of the irrigation infrastructure system, government management of environmental water and transparency of the program. Thampapillai (2009a) concluded that the government needed to provide irrigators and their rural community with alternative opportunities for the economic future, to secure a higher participation rate in the water buyback scheme.

Kuehne et al. (2010) emphasised the relevance of non-profit maximising values, such as plans for staying in farming in the future, years left to retirement, succession arrangements, being full-/part-time or hobby farmer, future employability, whether the water sale included the land, conditions of the farm exit grant package, and the price on offer. Overall, being optimistic or pessimistic about the future had a major influence on selling water. The study criticised the government's one-sided strategy that, so far, had concentrated on the profit-maximising approach to attract sellers. While confirming debt as a dominant reason for selling water entitlements, Bjornlund et al. (2011) also emphasised the role of irrigators' values, attitudes and wellbeing (financial security is only one driver of wellbeing).

Furthermore, using simple statistical comparisons a report on the review of the first round of the *Living the Murray* initiative found that program participants were primarily irrigating with less efficient infrastructure, owned a large proportion of water entitlements, were older, better educated, had a high gross income (with the majority earned on-farm) and were mostly selling because of financial planning (Walpole et al. 2010). The review of the first round of the water buyback program (*Water for the Future* initiative) found the primary motivation for water

sales was based on financial reasons (retiring debt) and the secondary motivation was found to be re-investment in the farm (Hyder Consulting 2008). Consistent findings were reported in the succeeding review by Wheeler and Cheesman (2013), which analysed surveys of irrigators who had sold water between 2008/09 to the end of 2011. Overall, this study found that 70% of the survey participants remained in farming, after they had sold parts (60%) or all (10%) of their water entitlements, and 30% exited farming after they had sold all of their water entitlements. Thus, exiting farming was not a major driver for the decision to sell water entitlements to the government. Dominant reasons for selling were debt (30%) and cash flow (30%), where the cash flow was primarily used to support farm income and increase viability (22%) and also to fund on-farm investment (8%). Further reasons for selling water were farm exit (15%), having surplus water (9%), age, and death/divorce. Other reasons included environmental reasons, family support, frustration with local IIO or the government, channel upgrades, unbundling of land and water as well as decreased water quality levels.

Besides Isé and Sunding (1998), international literature on determinants of selling in a government water buyback program is limited. The water buyback program in Mexico was briefly reviewed in Reed (2007), where it was suggested that access to pumps, soil salinity and distance to water sources/infrastructure promoted water sales to the government. For one region it was also found that, initially, farmers would hold on to their water rights, hoping that the government would invest in infrastructure, but realised that this possibility became minimal as farmers gradually sold their water.

### 3.3.2 Water trading in the private market

#### 3.3.2.1 Australian literature

There exists a comprehensive body of literature on private water market participation, especially for the water allocation market. Overall, several studies found that water trading increases economic efficiency by transferring water from lower value users to higher value users (e.g. high value crops). Correspondingly, water is sold by less-efficient users to high water efficient users (e.g. better soil quality or irrigation infrastructure) (e.g. Bjornlund & McKay 1995, 2002).

In Australia, the early years of water trading behaviour were assessed by Alankarage et al. (2002); Bjornlund (2004, 2006a, 2006b, 2007); Bjornlund and McKay (1995, 1996); Bjornlund and Rossini (2005) and Young et al. (2000). Those studies were primarily based on a non-econometric approach, but provided ground-laying insights into irrigators' water trading behaviour. For example, water entitlement trading until 1994 showed that water was traded out of regions suffering environmental problems (i.e. level of water table, water

supply, water and soil quality) (Bjornlund & McKay 1995) and away from low efficiency technology users (Bjornlund & McKay 1996). A large volume of unused water ('sleeper' water)<sup>63</sup> was sold into active production, mostly into the then high-value dairy production industry in VIC, which may have caused further environmental problems, as dairy farmers suffered from already high water tables (Bjornlund & McKay 1995). In SA, water entitlements were traded out of pasture, broadacre and non-farming uses into horticulture, viticulture and vegetable production (Bjornlund & McKay 1996). Correspondingly, Young et al. (2000) concluded that water entitlement purchases were more likely to be driven by farmers cultivating permanent crops (e.g. citrus, grapes) to secure long-term water security.

Overall, water entitlement buyers were younger, had higher education levels, were actively participating in training sessions, used fertilised pasture area and grain for supplementary feeding, had larger investments in infrastructure (e.g. used irrigation scheduling aid), a whole farm plan, larger entitlement holdings, access to alternative water use (groundwater), on-farm water storage facilities, fewer environmental problems (regarding soil degradation and soil salinity), higher gross margins of water use and larger/more viable units, which all indicates higher efficiency levels (Alankarage et al. 2002; Bjornlund 2004, 2007). Water entitlement buyers cultivated on more loamy soils, whereas water entitlement sellers were established on more sandy and clay soils (Alankarage et al. 2002). Generally, water entitlement trading was driven by the aspiration of long-term structural changes on the farm to control long-term risk exposure, e.g. to secure a particular level of water availability or change farm location or type, which may be followed by the use of the allocation market to adjust for the new risk position (Alankarage et al. 2002; Bjornlund 2006a; Turral et al. 2005).

In contrast, water allocation buyers could not be distinguished from sellers according to their efficiency level or any other environmental or resource related factors, and no specific spatial movement of water allocations between the regions was found. Water allocation traders principally aimed to adjust to fluctuations in commodity prices and water supply. Thus, water prices, farm product prices and seasonal water excesses/shortages were the major drivers of water allocation trading. For example, lower prices at the end of the farming season encouraged irrigators to buy water allocation to irrigate annual crops. Generally, water allocation trading was more likely to attract farmers cultivating annual crops and most of the buyers were dairy farmers and most of the sellers were cropping and grazing farmers (Alankarage et al. 2002; Bjornlund 2004, 2006a; Young et al. 2000). Furthermore, Young et al. (2000) suggested that water entitlement and allocation trading were linked by the

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<sup>&</sup>lt;sup>63</sup> During the early years of water trading, approximately 50% of the water sold was previously unused water (Bjornlund 2007).

following factors: price differential and price variations, resource constraints, tax laws, fines for exceeding water allocations, transaction costs, output prices, and water and land management practices.

Bjornlund (2006b) analysed water trading during the first 13 years (1991/92–2003/04) of trading in the GMID (VIC) and found that overall traders were driven by the value of production, soil productiveness, farm size, and water restrictions/scarcity due to drought and policy changes. During some of these years farmers were forced out of business for reasons of water scarcity and high water prices, in addition to available subsidies for dairy farm exits. The study found spatial differences in water trading, where the trading in Goulburn's west was driven by poor soils, high salinity levels and high water demand for grazing and mixed farming, while trading in the Murray system tended to be solely dependent on water allocation levels, i.e. scarcity issues. This suggested that Goulburn irrigators had made long-term farm adjustments to avoid dependence on seasonal conditions.

During the early years, the participation in water allocation markets tended to be higher compared to the participation in water entitlement markets, and this was due to several reasons. For example, many water allocation buyers could simply not afford to buy water entitlements, irrigators were concerned about decreasing land values if they were to sell water entitlements, and irrigators felt considerable policy uncertainty at the beginning of the water reforms (e.g. regarding the cap) (Bjornlund & McKay 2000).

Subsequent studies, confirmed the results of the earlier studies and offered additional insights into water trading behaviour. For example, Wheeler et al. (2009) expanded the analysis of early water allocation traders (1998/99) in the GMID comparing the profiles of water allocation buyers and sellers. Water allocation sellers were associated with having an agricultural qualification, smaller irrigated area, smaller percentage of land used for dairy, smaller percentage area connected to a reuse system, and a more favourable opinion about allocating water to the environment. Further, Wheeler et al. (2010b) compared the profiles of water allocation and entitlement traders and confirmed that the trader profiles vary, reflecting the short and long-term characteristics of the different markets. Water entitlement traders were more likely to act on the basis of long-term considerations that are largely based on farm characteristics (e.g. investment in farm technology), whereas water allocation traders were more determined by short-term considerations and personal characteristics.

The short-term perspective of water allocation traders was also found in other studies, which highlighted the market's ability to provide for risk and uncertainty adjustments within and between seasons (Brennan 2006; Loch et al. 2012; Zuo et al. 2014). Loch et al. (2012)

provided further insights into water allocation trading determinants, such as attitude to risk, institutional/policy changes and deriving an income out of trading. Zuo et al. (2014) confirmed the risk-reducing effect of buying water allocations, particularly for horticultural farmers. Wheeler et al. (2008) showed that price elasticity for water allocation demand varied over the water-trading season, indicating that demand and supply were highly dependent upon the time of the season and market conditions. Seasonality and water scarcity issues played the largest role in affecting water demand.

The influence of irrigators' attitudes and values on water selling was the focus in other studies (e.g. Maybery et al. 2005). It was found that irrigators classified as 'Investors' were more likely to sell water rather than the group of 'Providers' (i.e. related to higher family values) (Kuehne et al. 2008). Also, a more pessimistic attitude towards the future resulted in a higher probability of selling water entitlements (Kuehne et al. 2010).

NWC (2012) summarised the following main drivers of water allocation trading:

- Generating additional income e.g. reducing annual cropping production during water scarce periods to sell water allocations (thereby taking advantage of high water prices and covering for ongoing costs);
- Minimising input costs (i.e. dairy farmers used water allocation trading depending on the prices for feed);
- Maintaining productive capacity during water scarce periods (e.g. regarding perennial plantings);
- Improving farm production/productivity (e.g. temporarily expanding production due to favourable commodity prices/exchange rates); and
- Using the water as carry-over to the next season (e.g. as a supplement for buying water entitlements and to manage water availability across seasons).

NWC (2012) also showed that individual industry developments (e.g. the expanding almond industry, economic decline for wine grape growers and dairy farmers) triggered large water entitlement purchases or sales. Similar to selling water to the government, the overarching reason for water entitlement sales in the private market was to generate cash (69%), followed by ceasing irrigation farming (24%), decreasing farm production and switching to rely on the water allocation market (especially in the dairy and broadacre industries where farm production is more flexible). Some farmers also bought water entitlements 'locally' after selling their water to the government. Furthermore, this study found that many irrigators decided to hold onto their water delivery rights/access to irrigation infrastructure after selling water entitlements (60%), e.g. to be able to sell the property with the delivery share attached.

In general, water trading in the southern MDB increasingly forms part of a broader farm business strategy where water entitlement and allocation trading (and carry-over decisions) are complementing activities and, thus, should be considered collectively (NWC 2012). This study also concluded that water allocation traders, in particular, became more advanced over time (from 2009/10 onwards) in their use of market information for water trading decisions.

A number of studies discussed the influence of institutional/policy related factors on water trading. While the early water reforms in 1994 and 2004 initiated formal water trading; polices, information deficiencies and uncertainty can also adversely affect water trading and market efficiency. Examples here include; changes to carry-over rules, trading rule announcements, and uncertainty about future allocation levels, as well as limits on interregional water entitlement trading, such as the 4% cap on water entitlement transfer out of an irrigation area in VIC (NWC 2011b, 2012). Caps on water entitlement trading may lead to water entitlement sales at lower prices, or force irrigators to remain in unproductive farming whilst under financial pressure (NWC 2012), but these caps may also increase water allocation trading. Access to market information that improves the visibility and transparency of water markets can influence the ability and willingness of irrigators to participate in the market (NWC 2012). On the other hand, transaction costs and trading processing times may impede water trading, especially in water entitlement and interregional/interstate trading. However, improvements in these areas have been observed (NWC 2011d, 2012).

#### 3.3.2.2 International literature

The literature on water trading behaviour outside of Australia is relatively thin. In general, studies confirm the results found in the Australian case studies. For example, a Canadian study confirmed that irrigators generally opposed to water transfers were older, had lower education levels and had spent more years in farming (Lafreniere et al. 2012). Another Canadian analysis on water entitlement trading in an early market confirmed that the majority of sellers were motivated by having surplus water, and that most of the buyers wanted to increase long-term water supply security and were higher-value users, in some cases with more efficient irrigation infrastructure (Nicol et al. 2008). A state and county level analysis in western US provided insights into the different drivers on actual transactions in leasing and sale markets: The value of agricultural production was negatively associated with leasing out water, and the value of agricultural land was negatively associated with selling water (Hansen et al. 2014). A recent US study showed the impact of transfer costs on water markets theoretically, using the gravity equation, and empirically, using distance and institutional factors (Regnacq et al. 2016).

A study on groundwater trading determinants by Iranian irrigators suggested that socioeconomic factors were not as important as profit-maximising factors for participation in (informal) groundwater markets (Jaghdani & Brümmer 2015), indicating that the role of socio-economic factors may vary across countries. This study further found that decreased water quality, increased age of the farm, and increased size of the water quota had a negative effect on the participation probability, whereas more scattered plots, high water flow levels from pumping, and deeper wells had a positive impact on the probability of participation in groundwater markets. A Spanish case study further confirmed the potential of water markets to decrease risk and vulnerability during water scarcity conditions (Calatrava & Garrido 2005). Another Spanish study concluded that the most dominant obstacle for water market participation was farmers' ethical views towards trading water, as farmers did not generally view water as a commercial good (Giannoccaro et al. 2015).

#### 3.3.3 Synthesis, gap and hypotheses

Overall, the review on water trading behaviour in this chapter has shown that there are wide-reaching farmer, farm and other external factors influencing both water allocation and entitlement trading. It has been suggested that future studies need to include a wide range of factors to provide a complete picture of irrigators' water trading behaviour (e.g. Wheeler et al. 2012b). Figure 3.3 presents a simple framework of the major categories for determinants of water trading decision-making, which should be present in any approach to water trading behaviour modelling subject to data availability. Each category may consist of various explanatory variables depending on the study area, the spatial scale of the analysis and the type of water trade.

Regional and institutional characteristics

Farm characteristics

Farmer and household characteristics

Water tradling decision

Figure 3.3: Framework for water trading decision-making

Source: Own figure

The review in this chapter has discussed water market participation in the government and private markets separately; however, it was shown that the reasons for selling water entitlements in the private market or to the government were largely the same. It is likely to

involve different determinants, when the government program exclusively allows for the sale of all water entitlement holdings (such as in the USA), which means that farm exit is the dominant reason for selling water (Isé & Sunding 1998).

Overall, there is a lack of extending water trading behaviour models to a spatial analysis, and assessing a variety of spatial data to improve the knowledge on irrigators' water trading behaviour. Specifically, the influence of spatial (biophysical and socio-economic) factors on a regional and local scale in addition to the influence of neighbours' water trading decisionmaking (i.e. social influences or neighbourhood effect) are not fully observed yet. There is a particular need to shed light on the neighbourhood effect on irrigators' decision-making. As described in Section 3.2.5, anecdotal evidence showed that irrigators experienced social pressure and exclusion in the past when intending to sell or selling water entitlements from their area. The reviewed studies however did not analyse potential social influences or learning effects on irrigators, thus, it is unclear whether irrigators' decision-making in the southern MDB is affected by the decision-making in the neighbourhood. During a survey on irrigators' attitudes to water allocation and trading in the Goulburn-Broken (VIC) catchment, it was found that "Knowledge and understanding of the actions of other irrigators is generally strong among traders but weak among those water users who do not trade." (Tisdell et al. 2001, p. iii). Another study in the Loddon catchment (VIC) concluded that "the social interaction of farmers at locales reinforce patterns of behaviour and belief about farming" (Thomson 2001, p. ii). Thus, it can be expected that some of the irrigators in the southern MDB are likely to regularly interact with other irrigators in their community and potentially influence and learn from each other.

Furthermore, water entitlement trading behaviour studies are underrepresented in the literature compared to water allocation trading studies (possibly due to the fact that water allocation trading is generally more adopted amongst irrigators). The review in this chapter comprises regional and farm-level studies, however most of the reviewed studies focus on the discrete decision to trade water at the individual level. The regional studies from the earlier years of water trading in the private market provided insights into the spatial pattern and movement of water between regions, land uses and other locational characteristics. On the other hand, the farm-level studies showed further influences, mainly personal/farm related drivers, demonstrating the high complexity of water trading decision-making at the individual level. Thus, it can be assumed that spatial characteristics potentially have a stronger influence in regional analysis. Furthermore, apparent spatial movements were commonly found in trading water entitlements, as opposed to trading in water allocations. As water entitlement trading was also generally more affected by biophysical/environmental factors (long-term

considerations) than water allocation trading, it can be assumed that spatial characteristics have a larger impact on water entitlement trading.

Finally, there has been minimal research analysing decision-making behind trading volumes of water at a regional scale over time (as opposed to discrete choice studies). Determining factors that lead to high volumetric water trading decisions may additionally provide important insights into the potential adverse demand and supply effects in different regions.

From this review and synthesis, the following hypotheses are formulated:

*H1:* Spatial factors reflecting poorer resource areas (e.g. regarding water scarcity and quality, soil degradation) increase the likelihood of selling water entitlements in that area.

*H2:* Spatial factors have a stronger impact on water entitlement trading than water allocation trading.

*H3:* Irrigators located in neighbourhoods where increased numbers of farmers have sold water entitlements are more likely to sell their water entitlements (called the 'neighbourhood effect').

Further hypotheses on the influence of spatial characteristics are developed throughout the following chapters while reviewing spatial studies on farmers' decision-making. Chapters 5, 6 and 7 each list relevant hypotheses.

#### 3.4 Summary

This chapter has shown the complexity of farmers' decision-making in general and choices around water trading specifically. It was shown that, over time, research into farmers' decision-making has been influenced by various different disciplines (i.e. economics, sociology/psychology, and geography) as well as their sub-disciplines. Empirical research is dominated by studies on farmers' technology adoption behaviour and the adoption of other farm management practices and, more recently, farmers' adaptation behaviour to climate change. Water trading behaviour research can learn from this broad literature, since water trading can be categorised as an adoption or adaptation strategy, depending on the motives or forces behind the decision to trade water. The literature on water trading behaviour is evolving. Determinants of water trading decisions have, so far, largely been studied in Australia and these studies have primarily investigated water trading decisions in the private market. Generally, studies emphasised the heterogeneity of farmers' determinants to trade

water. Water trading is not a simple question of water demand/use, but involves a set of multifaceted factors, such as farmers' attitude towards farming and water, or the possibilities in switching between land uses and different water markets. Many studies have suggested that future research should explore an extended set of potential determinants to contribute to the understanding of water trading behaviour. Particularly, there is a need to assess potential spatial determinants (environmental and social). The farmer decision-making literature has long been emphasising the spatial variation of agricultural decisions, and thus, the role of spatial influences. However, little is known about spatial effects on water trading decision-making.

The identified gaps in the water trading behaviour literature are addressed in the following chapters by combining several spatial variables with different water trading datasets and farm-related information at the regional and farm-level, including volumes and discrete decisions of trade. Prior to that, the next chapter will briefly review how spatial analysis has been assisting the research and management of water resources.

Chapter 4 The contribution of spatial analysis to water management: a case study of the Murray-Darling Basin, Australia

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#### **Abstract**

The relevance of spatial economic analysis to water management issues is reviewed to highlight its contribution to the understanding of economic behaviour and regulatory or management processes in the context of water security problems. Spatial analysis refers to mapping and analysing the spatial distribution of biophysical factors and accounting for spill-over effects at global, regional and local scales. Given predicted decreased water availability in the future, spatial analysis can contribute to the understanding of regional and local changes to the water quantity and quality level by highlighting the impact of regional and local spatial processes in agriculture, e.g. land-use changes, water trading, adoption behaviour of farm management practices. We review spatial theories and methodologies and their application in the empirical literature in (water) resources management. Australia's Murray-Darling Basin is used as a case study to highlight how spatial analysis can be increasingly used in the future to inform rural water management policies.

Keywords: Spatial analysis, water resources management, Murray-Darling Basin

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Name of Principal Author (Candidate)	Juliane Haensch
Contribution to the Paper	Undertook the literature review. Collected spatial data and prepared maps. Wrote the manuscript.
Overall percentage (%)	80%
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 02.12.16

#### 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	Assoc. Prof. Sarah Wheeler										
Contribution to the Paper	Supervised development of work, contributed to the design of the manuscript, helped in manuscript evaluation/editing and acted as corresponding author.										
Signature	Date 21/11/16										

Name of Co-Author	Dr Alec Zuo
Contribution to the Paper	Helped to evaluate and edit the manuscript.
Signature	Date 2// 11/16

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#### NOTE:

This publication is included on pages 93 - 105 in the print copy of the thesis held in the University of Adelaide Library.

## Chapter 5 The impact of water and soil salinity on water market trading in the southern Murray-Darling Basin

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#### **Abstract**

Irrigators in the Murray-Darling Basin of Australia face a salinity triple threat, namely: dryland salinity on their land and surface-water and groundwater salinity in their irrigation water. Water trading has now been adopted to the point where it is a common adaptation tool concerning environmental changes used by the majority of farmers in the Basin. This study uses a number of unique water market and spatial databases to investigate the association between the severity and extent of areas which suffer from salinity (namely dryland, groundwater and surface-water salinity) and permanent trade over time, holding other regional characteristics constant. It was found that larger volumes of permanent water were likely to be sold from areas suffering from higher dryland salinity. In addition, increases in the concentration of groundwater salinity was found to decrease volumes of surface-water entitlements sold, providing evidence that groundwater entitlements (where they are viable substitutes) have been increasingly used as substitutes for surface-water entitlements in recent years. Other key influences on water sales included prices and net rainfall.

Key words: salinity, water trading, Australia, irrigation, water markets

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Contribution to the Paper	Undertook the literature review. Collected the majority of the data. Prepared data for analysis and performed spatial data analysis and regression modelling. Interpreted data and wrote the majority of 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 02.12/16								

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

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- 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	Assoc. Prof. Sarah Wheeler								
Contribution to the Paper	Supervised development of work, wrote parts of the manuscript, helped in data interpretation, manuscript evaluation and acted as corresponding author., devised, methicalclessy								
Signature	Date 21/11/16								

Namo of Co-Author	Dr Alec Zuo
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Signature	Dale 21/11/16

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Contribution to the Paper	Helped to evaluate and edit the manuscript.	
	•	
Signature		Date 21/11/16
		1

#### **5.1 Introduction**

Similar to the rest of the world, Australia faces many major environmental problems and challenges. These include habitat and biodiversity loss, degradation and fragmentation of ecosystems, invasive non-native species, unsustainable use and management of natural resources, changes to the aquatic environment and water flows, changing fire regimes and climate change (Beeton et al. 2006; Biodiversity Decline Working Group 2005). The salinization of water and soil was, at the beginning of this century, identified as a problem which would become increasingly severe in the future. In 2000, approximately 5.7 million hectares (ha) of Australian land (12% of the total arable land), of which 1.3 million ha belong to the Murray-Darling Basin (MDB), were classified as saline. By 2050 dryland salinity is predicted to increase threefold (MDBA 2015b; SoE Committee 2011). Likewise river salinity in the lower River Murray is expected to exceed the recommended threshold level (800 Electrical Conductivity (EC)) for drinking water within the next 50 to 100 years (MDBMC 1999).

In particular, salinity has been a risk within the MDB for many years. For example, in the state of New South Wales (NSW) approximately 70 to 80% of the total irrigated acreage is affected by salinity or waterlogging (NSW Government 2000). The MDB is an area of great agricultural, ecological, cultural and recreational significance. It is often called the 'foodbowl' of Australia, and is an area that suffered enormously in the recent Millennium Drought (period of severe drought in the early 2000s to 2009). The Millennium Drought resulted in reduced river flows, and thus reduced dilution flow, due to low rainfall (SKM 2011; Wheeler 2014). During the Millennium Drought salinization put Australia's biodiversity increasingly at risk, especially in the southern MDB. This led to the introduction of major national programs, such as the National Action Plan for Salinity and Water Quality (SoE Committee 2011).

The geological and climatic characteristics of the MDB make the Basin naturally prone to salinity. The introduction of irrigated agriculture and periods of drought have triggered secondary salinization, abating the natural process of leaching salt through the soil and raising the salinity levels in rivers, groundwater and land (MDBMC 1999). High salinity levels can cause declining crop yields, disturb aquatic ecosystems and vegetation and impair infrastructure (Letey & Dinar 1986; MDBA 2015b). Furthermore, salinity can reduce agricultural profitability due to salt mitigation processes, a required change in land use and

<sup>&</sup>lt;sup>65</sup> According to Worldbank (2015) the total arable land in Australia amounted to 47,304,000 ha in 2000.

<sup>&</sup>lt;sup>66</sup> Dryland salinity is the accumulation of salt at the soil surface (soil salinity) (MDBA 2015b).

soil erosion in response to land salinization. Because of the impact of soil erosion, salinity can be associated with declining soil quality and reduced native vegetation. The costs of lost agricultural production due to dryland salinity in Australia have been estimated at a minimum of AUD\$130 million per year (MDBMC 1999; NSW Government 2000).

Farmers in the MDB have had to adapt to changing environmental conditions, including climatic changes (Connor et al. 2012). Water trading has been widely adopted by irrigators in the MDB to adapt to a changing environment (Wheeler et al. 2014b). What is unknown is how various salinity issues on water and land have influenced the adoption of water trading. The literature on irrigators' water trading decision-making suggests that physical or environmental/spatial factors might have a significant impact on water trading behaviour, in addition to socio-economic and farm characteristics (e.g. Isé & Sunding 1998; Wheeler et al. 2012b). In particular, water entitlement trading is expected to be more influenced by environmental features given the permanent nature of these water rights, as compared to the temporary nature of trading water allocations (e.g. Bjornlund 2006a; Wheeler et al. 2010b). However, to date there has been limited research conducted on what role salinity features have played in water market trade, mainly because of the difficulty in obtaining water market, spatial and environmental data.

This study provides a detailed analysis of the association between spatial aspects of the environment, for example, salinity of land, surface-water and groundwater, and water trading activities over the past decade in the southern MDB. Our study combines a unique database of individual water trade records and regional water trade data with numerous spatial databases of various environmental and salinity information of the southern MDB. In particular, we seek to answer one key research question: Are irrigators within areas that suffer greater salinity issues (in terms of higher salinity levels for soil and surface-water) and that are characterised by lower groundwater salinity levels more likely to sell higher volumes of permanent water?

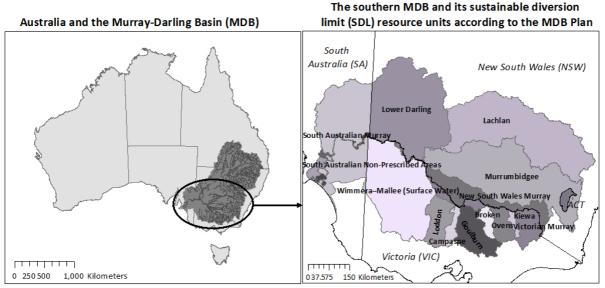
#### **5.2 Case Study**

#### 5.2.1 Southern Murray-Darling Basin

The MDB is Australia's largest agricultural production region with the primary uses of irrigation water for cotton, pasture for grazing and other cereals for grain or seed, and fruit. It is located in south-eastern Australia (see Figure 5.1 for more detail) and includes parts of Queensland, NSW, Victoria (VIC), South Australia (SA) and all of the Australian Capital Territory (ACT). The area uses more than half of the irrigation water applied nationally

(MDBA 2011c). The southern part of the MDB along the River Murray (includes bottom half of NSW, top part of VIC and parts of SA) is of most interest for studying water market behaviour, as it is hydrologically linked, and thus allows for interregional and interstate water trading.

Figure 5.1: Australia and the southern Murray-Darling Basin (MDB) including sustainable diversion limit (SDL) resource units according to the MDB Plan



Map layer sources: Geoscience (2006) and MDBA (2013b)

Source: Own figure

#### 5.2.2 Water trading in the southern Murray-Darling Basin

The Australian government has implemented many initiatives and reforms to combat declining water availability and water quality (e.g. Connell & Grafton 2008; Crase 2008b). Among these initiatives, the introduction of water trading is regarded to be an important tool to manage water scarcity, and Australia is the most advanced country in the world when it comes to the development of water markets (NWC 2007, 2011e; Wheeler & Cheesman 2013).

Two different water products are commonly traded in Australia: a) water entitlements (water access licenses providing permanent rights to a share of water and otherwise known as permanent water) and b) water allocations (seasonal and proportional access to a water access license and otherwise known as temporary water). There exist a wide range of water systems and water products in the MDB. For example, water entitlements and water allocations can be traded in the form of groundwater or surface-water in a regulated or unregulated water system. Furthermore, water entitlements have differing types of security attached to each license: they can be high security (which exist in NSW, VIC and SA); general security (exist mainly in NSW); and low security (mainly only in VIC). Water allocations, which are water yielded by water entitlements, can be extracted and used. Commonly, water trading occurs in

regulated surface-water systems (MDBA 2015d; NWM 2015). Trading water has become very commonplace in the MDB: Wheeler et al. (2014b) found that at least 55% of all irrigators have traded water allocations and 25% have traded water entitlements since official water trade began in the southern MDB in the 1980s.

#### 5.2.3 Salinity in the southern Murray-Darling Basin

Historically, salt naturally occurred and accumulated in Australia's environment, e.g. in the groundwater, due to the combined effect of a typically flat terrain, low rainfall and high evaporation. Groundwater salinity is highly variable across the MDB depending on the local hydrology (MDBMC 1999). Naturally, higher groundwater salinity levels are found in the downstream river region, such as the SA Murray River (Heaney & Beare 2001). Since European settlement, land-use changes comprising of clearing native vegetation (primarily deep rooted forests) and introducing irrigated agriculture (including shallow rooted plants) started the process of secondary salinization. Initially, deep rooted natural vegetation helped to keep salt-enriched saline water below the root-zone while transpiring the pure water. Following the removal of native vegetation and the introduction of irrigation, shallow aquifers began to rise and salt was lifted to the surface, creating increased surface-water salinity after discharges and dryland salinity after evaporation. The natural flushing process of the salt was impaired by regulating rivers with dams and weirs and by increased consumptive use (MDBMC 1999).

To combat problems arising with high salinity levels, several national and state-level policies and programs have been employed since the 1980s. For example, the Basin Salinity Management Strategy (BSMS) was implemented resulting in water trade limits by identifying low to high salinity impact zones and/or preferred development zones across the three states and restricting trade via higher development or salinity credit costs. In VIC trade into high impact zones was associated with a salinity impact payment and trade out of high impact zones was associated with a bonus payment by the government. Later VIC moved away from water trading limits into salinity impact zones to limiting water usage by attaching 'annual use limits' to each water entitlement depending on the crops grown. A similar system was introduced in SA, and in both states a market for annual use limits was made available. Other approaches to minimise the salinity impact include: additional water capital charges in salinity risk zones; various salt interception schemes; various salinity offset methods; and land-use conditions (NWC 2012). From 2008, national policies shifted investment priorities to other environmental problems. In some regions, until 2008, dryland salinity decreased which was largely accredited to below-average rainfall and the subsequent decreased saline water tables (Pannell & Roberts 2010). Thus, dryland salinity was found to be a cyclic problem

conditional on climatic factors, e.g. the level of the water table changes with wet/dry years (MDBA 2013c). Widespread drought in southern Australia caused groundwater levels to fall; hence, reducing salt mobilisation to soils and rivers. But at the same time the reduced river flows caused local increases in river salinity in many regions in the MDB, such as the Lower Lakes and the Coorong (Pannell & Roberts 2010; SoE Committee 2011).

#### **5.3 Literature Review**

#### 5.3.1 The relationship between irrigated agriculture and salinity

In addition to an increased interest in the impact of climatic changes on global water resources, a range of international studies have investigated the salinity impact of climatic changes. Salinity is considered to exacerbate the water availability problem, as water application rates may be increased for salt leaching purposes (Connor et al. 2008). In general, studies forecast future increases in salinity levels (e.g. Hopmans & Maurer 2008). Yeo (1998) found a negative yield effect in arid and semi-arid regions in response to climate change effects, such as salinity. Economic models generally predict significant decreases in returns of irrigated agriculture due to reduced future water supply and related consequences, such as lower water quality (e.g. Hurd et al. 2004; Xu et al. 2014). Hopmans and Maurer (2008) suggest that adoption of more water efficient technology may partially mitigate salinity increases; while Yeo (1998) suggests that the negative yield effect cannot be overcome by expected water use efficiency increases. Schwabe et al. (2006) identified reuse as an efficent strategy to combat salinity and drainage problems in the San Joaquin Valley, USA. Furthermore, the study showed that efficient techniques for landholders (e.g. land uses, irrigation efficiencies, water application rates) depend on the shadow value of drainage and land.

More specifically, a recent study by Schwabe and Knapp (2015) found a decreasing demand for groundwater as groundwater salinity levels increase. Furthermore, they concluded that efficient groundwater management decreases goundwater usage, and thus, the salt level of groundwater. A drier climate leads to intial increases in groundwater uses with a decreasing rate in the long-term due to increased salinity levels and pumping costs of lower water tables.

A few Australian studies have investigated the adaptation of irrigated agriculture to water quality changes, such as higher salinity levels. For example, Connor et al. (2012) modelled the combined effect of a more saline, reduced and variable water supply on irrigation adaptation and agricultural food production in the southern MDB. They found that a higher water application rate is potentially an economically optimal adaptation strategy to increased

salinity levels, by leaching salt through the soil and thereby minimising yield shortfalls. However, if water prices prevent a landholder from buying additional water, higher water application rates result in a reduction of the area under irrigation. The study further concluded that changes to agricultural production would vary spatially. Similarly, Bjornlund (1995) found that irrigators responded differently to high salinity levels depending on their location and crops grown. Horticultural farmers, who are located close to fresh surface-water and grow highly salt-sensitive crops, reacted first by recharging (i.e. increasing water flow to the groundwater system). Conversely, the response of lucerne farmers, located further away from fresh surface-water, to higher salinity was delayed. In the beginning, they introduced new irrigation technology along with water efficient and salt-resistant crops. However, over time as salinity increased further they also began to recharge despite increased water piping costs. Furthermore, Barr (1999) found mixed responses from irrigators that irrigated saline soils between 1989/90 and 1994/95 in northern VIC. Irrigators were found to follow strategies consisting of: i) continuing irrigation on saline land (one third of all irrigators); ii) ceasing irrigation and investment on saline land (one third); and iii) ceasing irrigation but improving the quality of the land (fencing and 'establishment of halophytes') (one third).

### 5.3.2 Water markets and salinity levels

Several studies identify water trading as a feasible strategy to adapt to a drier climate with decreased water availabilty and water quality. Traditionally, water markets were regarded as a tool to efficiently allocate an increasingly scare water resource (e.g. Gardner & Fullerton 1968; Randall 1981). More recent studies suggest water markets can additionally alleviate water quality deterioration (e.g. Colby 1990; Dinar & Letey 1991). However, overall the effects of water trading on soil and water salinity are not fully understood (e.g. Khan et al. 2009) and study results are inconsistent, as the impact on return flows varies spatially depending on agronomic and hydrological factors (e.g. Gordon et al. 2005; Heaney et al. 2006).

On the one hand, it is possible that water trading can cause negative externalities, such as increased salinity levels, in areas where water is traded out. Khan et al. (2009) concluded minimum irrigation intensities are necessary in highly saline areas with low water tables for salt flushing purposes. This needs to be taken into consideration, when water markets cause large water entitlements to move out of highly saline zones and irrigation practices stop. Bjornlund (1999) suggested that the impact on surface-water salinity of early water trading, moving water from downstream to upstream areas in SA between 1987 and 1996, may have been an increase in the salinity level (0.6 EC) at Morgan (SA). Beare and Heaney (2002) also found a negative externality, i.e. water trade can cause lower reductions in salinity, compared

to a no water trade scenario, in areas where water trade provides for continued irrigation. If irrigation remains on the same level in higher value horticultural regions, highly saline groundwater continues to be discharged resulting in higher salt loads in the study's simulation model. Similarly, it was found that many irrigators turned to groundwater substitution (where there were suitable groundwater substitutes available) after selling surface-water entitlements to the government (Wheeler & Cheesman 2013; Wheeler et al. 2016). Increased groundwater use can lead to increased salinity problems if saline groundwater flows into rivers due to discharge.

On the other hand, a number of studies found that water markets can help decrease salinity levels when water is traded away from high impact areas (e.g. Lee et al. 2012). Using a biophysical and economic model, Weinberg et al. (1993) found that introducing water trading can decrease overall water use and associated deep drainage. Reviewing the evidence for Australia, NWC (2012) concluded that the impacts of increased water trade on salinity appeared to be inconsequential. They found that if water is traded to an identified low salinity impact area, water trading can have a positive effect on salinity levels (suggesting policy programs should focus on those trades). In another case, where water is being traded between areas of similar hydrological and agronomic characteristics, there may not be deterioration in water quality and policy intervention would not be needed. This supports Heaney et al. (2006) who suggested that the effects of water trading on salinity levels vary with the source and destination of the water that is being traded. In the southern MDB, water trade has resulted in larger movements of water to downstream areas which encouraged irrigators upstream, who sold water, to become more water-use efficient (Wheeler et al. 2014b).

#### 5.3.3 Water trading behaviour literature

A range of studies have analysed the determinants of irrigators' water trading decisions. It is important to note the difference between water allocation and water entitlement trading. In general, water allocation trading is associated with short-term considerations in seasonal fluctuations in prices or climate changes (to provide for risk and uncertainty adjustments within and between seasons) and personal characteristics (e.g. Loch et al. 2012; Wheeler et al. 2010b); while water entitlement trading is more likely to be based on long-term considerations that are largely based on farm characteristics (e.g. investment in farm technology, farm productivity) (e.g. Bjornlund 2006a; Isé & Sunding 1998; Wheeler et al. 2010b; Wheeler et al. 2012b).

Thus, it is hypothesised that water entitlement trading is more responsive to salinity than water allocating trading, and consequently this paper focuses mainly on water entitlement trading.

Bjornlund and McKay (1995, 1996) and Alankarage et al. (2002) are at present the sole studies investigating the relationship between regional salinity levels and water trading, and do so by using simple descriptive statistics on cross-sectional survey datasets. Bjornlund and McKay (1995) found that water entitlements in VIC are traded out of regions affected by high salinity levels into high value producing areas, such as dairy production, with lower salinity levels (n=337). Bjornlund and McKay (1996) found that early water trading in SA moved water from the lakes area at the mouth of the river upstream into the horticultural areas with negative impact on surface-water salinity. Alankarage et al. (2002) suggested that water entitlement buyers in the Goulburn area in northern VIC have greater access to groundwater and are more likely to have built their farm on less saline land (n=200). Conversely, water allocation trading did not seem to be significantly affected by soil salinity and the level of groundwater despite the severity of the groundwater level for various farms.

This study extends the literature by empirically testing the relationship between water trading and three types of salinity, over time and across three states.

## **5.3.4 Salinity and Trade Hypotheses**

Given previous findings, the hypotheses that are put forward in this study are:<sup>67</sup>

*H1:* An increase in a region's dryland salinity is associated with an increase in the volume of surface-water entitlements sold from that region (given the area's lack of comparative advantage to produce higher value crops);

*H2:* An increase in a region's groundwater salinity (i.e. concentration of salinity in mg/l) is associated with a decrease in the volume of surface-water entitlements sold from that region (given groundwater's lack of eligibility as a viable substitute for surface-water use); and

*H3:* An increase in a region's surface-water salinity is associated with an increase in the volume of surface-water entitlements sold from that region (given surface-water's lack of eligibility as a water source for higher value crops).

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<sup>&</sup>lt;sup>67</sup> These hypotheses are sub-hypotheses of H1 from Chapter 3. Because this is a published article H1 - H3 were the original numbers.

#### 5.4 Methodology

#### 5.4.1 Data and spatial data manipulation

Two sources of water market data were used. Firstly, individual records of water allocation and water entitlement trade were collected from Waterfind (Australia's largest privately owned water broker) from 2003/04 to 2013/14. Intentional (bid and offer) and actual (sale and purchase) water trade data were summarised per postcode area for the southern MDB. The boundaries of postcode areas in Australia were sourced from the Australian Bureau of Statistics (ABS) in a spatial format (ABS 2011b) and the mean postcode area size in the study area is 1,665km². Although one downside of using water market broker data for the analysis is that it does not cover the entire region's water trade figures, it is the only source of water market data available that allows a postcode area to be identified for the water source. Because the water market broker data does not provide information on the total water sold out of each region, we used the data to observe water sales/purchases and regional salinity spatially and used a second source for water trading information for the economic analysis.

Secondly, water entitlement trade and supplementary data were sourced from MDBA's Water Audit Monitoring (WAM) reports for 2000/01–2010/11 (e.g. MDBA 2012e). The WAM reports present various information on water entitlements issued by region, water trade, groundwater use and diversion limits by regions. The latest year available was 2010/11. Collected data from the WAM reports are based on MDB's local surface-water sustainable diversion limit (SDL) resource units.<sup>68</sup> The SDL units were defined by the MDB Plan (for more comment and detail see MDBA (2011c)) for each water resource plan area. Figure 5.1 shows the study area and the 17 SDL regions, that the subsequent analysis is based on.

Data on dryland, groundwater and surface-water salinity were collected from different sources and for various years (Table 5.1). In 2001, the National Land and Water Resources Audit (NLWRA) produced spatial maps presenting the distribution of areas assessed as having either a high dryland salinity risk or a high dryland salinity hazard.<sup>69</sup> It is important to consider that subsequent local studies on dryland salinity suggested the NLWRA audit overestimated dryland salinity in Australia. The studies expressed doubt as to the suitability of the data and methods used in the NLWRA audit, as the data were highly variable across the

compromise key environmental assets and outcomes of the water resource (MDBA 2011c).

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<sup>&</sup>lt;sup>68</sup> An SDL resource unit refers to a geographical area defined by the MDB Plan, largely based on catchments and containing a set of surface-water resources. The objective of identifying SDL units was to define the maximum long-term annual average quantity of water allowed to be taken for consumptive uses from (parts of) the water resources of each water resource plan area, thus limiting the take of water. For each area a SDL was based on an environmentally sustainable level of take that describes the maximum level of water that can be taken as to not

<sup>&</sup>lt;sup>69</sup> Dryland salinity hazard mapping is based on the assessment of biophysical characteristics and dryland salinity risk mapping additionally assesses socio-economic characteristics (Csaky & Please 2003).

states and the assessment was mainly based on groundwater table depth (e.g. Csaky & Please 2003; Pannell & Ewing 2006). However, the NLWRA dryland salinity maps have not been replaced by more advanced estimates thus far and, hence, provide the sole source for dryland salinity analysis across several states in Australia. Therefore, the NLWRA dryland salinity maps are used in this paper (but only based on the 2001 data, no salinity projection data are used) as a proxy for dryland salinity risk and hazard and a likely overestimation is taken into account. The spatial dataset of groundwater salinity is a composite data layer using information on groundwater salinity from various sources (e.g. MDBA, state governments) and various years (1994–2009) (BoM 2014). Surface-water salinity data was collected from annual implementation reports regarding the Basin Salinity Management Strategy by the MDBA per farming year from 2007/08 onwards (e.g. MDBA 2014a). Table 5.1 also lists additional data that was collected for the subsequent panel regression model, such as prices, allocation and land uses, to accurately model water entitlement selling decision (their choice was suggested by the general water trading behaviour literature presented in Section 5.3 (e.g. Wheeler et al. 2012b)).

Water trading and salinity data were analysed and mapped using a Geographic Information System (GIS) (ArcMap 10.2). First, water trading information per postcode area was matched with the spatial postcode area dataset from ABS. Postcode areas were selected that have their centroid points located within the southern MDB (n=383). The water trading dataset per postcode area was used to spatially compare the occurrence of salinity and net water trading activity (maps are shown in Section 5.5). Further, for the subsequent data analysis and modelling, using ArcMap's geoprocessing tools, the percentage of dryland salinity affected areas per total agricultural area and the mean level of groundwater salinity per river valley (SDL unit) were calculated as well as the average yearly surface-water salinity level per salinity gauging station matched with the closest SDL resource area.

Table 5.1: Overview data sources and timeframes

Data	Source	Year or period
<ul> <li>Water trading data by postcode areas</li> <li>Bid and offer data (water market bids, not actual sales)</li> <li>Purchase and sale data (actual purchases and sales in the market)</li> </ul>	Waterfind (private access through broker)	2003/04–2013/14
Water entitlement sales data by SDL area	MDBA (WAM reports, e.g. MDBA (2012e))	2000/01–2010/11
Boundaries of the SDL resource areas	MDBA (2013a)	2013
Boundaries of postcode areas	ABS (2011b)	2011
Dryland salinity (area)	NLWRA (2001)	2001
Groundwater salinity (mg/l)	BoM (2014)	1994–2009 (composite dataset)
Surface-water salinity (EC) per SDL area	MDBA (e.g. MDBA 2014a)	2007/08–2012/13
Total volume of entitlements (ML) owned per SDL area	MDBA (WAM reports, e.g. MDBA (2012e))	2000/01–2010/11
Water entitlement prices (\$/ML) per SDL area	Kaczan et al. (2011); NWC (2011e, 2013b)	2000/01–2010/11; some price data before 2007/08 are not available, in this case price data were calculated relative to the price changes in Goulburn (for VIC valleys) and Murrumbidgee (for NSW valleys)
Percentage of allocation per SDL area	MDBA (WAM reports, e.g. MDBA (2012e))	2000/01–2010/11
Groundwater use (ML) per SDL area	MDBA (WAM reports, e.g. MDBA (2012e))	2000/01–2010/11
Groundwater allocation (ML) per SDL area	MDBA (WAM reports, e.g. MDBA (2012e))	2000/01–2010/11
Percentage of dairy production	ABARES (2012)	VIC: 2009, SA: 2008, NSW: 1999-2004 (composite dataset)
Percentage of land in transition (degraded,	ABARES (2012)	VIC: 2009, SA: 2008, NSW:
abandoned land or under rehabilitation)		1999-2004 (composite dataset)
Rainfall-evapotranspiration (mean mm/day)	Raupach et al. (2009, 2012)	2000/01–2010/11

<u>Note</u>: Some data were not available for the entire panel model period (2000/01 - 2010/11). In this case, surfacewater salinity and water entitlement price data were averaged for missing data. However, groundwater salinity, dryland salinity and land use data were only available for one year or as a composite dataset.

#### 5.4.2 Data analysis methods and variable description

Two forms of data analysis were used to highlight the associations between water trade information and the three types of salinity. Firstly, average net water entitlement trade in/out of each river valley (SDL unit) was calculated over the past decade (2000/01–2010/11). Differences in net water entitlement trade were statistically tested across the three levels of salinity measures using a one-way ANOVA F-test for the equality of means and a Bonferroni multiple comparison test for any pairwise differences across the three levels of salinity measures.

Secondly, a random-effects panel model of water entitlements sold per river valley between 2000/01 and 2010/11 was employed, to analyse the relationship between water entitlement selling and salinity influences over time and to control for various additional influences. The random-effects panel model estimated was (Greene 2003, pp. 200-203):

$$y_{it} = x'_{it}\beta + \alpha + u_i + \varepsilon_{it} \tag{1}$$

assuming strict exogeneity:

$$E[\varepsilon_{it}|X] = E[u_i|X] = 0; \ E[\varepsilon_{it}^2|X] = \sigma_{\varepsilon}^2; \ E[u_i^2|X] = \sigma_u^2; \ E[\varepsilon_{it}u_j|X] = 0, \forall i, t, j;$$

$$E[\varepsilon_{it}\varepsilon_{js}|X] = 0, \text{ if } t \neq s \text{ or } i \neq j; \ E[u_iu_j|X] = 0, \text{ if } i \neq j$$

$$(2)$$

for MDB region i=1,...,N with observations at yearly time periods t=1,...,T and where  $(y_{it})$  is the dependent variable of water entitlement sold in ML by region,  $(x'_{it})$  is a K-dimensional row vector of independent variables (explained in Table 2),  $(\beta)$  is a K-dimensional column vector of slope parameters,  $(\alpha)$  is the intercept,  $(u_i)$  is the fixed individual-specific effect and  $(\varepsilon_{it})$  is the error term.

Since dryland and groundwater salinity data are time invariant, a fixed-effects model will not work, hence, the reason a random-effects model was employed. Potential endogeneity problems (such as, the relationship between current water prices and total water trade in a valley) were addressed by including water entitlement prices from the previous year per river valley and farming year. Environmental salinity measures were representative for the year in question, or where information was not currently available, we used the next previous year's information instead. We also tested groundwater use for endogeneity (using groundwater allocation as an instrument):<sup>70</sup> Firstly, we tested the endogeneity of groundwater use and weak instrument in the fixed effects model excluding time invariant variables (using instrumental variable panel regression and the post-model test 'weakiv' in STATA), because the test cannot be implemented after a random effects model. Results suggest that variables are consistent with the random effects model and groundwater allocation is not a weak instrument. Secondly, we ran a Davidson-MacKinnon test of exogeneity to test the endogeneity of groundwater use. The p-value is 0.31 which indicates groundwater use is not endogenous to surface-water entitlement sales and instrumental variable regression is not required. Thus, groundwater use can be treated as exogenous in the presented random-effects

<sup>&</sup>lt;sup>70</sup> We use groundwater allocation as a proxy for groundwater entitlements (on issue) per region, as groundwater allocation is generally 100%.

model. Table 5.2 summarises and explains all variables in detail. Table C.1 summarises the descriptive statistics for the variables used in the following regression model.

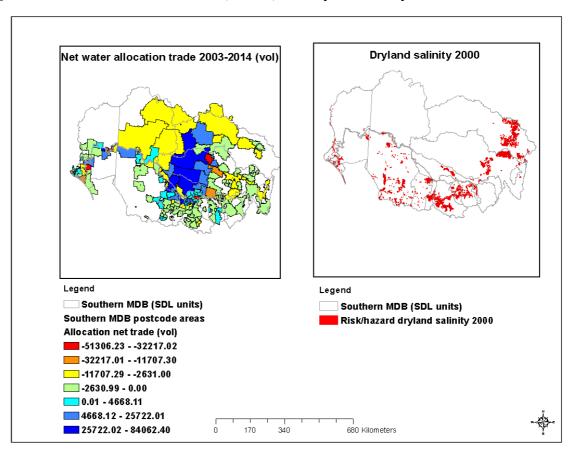
**Table 5.2: Variable definitions** 

Variable name	Details					
Dependent variable:						
Water entitlements sold	Sum of the volumetric entitlements (ML) sold per river valley in natural logarithm					
Independent variables:						
Water entitlement owned	Sum of the volumetric entitlements (ML) in the valley in natural logarithm (in NSW this is the sum of general and high security entitlements; includes unregulated stream entitlements where these are expressed volumetrically (e.g. in VIC)).					
Allocation percent	Largest announced percentage of water allocation in the season per valley					
Water entitlement price	Approximate prices of high security water entitlements (\$/ML) of the previous year in natural logarithm, averaged over the water season					
Groundwater use	Volume groundwater used (ML) in the valley in natural logarithm					
Dryland salinity (dummy)	1 = Percentage of dryland salinity risk/hazard area per total agricultural area in the valley is greater than 4%; $0 =$ otherwise					
Groundwater salinity (dummy)	1 = Percentage of the valley with saline groundwater (>3000 mg/l) is greater than 70%; 0 = otherwise					
Surface-water salinity (dummy)	1 = Mean salinity level per valley is greater than 325 EC (using the salinity station that is inside or closest to the valley); 0 = otherwise					
Dairy	Percentage of land under dairy production					
Land in transition	Percentage of land under dryland or irrigated land in transition (i.e. degraded, abandoned land or under rehabilitation)					
Rainfall-evapotranspiration	Rainfall minus evapotranspiration per valley (mean annual, mm/d)					

#### 5.5 Results and discussion

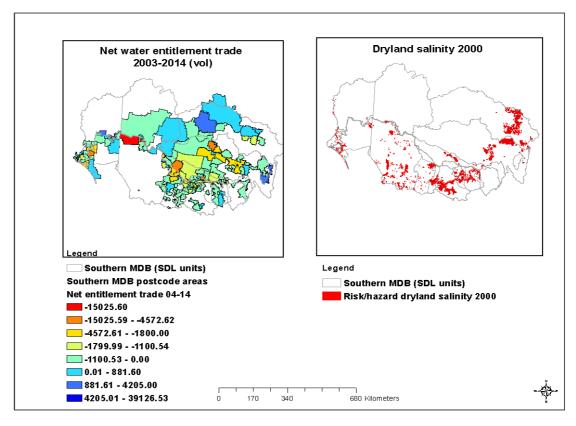
Net water trading activity (i.e. net trade on a postcode basis) in the southern MDB and local salinity characteristics is illustrated in Figures 5.2 – 5.5. Only dryland and groundwater salinity maps are shown as surface-water salinity varies only by region in total. The maps reveal a first indication of the relationship between water trading and salinity levels. Water allocation trading out of a region seems to be associated with high risk/hazard of dryland salinity (Figure 5.2), whereas water entitlement sales do not seem to concentrate around dryland salinity areas (Figure 5.3). Also higher groundwater salinity areas (>3000 mg/L) seem to be associated with water allocation sales, except for the south-eastern part of the southern MDB (Figure 5.4). It is a less clear picture for net water entitlement trade (Figure 5.5).

Figure 5.2: Net water allocation trade (volume) and dryland salinity



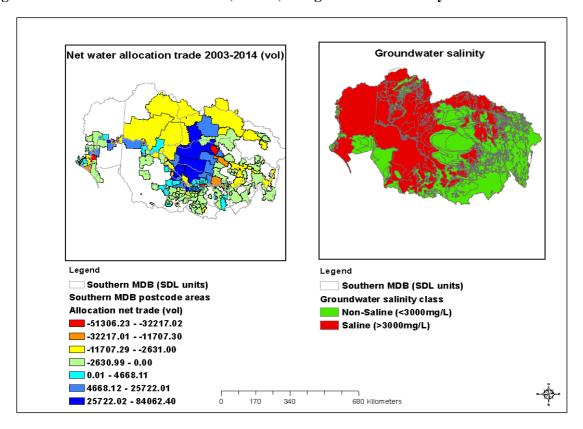
Own figure (base map sources: ABS (2011b), MDBA (2013a) and NLWRA (2001))

Figure 5.3: Net water entitlement trade (volume) and dryland salinity



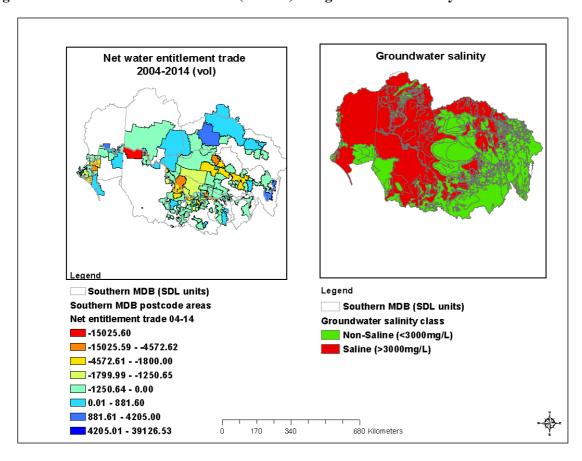
Own figure (base map sources: ABS (2011b), MDBA (2013a) and NLWRA (2001))

Figure 5.4: Net water allocation trade (volume) and groundwater salinity



Own figure (base map sources: ABS (2011b), MDBA (2013a) and NLWRA (2001))

Figure 5.5: Net water entitlement trade (volume) and groundwater salinity



Own figure (base map sources: ABS (2011b), MDBA (2013a) and NLWRA (2001))

Table 5.3 presents the next set of results for percentages of net water entitlement trade for average levels of salinity per river valley using data from the Australian Water Monitoring Reports. The results for the Bonferroni test are not presented but are discussed below and available upon request.

As hypothesised, the results in Table 5.3 suggest that regions with a high percentage of the land area affected by dryland salinity are more likely to sell water entitlements and vice versa for regions with a low percentage of their land affected by dryland salinity (supporting *Hypothesis 1*). The ANOVA F-test produced a significant F-value at the 1% level (i.e. the means are different) and the Bonferroni multiple comparison test showed pairwise significant differences in the means except between medium and high salinity levels.

Also as hypothesised, the higher a region's groundwater salinity level the more surface-water entitlements were bought and the opposite was true for lower groundwater salinity regions (in favour of *Hypothesis 2*); but the ANOVA F-test discovered no significant difference between the means (and no significance was found for any pair-wise comparison).

Water entitlements were more likely to be sold in areas with high surface-water salinity, supporting *Hypothesis 3*. Although the net trade percentage for the low surface-water salinity category is negative, it is not statistically different from that of the medium surface-water salinity category, according to the Bonferroni test. The F-test was significant at 1%, largely due to the difference between high and low, and high and medium surface-water salinity categories.

A panel regression model was subsequently performed to control for additional influences on water selling decisions. Table 5.4 presents the results for the panel regression model of water entitlements sold per river valley between 2000/01–2010/11. The model performed well according to the results of the overall R<sup>2</sup> and the Wald chi squared test. Pairwise correlations suggest that there is no serious multicollinearity and robust standard errors were used to mitigate the effect of heteroscedasticity.

Table 5.3: Average net entitlement trade (%) per high, medium and low average salinity levels per river valley from 2000/01 to 2010/11

Av. Entitlement trade (purchase		2000/	2001/ 02	2002/	2003/ 04	2004/ 05	2005/ 06	2006/ 07	2007/ 08	2008/	2009/ 10	2010/ 11	Ave. 2000/01 to 2010/11	Std. Dev.	Freq.	One-way ANOVA F-test
Dryland	High	0.13	0.00	0.31	0.00	-0.06	-0.02	-0.97	-0.12	-0.14	-2.47	-0.44	-0.34	1.40	33	8.94***
Salinity (% area) n=14	Medium	-0.05	-0.19	-0.12	-0.71	-0.64	-0.63	-1.51	-0.09	-0.23	-0.34	-0.75	-0.48	0.93	44	
valleys	Low	0.04	0.08	-0.01	0.22	0.29	0.21	0.48	0.02	0.08	0.11	0.23	0.16	0.42	76	
Groundwater	High	0.28	0.09	0.01	-0.03	0.30	0.14	0.78	0.00	0.00	0.00	0.00	0.14	0.36	22	1.34
Salinity (mg/L), n=14	Medium	0.00	0.05	-0.18	0.00	0.00	0.00	-1.54	-0.09	-0.15	-0.40	-0.70	-0.27	0.71	22	
valleys	Low	-0.01	-0.05	0.07	-0.12	-0.18	-0.14	-0.41	-0.04	-0.05	-0.75	-0.13	-0.16	1.01	109	
Surface-water Salinity (EC), n=13 valleys	High	0.00	0.05	0.29	0.00	0.00	-0.03	-3.00	-0.17	-0.37	-4.11	-0.70	-0.73	1.76	22	5.54***
	Medium	0.19	0.06	0.01	-0.02	0.20	0.09	0.52	0.00	0.00	0.00	-0.67	0.03	0.40	31	
ii–15 valleys	Low	-0.01	-0.06	-0.03	-0.15	-0.23	-0.16	-0.15	0.00	-0.01	-0.02	0.00	-0.07	0.73	3 89	

Note: \*\*\* p-value < 0.01

Table 5.4: Results of the random-effects regression model of water entitlements sold (ML) per river valley between 2000/01 and 2010/11

Independent variables	Coefficient	Robust SE	p-value
Water entitlements owned	1.912***	0.271	0.000
Allocation percent	0.004	0.012	0.708
Water entitlement price	2.900***	0.893	0.001
Groundwater use	-0.073	0.085	0.390
Dryland salinity	2.350***	0.693	0.001
Groundwater salinity	-4.428***	0.805	0.000
Surface-water salinity	0.991	0.850	0.243
Dairy	-0.107***	0.026	0.000
Land in transition	1.393	2.283	0.542
Rainfall-evapotranspiration	-1.007**	0.417	0.016
Constant	-34.395***	7.744	0.000
Number of observations	126	Wald chi <sup>2</sup> (10)	1498.89
Number of groups	13	Prob > chi <sup>2</sup>	0.000
Rho	0.113	R <sup>2</sup> overall	0.594

*Notes:* \*\* p < 0.05; \*\*\* p < 0.01

As hypothesised and as suggested by Alankarage et al. (2002), the results suggest that regions with a high percentage of land affected by dryland salinity were more likely to sell water entitlements. This result supports *Hypothesis 1*. Also as hypothesised, the higher a region's percentage of saline groundwater (>3000 mg/l), the less surface-water entitlements were sold as groundwater use decreases (note though groundwater use was not significant in the model), supporting *Hypothesis 2* and which was also shown by Schwabe and Knapp (2015). Thus, there appears to be a substitution effect between groundwater and surface-water use, as suggested by Wheeler and Cheesman (2013) and Wheeler et al. (2016). Such evidence of the substitutability of groundwater for surface-water needs further investigation, as it may have significant ramifications in terms of the total amount of water used in the Basin, reflows into the system from connected groundwater and the actual amount that is available for environmental flows in rivers.

There was no significance shown between water entitlement selling and surface-water salinity. This result may reflect the fact that irrigators' responses to salinity vary spatially and can combine differing strategies, as outlined in Section 5.3. However, the sign of the coefficient for surface-water salinity is positive and in the hypothesised direction (*Hypothesis* 3), indicating the higher the surface-water salinity level, the more water entitlements seem to be sold.

The model results additionally confirm relationships between water entitlement selling and water entitlement ownership, water entitlement prices, land use and climate as suggested by previous studies (e.g. Wheeler et al. 2012b). Specifically, a higher volume of water

entitlements are more likely to be sold in regions that own larger amounts of water entitlements and that have higher water entitlement prices. Water entitlements are also more likely to be sold in areas with less percentage under dairy/grazing production, indicating the significance of water entitlements for dairy producers, at least in the period that is studied. This is continuing on from previous findings in Bjornlund and McKay (1995). However, although this may be the case on average for the entire period up to 2010/11, it may not necessarily be true for later years since then, especially since northern VIC has recently seen an exodus of dairy farming due to low milk prices. Unfortunately, data is currently not available to allow us to explore this further and will have to be left to future research. Furthermore, the more rainfall was available in the regions after subtracting evapotranspiration, the lower the volume of water entitlements sold. Hence, farmers in areas suffering greater water scarcity are selling their water entitlements, or conversely, regions that have greater rainfall (and are therefore potentially more productive) are more likely to be buying water entitlements for agricultural production.

This research suggests that environmental factors, such as salinity and rainfall, do seem to play a part in the spatial distribution of traded water. But, dryland and groundwater salinity seem to have a more important influence than surface-water salinity. This link between farm behaviour and salinity indicates the wide-reaching influence that salinity is having on Australian agriculture. On the one hand, it supports the claim that the presence of water markets in Australia provides a very important adaptive tool for farm management. While further advances within markets and greater adoption in Australia is warranted from a policy perspective, it is obvious that further research in farm management strategies to deal with salinity is also needed.

Pannell and Roberts (2010) suggest that the current lack of focus on salinity issues in Australia, as compared to the start of the 2000s, is a reflection of the recognition that salinity was never a 'crisis', as well as the fact there are very few cost-effective ways of dealing with the problem. The 'intractability' of salinity again emphasises the need to enhance farmers' ability to adapt to it (such as through the use of water markets), rather than advocating the adoption of very costly (and at times ineffective) solutions. Suggestions made by Pannell and Roberts (2010) for further salinity program investments include: using technical information to guide investment prioritisation; using socio-economic information and integrating it with other scientific information for prioritisation; selecting appropriate targets; choosing appropriate policy mechanisms; and providing incentives and support to landholders.

This research's analysis is based on a broad and regional perspective. Hence, although it has involved the amalgamation of a large number of environmental, regional and water trade databases, the results provide a first indication of the relationship between water trading and environmental factors, such as salinity. Future research will be needed to undertake more detailed analysis on the impact of environmental (regional) factors on water trading. Such research could involve using large individual farm survey data, coding each farm's spatial location and attaching the wide array of potential spatial influences to farm survey information to obtain a robust result on the influence of salinity factors on water trade. Further work on these relationships will help to identify areas likely to sell/buy water and plan for potential farmer exit.

#### **5.6 Conclusion**

The triple threat of salinity for irrigators in the MDB has meant that irrigators have adapted their farm management in as many ways as possible to deal with these environmental issues. Because of this and the growing reality of water scarcity for irrigators, water trading has now developed to where it is a common adaptation tool used by the majority of irrigators. This study sought to detect any particular association that may exist with water trading and salinity threats in the MDB. Results indicated that water entitlement trading has been used to deal with long-term productive issues, such as dryland salinity. Areas in the MDB that suffered from higher dryland salinity sold larger volumes of water entitlements. This suggests that regions suffering from higher dryland salinity levels are more likely to be selling their water entitlements, as the comparative return on their land is lower, compared to other regions. On the other hand, increases in groundwater salinity was found to be negatively associated with regions selling larger volumes of water entitlements, providing some evidence of the substitutability of groundwater for surface-water. There was a lack of evidence for surfacewater salinity, though there is some very weak evidence that areas with high surface-water salinity have sold more water entitlements. Future research needs to be done to understand the inter-relationships between the three types of salinity, and to provide a more detailed understanding of the impact of salinity and spatial characteristics on farm water market trade.

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# Chapter 6 Identifying spatial drivers of water entitlement and allocation trading in the southern Murray-Darling Basin

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Contribution to the Paper	Undertook the literature review. Collected the spatial data. Prepared data for analysis and performed data analysis. 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		
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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
- the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Contribution to the Paper	Supplied water trading data from a water broker, helped with data analysis and the editing of the manuscript.
Signature	Date 2(1/1/16

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

# **6.1 Introduction**

Following on from Chapter 5, which focused on the impact of salinity issues on water trading at the regional (river valley) level, this chapter provides a more detailed analysis of spatial influences (including salinity factors) on water trading in the southern MDB, at a smaller regional (postcode area) level. Modelling at a postcode level allows for a more detailed understanding of spatial influences on water trading. Furthermore, the analysis in this chapter extends the modelling framework to all water market transactions, i.e. water entitlement selling and buying as well as water allocation selling and buying, and observes water trading behaviour for the more recent years; 2010/11–2013/14. The water trading behaviour literature (Chapter 3) suggested that environmental/spatial factors are more likely to affect water entitlement trading than water allocation trading, due to the long-term characteristics of water entitlements, and this chapter seeks to test these findings.

The previous chapters have highlighted the severity of global and national water scarcity problems and the relevance of understanding farmers' decision-making; given agriculture is the largest water user. Long-term low water availability, environmental problems and predicted increased rainfall variability have prompted re-thinking in water management and water policies. Spatial analysis and spatial modelling can inform agent-based modelling and resource flow management (Pahl-Wostl 2002). This chapter focuses upon the role of spatial analysis in informing farmers' decision-making research and water trading behaviour in particular.

Thus, this chapter first explores the literature in spatial economic research on farmers' decision-making, complementing Chapters 3 and 4. The aim is to shed light on the significance of spatial determinants on farmers' decision-making and to filter out potential spatial influences on farmers' water trading decision-making, which culminates in this chapter's hypotheses. The review also includes a reflection on the advantages and disadvantages of spatial analysis at different spatial scales.

Adding a spatial perspective to traditional economic research opens up the opportunity to conceptualise spatial relationships. For example, spatial analysis can contribute to the understanding of distributional effects of policies or, more specifically, the cost savings of targeted policy action (e.g. Bell & Dalton 2007; Newburn et al. 2005). New insights into water trading patterns are intended to inform future water and environmental management policies in Australia and other countries. Policy implications may comprise a spatial targeting approach, similar to suggestions provided by Crossman et al. (2010a), detailing a land use

reconfiguration policy approach using spatial planning to optimise local environmental and socio-economic outcomes.

This chapter uses and combines unique datasets of regional water trade data (from a private water broker) including a range of spatial data containing regional biophysical and socioeconomic information. In particular, this chapter seeks to answer the following key research questions: are irrigators located within areas that suffer greater resource scarcity and deterioration (regarding soil and water), greater regional decline (e.g. regarding population decline) and longer distances to markets, infrastructure and other services more likely to sell higher volumes of water entitlements? Is irrigators' water allocation trading behaviour equally impacted by aforementioned spatial characteristics?

# 6.2 The importance of location in farmers' decision-making

# 6.2.1 Application areas, spatial determinants and methods

Datasets in agriculture typically have a spatial pattern in relation to the landscape that is studied. Agricultural economists assess a wide variety of research problems using a spatial perspective (Bell & Dalton 2007; Swinton 2002). As Ilbery (1978, p. 453) had pointed out: "Since the decision-making process in agriculture has a spatial dimension, many of the factors affecting decision behaviour may be expected to differ spatially."

There is some debate about the spectrum of spatial analysis, with regards to spatial methods (e.g. concepts of distance) and scales (e.g. individual<sup>71</sup>/micro- or regional/macro-scale) (Logan 2016). The literature review in this chapter selected seminal and empirical studies, if these studies adopted a spatial modelling approach, or used spatially explicit variables in a standard econometric model, with regards to an agricultural decision at various spatial scales (farm, regional or national level). A common aim amongst these reviewed studies is to resolve and account for spatial dependency issues in the datasets and interpret spatial influences for suitable public policy implications. The literature reviewed is summarised chronologically in Table D.1. This summary does not represent a complete list of studies in this field, but rather

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<sup>&</sup>lt;sup>71</sup> Traditionally, studies were characterised as 'spatial' when the analysis was based on ecological units, such as cities, counties or other administrative boundaries (Voss 2007). But over time it became more acceptable to extend the understanding of 'spatial' to the individual level. Counties or cities as well as people have place attributes and questions of location are equally 'spatial' regardless of the unit of study (Entwisle 2007; Logan 2016). It is however common that people are assigned to higher spatial scales (where it is then assumed that people live at the centroid of the area), such as counties, as it can be rare to receive accurate locational information at the individual level (Logan 2016).

aims to provide an overview of the different application areas, types of models/methods used and spatial determinants assessed at various spatial scales.

Table D.1 shows that a growing body of literature linking spatial and economic analysis has been evolving rapidly, and has highlighted the importance of place and space for farmers' decision-making. According to Bell and Dalton (2007), application areas of spatial analysis in agricultural economics can be divided into three major categories: 1) land use, 2) agricultural land value<sup>72</sup> and 3) technology adoption. Furthermore, this review shows that application areas for spatial analysis can be quite diverse, such as covering other adoption studies or investigating the willingness to participate in policy programs. Some farm decisions, such as market participation, have received less attention in the spatial literature. Overall, most studies concern a land use analysis, which typically provides a classic example for analysing spatial dependence because land uses are often affected by neighbouring land uses or by the same unobserved variables. Neighbouring land uses may generate spatial externalities in the form of increased information spill-overs, technology adoption and labour market pooling (e.g. Li et al. 2013). Thus, land use studies often investigate a potential neighbourhood effect.<sup>73</sup> where land use conversion may depend upon the neighbouring landowners' land use decision (e.g. Holloway et al. 2002; Li et al. 2013). This can be a challenging analysis, as there are various external influences on land developments, such as infrastructure, natural environment, or socio-demographic changes (Irwin & Bockstael 2002).

Besides examining neighbourhood (spill-over) effects, commonly assessed spatial determinants involve land and soil quality information (e.g. slope, soil texture), climate data (e.g. rainfall, degree days), population growth/density, distance to roads/markets, or percentage of urban centres/rural areas. Land quality was found to have a negative effect on agricultural land value (Patton & McErlean 2003) and several studies found no significant relationship between land quality and, for example, land use or farm production costs/farm income (e.g. Li et al. 2013; Wu et al. 2011).

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<sup>&</sup>lt;sup>72</sup> Agricultural land values are indirectly related to farmers' decision-making.

<sup>&</sup>lt;sup>73</sup> As briefly introduced in Chapter 3, the term 'neighbourhood effect' is typically used to describe the influence of neighbouring farmers' decision-making on a particular farmer (e.g. Läpple & Kelley 2014), or in other words the spatial externality of the dependent variable (e.g. discrete choices are correlated) (e.g. Holloway & Lapar 2007). It is sometimes referred to as spill-over effect, or in spatial regression as the spatial auto-regression parameter. The neighbourhood effect may be a result of the interaction and communication between farmers in a neighbourhood. Chapter 7 deals with the neighbourhood effect in more detail.

Population growth/density<sup>74</sup> also can produce varying outcomes depending on the study area and research question. For example, population growth/density can be positively associated with farmland abandonment (Gellrich et al. 2007), farm land value (Benirschka & Binkley 1994; Dall'erba & Domínguez 2016; Huang et al. 2006; Mukherjee & Schwabe 2015), farm production costs and net farm income (Wu et al. 2011), and negatively associated with organic farming (Gabriel et al. 2009) or have no significant effect, e.g. for land uses (e.g. Isik 2004). Population growth is related to several positive and negative externalities for agriculture. Increased population (i.e. in some cases urbanisation) is likely to increase offfarm work opportunities and the cultivation of high value crops (due to a new customer base), which in turn may lead to either a farm exit or an increased farm income (Gellrich et al. 2007; Wu et al. 2011). Moreover, population growth may result in increased input costs (due to less agricultural activity in the area in favour of off-farm jobs) and labour costs (due to increased competition for labour) (e.g. Wu et al. 2011). Thus, the effect of population (growth) varies with local institutional and other factors. For example, Roe et al. (2002) found that the relationship between population size and hog production varies across US counties, which may depend on local land availabilities, property taxes and environmental regulations.<sup>75</sup>

Similarly, distance to markets/roads significantly affected various land use decisions (e.g. Chomitz & Gray 1996; Li et al. 2013; Nelson & Hellerstein 1997). For example, rural/agricultural growth was associated with closer distances to cities/roads (e.g. Cho & Newman 2005; Chomitz & Gray 1996) and organic farming was more likely with greater distances from towns (Gabriel et al. 2009). Also, higher agricultural land prices were found in proximity to urban areas (Huang et al. 2006; Mukherjee & Schwabe 2015; Patton & McErlean 2003) and roads (Polyakov et al. 2014). The latter study further found varying effects with farm sizes. Benirschka and Binkley (1994) showed that variation in land prices was higher as the distance to market increased. There was further an increased likelihood of participation in a land development rights purchase program with increasing distances from cities (Lynch & Lovell 2003). Conversely, other studies found no significant relationship (e.g. Holloway et al. 2002; Läpple & Kelley 2014).

<sup>&</sup>lt;sup>74</sup> Variables on population may refer to agglomeration economies that are associated with declining costs due to greater availability of resources and knowledge if farmers or particular practices and technologies are increasingly clustered. The theory of agglomeration economies originated in urban research, where the effects of concentrating firms and industries in one location were studied (e.g. Porter 1996).

<sup>&</sup>lt;sup>75</sup> One examiner suggested to relate this literature to water trading to build a conceptual framework. For example, in the case of water entitlement sales followed by farm exits, total agricultural production may decrease. As a consequence demand for agricultural inputs (e.g. fertiliser, seeds) may decrease which may lead to local input suppliers closing down. Similarly, local processors may be closing and farmers may face lower output prices or additional transport costs for their output. Hence, what is happening at the regional level affects individual farmers' decisions.

Reviewed studies employed various spatial methods, subject to the structure of the data and computational possibilities. Methods ranged from the classic spatial regression models, using different estimation procedures (e.g. Bayesian) (e.g. Holloway et al. 2002), to the spatial Durbin model (e.g. Läpple & Kelley 2014) and to applying spatial sampling techniques (e.g. Nelson & Hellerstein 1997), or including spatial proxy variables to standard econometric models (e.g. Lapar & Pandey 1999; Wu et al. 2011). Spatial econometrics is a dynamic, continuously advancing field and is increasingly incorporated in (agricultural) economic research (e.g. Arbia 2016). The difficulty and complexity, yet necessity, of modelling spatial relationships in economic research is increasingly recognised, in order to avoid biased and inefficient results that may cause misleading inferences (e.g. Corrado & Fingleton 2012; Holloway et al. 2002).

Conversely, some studies discussed the relevance and applicability of spatial econometrics in the context of (spatial) economic theories (Gibbons & Overman 2012; Martin 1999), and specifically regarding the definition of the spatial weight matrix (*W*), which forms the basis for spatial econometric analysis (e.g. Corrado & Fingleton 2012; Halleck Vega & Elhorst 2015; Pinkse & Slade 2010). "Modelling spatial interaction in the economic context means in many cases modelling externalities and spill-overs. These are elusive and difficult to pin down, which is probably why we have considerable difficulties in defining the structure of *W* unambiguously." (Corrado & Fingleton 2012, p. 236). Several studies highlighted identification problems in spatial econometrics, specifically regarding different spatial models and different specifications of the spatial weight matrix (Gibbons & Overman 2012; Halleck Vega & Elhorst 2015; McMillen 2012). Furthermore, some of these studies found little argument for employing spatial econometric techniques, when non-spatial models resulted in only a relatively small bias on estimated coefficients (e.g. Patton & McErlean 2003; Robertson et al. 2009). The applicability of spatial econometrics is, thus, highly case specific.

#### **6.2.2** The importance of scale

Many processes in agricultural economics take place at different spatial scales, which has long been recognised:

"At the micro-scale [..], ideas and innovations may spread through a social communication network linking individuals to one another. But considered at the regional level, a different network of communication may come into play [..], probably closely aligned to the pattern of linkages between central places. Finally [..] at the national or even international level, macro-flows of information, warped and shaped by great metropolitan fields, diplomatic relationship sand ties, political consideration

and so on, guide the course and intensity of diffusion processes." (Gould 1969, pp. 33-34)<sup>76</sup>

Multi-scale analysis explains the different processes that take place at different scales and may produce varying modelling outcomes depending on the scale. For example, Hein et al. (2006) found differences in ecosystem services valuation at different stakeholders' spatial scales, and Ilbery and Maye (2011) showed a regional aggregation effect of organic farming but no significant neighbourhood effect at the local scale.

Exploring data at different spatial scales can lead to several advantages and disadvantages. A strong advantage of micro-scale analysis is that more detailed/individual data can be examined and observations correspond to the economic decision-making to be analysed, as well as to the underlying spatial processes (Antle & Capalbo 2001; Bell & Irwin 2002). Finer scale data more adequately represents localised knowledge and variation, e.g. in climate and soil (Adams et al. 2003). This may result in a clearer picture of determinants with relevance to the individual farmer (Risbey et al. 1999) and a higher variability of effects captured, leading to better insights on spatial pattern (Medellín-Azuara et al. 2010). On the other hand, large micro-level datasets may pose numerical and imputing challenges, especially in the case of large spatial weight matrices (Bell & Irwin 2002).

By contrast, using aggregated data, macro-scale analysis provides an overview of key issues affecting a particular industry and complements micro-scale analysis by providing an understanding of the evolution of aggregate-level patterns and the effect of regional public policies (Chakir & Le Gallo 2013). Regionally aggregated analysis captures average-farm adaptation to policy changes or external shocks (Medellín-Azuara et al. 2010). Macro-scale studies are also useful in revealing strategic and structural adaptation issues which national/regional agricultural institutions and planning agencies need to deal with when setting priorities for long-term adaptation in agriculture. Those stakeholders often focus on larger environmental and economic conditions impacting the agricultural industry as a whole (Risbey et al. 1999). One shortcoming of aggregated data is that the heterogeneity of many factors cannot be appropriately accounted for (e.g. different soil qualities in a region) and, thus, complex interactions between farmers' decisions are not accounted for (e.g. Chakir &

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<sup>&</sup>lt;sup>76</sup> Martin (1999, p. 83) added to this observation: "In reality, economic life is conducted in and across space (local, regional, national and global): it is organised geographically, and this spatial organisation has a crucial bearing on how the economy functions, on the performance of individual firms and on the welfare of individual households. It is not merely a case of recognising that the mechanisms of economic development, growth and welfare operate unevenly across space, but that those mechanisms are themselves spatially differentiated and in part geographically constituted; that is, determined by locally varying, scale-dependent social, cultural and institutional conditions."

Parent 2009; Li et al. 2013). As a result, explanatory variables may be difficult to define, interpret and identify (Storm et al. 2015).

Analogous to defining the spatial weight matrix (as discussed above), defining the spatial scale can introduce similar ambiguity. Often the scale and size of the spatial unit corresponds to the research area, for example, political studies examine countries, environmental research uses river valleys, or urban research is based on cities.<sup>77</sup> The applicability and intensity of boundaries is case specific and studies need to consider different concepts (i.e. sharp edges, extended zones of transition, or continuous surfaces) (Logan 2016). In addition, care needs to be taken when assessing explanatory variables at different spatial scales (e.g. regional data in micro-scale analysis) (Moulton 1990). This is, however, a common case as in practice spatial data collection can be challenging.

In the case of water resources management, over the years, many countries moved from local to more regional (river basin) water management plans across regional or national boundaries, e.g. in Australia (Wheeler 2014) and in the European Union (Pahl-Wostl 2002). Moreover, global climate change initiated the rise in global analysis and perspectives on water resource issues (see Chapter 4) (Pahl-Wostl 2002). Global climate change has also shifted the focus to multi-level analysis, in order to evaluate all dimensions and scales relevant to climate change risks on agriculture (Esteve et al. 2015). In river basin studies it is increasingly recognised that, in addition to farm related aspects, climate change and adaptation risks in one irrigation community depend on "water management within the community, decisions made in neighbouring irrigation areas, and spatial location in the basin." (Esteve et al. 2015, p. 57).

This section has shown the relevance of spatial analysis in empirical agricultural economics research, as well as the complexities and pitfalls associated with spatial analysis. Researchers need to make several decisions and assumptions when analysing data spatially (e.g. concerning the spatial scale, spatial weight matrix and model type). Thus, it is recognised that empirical spatial data analysis can be a highly contested field (Pinkse & Slade 2010).

# **6.3 Hypotheses**

Building on the findings of the studies reviewed in the previous section and in Chapter 3, the following hypotheses on spatial determinants of water entitlement trading will be examined.

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<sup>&</sup>lt;sup>77</sup> Antle et al. (1999, pp. 10-11) concluded that the economically optimal spatial scale for data analysis was an "increasing function of the scale at which the observed data exhibit maximum variability" and the optimal scale for data collection was "decreasing with the unit cost of data collection, and increasing as the per unit value of the outcome increases."

*H1:* Areas affected by poorer resources (specifically related to soil quality, water scarcity and water quality) are associated with increased volumes of surface-water entitlements sold from that area (due to the area's lower capability to produce high profits from irrigated agriculture).

This hypothesis can be split into several sub-hypotheses:

*H1a:* Areas characterised by soils with lower water holding capacity (i.e. sandier soils) are associated with increased volumes of surface-water entitlements sold from that area.

*H1b:* Areas suffering from worsening water scarcity (e.g. low rainfall levels) are associated with increased volumes of surface-water entitlements sold from that area.

The following three sub-hypotheses on salinity were equally tested in Chapter 5:

*HIc:* An increase in a region's dryland salinity is associated with an increase in the volume of surface-water entitlements sold from that region (given the area's lack of comparative advantage to produce higher value crops);

H1d: An increase in a region's groundwater salinity is associated with a decrease in the volume of surface-water entitlements sold from that region (given groundwater's lack of eligibility as a viable substitute for surface-water use); and

*H1e:* An increase in a region's surface-water salinity is associated with an increase in the volume of surface-water entitlements sold from that region (given surface-water's lack of eligibility as a water source for higher value crops).

The literature in Chapter 3 suggests that water entitlement trading is more affected by long-term planning/characteristics than water allocation trading, due to the permanent nature of this water right. Thus, this chapter also explores the following hypothesis:

*H2:* Water allocation trading is less likely to be affected by long-term spatial determinants (e.g. soil quality, access to markets) than water entitlement trading.

From the literature reviewed in Section 6.2, this chapter furthermore derives the following two hypotheses:

*H4:* Areas affected by regional socio-economic decline (specifically regarding population growth and business income) are associated with increased volumes of surface-water entitlements sold from that area (due to the area's potential disadvantages/lower capability to produce high profits from farming).

*H5:* Areas with low access to markets, infrastructure and other services are associated with increased volumes of surface-water entitlements sold from that area (due to the area's lower capability to produce high profits from farming).

In addition, regional dummy variables for the larger river valleys, in terms of total water ownership, will be included to capture some additional regional and institutional characteristics, which cannot be accounted for otherwise.

This chapter will further control for water entitlements on issue, groundwater use, land use, water prices and other regional factors, based on findings from the water trading behaviour literature (Chapter 3).

# **6.4 Methodology**

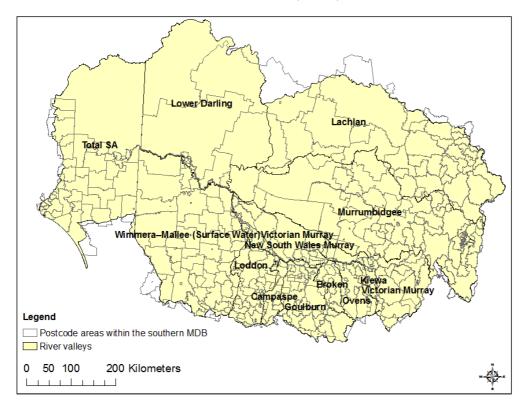
## 6.4.1 Water market data and study area

Water entitlement and allocation trading information by postcode area were compiled and sourced from a private water broker (Waterfind). Water trading and the spatial data (described in the following section) were analysed and mapped using GIS (ArcMap 10.2). Firstly, water trading information per postcode area was matched with the spatial postcode area dataset from ABS. This chapter focuses on postcode areas that have their centroid within the boundaries of the southern MDB (n=383) (Figure 6.1). Due to the size of the southern MDB, there are postcode areas where water trading is unlikely to occur (e.g. no farming area or no entitlements issued), thus, the analyses are based on postcode areas that have had at least one water allocation and entitlement transaction respectively in at least one of the years considered. As a result, there are different numbers of observations for the different models.

78 Waterfind is currently the leading Australian water broker. Waterfind's water volume traded and market share

has grown steadily. In 2013/14, a total 367,126 ML of water entitlements and allocations were traded (Waterfind 2015). As at 2016, Waterfind has completed 13,000 water trades servicing 11,000 clients (Waterfind 2016).

Figure 6.1: Postcode areas within the southern MDB (n=383)



Own map (base map sources: ABS (2011a) and MDBA (2013a))

The dependent variables were calculated by summing the volumes of all approved sales/purchases within a postcode area for each year. Water entitlement trading data include high and low security water entitlements. This chapter focuses on water trading data between 2010/11 and 2013/14, given Waterfind (established in 2003) reached strong market dominance from 2010/11 onwards, particularly from 2012, when a competitor in VIC ceased business (NWC 2013b). Table 6.1 summarises average and sum of volumes of water trading per season at Waterfind between 2010/11 and 2013/14.

Table 6.1: Sum and average volumes (ML) of water traded at Waterfind between 2010/11 and 2013/14

		2010/11	2011/12	2012/13	2013/14
Entitlement	Average	167	279	106	154
sales	Sum	22,877	38,169	14,538	21,157
Entitlement	Average	392	953	130	213
purchases	Sum	34,487	83,876	11,398	18,762
Allocation	Average	1,606	1,348	1,254	1,239
sales	Sum	285,893	239,888	223,116	220,488
Allocation	Average	1,813	2,428	2,075	1,799
purchases	Sum	230,255	308,398	263,478	228,466
Total traded		573,518	670,331	512,529	488,873

It has been suggested that basing spatial research on administrative boundaries, may not be suitable in addressing the underlying research problem (e.g. Logan 2016). For the purpose of

a regional analysis, postcode areas are typically the smallest geographic area that can be associated with individual farms (e.g. Roberts & Key 2008). The postcode area boundaries used in this chapter are an approximation of Australia Post postcodes and are based on statistical areas level 1 (SA1) created by ABS. SA1 areas are designed to contain broadly similar population sizes (ABS 2011b). Thus, postcode areas vary in area size, but much less in population size, which is assumed to fit the purpose of this analysis.

Other data related to the water market and water use (i.e. prices, water use, water allocation levels) were primarily sourced from the MDBA, NWC and web sources from the separate states (similar to Chapter 5). This data is typically only available at the river valley level. Thus, postcode areas were assigned to the relevant river valleys if they fell inside or were closest to it. To account for potential endogeneity, water entitlement and allocation prices were lagged (previous year) in the respective model.

# 6.4.2 Spatial and other regional variables

A GIS-database was compiled by collecting secondary spatial data, covering biophysical, climate, land use and socio-economic information. A search of available spatial data across the southern MDB was performed using, primarily, government search tools and databases.<sup>79</sup> Spatial data was chosen based on the smallest available resolution, to obtain the most detailed and accurate dataset, which primarily represented the whole southern MDB area, and met the study period timeframe. One drawback was that not every dataset needed for the analysis was available for the years relevant to the study period. This is negligible for factors that have a rather permanent character, i.e. features tend to remain unchanged over a certain period of time. According to FAO (1985) permanent features include, for example, soil texture.<sup>80</sup>

Hence, this chapter comprises several time variant and time invariant variables. Time invariant variables were soil texture, density of city, dryland and groundwater salinity, and land use. Though land use and salinity are prone to changes over time, data sources did not allow for the collection of data across the study time period and area. However, land use and groundwater salinity were sourced from composite datasets, covering several years.

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<sup>&</sup>lt;sup>79</sup> For example, the (former) Australian Spatial Data Directory (ASDD), Data.gov.au or the online data catalogue/directory of the individual states (see Table E.1). These databases and search tools provide information about the spatial data and links to their sources. At the time of the data collection many spatial environmental datasets were not available for all states, but over recent years there has been progress towards compiling and providing national spatial datasets (DPMC 2015).

<sup>&</sup>lt;sup>80</sup> Australia wide soil data was first compiled by Northcote et al. (1960-1968) (CSIRO) on 10 hardcopy map sheets in the 1960s. These maps were followed by additional work by McKenzie et al. (2004), which provided interpretation from Northcote's soil classification to the new Australian Soil Classification (ASC). Northcote's foundation work from the 1960s is still the basis for many Australia wide soil maps and analyses today. Information on these developments and datasets is compiled by the Australian Soil Resource Information System (ASRIS 2013).

Furthermore, Chapter 5 (Section 5.4.1) specifically discussed the practicability of the dryland salinity dataset.

When modelling water entitlement trading, time variant variables need to be lagged (e.g. previous 5 years) to reflect long-term issues, which are more relevant for this permanent water right. The time variant socio-economic variables (population growth and business income), to some extent, might be endogenous to water entitlement sales (e.g. in the case of farm exits and farmers moving out of the region). Using the average population growth of the previous five years is assumed to lower the risk of endogeneity and provide a longer-term picture of the state of regional population. Previous year's business income from primary production (PP) instead of current year's value was used for the same reason.

Table 6.2 provides an overview of all variables (including sources and spatial scale), which are examined in the following regression models on water trading decisions. GIS was employed to generate spatial statistics for the spatial and regional variables. Spatial information was overlayed, with the postcode area layer (reference area) and information extracted using ArcGIS's toolboxes, e.g. 'Tabulate area' and 'Zonal Statistics as Table' from the spatial analyst toolbox (see Table F.1 for a list and description of GIS tools used in this thesis). All spatial data layers were converted to the same coordinate systems. <sup>82</sup> Figures 6.2 and 6.3 show several maps presenting the spatial variables.

CSIRO was the source of the soil texture data in soil layer 1 (A-Horizon). Data was modelled from spot observations and is presented at a spatial resolution of approximately 1.1km. Soil texture is defined as "a measure of the behaviour of a small handful of soil when moistened and kneaded into a ball and pressed out between the thumb and forefinger. The proportions of sand, silt and clay are the main determinants of field texture" (CSIRO 2001, p. 1).

Annual rainfall and evapotranspiration raster<sup>83</sup> data layers were obtained from CSIRO's Australian Water Availability Project (AWAP) at a spatial resolution of 5km. Rainfall data was interpolated from BoM's weather stations to smooth raster surfaces. Evapotranspiration

<sup>81</sup> It needs to be noted that using lagged variables may not completely solve potential endogeneity problems.

locates points on the Earth's surface using decimal degrees as the unit of measure. A projected coordinate system is a flat and two-dimensional surface with constant lengths, angles, and areas across the two dimensions (usually using metres as the unit of measure) (ESRI 2012).

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However, no suitable instruments can be found for variables such as population growth and business income PP. <sup>82</sup> In this thesis the specified coordinate systems are the GCS-GDA-94 (geographic coordinate system) and Geoscience GDA Lambert system (projected coordinate system). The national Geoscience GDA Lambert coordinate system was employed because the southern MDB stretches over two grid zones (54 and 55). All spatial data used in this thesis was projected to these coordinate systems to ensure uniformity for the spatial analyses, e.g. distance measuring. A geographic coordinate system is a three-dimensional reference system that

<sup>&</sup>lt;sup>83</sup> There are two major data types in GIS: raster and vector data. Raster data consists of a matrix of cells (pixels) organised into rows and columns (grid). Each cell contains a value representing some characteristic of that location, e.g. rainfall or elevation (ESRI 2012).

data was modelled and relevant equations are explained in Raupach et al. (2009). Using the 'Raster Calculator' in GIS (see Table F.1) averages for rainfall and evapotranspiration over the previous five years were calculated. Finally, net rainfall was estimated by subtracting evapotranspiration from rainfall data.

The sources for dryland, groundwater and surface-water salinity refer to Chapter 5 (Section 5.4.1).

Annual population data per statistical area level 2 (SA2) was sourced from the ABS. Population growth was estimated between the relevant years. Postcode areas were allocated to the relevant SA2 if it fell inside or was closest to it. SA2 is the lowest level of the Australian Statistical Geography Standard (ASGS) structure for which population information is made available by ABS. SA2 are general-purpose medium-sized areas built from SA1. Their purpose is to represent socially and economically interacting community areas. SA2 are delimited according to the following criteria (in order of importance): population (average population size is 10,000), functional area (access of services), growth (development areas and future growth areas), gazetted suburbs and localities, Local Government Area (LGA) boundaries, and zero SA2/special purpose SA2 (ABS 2010a).

ATO Taxation statistics provided the net business income/loss for PP and the number of primary production businesses per postcode area for the relevant financial years. PP activities include plant or animal cultivation, fishing or pearling, and tree farming or felling (ATO 2016).

Locations of cities were obtained from ABS. Cities with a population of minimum 5,000 people<sup>84</sup> were selected to calculate the density of cities for the southern MDB. In this chapter the density of cities is used as a proxy for distance to markets, and other infrastructure and services in the region.

The land use dataset was sourced from ABARES's 'Catchment Scale Land Use' dataset of Australia, which is the most current national land use map. Land use data was compiled from the different states and territories and, hence, vary in currency (1999–2009) and scale (1:25,000 to 1:250,000). Land uses were classified according to the 'Australian Land Use and Management Classification' using three hierarchy levels, and spatial statistics were calculated for the second hierarchy (Table E.2 shows the list of covered land uses in this chapter's analysis and ABARES's classification).

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<sup>&</sup>lt;sup>84</sup> S. Walpole (personal communication, February 05, 2016) suggested that smaller cities up to 10,000 people represent relevant rural service areas for farmers.

Finally, regional dummy variables for the largest river valleys, in terms of volume of licensed water entitlements, comprised Murrumbidgee, Goulburn, VIC Murray, SA, NSW Murray, Lachlan, Loddon, and Wimmera-Mallee (river valley accounted for more than 1% of the total licensed water entitlement in the southern MDB).

Table 6.2: Variable description, data scale and sources

Variable	Details	Scale	Source
Dependent vario	ubles		•
Entitlement sale Entitlement purchase Allocation sale Allocation purchase	Total volumetric entitlements (ML) sold per year between 2010/11–2013/14 in natural logarithm  Total volumetric entitlements (ML) purchased per year between 2010/11–2013/14 in natural logarithm  Total volumetric allocations (ML) sold per year between 2010/11–2013/14 in natural logarithm  Total volumetric allocations (ML) purchased per year between 2010/11–2013/14 in natural logarithm	Postcode area	Waterfind (private access through broker in 2014); Postcode area boundaries: ABS (2011a)
Spatial independ	dent variables		
Soil texture	Index of soil texture in the soil layer 1 (mean): 1=sands, 2=sandy loams, 3=loams, 4=clay loams/light clays, 5=clays	Postcode area	CSIRO (2001)
Net rainfall Previous 5 years	Rainfall minus evapotranspiration (mean annual, mm/d), 2010–2013 respectively  Rainfall minus evapotranspiration (mean annual, mm/d), averaged for the previous 5 years, comprises the years 2005–2013	Postcode area	Raupach et al. (2009, 2012)
Dryland salinity (dummy)	1=Percentage of dryland salinity risk/hazard area per total agricultural area is greater than 4%; 0=otherwise	Postcode area	NLWRA (2001); Agricultural area: ABARES (2012)
Groundwater salinity (dummy)	1=Percentage of the area with saline groundwater (>3,000 mg/l TDS <sup>d</sup> ) is greater than 70%; 0 = otherwise	Postcode area	BoM (2014) <sup>e</sup>
Surface-water salinity (dummy)	1=Mean salinity level EC (μS/cm) is greater than 325EC <sup>f</sup> (using the salinity station that is closest), 2010/11–2012/13 respectively (average values for 2013/14)	Postcode area	MDBA (e.g. MDBA (2014a))
Population growth  Population growth previous 5 years	Percentage of regional population growth, comprises the years 2009–2013 (e.g. 2009 to 2010 for the water trading year 2010/11)  Percentage of regional population growth averaged for the previous 5 years, comprises the years 2005–2013 (e.g. 2005 to 2010 for the water trading year 2010/11)	SA2	ABS (2015c); SA2 boundaries: ABS (2010a)
Business income (PP)	Net business income/loss for PP businesses in the previous year (2009/10–2012/13) by business numbers (in thousands)	Postcode area	ATO (2016)
Density cities	Density of cities with population greater than 5,000 (Kernel density (default radius 115km): Magnitude-perunit area based on a kernel function to fit a smoothly tapered surface (ESRI 2016a).)	Postcode area	ABS (2012a)

Variable	Details	Scale	Source	
Other regional i	independent variables			
Entitlements owned	Total volumetric entitlements (ML) issued per year between 2010/11–2013/14 in natural logarithm (high security water entitlements; for NSW it is high and general security)	River valley	NSW: DPI Water (2016); VIC: VIC Water	
Allocation level Allocation level previous 5 years	Seasonal irrigation water allocation levels in percent between 2010/11–2013/14  Seasonal irrigation water allocation levels in percent, average for the previous 5 years, comprises the farming seasons 2005/06–2012/13	D.	Accounts, e.g. DSE (2012); SA: DEWNR (2016); ACT: EPD (2016); MDBA (WAM reports, e.g. MDBA (2012e)) <sup>a</sup>	
Groundwater use	Groundwater use (ML) per year between 2010/11–2013/14 in natural logarithm (long-term averages were used where data were not available)	River valley	MDBA (WAM reports, e.g. MDBA (2012e); VIC Water Accounts, e.g. DSE (2012)	
Entitlement price	Market prices (average AUD\$/ML) of high security water entitlements (general security for Lachlan, NSW), per year between 2010/11–2013/14 in natural logarithm	River valley	DoE (2016); NWC (2013b) <sup>b</sup>	
Entitlement price previous year	Market prices (average AUD\$/ML) of high security water entitlements (general security for Lachlan, NSW) for the previous year (2009/10–012/13) in natural logarithm			
Allocation price Allocation price previous year	Prices for water allocations (average AUD\$/ML), per year between 2010/11–2013/14 in natural logarithm  Prices for water allocations (average AUD\$/ML) for the previous season (2009/10–2012/13) in natural logarithm	River valley	Aither (2015); NWC (2010a, 2011a, 2013a, 2013b)	
Irrigated cropping Irrigated horticulture (perennial) Irrigated horticulture (seasonal) Irrigated	Percentage of land under irrigated cropping (e.g. cereals, hay, silage, oil seeds, sugar, cotton, pulses)  Percentage of land under irrigated perennial horticulture (e.g. tree fruits, tree nuts, vine fruits, shrub nuts/fruits, citrus, grapes, perennial vegetables and herbs)  Percentage of land under irrigated seasonal horticulture (e.g. seasonal fruits/nuts/vegetables/herbs, turf farming)  Percentage of land under irrigated grazing/modified	Postcode area	ABARES (2012) <sup>c</sup>	
grazing  Land in transition	pastures (e.g. woody fodder plants, pasture legumes, legume/grass mixture, sown grasses)  Percentage of irrigated or dryland in transition (i.e. degraded, abandoned land or under rehabilitation)			
River valley	Dummy variables for the largest river valleys in terms of water ownership (e.g. Murrumbidgee=1 if the postcode area falls into Murrumbidgee region, 0=otherwise)	Postcode area	River valley boundaries: MDBA (2013a)	
Years	Dummy variables for farming seasons (e.g. 2010/11=1 if farming season 2010/11, 0=otherwise)	Postcode area		

<sup>&</sup>lt;sup>a</sup> Data from the MDBA WAM reports was only used where the individual state web sources did not offer data for all years (e.g. in Kiewa, Ovens).

<sup>&</sup>lt;sup>b</sup> For smaller river valleys (e.g. Kiewa, Ovens, Broken) price data is not available for all years. In this case prices for VIC Murray above or below Barmah Choke were used.

<sup>&</sup>lt;sup>c</sup> Composite dataset covering the following years: VIC: 2009; SA: 2008; NSW: 1999–2006.

<sup>&</sup>lt;sup>d</sup> The level of groundwater salinity not suitable for irrigation is defined as above 3,000 mg/L (Harrington & Cook 2014).

<sup>&</sup>lt;sup>e</sup> Composite dataset over the years 1994–2009.

 $<sup>^</sup>f$  Most crops accept irrigation water salinity levels up to 700 to 800 EC ( $\mu$ S/cm). However, care needs to be taken above 300 EC ( $\mu$ S/cm), e.g. when using overhead sprinklers which may cause leaf scorch (DEDJTR 2015b).

Figure 6.2: Maps presenting the spatial variables (biophysical factors and density cities)

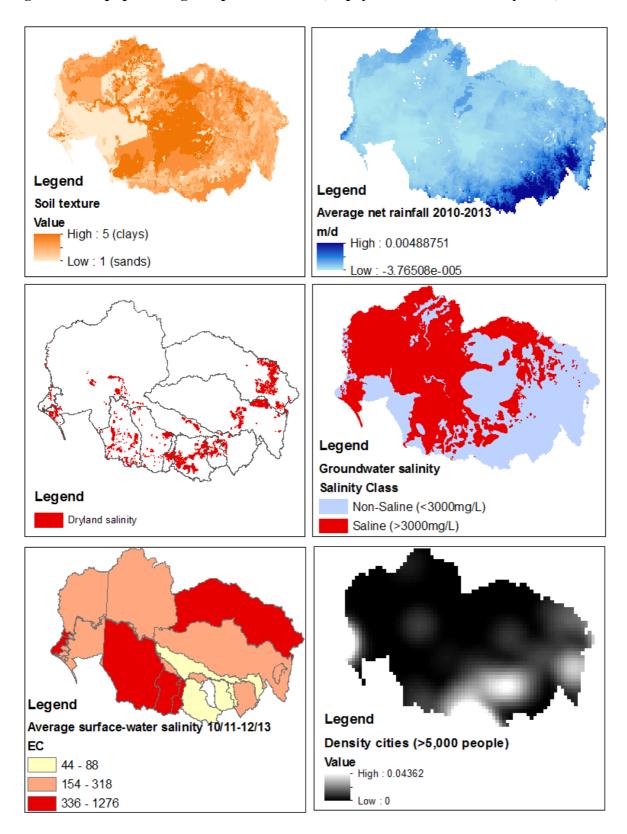
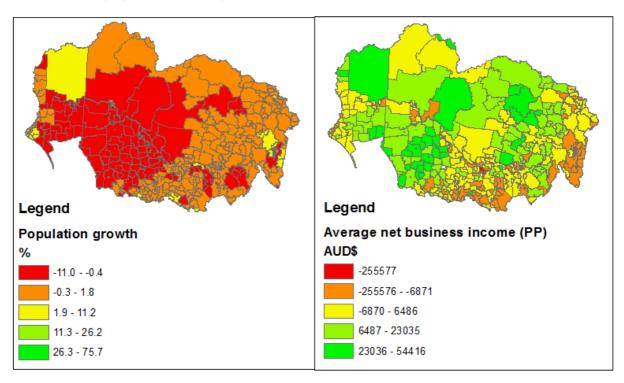


Figure 6.3: Maps presenting the spatial variables (socio-economic factors)



During the initial model testing phase the influence of other spatial data was assessed. For example, the variability of rainfall over the previous five years, soil type according to the agricultural potential, population by age, unemployment rate, different population sizes of cities, government benefit payments and distance to dams. However, these variables did not improve the modelling outcome, or were discarded due to lack of relevance to the research question when compared to other spatial variables.

Table 6.3 details the descriptive statistics.

**Table 6.3: Descriptive statistics** 

Variable	Obs.	Mean	Standard deviation	Min	Max
Entitlement sales (ln ML)	548	2.50	2.62	0.00	9.67
Entitlement purchases (ln ML)	352	2.20	2.61	0.00	10.93
Allocation sales (ln ML)	712	4.21	3.33	0.00	10.90
Allocation purchases (ln ML)	508	4.41	3.45	0.00	11.18
Soil texture (index)	896	3.12	1.01	1.00	5.00
Net rainfall (mm/d)	896	0.19	0.33	-0.86	1.96
Net rainfall previous 5 years (mm/d)	896	0.19	0.22	-0.29	1.60
Dryland salinity (dummy)	896	0.44	0.50	0.00	1.00
Groundwater salinity (dummy)	896	0.35	0.48	0.00	1.00
Surface-water salinity (dummy)	896	0.35	0.48	0.00	1.00
Population growth (%)	896	0.04	2.29	-22.50	31.17
Population growth previous 5 years (%)	896	0.13	2.42	-13.63	32.73
Business income (PP; \$ in thousands)	896	-0.73	26.33	-635.12	86.68
Density cities	896	10.91	9.95	0.00	45.84
Entitlements owned (ln ML)	889	13.03	1.56	6.98	14.63
Allocation level (%)	896	90.95	20.17	4.31	134.45 <sup>a</sup>
Allocation level previous 5 years (%)	896	54.04	22.09	1.00	100.00
Groundwater use (In ML)	896	9.31	2.98	0.00	12.49
Entitlement price (ln \$/ML)	847	7.37	0.29	5.98	7.63
Entitlement price previous year (ln \$/ML)	855	7.47	0.29	6.18	7.97
Allocation price (ln \$/ML)	764	3.59	0.52	2.56	4.34
Allocation price previous year (ln \$/ML)	772	3.79	0.82	2.56	5.23
Irrigated cropping (%)	896	5.78	9.81	0.00	49.90
Irrigated horticulture (perennial) (%)	896	3.24	8.21	0.00	53.12
Irrigated horticulture (seasonal) (%)	896	0.33	0.81	0.00	7.61
Irrigated grazing (%)	896	6.80	13.18	0.00	59.95
Land in transition (%)	896	0.19	0.60	0.00	5.48
Murrumbidgee (dummy)	896	0.13	0.33	0.00	1.00
VIC Murray (dummy)	896	0.10	0.30	0.00	1.00
Goulburn (dummy)	896	0.12	0.33	0.00	1.00
SA (dummy)	896	0.20	0.40	0.00	1.00
NSW Murray (dummy)	896	0.06	0.23	0.00	1.00
Lachlan (dummy)	896	0.05	0.22	0.00	1.00
Loddon (dummy)	896	0.10	0.30	0.00	1.00
Wimmera Mallee (dummy)	896	0.08	0.27	0.00	1.00
2010/11 (dummy)	896	0.25	0.43	0.00	1.00
2011/12 (dummy)	896	0.25	0.43	0.00	1.00
2012/13 (dummy)	896	0.25	0.43	0.00	1.00
2013/14 (dummy)	896	0.25	0.43	0.00	1.00
Some postcode gross fall incide NSW river velley Lechler				l	

<sup>&</sup>lt;sup>a</sup> Some postcode areas fall inside NSW river valley Lachlan, which received over 100% allocation in 2010/11 and 2011/12.

#### 6.4.3 Methods

Several random-effects panel models of water entitlement and allocation trading per postcode area between 2010/11 and 2013/14 were employed, sto analyse the relationship between water trading and various spatial influences over time (while controlling for other additional influences). In contrast to fixed-effects panel models, random-effects panel models allow for inclusion of time invariant variables. Please refer to Chapter 5, Section 5.4.2 for the random-effects panel model equation or Greene (2003, pp. 200-203). During the model estimation, robust standard errors were used to account for heteroscedasticity. As a robustness check, fixed-effects models were run on the time-variant variables and are shown in Appendix G. However, only a few spatial variables that are of interest for this chapter's hypotheses are time-variant, thus, the discussion of the results concentrates on the random-effects model results.

All final models in this thesis were obtained using the backward elimination method, which arrives at a reduced form starting from a full model containing all variables of interest (e.g. Draper & Smith 1998). The impact of each variable removed is assessed according to its significance value (p-value).

In addition, tobit models (also called censored regression or limited dependent variable models) were estimated as a robustness check of the random-effects panel model results. Tobit models are typically used because of left- or right-censored dependent variables (Greene 2003, p. 764; Tobin 1958):

$$y_i^* = x_i'\beta + \varepsilon_{i},$$

$$y_i = 0 \quad \text{if } y_i^* \le 0,$$

$$y_i = y_i^* \quad \text{if } y_i^* > 0.$$

In this chapter, the tobit model treats postcode areas for which no transactions were observed in the dataset as censored observations. The relevant marginal effects were estimated on the expected outcome conditional on the censored value (i.e. censored expected value  $E(y_i^*)$ ) (StataCorp 2016, p. 3).

The analysis in this chapter did not employ spatial regression due to a number of reasons: As described in the previous section, the models are accounting for those postcode areas only where water entitlements and allocations respectively were traded at least once during the study period. Thus, the analysis is not covering the total postcode areas of the region, which

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<sup>&</sup>lt;sup>85</sup> Regression modelling in this thesis is carried out using STATA.

violates one of the conditions for spatial econometrics (Anselin 1988; Arbia et al. 2016). Furthermore, some postcode areas are isolated in space (i.e. have no neighbours). Thus, this dataset does not allow for the estimation of an accurate spatial weight matrix. In this case, it is acceptable to use 'ad-hoc' measures to account for potential spatial dependence in the dataset, such as including regional or zonal dummy variables and other spatially lagged (e.g. biophysical) variables in the model (e.g. De Pinto & Nelson 2007; Staal et al. 2002; Swinton 2002) as proven in other empirical agricultural studies (e.g. Carrión-Flores & Irwin 2004; Cho & Newman 2005; Lapar & Pandey 1999; Wu et al. 2011).

#### 6.5 Results and discussion

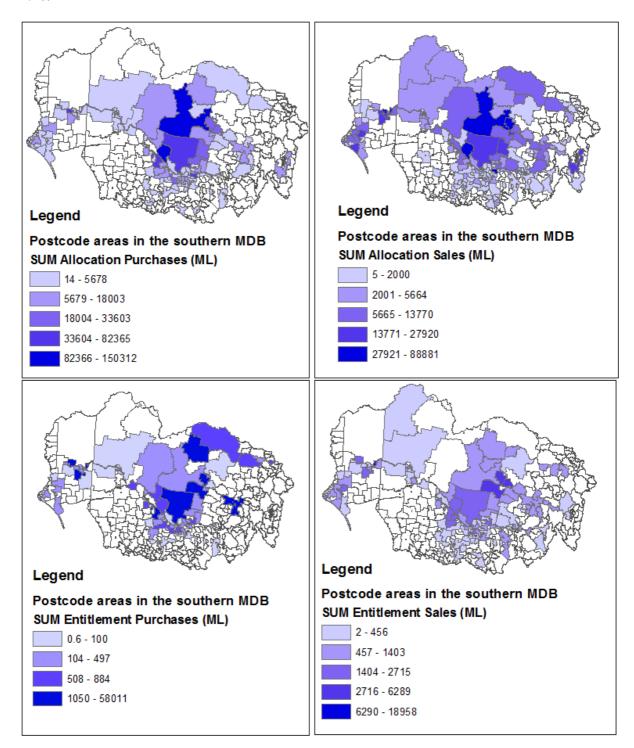
Tables 6.4 and 6.5 show the results of the random-effects panel models for water entitlement and allocation trading respectively (the coefficients in linear models equal the marginal effects). The results for the respective tobit models and their marginal effects are shown in Appendix G. The results for the tobit models vary only for a few variables, which are incorporated in the below interpretation and discussion of the individual results.

Preliminary models were affected by high multicollinearity for the river valley dummy variables SA, Lachlan and Wimmera-Mallee (as tested through the Variance Inflation Factors (VIF) and high correlation levels). Hence, these river valley dummy variables were dropped from all models. Furthermore, current year's water allocation prices were highly correlated with yearly dummy variables. Thus, yearly dummy variables were excluded in the water entitlement models, as current year's water allocation prices in these models reflect the effects of different years. The water allocation models include yearly dummy variables, as these models account for the previous year's allocation prices to avoid endogeneity problems with the dependent variables. Some correlation coefficients remained relatively high, but at a commonly acceptable level (see Appendix G for the correlation matrices and VIF statistics).

Furthermore, models are presented using logged variables for the dependent variable and some independent variables to account for outliers in volumes of water traded, used or owned as well as in water prices. Estimating the model without logged variables returned less robust results; hence, this section only presents models with logged variables. All estimated models are statistically highly significant, proven by the results of Wald-Chi-square tests (p<0.001).

Figure 6.4 shows the total water allocation and water entitlement trading activities (in ML) in the southern MDB for the study time period.

Figure 6.4: Total water trading volume (ML) in the southern MDB postcode areas, 2010/11 to 2013/14



## 6.5.1 Water entitlement trading

#### 6.5.1.1 Spatial variables

Effect of poorer resource areas (**Hypothesis 1**)

In the water entitlement trading models (Table 6.4) soil texture was found to significantly affect water entitlement purchases but not sales. Increased water holding capacity of the soil (i.e. clay content) led to increased volumes of water entitlement purchases, providing

evidence that favourable soil conditions (depending on the land use) do impact on water entitlement trading decisions and underlying decisions in irrigated agriculture. This is consistent with previous findings in the water trading behaviour literature (e.g. Alankarage et al. 2002). However, hypothesis *H1a* (areas characterised by soils with lower water holding capacity (i.e. sandier soils) are associated with increased volumes of surface-water entitlements sold from that area) could not be confirmed.

A decrease in net rainfall (over the previous 5 years) significantly increased the volumes of water entitlement trading (i.e. sales and purchases). Thus, as expected, water scarcity was a driver of water entitlement sales (e.g. irrigators change land uses or terminate irrigation as a result of lower water availability) and water entitlement purchases (e.g. irrigators buy water to meet production needs). However, net rainfall was not significant in the tobit model for water purchases (Table G.7). In contrast, allocation levels (over the previous 5 years) had no significant influence on water entitlement sales, but showed a significant positive relationship with water entitlement purchases. While this is a weak result (at the 10% level), it may indicate that water entitlement purchases facilitated some irrigation production expansion during favourable periods of higher water availability. The insignificance of allocation level in the water entitlement sales model, and the negative relationship between net rainfall and water entitlement purchases, may also indicate farmers' increased adaptability to climate change in the southern MDB in recent years, reflecting the findings in other studies (e.g. Li et al. 2013).

Table 6.4: Random-effects panel models of water entitlement sales and purchases, 2010/11-2013/14

	Entitlement sales (ln ML)			purchases (ln IL)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	-0.148		0.647**	0.942***
	(0.221)		(0.256)	(0.203)
Net rainfall previous 5 years (mm/d)	-1.204	-1.747***	-1.070	-1.923**
•	(0.824)	(0.661)	(0.835)	(0.756)
Dryland salinity (dummy)	0.601**	0.520**	-0.242	
	(0.300)	(0.253)	(0.338)	
Groundwater salinity (dummy)	0.105		0.544	
	(0.358)		(0.557)	
Surface-water salinity (dummy)	-0.443	-0.770***	0.0750	
	(0.333)	(0.226)	(0.340)	
Population growth previous 5 years (%)	0.117		0.158	
	(0.149)		(0.172)	
Business income (PP; \$ in thousands)	0.007***	0.006***	0.005***	0.005***
	(0.002)	(0.002)	(0.001)	(0.001)
Density cities	-0.036*	-0.028**	-0.026	
•	(0.020)	(0.014)	(0.024)	
Other regional variables:				•
Entitlements owned (ln ML)	0.189		0.633**	0.608**
, ,	(0.229)		(0.295)	(0.237)
Groundwater use (ln ML)	0.145***	0.137***	0.041	, , , ,
,	(0.043)	(0.030)	(0.075)	
Allocation level previous 5 years (%)	0.009	` /	0.032*	0.029*
1	(0.013)		(0.019)	(0.015)
Entitlement price previous year (ln \$/ML)	0.291		-0.299	(212 2)
	(0.566)		(0.700)	
Allocation price (ln \$/ML)	-0.202		0.656*	0.778***
	(0.330)		(0.365)	(0.299)
Irrigated cropping (%)	0.070***	0.052***	0.034*	(27.2.2)
S	(0.019)	(0.019)	(0.019)	
Irrigated horticulture (perennial) (%)	-0.020	` /	0.002	
8	(0.016)		(0.013)	
Irrigated horticulture (seasonal) (%)	-0.272**	-0.452***	-0.467	
8	(0.137)	(0.132)	(0.334)	
Irrigated grazing (%)	-0.013	-0.019*	0.002	
6 6 6 ()	(0.013)	(0.011)	(0.016)	
Land in transition (%)	0.378	` /	0.493*	0.516**
	(0.391)		(0.257)	(0.205)
Murrumbidgee (dummy)	-0.180		-1.630	-1.945**
<i>y</i>	(0.799)		(1.064)	(0.802)
VIC Murray (dummy)	-0.941		-3.600***	-3.894***
	(0.915)		(1.168)	(0.809)
Goulburn (dummy)	-0.644		-2.216**	-2.195**
- · · · · · · · · · · · · · · · · · · ·	(0.808)		(1.069)	(0.903)
NSW Murray (dummy)	-0.041		-1.582	-2.458***
·· ·· ·· · · · · · · · · · · · · · · ·	(0.909)		(0.990)	(0.841)
Loddon (dummy)	-0.098		-0.002	(2.2.2)
· · · · · · · · · · · · · · · · · · ·	(0.603)		(0.816)	
Constant	-2.496	1.760***	-9.655	-12.110***
Consumit	(5.652)	(0.351)	(7.488)	(3.421)
Observations	484	548	319	320
Wald chi <sup>2</sup>	114.50***	79.07***	152.62***	125.55***
wala cni-				

Notes: robust standard errors in parentheses. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

As also found in Chapter 5, this chapter' analysis suggested that the presence of dryland salinity increased water entitlement sales between 2010/11 and 2013/14. Irrigators affected by dryland salinity typically produce on less productive soils (see Chapter 5) and, thus, may not generate sufficient profit to sustain in the long-term, leading to land-use changes or irrigation exits, reflected in higher water entitlement sales. It is important to be aware, as noted in Chapter 5, that the dryland salinity dataset is now dated and thus, the results found here can only serve as an indication, given that the current extent of soil salinity is not measured for the majority of the southern MDB. However, some regional and more recent studies confirm the continued occurrence of dryland salinity in some areas of the southern MDB (e.g. Clark & Wayne 2008; Fawcett 2013).

In contrast to the overall regional analysis in Chapter 5, in this chapter groundwater salinity was not found to have a significant impact on water entitlement sales. This result may be caused by inconsistent measurements of groundwater salinity that, overall, may not adequately represent underlying issues, due to the composite dataset which amalgamated data from different time horizons (BoM 2014). Nevertheless, groundwater use had a strong impact on water entitlement sales in this model, and may be depicting the substitution effect between groundwater and surface-water use in this chapter (groundwater use was not found to be endogenous in Chapter 5 in the river valley level model, when tested with instrumental variable panel regression in Section 5.4.2). Furthermore, tobit model results (Table G.7) support this substitution effect, indicating that groundwater salinity significantly increased volumes of water entitlement purchases.

Furthermore, surface-water salinity showed an unexpected negative relationship with volumes of water entitlements sold, suggesting that irrigators resort to other measures, rather than changing the level of irrigation production to combat surface-water salinity problems. Other measures may comprise adopting salt resistant crops, mulching (horticulture), measuring the water's salt level or salt leaching through the soil (i.e. increasing water application rates) (e.g. Cross 2001). Thus, surface-water salinity is not a major driver of water entitlement sales volumes at the regional level and does not constitute a major barrier to irrigated agriculture, as there are other measures available to alleviate surface-water salinity issues.

None of the salinity variables significantly impacted water entitlement purchases (despite groundwater salinity in the tobit model (Table G.7)).

Population growth (over the previous 5 years) was found to have no influence on water entitlement trading. Thus, a regional population decline (including regional farm exits) has no effect on irrigators' water entitlement trading decisions at the regional level. It was expected to find evidence for a negative relationship between population growth and water entitlement sales, as other studies concluded that population decline increases farmland abandonment due to a more isolated location (e.g. MacDonald et al. 2000). But, as discussed in Section 6.2.1, population growth can have multifaceted effects, e.g. other studies showed a positive connection between population growth and farmland abandonment, indicating that increased population may be related to increased off-farm job opportunities, thereby increasing the opportunity costs for labour in agriculture (e.g. Gellrich et al. 2007; Romero-Calcerrada & Perry 2004). These multifaceted effects may be the reason for the insignificant result of population growth.

Nevertheless, regional business income for PP showed a strong positive relationship with water entitlement trading, increasing both volumes of water entitlement sales and purchases. Irrigators in areas with active and profitable agricultural production and viable communities may use the water entitlement markets to sell surplus water (and possibly switch to the water allocation market to buy water), or purchase water entitlements to expand or continue production levels. This result confirms findings of previous studies for water purchases (e.g. Alankarage et al. 2002; Bjornlund 2004). Overall, participation in the water entitlement market seems to be associated with farms' profitability, due to the long-term investment characteristic of water entitlements. This variable may also partly reflect the effect of population size/growth in the area. However, business income for PP showed no significant effect in the tobit model (Table G.7).

Effect of access to markets, infrastructure and services (Hypothesis 5)

Density cities (with over 5,000 people) showed a negative relationship with water entitlement sales. As expected, this indicates that irrigators in more rural areas, with longer distances to markets, infrastructure and other services, were more likely to sell water entitlements. Irrigated agriculture in these areas can be more cost intensive and disadvantaged, for example in relation to the connection to water infrastructure or resources (e.g. no investment priority for infrastructure upgrades or lower water security level). This result supports findings from other studies (see Section 6.2.1) that showed closer distances to markets drive agricultural growth (e.g. Cho & Newman 2005) and agricultural land values (e.g. Patton & McErlean 2003).

# 6.5.1.2 Other regional variables

The results for entitlements owned, groundwater use and water prices need to be interpreted with caution as the data was provided only at the river valley level. Volumes of water entitlements owned were driving volumes of water entitlement purchases, but not sales. Hence, areas accounting for larger volumes of water, were more active in the water market purchasing water – which is an expected result. A positive significant result was however primarily expected in the sales model, following the findings in Chapter 5 and other studies (e.g. Wheeler et al. 2012b). But the non-significant result may be due to the aforementioned measurement issues.

As discussed in the previous section, a strong finding was that the larger the amount of groundwater used, the more volumes of water entitlements were sold. This result provides evidence for the substitution effect between groundwater and surface-water (i.e. where groundwater resources are available and used in large amounts, surface-water entitlements can be sold on the market as surplus water), confirming the results of Chapter 5 and other studies (e.g. Wheeler & Cheesman 2013; Wheeler et al. 2016).

Entitlement prices did not seem to have a large effect on water entitlement trading, but it needs to be noted that price data comprised high security water entitlements only (except for Lachlan) at the river valley level. Nevertheless, the influence of prices was evident through water allocation prices which showed a positive significant impact on water entitlement purchases, indicating irrigators buy more volumes of water entitlements during periods and in areas of high water allocation prices (i.e. high water scarcity). This result may also reflect the gradual recovery/expansion of irrigated agriculture after the drought (see Chapter 2) in addition to increased adoption of water entitlement trading over time, given water allocation prices also reflect the effect of years in this model (with higher water allocation prices in the final years of the study period). This is why yearly dummy variables were dropped in the water entitlement models.

As expected from the literature (see Chapter 3) land uses in the postcode area were significant drivers of water entitlement trading, especially water entitlement selling. In particular, irrigated cropping and irrigated horticulture (seasonal) showed the strongest impact on water entitlement sales. An increase in acreage under irrigated cropping increased volumes of water entitlements sold, whereas increased acreage under irrigated horticulture (seasonal) decreased volumes of water entitlements sold. According to the tobit model (Table G.7) an increase in acreage under irrigated cropping also increased volumes of water entitlement purchases, but it is not significant in the reduced form tobit panel model. Cropping irrigators may have sold

higher volumes of water entitlements since broadacre irrigators in VIC/NSW generally own large-scale general security entitlements. <sup>86</sup> Improved rainfall levels during the study period compared to the drought years may also have resulted in water surpluses. Furthermore, irrigators selling water entitlements may be switching to rely on the water allocation market <sup>87</sup>, given water (allocation) trading was gradually adopted more over time (see Chapter 2). The result for irrigated horticulture (seasonal) (lower volumes sold) is an expected result, since irrigators tend to irrigate seasonal plantings with water allocations (e.g. NWC 2012; Young et al. 2000) and, therefore, own less water entitlements, confirming results in Wheeler et al. (2012b). Furthermore, an increase in the acreage of irrigated grazing decreased volumes of water entitlements sold, though this is a weak result and not significant in the tobit model (Table G.7). An increase in the acreage of land in transition (i.e. classified as degraded, abandoned land or under rehabilitation) increased volumes of water entitlements purchased, giving evidence that irrigated agriculture improved during the years after the Millennium Drought and fallow land prior to 2010 was rehabilitated to irrigated farmland.

Finally, dummy variables for the river valleys were found to have no significant effect on water entitlement sales, but the larger river valleys (in terms of volumes of water entitlements owned) in NSW (i.e. Murrumbidgee and NSW Murray) and VIC (i.e. VIC Murray and Goulburn) showed a negative relationship with water entitlement purchases. These results can be explained by the historical pattern of water trading provided in Chapter 2, which showed that volumes of water entitlement trading may be driven by other river valleys. An example of this is SA; since SA irrigators are more dependent on water entitlements due to the dominance of permanent horticultural production. The larger river valleys in NSW and VIC use more water allocations and were traditionally more active on the water allocation markets.

Overall, spatial variables and some other regional factors, such as land use and groundwater use, were determining factors behind the water entitlement sale decision rather than the water entitlement purchase decision. Water entitlement purchases were mainly influenced by the river valleys, allocation prices and some spatial variables (net rainfall, soil texture, business income). Major differences in the determinants of water entitlement selling and purchasing can be expected. Water sale decisions are often connected to major life or farm changes (e.g. decreasing or exiting farm production, converting to dryland agriculture) and irrigators often

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<sup>&</sup>lt;sup>86</sup> Earlier studies (e.g. Bjornlund 2007; Bjornlund & McKay 1995) showed that these farmers were the early sellers (selling 'sleeper' or 'dozer' (unused or underused) water). This result indicates that some farmers held on to their water surpluses in the early years of the water market to sell it later.

<sup>&</sup>lt;sup>87</sup> As described in Chapter 3, other studies (e.g. NWC 2012) also found that some industries, such as dairy and broadacre where farm production is more flexible, tend to sell water entitlements to purchase water on the water allocation market.

place a high value on their water entitlements as they have a strong connection to the land (see Chapter 2), whereas water purchasing often means either continuing or expanding the farm production level.

#### 6.5.2 Results for water allocation trading

Initially, water allocation trading models were estimated using the spatial and long-term (lagged based on the previous five years) variables used in the water entitlement trading models. As it was expected, the majority of those long-term variables had no influence on water allocation trading. To improve the water allocation models, variables based on the long-term perspective of the previous five years were replaced by the complementing variables for the same or previous year.

Results for water allocation trading per postcode area between 2010/11 and 2013/14 are shown in Table 6.5. Overall, few variables showed a similar relationship compared to the water entitlement trading models; such as entitlements owned, net rainfall, surface-water salinity, population growth and VIC Murray. No significant relationship was found with groundwater use, allocation price previous year, allocation level, soil texture, population growth and business income for PP.

#### 6.5.2.1 Spatial variables (Hypothesis 2)

As expected, water allocation trading was less likely to be affected by spatial factors than water entitlement trading.

Regarding the salinity variables, the results showed only a weak effect between water allocation purchases and dryland/groundwater salinity (but not significant in the reduced form model). Tobit models (Table G.9) also found a positive (weak) relationship between dryland salinity and water allocation sales, and confirmed the negative effect of groundwater salinity and water allocation purchases in the reduced form model. Additionally, similar to the water entitlement models, decreased surface-water salinity levels increased volumes of water allocation sales (but not significant in the reduced form tobit model (Table G.9)). In other words, with increased surface-water salinity levels, irrigators tended to not sell much of their water (allocations and entitlements). As mentioned in the previous section, this result indicates that irrigators adopted measures other than water trading to combat higher surface-water salinity levels. In this case it may mean irrigators hold on to their water to be able to apply high water application rates to stimulate the soil leaching process of saline irrigation water, as described in Chapter 5 and suggested in other studies (e.g. Bjornlund 1995; Connor et al. 2008; Connor et al. 2012). As the data were only available at a broad-scale, this result needs further investigation to improve the understanding of how irrigators cope with

increased surface-water salinity levels. The result may have significant ramifications in terms of total water usage, and may show how irrigation water use can worsen salinity levels through secondary salinization processes that are caused by raising the water table due to increased water application rates. This would be a case where water markets would not necessarily encourage water to be moved from low efficient to high efficient users (e.g. Crossman et al. 2010a; Wheeler et al. 2009).

The insignificant result for business income for PP potentially shows that water allocation markets attracted farmers regardless of their profitability (as opposed to water entitlement trading shown in the previous section) due to the shorter-time nature characteristics involved in selling or buying water allocations.

Furthermore, a negative relationship was found between density cities and water allocation purchases. Together with the result in the water entitlement model (Table 6.4), this means that irrigators in more rural regions with less access to markets, infrastructure and services sold more volumes of water entitlements and purchased more volumes of water allocations. This indicates that some farmers in more rural and isolated areas used water markets to adapt to their disadvantaged location by switching to rely more on water allocation markets (and possibly changing land uses). This may also be a reflection of debt and other issues. Following previous studies, e.g. Bjornlund (2002), irrigators relying more on water allocation markets have potentially started a farm structural adjustment process to prevent farm exit in the present time while considering long-term responses. This facilitates several opportunities, e.g. giving farm families and communities more time to adjust, earning an income from annual cropping or water allocation sales. Farmers in rural areas, with longer distances to water resources, may also have a higher perception of dryness which can affect farmers' climate change adaptation behaviour (Brown & Schulz 2009), and ultimately farmers' water trading behaviour. This result confirms other studies that projected a shift from perennial to annual cropping (e.g. Connor et al. 2009).

Table 6.5: Random-effects panel models of water allocation sales and purchases, 2010/11-2013/14

	Allocation sales (ln ML)			ourchases (ln IL)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	0.248		0.262	
	(0.281)		(0.325)	
Net rainfall (mm/d)	-1.394**	-2.034***	-1.784**	-1.815***
	(0.710)	(0.548)	(0.737)	(0.646)
Dryland salinity (dummy)	0.574		0.820*	
	(0.356)		(0.444)	
Groundwater salinity (dummy)	-0.572		-1.028*	
	(0.446)		(0.582)	
Surface-water salinity (dummy)	-0.711**	-0.554*	0.406	
	(0.329)	(0.293)	(0.463)	
Population growth (%)	0.011		0.069	
	(0.138)		(0.155)	
Business income (PP; \$ in thousands)	0.0005		-0.0002	
	(0.002)		(0.002)	
Density cities	-0.028		-0.082**	-0.061**
	(0.028)		(0.033)	(0.025)
Other regional variables:				
Entitlements owned (ln ML)	0.715***	0.335***	0.659**	0.446***
	(0.235)	(0.100)	(0.328)	(0.163)
Groundwater use (ln ML)	-0.003		0.004	
	(0.063)		(0.089)	
Allocation level (%)	-0.002		-0.016	
	(0.007)		(0.012)	
Entitlement price (ln \$/ML)	0.204		1.481*	
•	(0.739)		(0.872)	
Allocation price previous year (ln \$/ML)	0.003		-0.532	
	(0.347)		(0.646)	
Irrigated cropping (%)	0.039		0.042*	0.040**
	(0.024)		(0.024)	(0.020)
Irrigated horticulture (perennial) (%)	-0.048**	-0.055***	0.015	
	(0.022)	(0.017)	(0.022)	
Irrigated horticulture (seasonal) (%)	0.048		-0.416	-0.509***
_	(0.198)		(0.257)	(0.182)
Irrigated grazing (%)	-0.0002		0.059***	0.054***
	(0.019)		(0.019)	(0.017)
Land in transition (%)	0.821***	0.796***	0.545	
	(0.226)	(0.225)	(0.409)	
Murrumbidgee (dummy)	-1.859*		-0.949	
-	(1.071)		(1.184)	
VIC Murray (dummy)	-2.405**		-2.535**	-1.928**
	(1.069)		(1.104)	(0.750)
Goulburn (dummy)	-3.296***	-1.655***	-3.570***	-2.988***
	(0.886)	(0.465)	(1.112)	(0.818)
NSW Murray (dummy)	-1.818*		-1.984*	
• • • • • • • • • • • • • • • • • • • •	(1.080)		(1.199)	
Loddon (dummy)	-1.371***	-1.177***	-0.696	
•	(0.518)	(0.399)	(0.884)	
2010/11 (dummy)	-2.475***	-2.260***	-2.057**	-2.406***
· • • • • • • • • • • • • • • • • • • •	(0.547)	(0.312)	(0.845)	(0.337)
2011/12 (dummy)	-2.108***	-2.124***	-2.089***	-1.831***
	(0.337)	(0.268)	(0.476)	(0.307)
2012/13 (dummy)	-0.437	-0.367*	-1.551**	-0.978***
- " \	(0.399)	(0.213)	(0.708)	(0.271)

Constant	-4.354	1.889	-10.35	0.427 (2.081)
	(6.310)	(1.271)	(6.964)	
Observations	623	709	442	506
Wald chi <sup>2</sup>	426.48***	360.71***	296.98***	209.55***
R <sup>2</sup> (overall)	0.30	0.27	0.33	0.27

Notes: robust standard errors in parentheses. \*p<0.10, \*\*p<0.05, \*\*\* p<0.01

#### 6.5.2.2 Other regional variables

Similar to the water entitlement models, entitlements owned were a strong driver of water allocation sales and purchases. Hence, irrigators in areas accounting for higher volumes of water entitlements were generally more active in water markets.

A weak result was found for increased entitlement prices showing a positive relationship with water allocation purchases (but not significant in the reduced form model). This indicates that some irrigators switched to buying water allocations during periods with higher water entitlement prices. Furthermore, the insignificant result for water allocation prices (in the previous year) is assumed to be caused by the large effect of the yearly dummy variables. As mentioned in Section 6.5.1.2, the dummy variables for the years reflect the changes in water allocation prices in the current years. The results for the yearly dummy variables demonstrate that the likelihood of water allocation trading increased over the years, due to higher water allocation prices in 2012/13 and particularly in 2013/14 (the negative relationship between 2012/13 and water allocation sales was not significant in the tobit model (Table G.9)). This effect may be exacerbated as irrigators became more experienced and accustomed with water allocation trading during recent years.

Analogous to the water entitlement selling model (Table 6.4), land use was a strong driver of water allocation trading. Overall, irrigators in irrigated cropping production bought increased volumes of water allocations and sold increased volumes of water entitlements (Table 6.5). Thus, this result gives evidence for the rise in irrigators shifting to water allocation trading after selling water entitlements (as discussed in Section 6.5.1.2 and found in previous studies, such as NWC (2012)). However, contrary results were found in the tobit models (Table G.9), i.e. increased acreage of irrigated cropping did not significantly affect water allocation purchases and significantly increased volumes of water allocation sales (though this a weak result and was not significant in the reduced form tobit model). Furthermore, increased acreage of irrigated horticulture (perennial) decreased volumes of water allocation sales, due to the stronger reliance of horticultural farmers with permanent plantings on water entitlements as suggested in other studies (e.g. Nauges et al. 2016). On the other hand, irrigated horticulture (seasonal) showed an unexpected negative relationship with water allocation purchases. It was anticipated that irrigated horticulture (seasonal) relies more on

water allocation markets, as the extent and type of seasonal plantings are more likely to be adjusted according to current environmental and economic conditions (e.g. NWC 2012). But this negative relationship with water allocation purchases was found to be insignificant in the tobit model (Table G.9).

Furthermore, increased acreage of irrigated grazing increased volumes of water allocation purchases. Together with the negative significant result in the water entitlement sales model (Table 6.4), it can be concluded that farmers in irrigated grazing production were more likely to rely on water allocation markets. As outlined in Chapter 2, water allocations are used more in VIC and NSW and this is where the majority of grazing/dairy activities take place. The dairy sector has experienced much turbulence in recent years (e.g. water scarcity, declining milk prices, raised grain prices). That is why it was expected that irrigated grazing was related to higher water sales overall, leading to some farm exits. But current statistics show that during the study period 2010/11–2013/14, the dairy sector was recovering from the shock of the drought with slowly increasing net farm income in 2010/11, 2011/12 and especially during 2013/14 when the region received above average rainfall rates (Ashton & Oliver 2015; DEDJTR 2015a). However, in 2012/13 net farm income had plunged again in northern VIC with fallen milk prices and raised input costs (DEDJTR 2015a). An overall recovery of dairy farm profitability and an increase in milk production following the drought years may explain increased water allocation purchases and decreased water entitlement sales for irrigated grazing.

Moreover, increased acreage of land in transition increased volumes of water allocation sales. This means overall that irrigators in regions with increased acreage of land in transition were selling more water allocations and buying more water entitlements (Table 6.4). This indicates that the previously abandoned land was rehabilitated to irrigated agriculture with primarily permanent plantings (e.g. as a result of the recent expansion of almond production (see Chapter 2)). But irrigators in those areas may also sell due to favourable market conditions (strategic water allocation sales) or water surpluses.

Finally, the river valley dummy variables showed a similar and unexpected relationship compared to the water entitlement models, i.e. the larger river valleys (in terms of volumes of water owned) were not driving volumes of water allocation trading. However, the results are weak for Murrumbidgee and NSW Murray (not significant in the reduced form). The relationship between water allocation sales and VIC Murray was also not significant in the reduced form model but strongly negative significant for water allocation purchases. Loddon was only significantly associated with water allocation sales. Goulburn showed a strong

negative relationship with water allocation trading. As it was found in Chapter 2, the number of water allocation transactions in Goulburn is high, yet volumes of water allocation trading per transaction are low.

#### **6.6 Conclusion**

This chapter has added a spatial element to traditional economic research in water trading. In addition to known influences on water trading, such as land use and prices, this chapter controlled for a range of spatial influences at the regional level. In particular, the chapter aimed to observe the effect of various regional resource characteristics, socio-economic factors as well as access to markets, infrastructure and other services.

The results show that at the regional level spatial influences significantly impact water entitlement markets in the southern MDB, especially water entitlement sales. Overall, in the reduced form models, groundwater use, land use, net rainfall (over the previous 5 years), dryland and surface-water salinity, business income for PP (previous year) and access to markets, played a significant role on water entitlement sales decision-making. Entitlements owned, land in transition, allocation price, net rainfall (over the previous 5 years), allocation level (over the previous 5 years), soil texture, primary production business income (previous year) and the river valley location, showed a significant relationship with water entitlement purchases.

In contrast, and as expected, spatial (long-term) effects were less likely to affect water allocation markets. Nevertheless, controlling for spatial factors in the water allocation trading behaviour models provided further insight into water allocation trading and the connection to the water entitlement market. Results showed how farmers potentially switch between water entitlement and allocation markets to meet their farm business needs (e.g. clearing debt), water demands, or to facilitate a structural adjustment process, as similarly found in other studies (e.g. Bjornlund 2002; NWC 2012). Specifically, farmers in more rural/isolated regions, who may be disadvantaged in terms of access to various infrastructure and services, sold more volumes of water entitlements and bought more volumes of water allocations. Thus, water markets provide an important adaptive tool for farmers in response to unfavourable conditions, such as being located in isolated areas. This was similarly suggested in Chapter 5 and other studies (e.g. Wheeler et al. 2014b). On this aggregated/regional level, agriculture in more rural and isolated areas may change to more flexible approaches in farm management and land use (e.g. giving preference to annual crops) if farmers rely more on water allocation markets. But this effect needs to be verified by further long-term research.

This chapter has also identified potential adaptation needs, as the negative relationships between surface-water salinity and water sales require further investigation in terms of how irrigators deal with increased surface-water salinity and resulting environmental consequences. As highlighted in previous studies (e.g. Crossman et al. 2010a), spatial planning in water and land use may resolve some of the counterproductive effects of irrigated agriculture. Spatially targeted information programs on the environmental consequences of irrigated agriculture, in addition to conservation programs, which aim, for example, to increase native vegetation (e.g. van Dijk et al. 2007) and optimise land use in general (e.g. Crossman et al. 2010a), are just some of the policy examples currently undertaken and likely to be enforced.

To summarise, this chapter provides new insights into the regional spatial pattern of water trading using aggregated data providing an overview of key environmental and socio-economic conditions affecting irrigated agriculture in the southern MDB. Thus, this chapter outlines broad influences and processes, such as the different influences of salinity issues or the varying effects of regional farm profitability on water trading. Understanding the spatial drivers of regional water trading is useful when designing regional agricultural, environmental and land use public policies and setting priorities for long-term adaptation in irrigated agriculture. Such a spatial analysis can identify areas where water use can be expected to decrease or increase, land use is potentially changing, surface-water is likely to be substituted by groundwater and where farmers have specific adaptation needs. As a result, future changes to the regional agriculture and biophysical processes can be predicted which relate to the individual farmers' decision-making. If needed, mitigation processes can be installed as well as assistance for farmers' adaptation needs can be provided and spatially targeted.

After analysing the spatial influences on water trading at the regional level, the next step is to assess the impact of spatial factors at the individual (farm) level. A farm-level analysis can contribute to the understanding of individual decision-making processes and their spatial dynamics, which completes the overall analysis of spatial influences on water trading. The following chapter presents this micro-scale analysis allowing to control for more individual characteristics and thus providing more detailed information to help guide a spatial policy design.

# Chapter 7 Location, Location, Location: the spatial influences on irrigators' water entitlement selling and water valuation

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

- 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.

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Signature	Date 21/11/16

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

## 7.1 Introduction

So far, the empirical analyses in this thesis (Chapters 5 and 6) have taken a broad-scale approach in investigating spatial influences on water trading behaviour. The two chapters have provided new insights into the spatial pattern of water trading in relation to a wide number of issues, such as regional salinity, socio-economic decline and access to markets and infrastructure. The literature reviewed in Chapter 6 suggested that spatial analysis at different spatial scales can produce different outcomes and can complement one another. Since regional analysis with aggregated data may mask complex processes and choices happening at the individual irrigator level (e.g. Gale 1994), this chapter aims to complement Chapters 5 and 6 by discerning the effect of spatial aspects on individual water trading decision-making (micro-scale). Thereby, this chapter accounts for detailed individual irrigator characteristics. This micro-scale analysis additionally controls for spatial farm interdependence, i.e. observing the influence of neighbouring irrigators' water trading decision-making (i.e. the 'neighbourhood effect' as introduced in Chapters 3 and 6), which was not accounted for by previous studies concerning actual<sup>88</sup> water trading decision-making.

This chapter's focus is on irrigators' water entitlement selling behaviour, given the water trading behaviour literature (Chapter 3) and results in Chapter 6 that suggested spatial influences primarily affected water entitlement trading (and especially water entitlement selling). Specifically, this chapter focuses on water sales to the government as part of the water buyback scheme for environmental purposes. As discussed in Chapter 2, buying water entitlements became an important instrument for the government to secure stability and longevity for environmental sites that were severely affected during the years of drought. There have been a variety of political questions raised about why irrigators might sell their water, and the corresponding regional impact. The issue still triggers much unrest in rural communities. Therefore, research focusing on irrigators' water trading behaviour is not only essential for the overall outcome of water markets but also for the success of environmental programs, such as the buyback scheme.

Additionally, this chapter extends the spatial analysis to irrigators' stated price choices when deciding at what price levels they would start buying or stop selling water entitlements. This analysis is related to the broad body of literature on willingness to pay (WTP) and willingness

<sup>&</sup>lt;sup>88</sup> A stated preference study on hypothetical water lease offers asked irrigators if the information on the percentage of neighbours in their community leasing water would influence their decision (Cook & Rabotyagov 2014). Half of the irrigators answered it would not influence their decision.

to accept (WTA) in agricultural and environmental economics.<sup>89</sup> This literature mainly focuses on WTP for resources protection, including valuation of ecosystem services, (e.g. Halkos & Matsiori 2014) and the WTA to compensate for a loss in environmental amenity (e.g. LeVert et al. 2009). A number of studies have focused on the spatial pattern of WTP in recent years (e.g. Campbell et al. 2009; Johnston et al. 2015; Loomis & Mueller 2013; Tait et al. 2012). The distance to environmental amenity is typically found to significantly explain WTP which proves relevance of accounting for spatial dependence to avoid biased WTP results (Loomis & Mueller 2013). Overall, revealing the spatial distribution of WTP supports policy makers in identifying areas of great value for the purpose of an efficient spatial targeting approach of public investment (Campbell et al. 2009). Hence, identifying the spatial distribution and determinants of irrigators' values for water entitlements facilitates identifying areas where irrigators place high or low values on water entitlements, which can be useful when planning for environmental programs, such as the water buyback scheme.

A few studies have investigated irrigators' stated preferences for water selling and buying prices (Giannoccaro et al. 2015; Zuo et al. 2015a). Giannoccaro et al. (2015) found that stated preferences in a temporary water market depended on the marginal productivity of water (e.g. regarding higher value crops), access to water (e.g. different preferences for irrigated and dryland agriculture), and water availability (e.g. drought years). Zuo et al. (2015a) showed that price elasticities of water entitlement trading are inelastic between AUD\$1,700 to \$2,100 (per ML), and that supply is relatively more inelastic than demand. Further, Zuo et al. (2015b) found that irrigators' willingness to exit irrigation is generally price elastic, but there are large regional differences in price elasticities. Other studies analysed revealed prices in water entitlement markets, such as Bjornlund and Rossini (2007) who concluded that prices were influenced by water allocation prices, seasonal allocation levels, vine grape prices and interest rates. Overall, most of the studies focused on stated WTP measures for buying temporary irrigation water (e.g. Alcon et al. 2014; Aydogdu 2016; Bakopoulou et al. 2010; Harun et al. 2015; Rigby et al. 2010) and there exists a broad literature on irrigation water valuation more generally using different methods (Birol et al. 2006; Hussain et al. 2007; Young & Loomis 2014). Studies exploring stated preferences for water sales and purchases (in the water entitlement market) are rare and none of the studies have employed a spatial approach, but it is generally recognised that values of water differ spatially (e.g. Hussain et al. 2007).

<sup>&</sup>lt;sup>89</sup> The contingent valuation method (CVM) is predominantly applied in stated preference studies for measuring economic values (Mitchell & Carson 1989; Young & Loomis 2014). During the survey design in CVM studies, it is important to be aware of several potential biases, e.g. the hypothetical bias where survey participants may reveal hypothetical WTP that overstate their actual WTP (Young & Loomis 2014).

In this chapter, irrigators' individual data, including their water trading behaviour information, was sourced from two surveys conducted in 2010 and 2011 in the southern MDB (n=1,462). Secondary spatial data was collected from various government sources. Using GIS, irrigator locations were geocoded and spatial characteristics were linked to the irrigator survey data. The subsequent model analysis on water entitlement sales expanded the model in Wheeler et al. (2012b) and tested whether accounting for spatial influences improved the outcome of the model. This methodology of combining socio-economic survey data with secondary spatial data, to be analysed using spatial and econometric methods, is not often found in the literature, due to extended data collection processes and other required resources. However, this chapter draws on a number of studies that have taken a similar approach (e.g. Lynch & Lovell 2003; Müller & Zeller 2002; Staal et al. 2002).

### 7.2 Neighbourhood effect and water trading

As described in Chapter 3, the motivation for investigating a neighbourhood effect amongst irrigators arose from anecdotal evidence that showed severe social pressure amongst irrigators in the 1980s and 1990s (e.g. irrigators were ostracised from the local pub) when (considering) selling water from their area (e.g. Fenton 2006). Although this social pressure started to disappear for selling water allocations, it remained for selling water entitlements right up into the late 2000s, potentially due to the long-term nature of this water right and the attachment to irrigators' land in the past.

Generally, it is increasingly recognised that interactions and interrelations among people shape human behaviour, such as the adoption of agricultural innovations (Palis et al. 2005). An increasing interest in exploring the potential interdependence of farm neighbours' decision-making is based on related key theories introduced by sociologists and geographers. Sociologists highlighted the strong impact of social capital, whereas geographers highlighted the spatial variation (see Chapter 3).<sup>90</sup>

Broadly, a neighbourhood effect may arise through information exchange or the influence of social norms (Holloway & Lapar 2007). Hence, neighbourhood effects existed amongst irrigators in the southern MDB through the influence of social norms/pressure. Over time, this neighbourhood effect may have been reversed, when gradually irrigators broke the social norm and started to sell water entitlements, which potentially encouraged more irrigators to

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<sup>&</sup>lt;sup>90</sup> "On the whole, the importance of dynamics within a farm district for participation should not be underestimated, as farmers are inherently sceptical about "outsiders" (i.e. from outside the district) telling them what to do on their farms. [...] "Dynamics within the farm district were of crucial importance for laggards and undecided farmers" (Wilson 1997, pp. 88-90).

participate in the market. In addition to increased information exchange (and hence lower transaction costs), irrigators may also sell their water in response to neighbours' selling decisions because they are worried about a decline of the local irrigation community, and an increase in irrigation infrastructure and other costs.

The literature review in Chapter 6 showed that decisions made by neighbours have a significant impact on farmers' behaviour in a range of spheres. For example, in land use decision-making, which can be related to water trading behaviour, it was found that farmland abandonment was related to whether neighbouring farmland was abandoned or continued to be in use (Gellrich et al. 2007). Farmers' decisions were also found to be spatially dependent in studies on market participation (e.g. Holloway & Lapar 2007) and the adoption of organic farming (e.g. Läpple & Kelley 2013), fertiliser (e.g. Isham 2002) and farm technologies (e.g. Case 1992). Agglomeration economies (see Chapter 6) are a common explanation for a neighbourhood effect, particularly in studies investigating the adoption of organic farming and farm technologies. In this case, the clustering of farmers with similar practices or technologies provide several production advantages and thereby promote further adoption (e.g. Wollni & Andersson 2014). However, in the case of water trading, other reasons, such as exchanging experience/information, are more likely to be relevant for a neighbourhood effect.

From a policy-planning point of view, it is useful to elucidate the location and size of the neighbourhood effect, or in other words, the externality associated with convincing one farmer within an area to adopt a preferred practice (Case 1992). Thereby, public spending (e.g. on extension services) can be optimally planned. Similarly, Holloway and Lapar (2007, p. 39) emphasised the role of a neighbourhood effect when devising a market-access policy which "can have important bearing on the precision with which policy prescriptions are formalised, the potency of policies enacted, and the ranking of policies designed to increase the regional density of market participation."

Analysing a potential neighbourhood effect can be challenging and is regarded as a "complex and highly heterogeneous aspect of household decision-making." (Holloway & Lapar 2007, p. 53). The key question in spatial studies is 'how big is the neighbourhood?' Studies have taken different approaches in defining the size of the neighbourhood, according to the study area and the study's capabilities. Some adoption studies claim that farmers learn from other farmers, who are closest to their farm fields (e.g. Palis et al. 2005). This could be relevant for the adoption of physical technology; however, it may be more complex in the case of water trading, since this is a practice that cannot be physically observed. Thus, there is a higher initial uncertainty as to water trading decision-making (e.g. in terms of the different water

rights and selling options), which may require frequent interaction and discussion with other irrigators in a wider network to increase the uptake of water trading. Thus, the farmer's wider community area may be more suitable for an analysis of a neighbourhood effect in water trading. This is further discussed in Section 7.4.2.2.

# 7.3 Hypotheses

This chapter's hypotheses refer to the previous chapter's hypotheses *H1*, *H4* and *H5* (Section 6.3) while focusing on spatial influences at the micro-scale and discrete choices of water entitlement sales. This chapter further tests the following hypotheses:

*H3*: An increase in a community area's numbers of irrigators having sold water to the government is associated with an increased likelihood of an individual's water selling decision by making it more socially acceptable (referred to as the 'neighbourhood effect').

*H6*: Including spatial variables in a traditional economic model of water entitlement selling (see Wheeler et al. 2012b) increases the explanatory power of the model.

*H7*: Spatial determinants have a larger impact on irrigators' price choices for selling water entitlements (WTA) rather than purchasing water entitlements (WTP) (in line with previous results suggesting spatial factors have a larger impact on water entitlement sales compared to purchases).

## 7.4 Methodology

#### 7.4.1 Survey data

Two datasets of irrigator surveys in the southern MDB were available to be used in this

chapter. Data was collected in 2010 (n=942) $^{91}$  and 2011 $^{92}$  (n=535) $^{93}$  for the previous farming seasons, 2009/10 and 2010/11 respectively. The survey data comprised farmer, farm and

location (address) information, the latter allowed for spatial analysis using GIS. Spatial

<sup>&</sup>lt;sup>91</sup> The 2010 survey was conducted via telephone through computer assisted interviewing techniques (30% response rate) and randomly selecting survey participants from farming lists (Wheeler et al. 2012b). To account for potential errors due to missing answers a sensitivity analysis revealed no significant changes to model results in Wheeler et al. (2012b).

<sup>&</sup>lt;sup>92</sup> The author assisted with the data collection and preparation during the 2011 survey as a Research Assistant prior to starting work on this thesis.

<sup>&</sup>lt;sup>93</sup> The 2011 mail-out survey contacted the same list of irrigators from the 2010 survey as a follow-up survey. The survey reached a 63% response rate. Comparisons were made with the original sample of the telephone survey and other regional data from ABS and ABARES, which confirmed that there was no non-response bias and that the survey results were highly representative for the southern MDB (e.g. Zuo et al. 2015b).

outliers (see Section 7.4.2.1) were dropped from the analysis, which resulted in the final numbers of observations: n=1,462 (2010: n=931, 2011: n=531). The 2011 survey was a subsample of the 2010 survey; hence, a spatial analysis across two farming seasons was possible for recurrent or time invariant survey data. Over the two survey years, survey respondents were evenly distributed over the states (NSW: 33%; SA: 28%; VIC: 39%) as well as the percentage of irrigators having sold water entitlements to the government (11%). In the 2011 survey, 29 farmers provided no information to this question. The full list of questions from both surveys, regarding irrigators' decision to sell water entitlements to the government, is provided in Appendix H.

Furthermore, this chapter's analysis incorporates additional data on water entitlement sales supplied by the Department of the Environment and Energy (DoEE) (formerly Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC)). The DoEE conducted a survey amongst willing sellers in the southern MDB in 2012. This chapter used the locations of those who had sold water to the government between 2008 and 2010 and who had not participated in the above described surveys specifically for analysing the neighbourhood effect. This provides for a more accurate representation of the irrigators' neighbourhoods and the neighbours' selling decisions.

In the 2011 survey, irrigators additionally provided information on their price choices for selling water entitlements (WTA) and purchasing water entitlements (WTP). More precisely, irrigators indicated how much water entitlements they would buy or sell at different prices. The price range for both water sales and purchases was AUD\$500/ML-AUD\$5,000/ML with an AUD\$500/ML increment (see Appendix H). This chapter's final analysis uses the average minimum price for high security water entitlement selling (WTA) and the average maximum price for high security water entitlement buying (WTP) to assess the relevance of spatial determinants on irrigators' stated preferences. The number of observations was 304 for willing sellers and 258 for willing buyers within this price range. Descriptive statistics reveal a large gap (i.e. AUD\$1,801/ML) between the average maximum price for buying water entitlements (AUD\$3,146.38/ML) across willing buyers and sellers respectively. This provides evidence for an existing 'endowment effect' for irrigators' water entitlements, which is discussed in Section 7.5.2.2.

Other survey data that control for farmers' socio-economic factors (e.g. age, education, income, health), farm characteristics (e.g. farm size, land use, farm plan, employees) and regional factors (percentage of seasonal allocation) in the water selling and price models are

based on the full model in Wheeler et al. (2012b). This survey data is described in Table 7.2 and Wheeler et al. (2012b).

### 7.4.2 Spatial data preparation

### 7.4.2.1 Geocoding

Farmers' address data<sup>94</sup>, which was provided in the 2010 survey, was geocoded using ArcGIS 10.1 to provide for display and spatial analysis capabilities. This means, farm locations were converted to a point position to be placed on a map with coordinates of the specified (see Chapter 6) coordinate system.

Address input and address reference data often lack in completeness and accuracy, especially within rural Australia. Rural addresses are often not standardised and may not represent the exact location of a residence, as they are typically created according to a rural mail route used by the local mail carrier (Vieira et al. 2010). In this chapter, it is assumed that the addresses given in the surveys belong to the irrigator's homestead and the relevant farmland nearby. But it needs to be considered that in some cases the farm postal addresses may not exactly represent the location of the farm production area, e.g. where farmland is dispersed over a large area or the farm homestead is not connected to the farm production. When geocoding rural addresses these obstacles need to be considered during the subsequent spatial analysis (e.g. selecting larger zones when extracting spatial data statistics) and the interpretation of results.

Prior to geocoding, farm addresses were checked to remove spelling and other errors, and were tested in the Google Maps application. A number of farmers provided a Post Box or urban address, or specified no street name (n=221). These addresses were reduced to the city or postcode area, as Post Box addresses and missing street names will not match to an accurate location within a reference address database, and urban addresses are assumed to not

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<sup>&</sup>lt;sup>94</sup> To maintain farmers' confidentiality, locations are presented on a broad scale only and farmers were identified by an ID number, i.e. no name details were exported during the geocoding process.

<sup>&</sup>lt;sup>95</sup> There is a consensus amongst a range of studies that rural address geocoding leads to higher positional errors compared to urban address geocoding (e.g. Cayo & Talbot 2003; Ward et al. 2005).

<sup>&</sup>lt;sup>96</sup> Rural addresses can consist of a Roadside Mail Box (RMB), Roadside Delivery (RSD) number, lot number, a Section or farm name/number that is added to the street name. Usage varies greatly among the states. During recent years rural addresses were replaced with a new rural addressing system in SA and areas in VIC and NSW based on the distance of a property entrance to the start of the main road (e.g. DPTI 2016). However, the addresses given in this chapter's survey data were based on traditional rural addressing.

<sup>&</sup>lt;sup>97</sup> According to Williams (1970) it can be assumed that the distance between rural farmers' homestead and farmland is on average less than 3km, if farmland is not fragmented.

<sup>&</sup>lt;sup>98</sup> Studies on farmland fragmentation in Australia are rare and dated. A study in western SA showed that the mean distance between homestead parcels and detached parcels within the study area was 12km and outside the study area 50km (Hill & Smith 1977). Another study on town-farmers in the Mallee regions of SA and VIC found the average distance between the town centre and farm parcels to be 14km with a maximum of 47km (Williams 1970).

represent the actual farm production area. Furthermore, 128 addresses were given in traditional rural address types, which were not likely to be geocoded to a high accuracy level, as reference address databases commonly have not recorded these address types.

During the geocoding process, multiple address locators were used (referring to Appendix I for more detail). The majority of the survey addresses were geocoded using the 'World Geocoding' address locator offered by ArcGIS online, which provides modern batch (bulk) geocoding capabilities. This service matches address data to the 'HERE' (formerly 'NAVTEQ') address reference dataset, which includes Australian address data at all geocoding accuracy levels (ESRI 2013b; Harold 2012). ArcGIS online provided for five different geocoding accuracy levels: *PointAddress*, *StreetAddress*, *StreetName*, *PostalLoc*, and *Postal*.

PointAddress and StreetAddress<sup>99</sup> deliver the highest geocoding accuracy level. StreetName<sup>100</sup> provides locations on the street with missing house numbers (medium accuracy level) and PostalLoc and Postal provide locations only regarding the city or postcode area (low accuracy level). The latter two need to be used with caution in micro-scale studies, as low geocoding accuracy locations may cause biased results (e.g. Goldberg et al. 2007; Hurley et al. 2003; Sheehan et al. 2000). There is no clear consensus about the acceptable level of the overall geocoding accuracy. The impact of geocoding errors depends on the study area and the spatial variation of the object of study (Ward et al. 2005).

ArcGIS online assigned the farmer addresses to coordinates according to a rated score of matched reference data locations. The geocoding results were reviewed and rematched if necessary (see example Figure I.1). Thereby, remaining mistakes could be resolved, e.g. regarding misspelling or mix-ups due to different street name suffixes (street, road, avenue, lane etc.). The matching score rate provides an indication of the likelihood of a correct match.

Another geocoding provider ('Callpoint Spatial') was used to cross-check addresses that could not be matched within the HERE reference data, to improve match rates and accuracy levels of farm locations. Callpoint Spatial used the Geocoded National Address File (G-NAF)

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<sup>&</sup>lt;sup>99</sup> For *StreetAddress* the house number is interpolated from a range of numbers (reference data contains street centrelines with house number ranges) (ESRI 2013a).

<sup>&</sup>lt;sup>100</sup> The StreetName locator can be accurate for short street segments, but less so for longer street segments (ESRI 2013a). ArcGIS online *StreetName* locator placed the location at the beginning of the street.

address reference data. This cross-checking provided further address matches, which improved the overall match rate. 101

The results of the geocoding process are shown in Table 7.1. Irrigators located outside of the boundaries of the southern MDB (spatial outliers) were dropped from the sample. This reduced the overall number of observations to n=931, with 709 (76%) locations of high or medium geocoding accuracy levels, and 222 (24%) locations of low geocoding accuracy levels.

Thus, it needs to be taken into account that over 20% of the locations were geocoded to a broad-scale level, which is less suitable for micro-scale spatial observations, since e.g. the distance between farming neighbours cannot be accurately calculated. Only 34% of the survey addresses were matched to the highest geocoding accuracy levels. This result is not surprising, considering the high number of obstacles involved with rural geocoding as described above. It was found that VIC maintains the most accurate rural street addresses, whereas SA rural addresses were predominantly assigned to lower accuracy levels. The resulting map of the farmers' locations in the southern MDB is presented in Figure 7.1. This map shows the clustered pattern of irrigators' location, particularly in VIC and SA when compared to NSW (which is a result of the historical developments of irrigation settlements described in Chapter 2). The additional locations of water sellers in the southern MDB from the DoEE database were also geocoded using ArcGIS online leading to 1,042 irrigator locations (46% at high/medium geocoding level) which are used for the neighbourhood variable (see the following section).

Table 7.1: Results of the geocoding process: number of geocoded locations by accuracy level and state

Geocoding accuracy level	VIC	NSW	SA	Total	%
High	258	35	21	314	34
Medium	55	217	123	395	42
Low	46	60	116	222	24
Total	359	312	260	931	100

<sup>102</sup> Urban studies may use postcode area geocoding as reasonable proxies to street geocoding (Bow et al. 2004), but in the case of rural areas in Australia, the four-digit postcode areas tend to be large in size and consequently mapping farmers' position according to their postcode areas denotes a regional analysis.

<sup>&</sup>lt;sup>101</sup> With a Callpoint Spatial trial account 100 addresses could be geocoded via a web-based application. Addresses were chosen that were not matched to a high accuracy level through ArcGIS online. As a result around half of the addresses could be matched to an *AddressPoint* and the other half to *StreetName*. Only 7 addresses were not found in G-NAF. However, from the 21 rural farm addresses that were tested only 2 addresses could be matched to an *AddressPoint*. Thus, rural farm addresses are likewise not easily geocoded within the G-NAF reference database and no further address checking was undertaken.

Legend
Irrigators' farm locations
Perennial rivers and lakes
States and Territory boundaries
River valleys

Lower Darling

Lachlan

Total SA

Murrumbidgee

Vommera–Mallee (Surface Water)
Levis South Wales Murray
Voite Han Nurray
Voite Han Nurray
Loddon

Broken Kiewa
Ovens Victorian Murray
Campaspe Gouburn

Figure 7.1: Irrigators' farm locations in the southern MDB

Own map (base map sources: Geoscience (2006) and MDBA (2013a))

200 Kilometers

### 7.4.2.2 Spatial variables and spatial units

Neighbourhood variable

50 100

Farmers' neighbourhood areas can be defined in various ways, e.g. based on distances, knearest neighbours<sup>103</sup> or defined zones. Exact information on the neighbourhood size is typically not available. Most of the studies reviewed in Chapter 6 that analysed a neighbourhood effect did not elaborate in detail about the potential size of the neighbourhood, but rather made assumptions about its possible size. The difficulty of identifying and measuring neighbourhood effects was emphasised by Krugman (1991, pp. 53-54): "Knowledge flows [...] are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them"

Thus, the size of the neighbourhood (or the spatial weight matrix when employing spatial regression), is often arbitrary and a neglected field of research, which may result in biased model estimations and inappropriate policy implications (e.g. Holloway & Lapar 2007; Storm et al. 2015). A radius that is too wide or too narrow may dilute effects or omit potential spatial influences respectively (Irwin & Bockstael 2002). Conversely, some studies argued that

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<sup>&</sup>lt;sup>103</sup> The neighbourhood is based on a specified number (k) of neighbours regardless of distance (within a maximum distance if specified) (ESRI 2016b).

model results are largely unaffected by the definition of the spatial weights matrix (LeSage & Pace 2011; Storm et al. 2015).

There exists no generalisation of the neighbourhood size, because it heavily depends on various locational, socio-economic and cultural factors as well as the dataset and the research question to be analysed. Thus, sensitivity analyses are suggested to examine different outcomes from alternate neighbourhood specifications (Anselin 2002; Bell & Dalton 2007). For example, Läpple and Kelley (2014) used 20km as a minimum and 50km as the maximum distance (i.e. radius) in an Irish study and tested the model outcome for 20, 30, 40 and 50km using an inverse distance matrix. <sup>104</sup>

Studies undertaken in countries that are, similar to Australia, large in size employed a neighbourhood size, for example of 80km (USA study) (Wu et al. 2011), or the three nearest neighbours (Brazilian study) (Garrett et al. 2013); however, both studies employed a broad-scale (county) analysis. Specific study areas have specific characteristics in terms of farm sizes, land allocation, and land management, along with how rural communities operate, which results in different farm neighbourhood sizes for different countries. Given the size of the study area in this chapter (47,0850km²) and considering Australia's vast land resources in general, Australian farms tend to be large in size and may therefore have long distances to overcome to neighbouring farms in a community, especially in rural areas. Neighbourhood sizes for the southern MDB also need to account for the different spatial patterns (clustered and dispersed) of irrigator locations (see Figure 7.1). Thus, it can be expected that neighbourhood sizes in the southern MDB differ across regions. Other studies, also suggested varying neighbourhood (social network) sizes (Thomson 2001), particularly for dispersed farm locations (Storm et al. 2015).

A neighbourhood based on a cut-off distance or on k-nearest neighbours is less suitable in this chapter's analysis since many irrigator locations were not geocoded to a precise accuracy level, and hence, distances between irrigators may not be represented accurately. Thus, such an approach would require dropping locations with low geocoding qualities and spatial outliers within the southern MDB, which would decrease the sample size substantially. If the entire sample would be considered for a distance-based neighbourhood specification, irrigators' dispersed distribution across the study area would result in a minimum distance<sup>105</sup>

<sup>105</sup> The distances between irrigators were assessed using the 'Calculate Distance band from Neighbour Count' tool in ArcGIS which computes the maximum, minimum and the average distance to a specified number of nearest neighbours.

<sup>&</sup>lt;sup>104</sup> An inverse distance matrix gives greater weights to points closest to the prediction location. Weights diminish as a function of distance (ESRI 2012).

of 85.5km, to ensure that each irrigator has at least one neighbour. Neighbourhood areas at a radius of 85.5km would be large in area size for all regions with highly variable numbers of neighbours (minimum of one neighbour and a maximum of 377 neighbours), which is not feasible.

That is why, this chapter employed zones that vary in area sizes (which can be regarded as 'community areas') to capture the neighbourhood effect. Pujol et al. (2006) defined irrigation districts as an appropriate irrigator community area. Though this seems to be a reasonable approach, a number of farmer locations in this chapter's dataset could not clearly be allocated to an IIO area or were private irrigators. Following ABS (2010a, web page), community areas are supposed to be captured by SA2: "Their aim is to represent a community that interacts together socially and economically." SA2 vary in sizes according to population sizes, which is expected to correspond to farming communities that are likely to be larger in size in more rural areas. 106 SA2 boundaries also align with state boundaries, ensuring that irrigators within one SA2 follow similar institutional settings. Additionally, studies confirm that often farmers perceive their community wider than just the immediate neighbourhood, e.g. in the case of New Zealand farmers (Sligo & Massey 2007). Choosing larger community areas (particularly for rural areas) also accounts for low geocoding qualities. Thus, SA2 were used to depict the potential social influence/spatial dependence in a neighbourhood by calculating the numbers of irrigators that had sold water entitlements per SA2 (see Figure 7.2 for SA2 boundaries).

A number of other studies also used administrative boundaries as appropriate neighbourhood sizes and argued that if there are no socio-cultural factors that define different neighbourhood sizes, then administrative boundaries are appropriate to specify the neighbourhood (e.g. Holloway & Lapar 2007). In contrast, it was also suggested to be vigilant when using administrative boundaries as neighbourhood areas, because this may introduce artificial boundaries where the area is better understood as the same neighbourhood, which can also cause spatial dependence in the dataset (Logan 2016; Sampson et al. 1999).

Measuring the neighbourhood effect by counting numbers of adopters (or in this case water sellers) in a neighbourhood area is a widely preferred method compared to elucidating social influences directly through surveys, because farmers are likely to view themselves as independent operators who are uninfluenced by neighbours' opinions/behaviour (Burton 2004b; Gasson 1973; Wilson 1996).

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<sup>106</sup> As described in Chapter 3, communities/social networks may also be defined by social and cultural characteristics ('communities of interest and identity'); however, this chapter focuses on 'communities of place' (ABARE-BRS 2010).

#### Other spatial variables

This chapter draws upon the GIS-database described in Chapter 6 (Section 6.4.2). Specifically, net rainfall, soil texture, <sup>107</sup> salinity information, population growth and cities were sourced from the same sources described in Chapter 6. But variable calculation in this chapter was based on the individual irrigator locations.

Spatial information regarding the farmers' location was calculated, extracted and combined with the relevant survey data. A 30km buffer zone around the farm locations was used as a base unit for calculating spatial statistics on the biophysical data (i.e. net rainfall, soil texture and various types of salinity). This accounted for the effect of low geocoding qualities for some locations as well as for other obstacles mentioned in sections (i.e. farmland may be dispersed in the region, or the address given belongs to farmers' homesteads potentially detached from farm production area). This further accounted for some farms that are large in size (maximum farm size in this study is 20,000ha, i.e. approximately 8km radius).

GIS methods were used to create the circular buffer zones around each farmer location. For the calculation of the spatial statistics, similar tools and techniques were used to those described in Chapter 6. An additional (user written) GIS toolbox (Noman 2013) was needed to be able to calculate spatial statistics from overlapping zones, given irrigators' buffer zones tended to overlay. Figure 7.2 illustrates the spatial units used for the analysis (irrigators' 30km buffer zones and SA2 boundaries).

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<sup>&</sup>lt;sup>107</sup> During the data collection process, several other soil data were collected (Table 7.8). Using a Principal-Component-Analysis (PCA) it was the aim to estimate soil quality measures, focusing e.g. on the physical or chemical properties of the soil. But the different spatial and temporal dimensions of those soil datasets prevented a robust PCA, which was left for future research.

<sup>&</sup>lt;sup>108</sup> In initial models, spatial variables were based on a net of rectangular cells (using the 'Create Fishnet' GIStool) that overlayed the southern MDB data layer at differing sizes for the rectangular (i.e. 30, 40 and 50km). But the individual farmer buffer zones are expected to better represent the environment and location of the individual farmer.

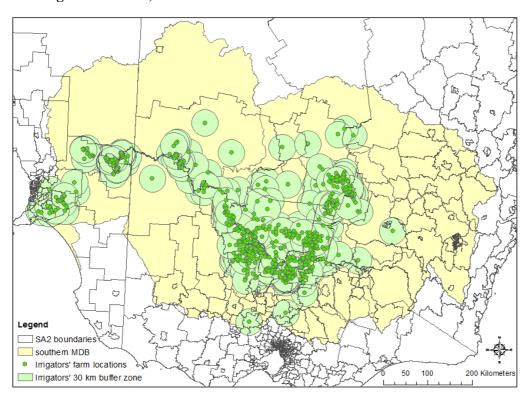


Figure 7.2: Irrigator locations, their buffer zones and SA2 in the southern MDB

Own map (base map sources: ABS (2010a) and MDBA (2013a))

The remaining spatial variables were distance based (i.e. Euclidean (straight-line) distances to cities and downstream area) and based on community areas (i.e. regional socio-economic data regarding population growth per SA2). Some misrepresentation of the distance variables for the farm locations at low geocoding quality levels is expected and needs to be considered when interpreting the results.

Table 7.2 provides a summary on all survey and spatial variables that were assessed in this chapter, including a variable description and the data source. Table 7.3 provides the relevant descriptive statistics.

Table 7.2: Variable description and data sources

Variable	Details	Source
Dependent varia		
Buyback	1=irrigator sold water entitlements to government for environmental purposes (in 2009/10 for 2010 survey and in 2010/11 for 2011 survey); 0=otherwise	Surveys
Price selling (WTA)	Average minimum price (AUD\$/ML) the irrigator would sell high security water entitlements (natural log) (categorical question: \$500–\$5,000/ML in \$500/ML increments) <sup>a</sup>	Survey (2011)
Price buying (WTP)	Average maximum price (AUD\$/ML) the irrigator would buy high security water entitlements (natural log) (categorical question: \$500–\$5,000/ML in \$500/ML increments) <sup>b</sup>	Survey (2011)
Independent sur	•	
Age	Farmers' age (years)	Surveys
Age squared	Farmers' age (years, squared)	Surveys
Low education	1=highest education level is Year 10 or below; 0=otherwise	Survey (2010)
Farm plan	1=has a whole farm plan <sup>c</sup> ; 0=otherwise	Survey (2010)
Government agency	1=information source is government agencies; 0=otherwise	Survey (2010)
Water entitlement owned	Sum of high security water entitlements (ML, natural log) before sale to the government (in NSW including general security entitlements)	Surveys
Groundwater entitlements owned	Sum of volumetric groundwater entitlements (ML, natural log)	Surveys
Carry-over	Carry-over water saved (ML, natural log) from the previous season	Surveys
Entitlement sale private market	1=sold water entitlements in the private market prior 2008 for 2010 survey and prior 2009 for 2011 survey; 0=otherwise	Surveys
Allocation trade	1=Irrigator is a net seller of water allocations, 0=otherwise, for 2010 survey; 1=was a net seller in 2009/10 and has sold water allocations in 2010/11, 0=otherwise, for 2011 survey	Surveys
Operating surplus	Net farm operating surplus (AUD\$, natural log)	Surveys
Off-farm income	Percentage of household income from off-farm work	Surveys
Debt	Farm debt to equity ratio (debt to land value ratio for 2011 survey)	Surveys
Debt 2010/11	Average farm debt (AUD\$, natural log) at the end of 2010/11(in categories: <\$20,000, \$20,000 to \$40,000, \$40,000 to \$60,000, \$60,000 to \$80,000, \$80,000 to \$100,000, >\$100,000)	Survey (2011)
Diverse	Index of how many farming activities the farm earns income from (crop types, one crop=1, two crops=2 etc.)	Survey (2010)
Farm size	Farm size (ha)	Surveys
Employees	Number of full time equivalent farm employees	Survey (2010)
Annual crops	Percentage of area in annual crops per irrigated area <sup>d</sup>	Surveys
Horticulture	Percentage of area in horticulture (incl. viticulture) from irrigation ha	Surveys
Organic	1=Certified organic produce grower; 0=otherwise (dummy)	Survey (2010)
Children	Number of children	Survey (2010)
Gender	1=male; 0=otherwise	Survey (2010)
Successor	1=expecting a family member to take over the farm; 0=otherwise	Survey (2010)
Health	Farmer health Likert scale: 1=poor, 2=fair, 3=good, 4=very good and 5=excellent	Survey (2010)
Risk type	Likert scale: from 1=totally unwilling to take risks to 5=completely willing to take risks	Survey (2010)
Productivity change	Likert scale of productivity change in the last 5 years: 1=strongly decreasing to 5=strongly increasing	Survey (2010)
Survey year	1=survey year 2010; 0=otherwise	Surveys

Variable	Details	Source			
Independent spatial variables:					
Net rainfall	Rainfall minus evapotranspiration, averaged for previous 5 years, 2005/06–2009/10 and 2006/07–2010/11 respectively (mean annual for the irrigators' 30km buffer zone, mm/d)	Raupach et al. (2009, 2012)			
Soil texture	Index of soil texture in the soil layer 1: 1=sands, 2=sandy loams, 3=loams, 4=clay loams/light clays, 5=clays (mean for the irrigators' 30km buffer zone)	CSIRO (2001)			
Dryland salinity	1=Irrigators' 30km buffer zone is affected by dryland salinity risk/hazard; 0=otherwise	NLWRA (2001)			
Groundwater salinity	1=Irrigators' 30km buffer zone is affected by saline groundwater (> 3,000 mg/l TDS); 0=otherwise; composite dataset (1994–2009)	BoM (2014)			
Surface-water salinity	1=Mean salinity level (EC) of the nearest salinity station is > 325 EC, 2007/08–2009/10 for 2010 survey and 2010/11 for 2011 survey	MDBA (2011a, 2012b)			
Regional population growth	Percentage of regional population change averaged for the previous 5 years, 2005–2009 and 2006–2010 respectively (per SA2)	ABS (2015c)			
Distance to cities	Distance to cities (km) with population > 5,000	ABS (2012a)			
Neighbours sold	Cumulative numbers of neighbours sold water entitlements to the government since 2008 (SA2), excluding the irrigators' own decision, including sales data from a DoEE survey in 2012	Surveys; DoEE (sales data in 2012)			
Distance to downstream area	Distance to downstream area/River Murray mouth (km)	Own calculation using GIS			
Other independe	ent regional variables:				
IIO charges	Irrigation Infrastructure Operator (IIO) charges (AUD\$/ML, natural log): Total annual irrigator bills (variable and fixed charges) for 250 ML of entitlement with delivery of 100% allocation (CIT: averages for pumping pressures, Murray Irrigation: weighted according to the ownership of general and high security water), 0=private irrigator only; for each survey year respectively	ACCC (2011, 2012)			
Allocation percent	Mean end-of-season allocations to high- and low-security entitlements for the previous 5 years, 2005/06–2009/10 and 2006/07–2010/11 respectively, weighted by individual ownership of high and low/general security water entitlements	NWC (2011c)			
Water entitlement price	High security water entitlement prices (AUD\$/ML, natural log) per river valley of the previous years, 2007/08 for 2010 survey and 2008/09 for 2011 survey (volume weighted average prices; general security prices only for Lachlan region)	Kaczan et al. (2011); NWC (2011f, 2013b)			

<sup>&</sup>lt;sup>a</sup> For example, the average between AUD\$1,000/ML and AUD\$1,500/ML was used when the irrigator indicated a minimum price for water entitlement sales at AUD\$1,500/ML (with a certain volume of water), as the exact threshold level was unknown.

<sup>&</sup>lt;sup>b</sup> For example, the average between AUD\$1,500/ML and AUD\$2,000/ML was used when the irrigator indicated a maximum price for water purchases at AUD\$1,500/ML (with a certain volume of water), as the exact threshold level was unknown.

 $<sup>^{\</sup>rm c}$  A whole farm plan comprises, for example, land classing, water supply, biodiversity, succession planning, drought management and identifying threats and assets (DEDJTR 2016).

<sup>&</sup>lt;sup>d</sup> In the 2011 survey, some farmers did not want to give detailed information about their production year 2010/11 and some farmers were flooded out so that no production was possible in that year.

**Table 7.3: Descriptive statistics** 

Variable	Obs.	Mean	Standard deviation	Min	Max
Buyback surveys combined (dummy)	1,432	0.11	0.32	0	1
Buyback 2010 survey (dummy)	931	0.11	0.32	0	1
Buyback 2011 survey (dummy)	501	0.11	0.32	0	1
Price selling (WTA) (ln)	512	8.21	0.38	6.62	8.52
Price buying (WTP) (ln)	531	6.65	0.53	6.21	8.57
Age	1,453	55.51	10.98	20	89
Age squared	1,453	7.41	0.75	4.47	9.43
Low education (dummy)	1,462	0.16	0.36	0	1
Farm plan (dummy)	1,462	0.72	0.45	0	1
Government agency (dummy)	1,462	0.07	0.26	0	1
Water entitlements owned (ln)	1,462	5.62	1.78	0	9.58
Groundwater entitlements owned (ln)	1,461	0.65	1.84	0	8.85
Carry-over (ln)	1,462	3.32	2.44	0	8.87
Entitlement sale private market (dummy)	1,462	0.09	0.28	0	1
Allocation trade (dummy)	1,462	0.25	0.43	0	1
Operating surplus (ln)	1,367	8.43	3.98	0	11.61
Off-farm income (%)	1,427	37.91	38.82	0	100
Debt (debt to equity ratio)	1,441	0.31	0.36	0	1
Debt 2010/11 (ln)	531	8.51	4.85	0	11.61
Diverse	1,462	1.53	0.72	1	5
Farm size (ha)	1,444	528.66	1,326.74	0	20,000
Employees	1,460	2.21	2.76	0	34
Annual crops (%)	1,462	33.60	41.89	0	100
Horticulture (%)	1,462	30.29	44.85	0	100
Organic grower (dummy)	1,462	0.06	0.24	0	1
Children	1,462	2.79	1.39	0	9
Gender (dummy)	1,462	0.88	0.32	0	1
Successor (dummy)	1,353	0.35	0.48	0	1
Health	1,462	3.57	0.98	1	5
Risk type	1,462	3.20	1.13	1	5
Productivity change	1,462	2.12	1.21	1	5
Survey year 2010 (dummy)	1,462	0.64	0.48	0	1
Net rainfall	1,462	0.02	0.04	-0.03	0.33
Soil texture	1,462	3.56	1.14	1.02	5.00
Dryland salinity (dummy)	1,462	0.60	0.49	0	1
Groundwater salinity (dummy)	1,462	0.92	0.26	0	1
Surface-water salinity (dummy)	1,462	0.31	0.46	0	1
Regional population growth (% per SA2)	1,462	-2.80	4.12	-9.47	17.30
Distance to cities (km)	1,462	52.59	45.92	0	142.79
Neighbours sold (per SA2)	1,462	31.99	21.26	0	84
Distance to downstream area (km)	1,462	434.59	185.10	20.69	783.73
IIO charges (\$/ML; ln)	1,451	3.62	0.98	0	5.18
Allocation percent	1,415	49.75	19.54	0	94
Water entitlement price (\$/ML; ln)	1,462	7.67	0.20	6.61	7.97

During the data collection, additional spatial data was obtained which was tested in the initial models: for example, variability of rainfall, growing season rainfall, temperature (maximum and average), degree days, soil type according to the agricultural potential, fertiliser use, other measures for water quality, population by age (SA2), different population sizes of cities, and distance to water resources and infrastructure, such as channels and dams (Table J.8 lists the additional spatial data and data sources). This chapter also attempted to explain whether farmers' potential environmental awareness would increase the likelihood of selling water to the government for environmental flows, by measuring the distance to environmentally significant ecosystems in the MDB (e.g. wetlands). These additional variables were dropped from final models as they were either of low quality (e.g. incomplete, broad-scale), caused high correlations with other key variables, did not improve the modelling outcome (according to the Bayesian Information Criterion (BIC)), or had relatively little relevance to the research question compared to other spatial variables.

# 7.4.3 Models and methods for data analysis

In general, the decision to sell water entitlements follows a discrete choice approach, in which a farmer decides to participate in the government market if the expected utility of selling outweighs the expected utility of not selling. Binary probit regression models of water entitlement selling were estimated, to analyse the relationship between water entitlement selling and spatial influences in addition to available survey data, expressed as follows according to Greene (2003, pp. 663-669):

$$y^* = x\beta + \varepsilon$$
 (1)  

$$\varepsilon \sim N(0,1)$$
  

$$y = \begin{cases} 1 & \text{if } y^* > 0 \\ 0 & \text{if } y^* \le 0 \end{cases}$$
 (2)

where  $y^*$  is the latent dependent variable that relates to the binary variable y (1=the irrigator has sold water entitlements to the government; 0 otherwise) according to equation (2), x is a vector of independent variables (see Table 7.2),  $\beta$  is a conformable parameter vector and  $\varepsilon$  is the error term. The probit model, which combined both survey years, was estimated using a pooled cross-section dataset, which requires a year dummy to account for aggregate changes over the study period (e.g. Wooldridge 2010). As described in Chapter 6, the backward elimination method was used on all models in this thesis to test the potential influence on an extended set of exploratory variables (i.e. survey, spatial and other regional variables).

Comparisons between the models' fit were made using the BIC estimates, where smaller BIC values show improved model fit. There is no obvious difference or advantage compared to the often-used Akaike information criterion (AIC). Both measures decline with increasing value for R<sup>2</sup> and decreasing model size. But the BIC prefers parsimonious models by putting an emphasis on lost degrees of freedom (Greene 2003).

The potential neighbourhood effect (or spatial dependence of irrigators' water selling decisions) was further analysed by employing spatial exploratory analysis methods. As discussed in Section 7.4.2.2, SA2 are used as proxies for community areas, to account for positional errors of some irrigator locations. If assuming that locational inaccuracies have no significant impact, spatial exploratory analysis can be used to identify potential neighbourhood sizes with significant spatial dependence by distances or k-nearest neighbours. For example, measuring the global Moran's I for the dependent variable at different radius distances detects distances with significant spatial dependence (i.e. clustering) of water entitlement sales. Using the 'Incremental Spatial Autocorrelation' tool (see Table F.1 for a description), it was tested whether irrigators' sales decisions spatially correlated between 30 and 100km with an interval of 5km. This distance range was chosen following the literature reviewed in Chapter 6, which tested spatial dependence in a farmers' neighbourhood at similar distances. The results of this analysis provide further insights into the existence and size of a neighbourhood effect in the southern MDB. The resulting distance with significant clustering was used to identify clusters and outliers using the 'Cluster and Outlier Analysis' employing Anselin's Moran's I measure (see Table F.1). 109

Furthermore, results of the spatial exploratory analysis are typically used to define the spatial weight matrix in a spatial regression model (i.e. confirmatory spatial data analysis). However, as was the case in Chapter 6, spatial regression is not considered in this chapter, as the spatial distribution and the low accuracy of some irrigator locations prevent a feasible spatial regression analysis. Particularly, the spatial weight matrix requires observations to be non-identical and the exact representation of the farmers' location to accurately identify neighbours. Furthermore, as some of the irrigators are dispersed over the large study area, a spatial weight matrix is potentially large in size, which can be problematic during the computation process, especially in the case of discrete or limited dependent variable spatial regression (Holloway et al. 2002; Li et al. 2013; Swinton 2002). As discussed in Chapter 6, if

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<sup>&</sup>lt;sup>109</sup> Both the global and the local Moran's I analysis measure the spatial dependence, however, from a different perspective. The global Moran's I analysis detects spatial dependence using the spatial distribution of the data on the whole map (study area). The local Moran's I measure detects variations when compared with the global spatial pattern or shows significant cold/hot spots (Anselin et al. 2013).

spatial regression is not feasible, 'ad-hoc' measures (e.g. through zonal and other spatial variables) can be employed to capture the spatial structure in the dataset (e.g. Swinton 2002).

To identify determinants of irrigators' price choices for their WTP and WTA for water entitlements, Heckman sample selection and tobit models were employed. Both models account for the large proportion of irrigators for which no prices are observed (i.e. irrigators would not sell or buy water entitlements within the specified price range). The Heckman sample selection model runs two equations, one probit model on the selection decision (irrigator was willing to buy/sell) and one regression on the stated price choices. The results indicated that there was no selection bias. In the next step, tobit models were employed (see Chapter 6 for the equation) to censor at the upper and lower end of the price distribution, in order to account for the unobserved price choices and to be able to run the models with the full sample. Specifically, the price choices for WTA (selling) model was censored from above at the maximum price level of AUD\$5,000/ML (natural log) for irrigators that were not willing to sell within the specified price range. Furthermore, this model only included irrigators that owned high security entitlements in 2010/11. The price choices for WTP (buying) model was censored from below at the minimum price level of AUD\$500/ML (natural log) for irrigators that were not willing to buy within the specified price range. Analogous to Chapter 6, the marginal effects were estimated on the expected outcome conditional on the censored value.

#### 7.5 Results and discussion

### 7.5.1 Water entitlement selling to the government

The results of the reduced forms of the probit models for selling water entitlements to the government, for both survey years combined and separately are summarised in Table 7.4. Marginal effects and full model results are shown in Appendix J. The models performed well according to the results of the pseudo R<sup>2</sup>.<sup>110</sup> Moreover, the prediction accuracy was reasonably high and the models had no serious multicollinearity issues (tested with VIFs and correlation analysis, see Appendix J), and were estimated with clustered robust standard errors.<sup>111</sup>

 $<sup>^{110}</sup>$  Pseudo  $R^2$  values between 0.2 and 0.4 are considered to indicate an extremely good model fit (Louviere et al. 2000); thus, the pseudo  $R^2$  results for this chapter's reduced form models, ranging between 0.11 and 0.16 are assumed to fit the model reasonably well.

<sup>&</sup>lt;sup>111</sup> To increase the number of observations, 'Multiple Imputation' was employed which accounted for some missing information in the survey variables. The results of the multiple imputation process did, however, not improve the overall model outcome and are therefore not presented in this chapter.

Following the values for BIC, the combined model fits best overall and the 2010 model fits better than the 2011 model (this serves only as an indication, as numbers of observations vary across the models, which prevents a direct comparison of model results). The spatial distribution of water entitlement sales from both surveys combined is presented in Figure 7.3.

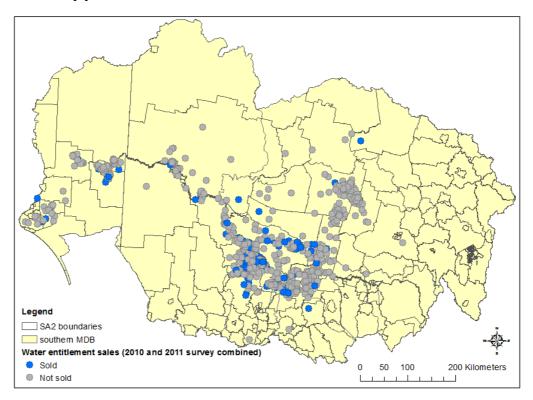


Figure 7.3: Spatial distribution of irrigators having sold water entitlements to the government across both survey years

Own map (base map sources: ABS (2010a) and MDBA (2013a))

Sensitivity tests were conducted using only those observations with high or medium geocoding qualities (Table J.5). Model results for the spatial variables were relatively robust, indicating that lower geocoding qualities introduced no significant bias in this model, or that the 30km buffer zone sufficiently accounted for geocoding errors.

## 7.5.1.1 Survey variables

Firstly, the model results in Table 7.4 confirm a number of relationships between irrigators' decision to sell water entitlement to the government and farm/farmers' (socio-economic) characteristics as found in Wheeler et al. (2012b). Specifically, results confirm associations with lower education levels, having a whole farm plan, using government agency as a main information source, increased volumes of water entitlements owned and having previous experience with water allocation trading.

**Table 7.4: Probit models of water entitlements sold to the government (reduced form)** 

	Surveys combined	2009/10 (2010 survey) <sup>a</sup>	2010/11 (2011 survey) <sup>b</sup>	
Survey variables:				
Age	-0.177** (0.077)	-0.262** (0.103)		
Age squared	2.552** (1.111)	3.714** (1.488)		
Low education (dummy)	0.258* (0.138)	0.401** (0.158)		
Farm plan (dummy)	0.349*** (0.127)		0.897*** (0.286)	
Government agency (dummy)	-0.400* (0.234)	-0.691** (0.348)		
Water entitlements owned (ln)	0.222*** (0.051)	0.381*** (0.058)	0.163*** (0.062)	
Carry-over (ln)	-0.0424* (0.023)	-0.0980*** (0.03)		
Allocation trade (dummy)	0.284*** (0.11)	0.448*** (0.133)		
Farm size (ha)	-0.0001** (0.00006)	-0.0002* (0.00008)	-0.0002** (0.0001)	
Gender (dummy)			-0.413* (0.227)	
Health		0.148** (0.058)		
Risk type	0.0790* (0.043)			
Spatial variables:				
Net rainfall		6.331* (3.802)		
Dryland salinity (dummy)	0.344*** (0.108)	0.495*** (0.133)		
Population growth (%)	-0.025* (0.015)	-0.038* (0.023)	-0.054** (0.021)	
Neighbours sold (SA2)	0.006** (0.003)	0.012*** (0.004)		
Distance to downstream area (km)	-0.002*** (0.0003)	-0.002*** (0.0004)	-0.001** (0.0005)	
Other regional variables:				
Allocation percent	-0.01*** (0.003)		-0.02*** (0.006)	
Constant	-11.52*** (4.039)	-16.83*** (5.401)	-1.427*** (0.542)	
Observations	1,364	925	475	
Wald $x^2$	98.02***	95.22***	34.66***	
Pseudo R <sup>2</sup>	0.11	0.16	0.14	
McKelvey & Zavoina's R <sup>2</sup>	0.24	0.39	0.35	
% correctly predicted	89	88	89	
AIC	0.65	0.63	0.63	
BIC	-8,874.21	-5,666.71	-2,593.41	
Log pseudo-likelihood	-427.95	-274.20	-142.43	

Notes: clustered robust standard errors in parentheses, \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

The significant impact of age, and age squared, suggested a non-linear relationship, where younger farmers tended to sell water entitlements to the government (as found in Wheeler et al. (2012b)), but also as farmers were getting older. When testing the survey years separately, this relationship was no longer present for the later farming season 2010/11. Correspondingly, it was expected to obtain a negative relationship between health and water sales in 2009/10; but irrigators with better health were more likely to have sold their water. This result may reflect the effect of younger irrigators selling as found above.

Having a whole farm plan had a strong positive impact on water entitlement sales in the combined model and in 2010/11 when testing the years separately. Previous studies have concluded that a farm plan increases the likelihood of participating in water markets (e.g. Wheeler et al. 2009). Having a whole farm plan may indicate higher irrigation efficiency

<sup>&</sup>lt;sup>a</sup> Dependent variable: 1=irrigator has sold water entitlements to the government in 2009/10; 0=otherwise

<sup>&</sup>lt;sup>b</sup> Dependent variable: 1=irrigator has sold water entitlements to the government in 2010/11; 0=otherwise

(Bjornlund 2002) or adaptation to climate change (Hogan et al. 2011), which indicates water entitlement sales based on strategic or water surplus reasons.

Across all models, smaller farm sizes showed a strong relationship with water entitlement sales. According to other studies, smaller farms are likely to receive less cost or price advantages compared to larger farms (e.g. Faris 1961). As a result, during the study period, smaller farms may have been more prone to farm management or land use changes, or even farm exits, in the face of drought and other pressures. Figure J.1 also shows that smaller farm sizes were widespread in SA and VIC. Similarly, it was concluded in Wheeler et al. (2012b) that SA and VIC irrigators were more likely to have sold water to the government compared to NSW irrigators.<sup>112</sup>

Irrigators who carried over lower volumes of water from the previous season were more likely to have sold water to the government in the combined and 2009/10 models. Hence, having lower volumes of carry-over water (i.e. lower water availability) prompted water entitlement sales in 2009/10, but less so in 2010/11. This result also indicates that those farmers had been selling their water allocations annually before selling their water entitlements, which resulted in lower carry-over water.

Furthermore, an unexpected result was found for gender in 2010/11, where female irrigators were more likely to have sold water to the government, in contrast to Wheeler et al. (2012b) who concluded that male irrigators were more willing to sell water in the initial years of the program.

# 7.5.1.2 Spatial and other regional variables

Effect of poorer resource areas (**Hypothesis 1**)

A key and strong finding amongst the assessed spatial variables was that the closer irrigators were to the River Murray's terminus to the sea (i.e. the closer they were to key environmental issues from low river flows in the River Murray) the more likely they were to sell water to the government. In other words, irrigators who were potentially more aware of environmental issues (e.g. declined water quality and quantity) were more likely to sell water for environmental purposes. Additionally, this result corresponds to the previously mentioned finding that SA and VIC irrigators were more likely to sell water entitlements to the government than NSW irrigators. This variable also relates to other regional and institutional

 $<sup>^{112}</sup>$  State dummy variables were not included in the models due to high correlations with other spatial/regional variables.

effects, which may have had an impact on water selling during the study period and which were not captured otherwise in the models.

Conversely, increased net rainfall rates (over the previous 5 years) were found to have increased the likelihood of selling in 2009/10. This effect may be masked, since net rainfall was measured over the period of the drought in which all regions received low rainfall rates. The effect of water scarcity may be better captured by the seasonal allocation level (measured as a weighted average over the previous 5 years). Allocation level had a significant negative impact on water sales in the combined and 2009/10 models. In other words, farmers, which have been in greater stress in terms of less water allocation levels, were selling water entitlements. Similarly, Wheeler et al. (2012b) found allocation levels to be a stronger driver of water entitlement sales than the regional net rainfall variable, and this chapter suggests it in the same way for net rainfall on a smaller spatial scale. Rainfall may be more associated with water allocation trading and water allocation prices (see Chapter 6).

Furthermore, model results confirm a positive relationship between dryland salinity and irrigators' water selling decisions, found in Chapters 5 and 6. Specifically, if irrigators' 30km buffer zone was affected by dryland salinity, irrigators were more likely to have sold their water to the government. As discussed in Chapter 5, dryland salinity indicates a poorer resource area (because of the soil's lower capacity to produce high-yielding crops) or inefficient/unsustainable irrigation practices, which in the long-term may encourage the farmer to change land use or exit farming, resulting in water sales.

Other spatial variables indicating poorer resource areas (i.e. soil texture, groundwater and surface-water salinity) were not found to be significant, but overall showed expected results; which was for example irrigators' affected by increased groundwater salinity were less likely to sell their surface-water (see full model results in Table J.2). Whilst several previous studies have concluded that low soil quality/productivity (e.g. Bjornlund 2006b; Isé & Sunding 1998) or increased soil degradation (Alankarage et al. 2002) were major drivers for water entitlement sales, this chapter's soil variable showed no significant impact. This indicates that such long-term productive issues of an important agricultural input have a larger impact on water trading decisions during the preliminary period of a water market. But it may also indicate that the effect of soil quality is more evident at the regional level when analysing aggregated water trading data, as suggested in Chapter 6. Furthermore, as described in Chapter 2, soil has numerous attributes and thus defining the quality or productivity of a soil is a highly complex procedure, which requires an intensive set of soil data to be evaluated in connection with the intended land use. This chapter used soil texture as an indicator for soil

water holding capacity, which can be expected to be one major decisive factor for irrigated agriculture. However, the results indicated that other soil characteristics play a larger role, e.g. dryland salinity, suggesting that future research should focus on factors contributing to soil degradation rather than concentrating on general soil types or qualities. The history of irrigated agriculture (see Chapter 2) has shown that many irrigation settlements began in areas with predominant sandier soils, given these soils are likely only to have been cultivated using irrigation. Thus, over time many farmers potentially have adjusted to this specific deficiency of the soil. This confirms other studies that concluded "soil is just one of the agricultural inputs and its quality is not necessarily an accurate proxy for the overall efficiency of the irrigator or an accurate predictor of where irrigators will seek to locate" (Crossman et al. 2010b, p. 12).

# Effect of population growth (Hypothesis 4)

An expected and consistent result for all models was the impact of population growth over the previous 5 years, where irrigators' located in regions that have experienced a population decline were more likely to sell their water. Over time, those regions may have suffered a general socio-economic decline, with a poorly performing agricultural sector (especially during the drought) and may have become more isolated and disadvantaged. As a result, farmers can be disadvantaged by less social cohesion and less economic viability, followed by decreasing availability of infrastructure and services. For example, decreasing population in community areas often lead to fewer education opportunities (e.g. adult learning choices) and, thus, farmers have fewer resources to learn how to cope with environmental and other problems (Golding et al. 2009). This variable may also reflect the number of farm exits over the previous 5 years after potentially selling water in the private market. These farm exists can be a strong trigger for water entitlement sales in the same region (potentially followed by other farm exits), in the case when farmers fear rising infrastructure costs or are otherwise adversely impacted by the loss in agriculture and social connections in their community (which relates to the neighbourhood effect discussed below). It could also reflect that those irrigators selling to the government in 2009/10 or 2010/11 might be laggards in a market adoption sense and use the government's program to act and profit from increased water entitlement prices. As similarly suggested in Chapter 6, the government water market provided an important farm management tool in response to various unfavourable conditions, in this case declining regional socio-economic conditions which may be connected with increased farm debt. As suggested by previous studies, many farmers used the proceeds from the water sales to clear their debt (e.g. Wheeler & Cheesman 2013). Overall, together with the results in Chapter 6, population growth seems to play a large role for farmers' individual

decision-making to sell water to the government, but does not affect the regional spatial pattern of water trading in the private market.

### Effect of distance to cities (**Hypothesis 5**)

The distance to cities with population greater than 5,000 was not found to be significant but showed an expected result, i.e. the further away irrigators were located from a city the more likely they were to sell their water (confirming findings in Chapter 6). The insignificant outcome of this variable may be due to the strong effect of population growth in all models, which can also reflect characteristics of rural/urban areas.

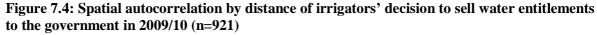
## Neighbourhood effect (Hypothesis 3)

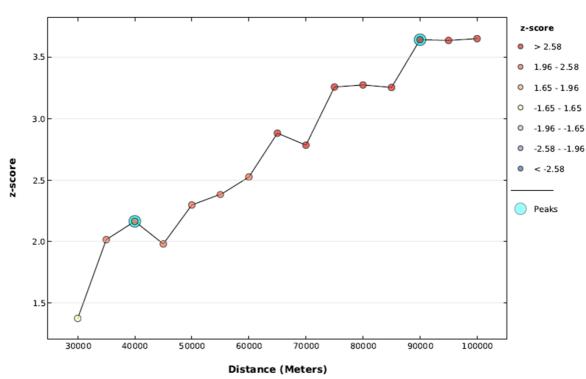
Another key finding was the evidence of a farmer social network (neighbourhood) effect. Holding other influences constant, irrigators in those SA2 areas (i.e. as a proxy for community areas) in which more neighbours had sold water entitlements to the government in the same/previous years were more likely to sell their water; hence, indicating a potentially increased social acceptance to do so. This result was evident in the combined and 2009/10 models. Networks have been shown to be an important influence on much human behaviour (see Chapter 3) and the results suggest this in water selling behaviour as well. As described in the beginning of this chapter, selling water was a controversial decision for irrigators to undertake in the past. The results indicate that as more irrigators decided to sell water entitlements, less irrigators felt social pressure not to sell.

As discussed in Chapter 6 and in Section 7.2, this neighbourhood effect can be the result of information spill-over effects, which may promote participation in the (government) water market. However, selling decisions may also cluster, as some irrigators become increasingly worried about rising costs for local irrigation channel infrastructure and a socio-economic decline in their farming community if large amounts of water entitlements were sold out of the region (potentially followed by farm exits). Alternatively, this neighbourhood effect may arise due to similar locational characteristics, which may favour farmers' decision-making in one direction or promote some targeted purchases by the government due to local environmental needs. However, a number of biophysical and socio-economic spatial variables in the models control for this spatial dependence in the neighbourhood. Overall, this result warrants further research to improve the understanding of the social structure and relationships within irrigation communities and the impact on water trading.

Spatial exploratory analysis provided additional insights into a potential neighbourhood effect and its size. Estimating global Moran's I measures at different neighbourhood distances

identified peaks where the spatial processes promoting clustering of water entitlement sales were most pronounced. Results shown in Figure 7.4 suggest that water entitlement sales in 2009/10 were spatially correlated at 40km (z-score: 2.16\*\*) and 90km (z-score: 3.64\*\*\*). Thus, spatial exploratory analysis confirms the existence of a neighbourhood effect and suggests it to be relevant within the radii of 40 and 90km (considering travel distances and a considerably high number of neighbours for some irrigators within a 90km radius neighbourhood, 40km seems to be the more reasonable distance). This also confirms that a relevant neighbourhood size may vary across the regions in southern MDB. A sensitivity test was undertaken with a reduced sample that omitted irrigator locations with low geocoding accuracy and with identical locations (e.g. same street name location without number). This test was run with 599 observations and similarly identified 40km (z-score: 2.97\*\*\*) and 80km (z-score: 3.65\*\*\*) as significant peaks for water entitlement sales (Figure J.2). As discussed in Section 7.4.3, the results of this analysis serve only as an indication for spatial dependence in the dependent variable, as location relationships could not be accurately represented for the whole sample.





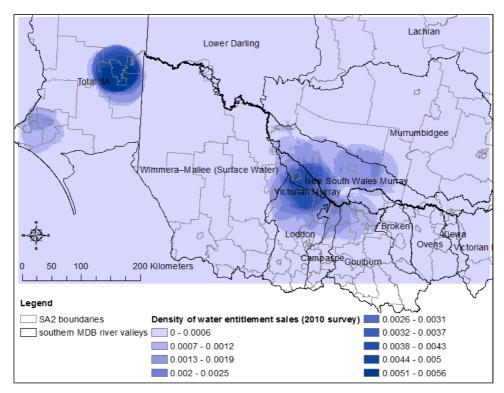
30km, and were subsequently dropped from the analysis. Consequently, the number of observations reduced to

n=921.

<sup>113</sup> The analysis required removing irrigators that had no neighbours within the specified distance range (otherwise results may be invalidated). Ten irrigators were identified to have no neighbours at distances below

With a potential neighbourhood size of 40km (radius; fixed distance), Figure 7.5 shows the density surface of water entitlement sales (using the 'Point Density' tool (see Table F.1)) and Figure 7.6 shows the distribution of local clusters and outliers (using the 'Cluster and Outlier Analysis' employing Anselin's local Moran's I measure (see Table F.1)). The cluster-outlier analysis identified statistically significant hot spots (HH), cold spots (LL), and spatial outliers (LH, HL). Each irrigator location was analysed within the context of its neighbouring locations (irrigators).

Figure 7.5: Point density of water entitlement sales to the government within a 40km radius (2010 survey)



Own map (base map sources: ABS (2010a) and MDBA (2013a))

Lachlan <u></u>
<u></u>
♠ower Darling Murrumbidgee Wimmera-Mallee (Surface Water Legend Not Significant Broken .oddon HH Ovens torian HL Campaspe<sub>Goulburn</sub> southern MDB river valleys 100 200 Kilometers

Figure 7.6: Cluster (HH) and outliers (HL) of water entitlement sales to the government within a 40km radius

Notes: HH – High-High clusters (i.e. statistically significant cluster of high values); HL – High-Low clusters (i.e. feature has a high value and is surrounded by features with low values indicating a statistically significant spatial data outlier). 2010 survey; excluding irrigators having no neighbours below 40km.

Own map (base map source: MDBA (2013a))

Figure 7.5 and 7.6 illustrate that major clusters of irrigators, having sold water entitlements to the government, were detected in SA's Riverland and across the VIC/NSW border in Loddon, VIC Murray and NSW Murray. Smaller clusters were detected near SA's eastern Mt Lofty Ranges and in northern NSW Murray as well as in Campaspe and Goulburn. Most of the spatial outliers (i.e. irrigators having sold water were significantly surrounded by irrigators having not sold water (HL)) were located in NSW (i.e. Murrumbidgee, NSW Murray), along the River Murray between SA's border and VIC's Loddon, and in VIC Murray and Goulburn. This indicates regions in which isolated irrigators started to act against potential local social pressure not to sell water. Significant clusters of low values (LL) and other spatial outliers (LH) were not detected.

Table J.7 includes further spatial exploratory analysis of the independent survey variables to observe a potential spatial dependence amongst farmers' socio-economic and other farm related data, which may have an impact on the neighbourhood effect, as suggested by the literature reviewed in Chapter 3. This global Moran's I analysis suggests significant spatial clustering for the following survey variables: low education level, having a farm plan, surface-water and groundwater entitlements owned, operating surplus, number of children,

farm size, off-farm income, productivity change, organic grower, risk type and carry-over water. Significant spatial clustering was detected at distances between 35km and 60km for the first significant peak and 65km and 90km for the second significant peak. Thus, the neighbourhood effect may be influenced by farmers' characteristics, such as education. According to Ilbery (1978) network effectiveness might be higher amongst highly educated farmers due to a higher social participation rate, being more active when seeking information, and thus potentially being an early adopter. Future research needs to confirm and investigate these findings and relationships with spatially more precise data.

### Overall effect of spatial variables (**Hypothesis 6**)

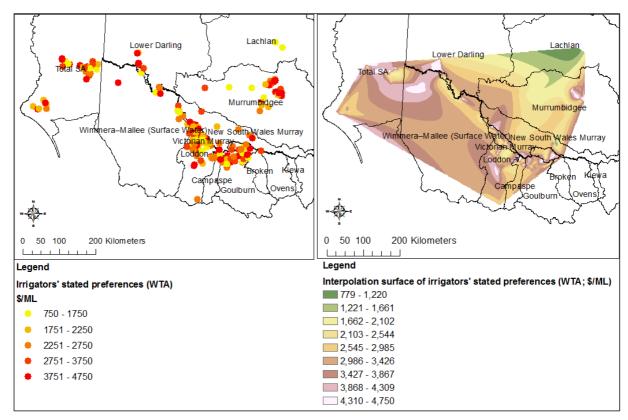
A direct comparison between the 2009/10 models from this chapter and Wheeler et al. (2012b) was carried out, to assess whether adding spatial variables improved the explanatory power of a traditional economic model on water entitlement sales. The results are shown in Table J.6. According to the BIC values, there is very strong support for the model including spatial variables (note: number of observations did not match due to different independent variables). Thus, overall results suggest that future research on water entitlement trading behaviour needs to account for spatial influences, as they explain a considerable part of water entitlement selling decisions.

### 7.5.2 Price choices for WTP (buying) and WTA (selling)

The results for tobit models of irrigators' price choices for WTP (buying) and WTA (selling) for high security water entitlements in 2010/11 are shown in Table 7.5 in the reduced form. Full model results are shown in Appendix K. Overall, the models fit the data reasonably well according to the F-statistic and R<sup>2</sup> values, and have no serious correlation issues (VIF statistics and correlation tables are presented in Appendix K).

Figures 7.7 and 7.8 show the spatial distribution of irrigators' price choices for WTP (buying) and WTA (selling) for willing sellers and buyers respectively. The interpolation surface of price choices used the 'Natural Neighbour' interpolation method (see Table F.1 for a description) to provide a simple interpolation surface of the spatial pattern of irrigators' price choices.

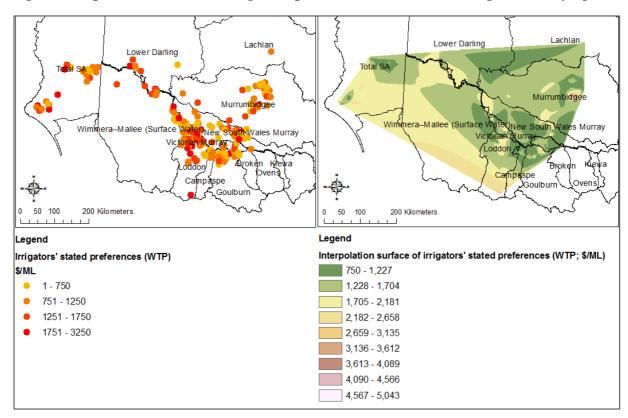
Figure 7.7: Spatial distribution of irrigators' price choices: minimum average WTA (selling)



Notes: only willing sellers, n=304.

Own maps (base map source: MDBA (2013a))

Figure 7.8: Spatial distribution of irrigators' price choices: maximum average WTP (buying)



Notes: only willing buyers, n=258.

Own maps (base map source: MDBA (2013a))

### 7.5.2.1 Survey variables

According to the results in Table 7.5, older irrigators would sell and younger irrigators would buy water entitlements at higher prices. This suggests that as age increases, irrigators increasingly value the water they own. This may indicate that older irrigators place a higher value on their water entitlements due to the historical attachment to their land, or due to holding traditional beliefs and being more risk averse. Furthermore, older irrigators may place a higher value on their farming lifestyle. They may also be more dependent on farm income, as lower income derived from off-farm work increased prices for selling water entitlements. The older irrigators during 2010/11 may also have aimed to remain on their farm due to succession arrangements, which is indicated by the positive sign of the successor variable. The younger irrigators' higher price values for water entitlement buying may signify better financial situations (i.e. being able to afford to buy or borrow money) with the aim of maintaining or expanding farm production, which could also be motivated by the end of the drought. Correspondingly, higher farm operating surplus, debt, diversity of farm income sources (i.e. crop diversity) and numbers of full-time employees increased the price choices for WTP for water entitlements. Irrigators who remained in irrigated agriculture throughout the Millennium Drought had made substantial investments in on-farm efficiency and are therefore likely to pay more for water (e.g. Aither 2016).

Furthermore, irrigators who owned lower volumes of surface-water and groundwater entitlements would sell their water at higher prices, indicating that those irrigators had no surplus or supplementary water, but relied on their water entitlements to meet farm production needs. This could also reflect that for very small volumes of water entitlements, transaction costs are higher, and hence, a higher price is needed to make the sale worthwhile.

Irrigators with no previous water trading experience resulted in higher price choices for water entitlement selling, which may reflect long-term plans to remain on the farm and maintain production levels. Furthermore, irrigators without water trading experience may not value water as accurately as those with trading experience. Since irrigators are generally risk averse, they tend to over-value rather than under-value water when selling, in the absence of an accurate valuation.

Table 7.5: Tobit models of irrigators' price choices for WTP and WTA for water entitlements in 2010/11 (reduced form)

	Price selling (WTA; ln)		Price buying (WTP; ln)	
	Coefficients (robust	Marginal	Coefficients	Marginal
	standard errors)	effects	(robust standard	effects
		(dy/dx)	errors)	(dy/dx)
Survey variables:				
Age	0.005* (0.002)	0.003	-0.018*** (0.004)	-0.010
Water entitlements owned (ln)	-0.085*** (0.021)	-0.050		
Groundwater entitlements owned (ln)	-0.059*** (0.018)	-0.035	-0.041* (0.025)	-0.021
Entitlement sale private market (dummy)	-0.195*** (0.069)	-0.115		
Allocation trade (dummy)	-0.181*** (0.069)	-0.107		
Operating surplus (ln)			0.034*** (0.010)	0.018
Off-farm income (%)	-0.002** (0.0006)	-0.001		
Debt 2010/11 (ln)			0.030** (0.011)	0.016
Diverse			0.134** (0.056)	0.071
Employees			0.029*** (0.010)	0.015
Successor (dummy)	0.185*** (0.058)	0.110		
Spatial and regional variables:				
Groundwater salinity (dummy)	-0.318** (0.143)	-0.188		
Surface-water salinity (dummy)	-0.192*** (0.064)	-0.114		
Distance to cities (km)	-0.003*** (0.0008)	-0.001		
Neighbours sold (per SA2)	-0.004*** (0.001)	-0.002		
Distance to downstream area (km)	0.0005** (0.0002)	0.0003		
Allocation percent	-0.008*** (0.001)	-0.005		
Water entitlement price (ln)	0.500** (0.205)	0.296		
Constant	5.623*** (1.634)		6.501*** (0.322)	
Sigma Constant	0.487*** (0.022)		0.892*** (0.036)	
Observations	458		515	
Left-censored observations	0		260 (at ln(500))	
Uncensored observations	276		255	
Right-censored observations	182 (at ln(5000))		0	
Log pseudo likelihood	-305.52		-507.46	
F-statistic	13.23***		12.52***	
McKelvey & Zavoina's R <sup>2</sup>	0.33		0.15	
AIC	643.03		1030.93	
BIC	709.06		1064.88	

*Notes:* \* *p*<0.10, \*\* *p*<0.05, \*\*\* *p*<0.01

## 7.5.2.2 Spatial and regional variables

Results for the variables depicting poorer resource areas are not homogenous among the price choices for WTP and WTA. Soil texture and dryland salinity showed no significant effect, whereas lower surface-water salinity increased the price choices for water entitlement selling. This indicates that irrigators' water valuation is impacted by surface-water quality but not by soil quality. Lower groundwater salinity also led to higher price choices for surface-water sales. According to the substitution effect between groundwater and surface-water (see Chapter 5) the opposite sign was expected, but this result may simply reflect areas with suitable resources where groundwater salinity is low. Analogous, Mukherjee and Schwabe (2015) showed a negative effect between groundwater salinity and farmland value in the US.

Model results further showed that lower final seasonal allocation levels over the previous 5 years increased irrigators' price choices for WTA. As a result, areas affected by increased water scarcity led irrigators to value their water entitlements more. Irrigators also specified higher prices (WTA) in areas with higher market prices for water entitlements in the previous year (as described in Chapter 6, potential endogeneity problems were addressed by including the lagged variable of entitlement prices).

Moreover, increased distances to the downstream area of the River Murray increased irrigators' price values for selling water entitlements. In other words, irrigators in NSW valued their water more than VIC and SA irrigators. This result can be expected, given poorer resource areas in the downstream areas led irrigators to devalue their water. In addition, according to the 2011 survey, NSW irrigators owned high value agricultural land (Figure K.1), and had larger farm sizes (Figure J.1).

The closer irrigators were located to cities with a population over 5,000 people, <sup>114</sup> the more they valued their water entitlements (WTA). Thus, more rurally based farmers placed lower values on their water entitlements. This reflects a potential higher agricultural production value (e.g. Wu et al. 2011) and higher agricultural land values (e.g. Patton & McErlean 2003) near cities, as a result of lower transportation costs, a greater consumer basis and other factors (see Chapter 6). This result is consistent with the findings in Chapter 6, which showed that irrigators located further away from cities sold more volumes of water entitlements.

In line with the neighbourhood effect found in Section 7.5.1, fewer neighbours that had sold water to the government within the irrigators' community area increased the price choices for WTA. This variable may reflect areas in the southern MDB where irrigators remained opposed to water sales (which in turn influenced other irrigators not to sell).

Furthermore, spatial exploratory analysis provided an indication for significant spatial clusters and outliers of irrigators' price choices for WTA<sup>115</sup> in the southern MDB (Figure K.2). The global Moran's I analysis suggested significant spatial clustering at a 50km neighbourhood radius (Figure K.2) and the Cluster-Outlier analysis revealed significant clusters of high values in two NSW river valleys (Murrumbidgee and Lower Darling) (Figure K.3). Significant clusters of low values were detected in Lachlan (NSW) and Loddon (VIC), and

<sup>114</sup> The full model (Table K.1) tested the effect of differing population sizes (i.e. for over 1,000, 5,000 and 10,000 people). Although not significant, results indicated that distance to cities may have differing impacts depending on the population size of the city. Future research needs to investigate this further to reveal the differing effects and characteristics of those cities. Differing impacts may depend on the specific region, the distances between those cities and differing infrastructure and services provided by or near the city.

<sup>&</sup>lt;sup>115</sup> Since the results in Table 7.5 showed that spatial variables were not a driver of irrigators' price choices for WTP, the spatial exploratory analysis was only conducted on irrigators' price choices for WTA. 202

significant outliers were found in NSW's Murrumbidgee and Lower Darling (low values were significantly surrounded by high values) as well as in VIC' Loddon, VIC Murray and Campaspe (high values were significantly surrounded by low values). No significant clusters or outliers were detected for SA. The results of this spatial exploratory analysis need to be interpreted with caution as the analysis was based on a reduced sample (only willing sellers and excluding irrigators that had no neighbours within a 30km radius).

Overall, spatial factors affect irrigators' price choices for WTA but not for WTP for water entitlements, which confirms Hypothesis 7. This also confirms findings in Chapter 6, where spatial factors better explained water-selling decisions. The difference between the influences on stated price choices for selling and buying water warrants further research. It could be argued that irrigators value their owned water based on more characteristics than the water they are going to own, and that this valuation process produces the price differential between selling and buying (i.e. AUD\$1,801/ML, see Section 7.4.1). However, the price differential is typically attributed to the 'endowment effect', i.e. people demand more when giving up an object than they are willing to pay to acquire it (Kahneman et al. 1990; Thaler 1980). In the case of selling water entitlements, Thampapillai (2009b) also suggested that the endowment effect is likely to inhibit water trading, as irrigators may wish to hold onto the property they own. This may be exaggerated by the fact that, historically, water entitlements were a fundamental part of irrigators' land rights. Similarly, Bauer (1998) observed that previous efforts in Chilean irrigated agriculture and the risk of returning droughts caused Chilean farmers to hoard their water rights regardless of the cost. Further research would answer if the endowment effect or further explanations account for the different valuation processes.

#### 7.6 Conclusion

Following the regional analyses in Chapters 5 and 6, this chapter illustrated the importance of spatial characteristics, such as location, biophysical factors and neighbourhood interaction, on water entitlement sales to the government, at the individual farmer level. The results confirm some of the spatial influences found in Chapters 5 and 6 and provided further insights into other spatial relationships.

Specifically, results suggest that environmental factors, which signify long-term productive issues such as salinity and water scarcity, do seem to play a part in the spatial distribution of irrigators' decisions to sell water entitlements to the government. Thus, irrigators' location (e.g. in downstream areas) and characteristics of their surrounding area (e.g. dryland salinity), signifying poor resource issues can be a strong trigger for water sales. The findings confirm

that water markets provide a very important adaptive tool for farm management. However, irrigators may also benefit from further research in farm management strategies to deal with poor environmental factors.

Furthermore, regional population decline was a strong driver of water entitlement sales decisions. This result shows how regional socio-economic decline associated with a population decline in the community area (e.g. decreased availability of infrastructure and services, less social cohesion) can impact irrigators' water selling behaviour. Irrigators have used the government water market to respond to a disadvantaged socio-economic state in their region. Over the long-term, this regional socio-economic decline may be exacerbated by increased water entitlement sales out of the region. But, to date, economic studies have found little evidence of this. This result warrants further investigation, since long-term decline remains a rural political issue.

Another key finding was the evidence of social influence amongst irrigators in community areas. Irrigators were more likely to sell water entitlements to the government if other irrigators in their community areas had already sold water to the water buyback program. This neighbourhood effect may be the result of similar spatial characteristics in the neighbourhood, but it may also show that previous social pressure not to sell water out of the region and an early distrust of irrigators regarding the water buyback program were alleviated through neighbours' selling decisions. Policy implications can apply for other countries in the developing stages of establishing water markets. Where it is the objective to increase adoption of water markets, it can be useful to target certain areas and community groups. Thereby, organising participatory extension services, which foster the communication amongst farmers, may be beneficial, as suggested in other farmer behaviour studies (see Chapter 3). This result was shown for defined community areas (SA2), which vary in area sizes depending on the size of the population. Spatial exploratory analysis indicated that this effect might also be evident within neighbourhoods of 40km and 80/90km radii. Further research is warranted to improve the understanding of such a neighbourhood effect, including the structure of the social relationships and the impact of peer influences amongst irrigators, the various effects of neighbours' water trading decisions, and the size of farming neighbourhoods/networks.

The water entitlement sales models additionally confirmed previously found relationships between farmers' socio-economic and farm characteristics (e.g. age, education, water owned) and water entitlement sales (e.g. Wheeler et al. 2012b). Furthermore, this chapter provided evidence that adding spatial variables to a traditional economic model of water entitlement sales strongly improved the explanatory power of the model. Future research into water

trading behaviour and water resource planning should incorporate spatial and neighbourhood effects relevant to the study area, to fully account for the complete set of irrigator influences and to effectively manage what is a scarce resource.

Finally, the spatial analysis of irrigators' price choices for WTP and WTA for water entitlements has also confirmed the relevance of spatial influences on irrigators' valuation of their water entitlements. The results particularly showed that poorer resources factors influence irrigators' stated price choices for water entitlement selling (WTA), but only relating to surface-water salinity and water scarcity. It was also shown that irrigators valued their water entitlements differently depending on their location in the southern MDB, i.e. concerning rural areas and the different states. Overall, it was found that various spatial factors influence irrigators' price choices for selling but not for buying water entitlements. Thus, irrigators value their water differently if they own it compared to hypothetically owning it, which may relate to the 'endowment effect'.

Overall, the research in this chapter can contribute to the policy planning stage of water markets and environmental programs, such as the water buyback scheme. It is suggested that spatial variations of water trading decisions need to be considered in the policy planning stage of relevant policy programs. Hence, policies may need to be adjusted to a spatially flexible approach targeting different purposes in different areas, as has been suggested in other spatial studies (e.g. Broch et al. 2013). Results in this chapter facilitate the identification of areas of high or low likelihood of water sales, suggesting for example, where selling could be promoted if water purchases are needed in a specific catchment for environmental flows. Farmer support programs can also be spatially refined to assist potential structural adjustments in specific locations, e.g. where farmers plan to relocate, make land use changes or exit farming. Results further illustrate not to undermine the relevance of neighbours' activities in community areas on water trading behaviour. Furthermore, the spatial distribution of irrigators' stated price choices for their water entitlements could contribute to optimally plan public spending of environmental programs.

#### 8.1 Summary of the thesis and findings

The concept and spectrum of spatial analysis and its potential contribution to water resources management was introduced at the beginning of the thesis and discussed throughout. Investigating and understanding the complex relationships between water, the economy, society and the environment can significantly improve the outcome of water markets in Australia and other countries, and associated environmental programs (e.g. the water buyback program in Australia). Obtaining an understanding of the influences of irrigators' water trading behaviour and incorporating it into water and other related policies is important for the success of water markets; for example for assessing future water trade and water availability to better manage a scarce resource in the face of a growing population and projected climatic changes.

This thesis has investigated the effects of various spatial aspects on water entitlement and allocation trading behaviour at differing spatial and temporal scales. In doing so, this thesis covers a significant gap in the broad body of literature regarding irrigators' water trading behaviour. Firstly, the regional analyses in this thesis provided an overview on key spatial influences that shape water-trading patterns. Secondly, the individual (farm) level analysis complemented the regional models by assessing the impact of spatial factors on individual irrigator water trade choices as well as their water valuation. Overall, results highlight the relevance of place and space behind irrigators' decision-making, particularly for trading their water entitlements, and emphasise the need for incorporating spatial relationships in the related policy measures of water and land management. Key findings from this thesis are the relationships between water entitlement trading and poorer resources (i.e. soil degradation, lower water availability and quality), regional socio-economic-decline (e.g. population decline), and lower access to infrastructure and services (i.e. more rural areas). These influences were particularly evident for water entitlement selling behaviour. Furthermore, the water entitlement selling decisions made by neighbours in a community area (i.e. the neighbourhood effect) also affected water entitlement selling behaviour.

The following sections summarise these findings in more detail:

Following an introduction to the study area, irrigated agriculture and water markets in Chapter 2, Chapter 3 reviewed previous research on the decision-making by farmers in general and, in

particular, in water trading. This chapter identified a gap in the literature; i.e. the incorporation of a spatial approach when examining water trading behaviour.

Chapter 4 reviewed spatial theories and methodologies, and their application in the water resources management empirical literature. This review highlighted the importance of spatial analysis in water resources research at various spatial scales, and has identified gaps and limitations/challenges to be addressed in future research (e.g. regarding the availability of spatial data and other resources). The relevance of spatial economic analysis to water management issues is particularly evident in the water quality literature and should be extended to other areas of water management, such as water trading. Overall, the aim of spatial economic analysis is to better understand economic behaviour in water resources management and the spatially explicit effects of relevant policy and management processes.

Chapter 5 investigated the impact of several salinity issues on water trading at a highly aggregated level (i.e. river valleys in the southern MDB). Key results from this chapter were 1) regions with a high percentage of land affected by dryland salinity were more likely to sell water entitlements; and 2) regions with a high percentage of land affected by saline groundwater were less likely to sell surface-water entitlements. These results confirm findings by previous studies (e.g. Alankarage et al. 2002; Schwabe & Knapp 2015). Thus, this chapter provides evidence for a substitution effect between groundwater and surface-water use (i.e. groundwater entitlements, where viable, have been increasingly used as substitutes for surface-water entitlements in recent years). This has also been suggested by other studies (e.g. Wheeler & Cheesman 2013; Wheeler et al. 2016). Moreover, the more net rainfall was available in the region, the lower the volume of water entitlements sold. Hence, farmers in areas suffering greater water scarcity are selling their water entitlements. This chapter additionally confirmed relationships between water entitlement selling and total volume of water entitlements owned per river valley, water entitlement prices and land use, as found in previous studies (e.g. Wheeler et al. 2012b). Overall, results suggest that spatially explicit environmental factors (associated with poorer resources), such as salinity and rainfall, do seem to play a part in the spatial distribution of traded water.

Chapter 6 combined a literature review (i.e. the application of spatial analysis in several studies on farmers' decision-making) with a panel analysis investigating various spatial influences on water allocation and entitlement selling, and purchasing behaviour at a smaller aggregated level (postcode areas). The literature review identified common spatial determinants impacting on various farmers' decision-making problems, such as distance measures to markets and other resources, population growth and the influence of the farmers'

neighbourhood. The results of this chapter's analysis show that spatial influences have a larger impact on water entitlement selling compared to water entitlement purchasing and water allocation selling/purchasing. The results in the water entitlement sales analysis confirmed the findings in Chapter 5 for water scarcity and dryland salinity, but not for groundwater salinity (the substitution effect was detected in the variable for groundwater use). Additionally, within areas with increased surface-water salinity, irrigators tended not to sell much of their water (allocations and entitlements), analogous to previous studies that found irrigators use high water application rates as one strategy to deal with surface-water salinity (e.g. Bjornlund 1995; Connor et al. 2012). Also, water entitlement trading was found to be associated with farm profitability, i.e. irrigators in more profitable areas sold and purchased higher volumes of water entitlements, which was suggested by previous studies of water entitlement purchasing behaviour (e.g. Bjornlund 2004). Furthermore, strategic water trading behaviour was suggested as farmers in more rural/isolated areas were more likely to sell larger volumes of water entitlements and buy larger volumes of water allocations (indicating a substitution effect between the two water products).

Chapter 7 complemented the regional analyses from Chapters 5 and 6 by incorporating spatial influences within a traditional economic model of water trading decisions at the individual (farm) level (focusing on irrigators' decisions to sell their water entitlements to the government water buyback program). Thus, this chapter observed the relevance of spatial factors at the individual decision level, while simultaneously accounting for an extended set of irrigators' individual characteristics. Results confirmed some of the spatial influences found in Chapters 5 and 6, and provided further insights into other relationships. Specifically, this research confirmed that environmental factors, which signify long-term productive issues such as dryland salinity and water scarcity, affect the spatial distribution of water entitlement trading. Furthermore, regional socio-economic decline, signified by a fall in population, increased the likelihood of irrigators' selling water entitlements to the government. Another key finding was that increasing numbers of neighbours in a community area, having previously sold water to the government, increased the likelihood of irrigators' water entitlement selling decisions. This chapter also confirmed previous findings (e.g. Wheeler et al. 2012b) regarding the influence of farmer and farm related factors, which highlights the complexity and heterogeneity of irrigators' decision-making towards water trading. Overall, this analysis provided evidence that adding spatial variables to a traditional economic model of water entitlement sales strongly improved the explanatory power of the model.

Chapter 7 extended this spatial analysis to assess whether irrigators' water valuation (i.e. price choices for WTP and WTA for water entitlements) were likewise affected by spatial

influences. Analogous to Chapter 6, it was found that spatial influences have an impact on the price choices for selling but not for purchasing water entitlements. This was evident for poorer resources areas, but only relating to surface-water salinity and water scarcity. It was also shown that irrigators valued their water entitlements differently depending on their location in the southern MDB, i.e. with regards to rural areas and the different states. Generally, irrigators' valued their water differently if they owned it compared to if they were going to own it, which may relate to the 'endowment effect' i.e. people demand more when giving up an object than they are willing to pay to acquire it (Thaler 1980).

Overall, this thesis found that spatial influences primarily affected water entitlement trading compared to water allocation trading, and particularly water entitlement selling compared to water entitlement purchasing. Table 8.1 provides an overview of significant relationships found in this thesis between spatially explicit variables and water entitlement trading.

Table 8.1: Summary of the results for the spatially explicit variables in this thesis

	Chapter 5	Chapter 6	Chapte	er 7
	Regional level	Regional level	Individua	l level
	Water entitlement selling	Water entitlement trading	Water entitlement selling	Price selling (WTA)
Environmental factors associated with poorer resou	ırces areas:			
Dryland salinity	X	X	X	
Groundwater salinity	X			X
Surface-water salinity		X		X
Net rainfall	X	X	X	
Soil texture	-	X		
Distance to downstream area	-	-	X	X
Regional socio-economic factors:				
Population growth	-		X	
Business income (PP)	-	X	-	-
Access to markets, infrastructure and services:	-	1		
Density cities/distance to cities	-	X		X
Neighbourhood effect (social influence):	•			
Neighbours sold water	-	-	X	X
Other locational factors (i.e. river valleys)	-	X	-	-

Notes: 'X' signifies a significant result; '-' signifies that the variable was not included in the model.

Spatial factors have an influence at both the regional (aggregated) and individual (farm) scale of water trading decisions, with only a few dissimilarities; soil texture, distance to cities, groundwater salinity and surface-water salinity seemed to play a larger role in capturing the average/aggregated water trading pattern at the regional level (when not considering the influences on the price choices for selling water entitlements). In the individual farm level models, population growth seemed to have a larger impact, in addition to the neighbourhood

effect and distance to downstream area, however the latter two variables were only tested in the farm level models.

### 8.2 Policy implications

Typically, spatial analysis leads to recommendations on spatial planning or spatially targeted policies, which aim to improve existing policies and strategies. This means, existing policy measures are refined and restructured by regions according to revealed spatial patterns, to meet local or regional structures. The following discussion about policy recommendations primarily focuses on water entitlement trading (particularly water entitlement selling), as spatial factors were found to predominantly drive water entitlement selling decisions.

#### 8.2.1 Spatially explicit policies in poor-resource areas

Environmental factors associated with lower agricultural potential prompted water entitlement sales. These factors naturally create regions with high numbers/volumes of water entitlement sales. In such areas, policy programs incentivising water entitlement sales (e.g. the water buyback program) need to be assisted with spatially refined farmer support programs to support farmers during processes of change, such as potential adaptation (e.g. aiming to manage uncertainty/water variability and other environmental problems while securing farm viability) or farm exits, as has been suggested in other studies (e.g. Golding & Campbell 2009; Wheeler et al. 2013b). Implementing rural support programs that minimise negative community impacts are likely to increase irrigator participation in government programs, such as the buyback scheme (Lane-Miller et al. 2013). Furthermore, if environmental flows are needed from poor resource areas, it may be cost-effective to encourage water entitlement sales from these areas. As suggested by Isé and Sunding (1998), having a greater emphasis on farmers' long-term physical factors rather than socio-economic factors (associated with rather short-term assessments) can lead to a more sustainable process of buying back water entitlements.

The water buyback program and its impact on rural communities has been subject to serious debate in Australia. It has been suggested that the water buyback program needs to be restructured by incorporating alternative water products into the scheme leading to more flexibility in recovering water, higher participation rates by irrigators, and providing farmers and communities more time to adjust (e.g. Wheeler et al. 2013a). Thereby, potential adverse socio-economic impacts on communities through large water entitlement sales in some areas can be reduced. Increasing the flexibility of agricultural policies in Australia to maintain agricultural profitability has been advocated widely (e.g. ABARE 2007; Hogan & Young

2013). Additionally, the current government's focus on recovering water through infrastructure upgrades, needs to be reconsidered as such infrastructure investment policies are not found to be cost-effective (e.g. Grafton 2010; Lee & Ancev 2009; Wittwer & Dixon 2013) and are not facilitating long-term flexible responses to variable and uncertain climatic conditions (Adamson & Loch 2014). Hence, parts of the public spending on infrastructure modernisation could be allocated towards restructuring the water buyback scheme and providing farm adjustment programs, in order to achieve a better overall environmental and socio-economic outcome (Wheeler et al. 2013a). Generally, recovering water for the environment can be more appropriately achieved through an optimal mix of flexible water recovery options (e.g. including physical caps/quotas or water pricing increases) depending on the region, country and local watering and socio-economic needs (Loch & Adamson 2015). Ultimately, policy makers need to 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). There are large questions surrounding the sustainability and effectiveness of the irrigation infrastructure program.

Furthermore, to combat salinity problems, which may be exacerbated by irrigated agriculture, the states (e.g. in VIC and SA) defined salinity impact zones where water use and water trading is regulated. The results of this thesis support such policies to control water application rates in high salinity impact zones, to prevent farmers from buying increased volumes of water and increasing water application rates to deal with surface-water salinity. This would be an example where water markets would not necessarily encourage water to be moved from low efficient to high efficient users (e.g. Bjornlund & McKay 1995; Crossman et al. 2010b). Additionally, policy makers may continue to support farmers in high salinity impact zones to enhance their ability to respond and adapt to salinity issues in various ways, such as adopting salt resistant crops, mulching (horticulture) or measuring the water's salt level (Cross 2001).

The evidence of substituting groundwater for surface-water should be increasingly incorporated into the planning of salinity zones and other water policies to prevent the over-exploitation of groundwater resources. Areas of e.g. low groundwater salinity levels and the associated wells can be spatially determined to monitor those areas where groundwater use is likely to increase. As the interconnectivity between groundwater and surface-water resources and the impact of increased groundwater use are not well understood, emphasis should be made on an integrated water management approach in the MDB focusing on this interconnectivity.

Overall, it was shown that water markets in Australia provide a very important adaptive tool for farm management in response to environmental problems. However, if water markets do not lead to an overall optimal outcome, regulations and other related policy measures (e.g. land use policies) can be spatially refined to support the implementation of water markets.

#### 8.2.2 Spatially explicit policies for socio-economically declined areas

Irrigators in more socio-economically declined regions (associated with a population decline) were more likely to sell water entitlements to the government. Over the long-term, this regional socio-economic decline may be exacerbated by increased water entitlement sales out of the region, although economic studies to date have found little evidence of this. But, long-term decline remains a rural political issue, and unfortunately water buybacks have increasingly been blamed as causing the decline. Ultimately, long-term socio-economic decline in rural communities is a wider issue than can be dealt with in this thesis, but what is important is to highlight the problems associated with policies, such as irrigation infrastructure investments that, although they are intended to help, may only exacerbate the situation they are trying to resolve. Hence, the focus must be kept up on the current water buyback program in Australia, given the remaining gap of 766 GL to be recovered and restored back to the environment by 2019.

#### 8.2.3 Social influences and spatial policy planning

The evidence of a neighbourhood effect on water entitlement trading decision-making (i.e. water entitlement selling became more socially acceptable where irrigators increasingly had sold water in a community area) leads to several policy implications.

Internationally, in the developing stages of water markets, when it is the aim to promote water trading amongst farmers, it can be useful to identify community/neighbourhood areas or groups, in which farmers are likely to interact, and areas with potentially less farmer interaction. Identified areas can be targeted with tailored information programs and extension services, depending on the area's needs. Encouraging social capital (e.g. social networks) by organising participatory or farmer-to-farmer extension services, which foster communication amongst farmers, may be beneficial to provide a platform for irrigators to exchange experience and information on water trading. Many other studies have highlighted the importance of forming farmer networks and supporting collective action to combat agricultural and natural resource problems (e.g. OECD 2012). Particularly, in the case of water entitlement selling, policy makers need to consider the social aspect of selling water entitlements in communities, and recognise that some irrigators may not adopt water trading if it is against their values or social norms. In this case, it may take time and many other

resources (e.g. on-farm consultations/direct training, identifying and targeting community leaders) to initiate rethinking. In general, plans and policies which engage local communities are most likely to succeed (e.g. Hurlimann & March 2012).

In Australia, this result can be useful for the current water buyback program in identifying areas where irrigators are potentially more willing to sell due to neighbours having sold water to the government, if environmental flows are needed from that area. Local extension services could also be adjusted to inform about the consequences of water sales in irrigators' areas to alleviate irrigators' concerns about the future of their irrigation community and infrastructure.

When planning such policy programs that are spatially refined to community/neighbourhood areas, policy makers need to further consider that community areas may vary in sizes depending on the ruralness of the area (i.e. larger community areas in more rural regions).

### 8.2.4 Considering spatially explicit values of water

The results of irrigators' price choices for selling water entitlements, which vary spatially, can contribute to the optimal planning of public spending in policy programs. Thereby, the allocation of investments for environmental projects, such as the buyback program, may need to be adjusted to account for the spatial pattern and determinants of irrigators' values for water. Thus, in addition to targeting water entitlements from willing sellers according to spatial influences (concerning for example poorer resources areas), the results can facilitate the cost-effective spatial targeting of water purchases.

#### 8.2.5 Policy summary

Overall, this research contributes to the policy planning stages of water markets and related environmental programs, and may be able to refine the planning of the last stages of the water buyback program (and any possible future extension) in Australia to meet environmental needs. Policies would benefit from incorporating spatially targeted/flexible approaches, focusing on different purposes for different areas, as was suggested in other spatial studies (e.g. Broch et al. 2013). Specifically, related environmental programs, such as the water buyback scheme, may benefit from spatial analysis to better plan: 1) the potential amount of water that can be recovered through water purchases from willing irrigators; 2) structural adjustment programs (for areas where many irrigators have sold or are likely to sell water entitlements); 3) extension services to promote water trading in areas where water is needed for the environment and where irrigators are less likely to sell; and 4) public spending on where not to invest in irrigation infrastructure and by identifying areas with high or low values for water. Generally, identifying areas of non-participation provides guidance for related future policies.

It is obvious that much of the investment in modernising irrigation infrastructure that has been undertaken in the past decade could have been better spent through greater use of spatial analysis and by identifying areas where further water entitlement sales are likely and, thus, infrastructure investments may not be effective in the long-term.

Spatial analysis also allows a greater understanding of how to help plan for long-term adaptation in irrigated agriculture. As recommended in previous studies (e.g. Crossman et al. 2010a) spatial planning in water and land use may resolve some counterproductive effects of irrigated agriculture.

The impact of spatial factors is generally evident, irrespective of administrative or political boundaries. Hence, policy-making and water resources management must continuously strive to improve the cooperation and collaboration between authorities at various spatial scales and across boundaries (i.e. vertical and horizontal integration in policy-making). This way, the environmental requirements and effects on local communities, which may overlap regional or state borders, can be appropriately addressed, as similarly suggested in other studies (e.g. Carter 2007).

In general, and as highlighted in previous sections, policy implications which are drawn from the spatial influences on water trading behaviour are not necessarily limited to water management areas but are closely linked to other policy areas, such as climate change adaptation policies, land use and technology adoption schemes or farm exit programs.

#### 8.3 Limitations and recommendations for future research

#### 8.3.1 Limitations

As discussed in Chapter 6, spatial analysis often comes with several pitfalls and challenges. This section briefly summarises the limitations that were encountered during this thesis, how they were dealt with and their effect on the findings:

- Rural geocoding: Several challenges were encountered when geocoding farmers' addresses in Chapter 7 to enable the spatial analysis at the individual farm level. For example, different styles of rural addresses, incompleteness of reference address databases used by geocoding services and farmers' willingness to disclose full addresses (e.g. only providing a Post Box address). Furthermore, farm addresses may not adequately represent the farms' production area in cases when farmland is dispersed. Those limitations were addressed by estimating the spatial variables on the basis of 30km buffer zones around the irrigators' locations, analysing the neighbourhood effect based on community areas (SA2) and conducting sensitivity analyses, which produced no major changes in the model results.

- Spatial data availability, scale and currency: Selecting the secondary spatial data can lead to further limitations, e.g. time gaps between the spatial data and the dependent variables, and the level of detail (regional or local scale) of spatial data.
  - Time gaps between the dependent variables and some biophysical characteristics, particularly regarding the dryland salinity dataset, were inevitable and were accounted for in the interpretation and discussion of the results. The dryland salinity dataset was also verified with more recent research concentrating on isolated areas in the southern MDB. Results for those variables can only lead to indications, which can be further investigated and confirmed by future research. Several biophysical factors were not available for more than one year, which is needed in a panel analysis; thus, panel models were estimated using the random-effects estimation process (Chapter 6).
  - Mixed spatial scales in the postcode area panel models in Chapter 6 were unavoidable as postcode areas are not typical units at which spatial or water use data are provided, e.g. the MDBA and the state's water resource managers typically supply water related information only at the larger river valley level. Thus, postcode areas needed to be allocated to the closest river valley. This also applied for some of the variables in the farm model in Chapter 7.
  - Further, it could be contested that the chosen spatial units of variables (e.g. postcode areas for the dependent variables in Chapter 6, SA2 for population growth and the neighbourhood effect in Chapter 7, and the 30km radius for the irrigators' buffer zones in Chapter 7) may not adequately represent the underlying spatial processes relevant to the farmer. Chapter 6 and 7 have outlined the process in deciding these spatial units. A sensitivity analysis (in this case a spatial exploratory analysis) regarding the size of irrigators' neighbourhood was additionally conducted in Chapter 7 confirming the evidence of a neighbourhood effect at varying sizes.

Another shortcoming of the models, not associated with the pitfalls of spatial analysis, relates to the influence of institutional factors on water trading behaviour. However, institutional factors are expected to be adequately captured by the locational (river valley) dummy variables in Chapter 6, and the distance to the downstream area and prices per IIO in Chapter 7.

#### 8.3.2 Future research

Several recommendations for future research can be drawn from this thesis:

Future research can extend this spatial analysis by employing spatial econometrics to fully account for the spatial dependence in the data. For this analysis, future surveys need to collect accurate location information from the farm (e.g. GPS coordinates) and information on the level of dispersion of the farm fields to facilitate an accurate spatial analysis (i.e. using a spatial weight matrix that accurately represents the relationships in farmers' neighbourhoods).

In this thesis a panel data analysis was only possible at the regional level. Hence, if suitable farm level panel data is available in the future, such an analysis would further improve the understanding of farmers' decision-making processes and their spatial-temporal dynamics, providing policy makers with more detailed information. This thesis may be extended by incorporating further potential spatial influences (e.g. other water or land quality measures, access to water resources and infrastructure) and more current and accurate spatial datasets (e.g. regarding dryland salinity). This thesis found that soil degradation measures might have a larger impact on water trading decision-making than broad soil types; thus, future research should focus on various factors contributing to soil degradation. It was further found that the distance to cities with differing population sizes might have differing impacts on water trading behaviour and water valuation. Future research may need to investigate this to reveal the differing effects and characteristics of those cities (e.g. differing impacts may depend on the distances between these cities and the type of infrastructure and services provided by or near the city).

The evidence of a neighbourhood effect warrants further research to improve the understanding of the social structure and neighbouring relationships within irrigation communities and the impact on water trading. Future research should also investigate the optimal size of farmers' neighbourhoods in the southern MDB, e.g. by testing several neighbourhood specifications in spatial models. Additionally, future studies may assess the impact of 'leaders' in the communities, the influence of farmers' socio-economic characteristics on the neighbourhood/network effectiveness and the various channels of farmer interactions (as discussed in the literature review in Chapter 3). It may be useful to combine such an analysis based on quantitative estimation processes with qualitative instruments, to better understand the neighbourhood/spill-over effects.

It may further be beneficial to focus future spatial analysis on a specific state or large irrigation production region (e.g. VIC or the connected irrigation areas in northern VIC and southern NSW) as more accurate spatial data is available at a state level, improved geocoding qualities can be achieved in VIC, and irrigators are influenced by similar institutional conditions and infrastructure characteristics (e.g. the channel system in northern VIC) and have similar numbers of (or distances between) neighbours in their communities. Thereby, the influence of access to off-farm water infrastructure can be analysed, which is expected to have an important impact on water trading decision-making.

In general, the results of a spatial analysis in water trading behaviour could be better understood if the impact of water trading, and particularly the impact of water recovery for the environment, on the viability of local communities and the diversity of local agriculture would be clearer. Thus, future research could focus on improving the understanding on how communities and agriculture are affected. For example, a recent study on the impact of water recovery on communities in the northern MDB (MDBA 2016d) could be expanded to the southern MDB.

Concerning the availability of appropriate spatial data, future research should focus on improving the spatial and temporal resolution of spatial data and the access to transboundary or national spatial datasets to facilitate detailed spatial analysis across boundaries. Spatial data should be produced at the smallest spatial scale possible and at several points in time for factors that are time-variant. For example, in the case of salinity, projects such as the 'River Murray Corridor (RMC) Salinity Mapping and Interpretation Project' should be conducted more frequently and extended to cover larger areas (in the case of the southern MDB, the three states of SA, VIC and NSW and their relevant agencies might need to work more closely when producing such spatial data). Particularly, the current national dataset for dryland salinity is out-dated and there is no clear consensus about the current extent of dryland salinity for the whole of the southern MDB. Other public agricultural data, such as ABS's land account, could be extended to and aligned with other states, or provided at smaller spatial scales (e.g. smaller levels of the statistical areas). Additionally, developments in satellite analysis may open up further possibilities.

Furthermore, future research is warranted to improve the understanding of the interrelationships between the different types of salinity, and to provide a more detailed understanding of the impact of salinity on water trading and the various farm management strategies to deal with salinity. Particularly, the evidence of the substitutability of groundwater for surface-water needs further investigation, as it may have significant ramifications in terms of the total amount of water used in the MDB, reflows into the system from connected groundwater, and the actual amount that is available for environmental flows in rivers.

Increased groundwater use can also lead to increased salinity problems if saline groundwater flows into rivers due to discharge. Hence, there is a need for more research on a fully integrated basin water management approach in the MDB. Results also indicated irrigators' responded to higher surface-water salinity with high water application rates, which may be one strategy to counter increased surface-water salinity levels. This result needs to be confirmed by future analysis and requires further investigation as to how irrigators deal with increased surface-water salinity and the resulting environmental consequences. This result may also have significant consequences for the total water use and may show how irrigated

agriculture can worsen salinity levels through secondary salinization processes, which are caused by raising the water table due to increased water application rates.

Finally, the stated price choice analysis for water entitlements in this thesis can be extended to other water products (e.g. other reliabilities) to facilitate a thorough planning of public spending (e.g. for the water buyback program) and to meet environmental flow targets with an appropriate mix of water products. Future research may also broaden this analysis by collecting price choices from an extended set of observations.

Overall, there is a clear need for future studies in water trading behaviour, and water resource planning in general, to consider the spatial scale of decision-making and to incorporate spatial and neighbourhood effects relevant to the study area, which will fully account for the complete set of irrigator influences, and thereby assist in effectively managing a scarce resource.

As this thesis is the first study that has employed a comprehensive spatial analysis on irrigators' water trading behaviour, and one of only a few studies undertaking a spatial approach in water resources management, further research is warranted to fully understand the spatial pattern of water trading behaviour and the spatial relationships among irrigators. By considering spatial influences and effects associated with water trading decisions, related policy programs can be spatially refined to improve the outcome of water markets (and related environmental programs) and relieve the pressure on social, economic and environmental systems.

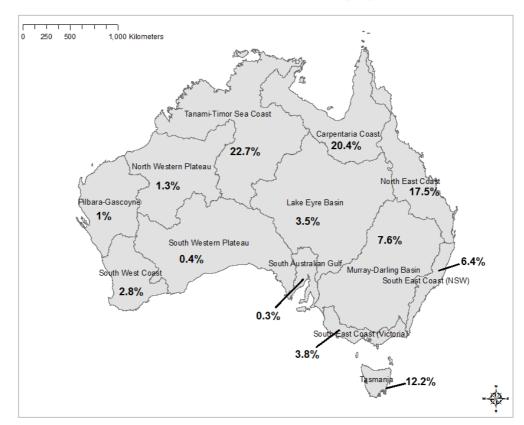
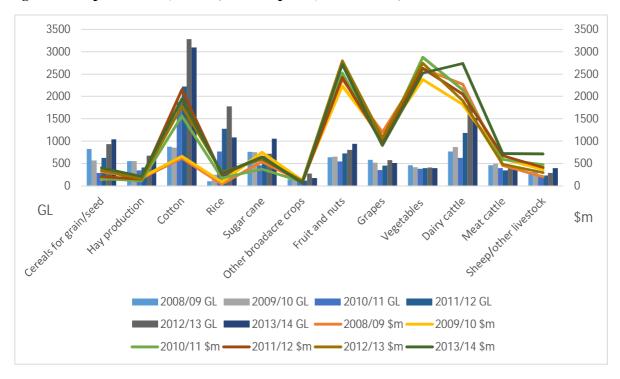


Figure A.1: Australia's surface-water drainage divisions and proportions of run-off

Own map (data source BoM (2014, 2015))

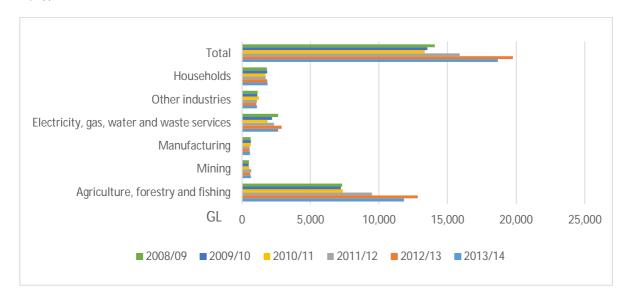
Figure A.2: Water consumption (GL) by agricultural activity and gross value of irrigated agricultural production (GVIAP; current prices) in Australia, 2008/09 to 2013/14



Notes: Care must be taken if the GVIAP is used to compare commodities, as irrigation depends on many regional factors. GVIAP refers to the gross value of agricultural commodities produced with the help of irrigation and is not a measure of productivity (ABS 2015b). Water consumption differs from total water use. Water consumption is the amount of water used in the economy and total water use includes instream-uses and other water uses, e.g. environmental water use (ABS 2015a).

Own figure (data sources: ABS (2015d, 2016a))

Figure A.3: Water consumption (GL) by industries and households in Australia, 2008/09 to 2013/14



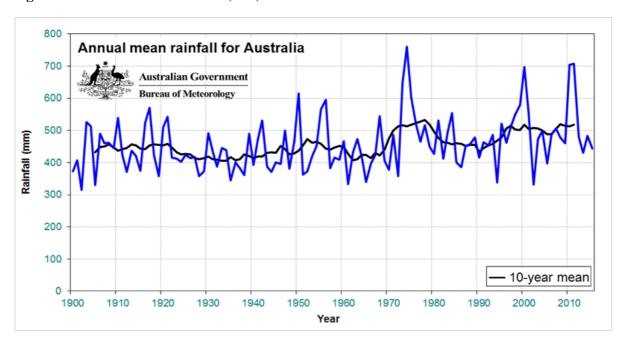
Own figure (data source: ABS (2016a))

Table A.1: Determinants for classifying the land suitability for a given land use

Crop (agronomic)	Management	Land development or improvement	Conservation and environment	Socio- economics
Growing period	Location	Land clearing	Long-term salinity, sodicity hazard	Farmers' attitudes to irrigation
Radiation	Water application management	Flood protection	Ground or surface water hazard	Others
Temperature	Pre-harvest farm management	Drainage	Long-term erosion hazard	
Rooting	Harvest and post- harvest	Land grading	Environmental hazard	
Aeration	Mechanization	Physical, chemical, organic aids and amendments		
Water		Leaching		
Nutritional (nitrogen, phosphorus, potassium)		Reclamation period		
Water quality		Irrigation engineering needs		
Salinity				
Sodicity				
pH, micronutrients				
and toxicities				
Pest, disease, weed				
Flood, storm, wind, frost, hail				

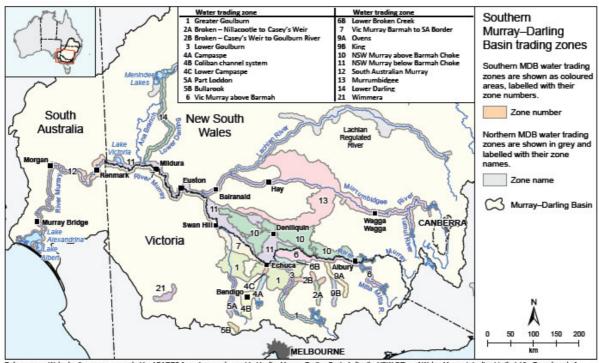
Source: adapted from FAO (1985)

Figure A.4: Annual mean rainfall (mm) for Australia



Source: BoM (2016)

Figure A.5: Water trading zones in the southern MDB

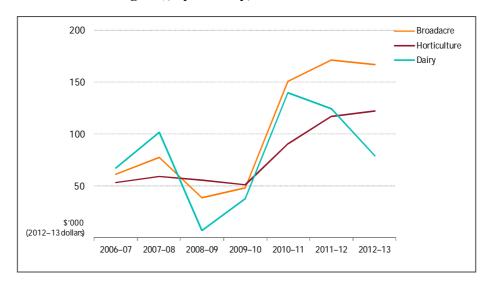


Data sources: Water trading zones generated by ABARES from documents provided by the Murray-Darling Basin Authority, NSW Office of Water, Murray Irrigation Limited, Vic. Department of Sustainability and Environment and SA Department of Environment, Water and Natural Resources. Topographic data: Geoscience Australia.

Map produced by ABARES © Commonwealth of Australia.

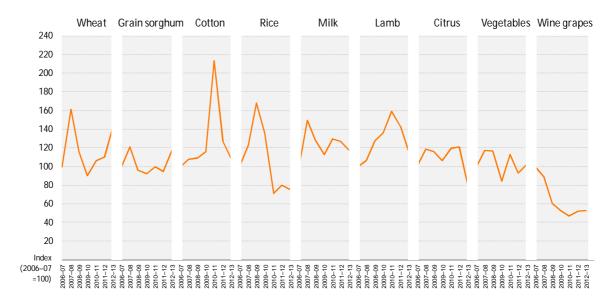
Source: NWC (2013b)

Figure A.6: Farm cash income (average per farm) in the southern MDB (Murrumbidgee, Murray, Goulburn-Broken regions), by industry, 2006/07–2012/13



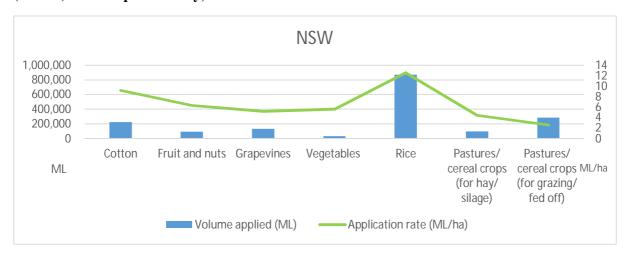
Source: Ashton (2014, p. 3)

Figure A.7: Index of commodity prices, 2006/07-2012/13



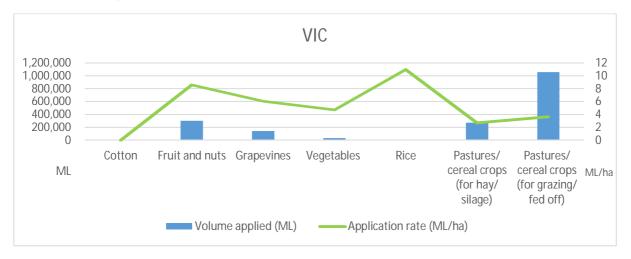
Source: Ashton (2014, p. 4)

Figure A.8: Volume of irrigation water applied (ML) and average water application rate (ML/ha) in NSW per industry, 2014/15



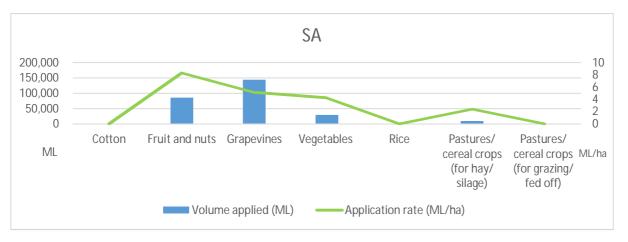
Own figure (data source: ABS (2016d))

Figure A.9: Volume of irrigation water applied (ML) and average water application rate (ML/ha) in VIC per industry, 2014/15



Own figure (data source: ABS (2016d))

Figure A.10: Volume of irrigation water applied (ML) and average water application rate (ML/ha) in SA per industry, 2014/15



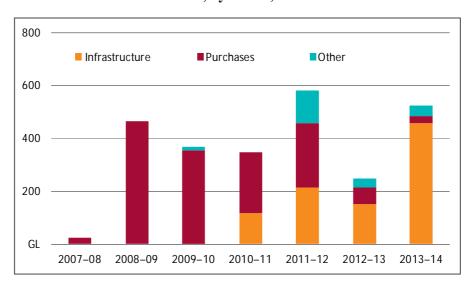
Own figure (data source: ABS (2016d))

Table A.2: Progress of water recovery (in GL) towards bridging the gap to SDLs, as at 31 July 2016

SDL Resource	Total	(	Commonwealth		State	Total	Total	
Unit (or Shared	target	Sl	RWUIP	Other	Government	Recovery	recovery	
Zone)		Buyback Infrastructure					remaining	
Northern Basin Zone Total	390.0	154.4	79.1	10.6	28.4	272.4	117.6	
Lower Darling		1.0	1.3			2.2		
Murrumbidgee		129.2	223.7	2.4	19.0	374.4		
NSW Murray		219.5	96.0			315.5		
Southern Basin NSW Zone	1048.0	349.6	321.0	2.4	19.0	692.1	355.9	
Southern Basin ACT Zone (ACT Murrumbidgee)	4.9	4.9	0.0	0.0	0.0	4.9		
Campaspe		6.3	0.1		22.6	29.0		
Goulburn		232.6	94.3		35.4	362.3		
Loddon		2.8	0.6		8.6	11.9		
VIC Murray		271.0	96.0		30.1	397.0		
Southern Basin VIC Zone	1052.3	512.7	191.2	0.0	96.7	800.5	251.8	
Southern Basin SA Zone (SA Murray)	183.8	89.2	12.3	36.0	6.4	143.9	39.9	
Southern Basin Total	2289.0	956.4	524.4	38.4	122.1	1641.4	647.6	
Lachlan	48.0	35.0	1.5		11.4	48.0		
Wimmera- Mallee	23.0	22.6				22.6	0.4	
Total Basin	2750.0	1168.4	605.0	49.0	161.9	1984.3	765.7	

Source: DoAWR (2016)

Figure A.11: Environmental water secured, by source, 2007/08 to 2013/14



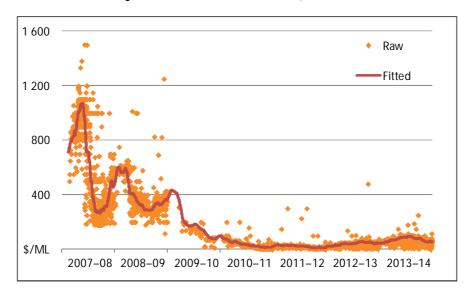
Source: Morey et al. (2015, p. 40)

Table A.3: Processes for water entitlement and allocation trading

		Water entitlement trading	Water allocation trading
1	Contract of	- Buyer and seller locate each other and	agree to a price
	sale	- A contract is drawn	
2	Lodgement	- Regulatory approval is sought in	- Regulatory approval must be sought
	of	cases where trade might impact on the	- Upon approval, water accounts are adjusted for
	application	water resource and the environment	buyer and seller and the transaction is registered
3	Settlement	- Sign transfer papers and exchange	- Buyer and seller are advised in writing of
		title documents	determination
			- Consideration amount is exchanged from
			buyer to seller
4	Registration	- Buyer lodges transfer documents	
		with appropriate registry (transfer	
		takes legal effect)	

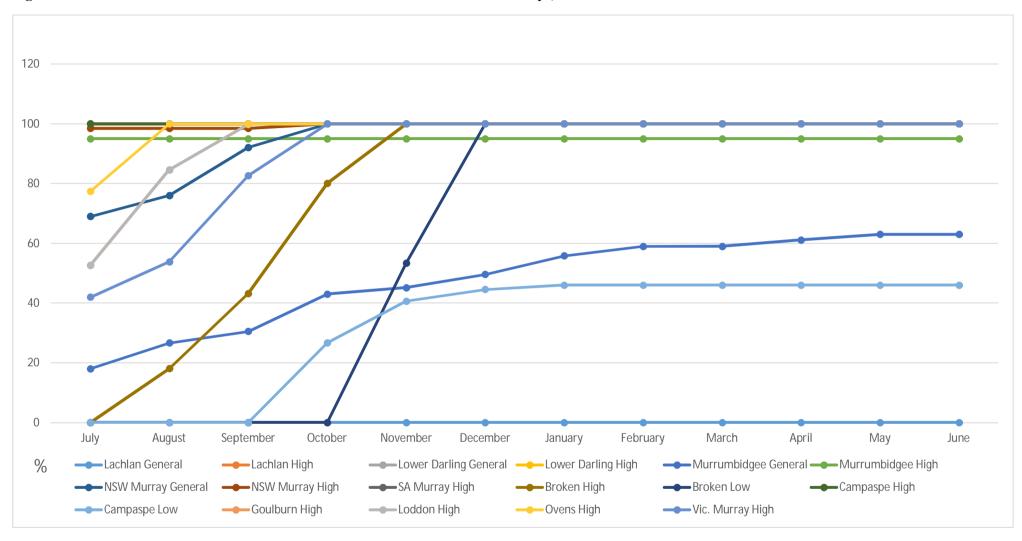
Source: adapted from NWC (2014)

Figure A.12: Water allocation prices in the southern MDB, 2007/08 to 2013/14



Source: Morey et al. (2015, p. 34)

Figure A.13: Intra-seasonal allocation announcements for southern MDB river valleys, 2013/14



Own figure (data source: Morey et al. (2015))

# Appendix B Excerpts from the Basin Plan: criteria for identifying environmental assets and ecosystem functions that require watering

#### Criteria for identifying an environmental asset (according to the Basin Plan):

"A water-dependent ecosystem is classed as an environmental asset that requires watering if it meets one or more of the following criteria. The criteria are that the ecosystem:

- is formally recognised under an international agreement, or with environmental watering would support species listed in international agreements;
- is natural or near-natural, rare or unique;
- provides vital habitat;
- supports Commonwealth-, state- or territory-listed threatened species or communities; and
- supports, or with environmental watering is capable of supporting, significant biodiversity." (MDBA 2011c, p. 95)

#### Criteria for identifying an ecosystem function (according to the Basin Plan):

"An ecosystem function requires support by environmental watering if it meets one or more of the following criteria. The criteria are that the ecosystem function:

- 1. supports the creation and maintenance of vital habitats;
- 2. supports the transportation and dilution of nutrients, organic matter and sediment through the Basin;
- 3. provides connections along a watercourse and to the ocean (longitudinal connections); and
- 4. provides connections across floodplains, adjacent wetlands and billabongs (lateral connections)." (MDBA 2011c, p. 97)

# **Appendix C Descriptive statistics for Chapter 5**

**Table C.1: Descriptive statistics** 

Variable	Observations	Mean	Std. Dev.	Min	Max
Water entitlement sold (ML; natural log)	143	6.31	4.07	0.00	12.92
Water entitlement owned (ML; natural log)	154	12.01	3.05	0.00	14.92
Allocation (%)	154	66.78	40.66	0.00	174.58
Water entitlement price (\$/ML; natural log)	143	7.06	0.50	5.80	8.67
Groundwater use (ML; natural log)	145	9.67	2.34	0.00	12.73
Dryland salinity (dummy)	154	0.50	0.50	0.00	1.00
Groundwater salinity (dummy)	154	0.21	0.41	0.00	1.00
Surface-water salinity (dummy)	154	0.34	0.48	0.00	1.00
Dairy (%)	154	32.94	14.88	1.44	54.49
Land in transition (%)	154	0.14	0.17	0.00	0.58
Rainfall-evapotranspiration (mm/day)	154	0.26	0.43	-0.36	2.40

### Appendix D Literature review: spatial studies in farmers' decision-making

Table D.1: Summary of some spatial studies in farmers' decision-making

Study	Farmers' decision (dependent variable)	Scale	Model	Neighbourhood (or spatial weight matrix) definition	Some spatial variables	Some findings	Country
Case (1992)	Technology adoption (sickle)	Farm level	Probit model (form of lag and error models)	District boundaries	Farm is near an agricultural centre	Strong neighbourhood effect in farmers' technology adoption decision	Indonesia
Benirschka and Binkley (1994)	Agricultural land value	Regional level (county)	OLS and maximum likelihood models	Contiguous counties	County loan rate (proxy for distance to markets), land quality, population growth and density	Land price variation increases with distance to markets; population growth is positively associated with land prices	USA
Fox et al. (1994)	Land use decision	Farm level	Multinomial logit and generalised least squares (GLS) model	Adjacency matrix of plots; 2.5km (distance matrix)	Road and stream proximity, slope elevation, region dummies	Results depend on the form of land use and confirm the necessity of developing infrastructure to encourage land use changes	Thailand
Pomp and Burger (1995)	Land use decision (cocoa)	Village level	Probit and tobit model	Cumulative proportion of adopters (village)	NA	Strong neighbourhood effect in all models	Indonesia
Chomitz and Gray (1996)	Land use decision	1km grid	Multinomial logit model (bootstrap procedure)	NA	Land quality characteristics (nitrogen, slope, phosphorus, pH, wetness, flood hazard, rainfall), distance to markets	Market access, land quality (e.g. nitrogen, phosphorus, pH) strongly affect the probability of agricultural use; agriculture becomes less attractive as distance to market increases	Belize
Nelson and Hellerstein (1997)	Land use decision	30-150 m <sup>2</sup>	Multinomial logit model (spatial sampling technique)	NA	Geophysical (elevation, slope, soil solar radiation etc.) and socioeconomic (access to road, urban centre, village) factors	Road access affects land use	Mexico
Lapar and Pandey (1999)	Farm management adoption (soil conservation)	Farm level	Probit model	NA	Distance to road, slope, membership in labour exchange group (percent share)	The relative importance of factors (e.g. effect of distance to roads and membership) on adoption differs across space	Philippine

Holloway et al. (2002)	Land use decision (HYV rice)	Farm/ village level	Bayesian spatial autoregressive probit (SARP) model	Village boundaries	Distances to nearest market, extension services and nearest rice mill, district dummies	Strong neighbourhood effect in farmers' choices; distance variables are insignificant	Bangladesh
Isham (2002)	Farm management adoption (fertiliser)	Village level	Random effects probit	Cumulative adoption	Social structure: ethnic affiliation, consultative norms, leadership heterogeneity	Cumulative adoption, consultative norms and ethnic affiliations have a positive effect depending on the region	Tanzania
Müller and Zeller (2002)	Land use decision	Village level	Multinomial logit model	NA	Rainfall, soil suitability, slope, elevation, population, distances to roads and capital city	Improved access to rural roads and markets enabled agricultural expansion	Vietnam
Roe et al. (2002)	Land use decision (hog production)	Regional level (counties)	Spatial lag model	Inverse distance (200miles)	County dummies, unemployment rate, population, population growth, distance measures	Influence of the spatial factors varies across counties	USA
Staal et al. (2002)	Technology adoption and land use decision	Farm level	Logit model	NA	Neighbourhood characteristics (access to infrastructure and services), distances to market/cities, population density, district dummies	Market access measures significantly affect farmers' choices	Kenya
Swinton (2002)	Land use decision and other (crop yield)	Farm level	Spatial lag and error model	Inverse distance and four nearest neighbours matrix	Zonal dummies, distance to paved road	Spatial structure in the fallow land model	Peru
Lynch and Lovell (2003)	Other (trading development rights)	Farm level	Probit model	NA	Distance to cities, percentage of prime soils, county dummies	Increased likelihood of participation in a land development rights purchase program with eligible soils and longer distances to the city	USA
Patton and McErlean (2003)	Agricultural land value	Farm level	Spatial regime spatial lag hedonic model	NA	Land quality score, distance to urban area	Spatial lag dependence exists, thus agricultural land prices have a spill-over effect; bias on estimated coefficients is relatively small; other spatial influences vary across regions	Northern Ireland
Caviglia-Harris (2004)	Land use decision	Farm level	OLS and 2SLS	NA	Distance to city centre, pesticide use	Access to markets influence deforestation and production decisions	Brazil
Isik (2004)	Land use decision (dairy cow)	Regional level (county)	Spatial lag model (two-stage least square (2SLS))	Inverse distance (200miles upper bound)	Land value, population unemployed, land area, population, climate etc.	Agglomeration economies are important for the spatial structure of dairy production/location; counties with less stringent environmental policies have a positive effect	USA

Wu et al.	Land use	Farm level	Multinomial logit	NA	Climate data, land quality, slope,	Conservation payments can increase crop	USA
(2004)	decision				county dummies	rotations and conservation tillage	
Huang et al.	Agricultural	Regional	OLS and spatial lag	NA	Distances to Chicago and other large	Accounting for spatial correlation improves	USA
(2006)	land value	level	model		cities (population greater than	the model fit; farmland values increase with	
		(county)			50,000), ruralness index, farm density	population density and decline with ruralness,	
					measures, population density	distance to cities, and swine farm density	
Gellrich et al.	Land use	Regional	Logistic/autologistic	Any of the 8	Climate (degree days, radiation) and	Neighbourhood effect is positive and	Switzerland
(2007)	decision	level	model	surrounding	soil (depth, stoniness, slope) factors,	improves the model; population growth	
	(farmland			observations	distances to roads, forest	positive significant; degree days, distance to	
	abandon-			(dummy)	edges/closest construction zone,	forest edge/roads negative significant	
	ment)				population change, land use		
Holloway and	Market	Farm/	Spatial lag probit	Nearest 3 zones	Distance to market	Significant neighbourhood effect exists	Philippine
Lapar (2007)	participation	regional	model				
		level					
Langpap et al.	Land use	Regional	Multinomial logit and		Spatial dummies	Effect of land use policies on watershed	USA
(2008)	decision	level	poisson model			health varies spatially depending on land use	
		(county)				mixes	
Gabriel et al.	Land use	Regional	Spatial autoregressive	35km and 65km	Arable suitability, ruralisation	Variables associated with lower agricultural	UK
(2009)	decision	level	model		(proximity to towns, population	potential have a positive effect on organic	
	(organic)	(postcode			density), soil hydrology/texture,	farming (promoting further conversion to	
		area)			woodland area	organic farming in the neighbourhood)	
Maddison	Agricultural	Farm level	Spatial lag model,	inverse distance (0–	Distance to cities with over 100,000	Land values are affected by the price of	UK
(2009)	land value		spatio-temporal model	75, 75–150, 150–	and 250,000 people, population (at	nearby land sold and its land quality; spatio-	
				225km)	least 100,000)/distance, land quality	temporally lagged values contribute to the	
						explanatory power	
Lewis et al.	Land use	Farm level	Probit and logit model	0-5 miles, 5-10miles	Distance to Organic Valley	Positive neighbourhood effect; distance to the	USA
(2011)	decision				headquarters	headquarters had a negative effect	
	(organic)						
Wu et al.	Other (farm	Regional	Random-effects panel	80km	Built-up land in neighbourhood,	Population density (urbanisation) increased	USA
(2011)	production	level	model		population density, government	farm production costs and net farm income;	
	cost; net farm	(counties)			payment, % population aged over 65,	proximities to cities increased production	
	income)				natural amenities, land quality,	costs and farm income, land quality was	
					highway density, distance to cities	insignificant	

Gaigné et al. (2012)	Land use decision (hog production)	Regional level	Spatial lag/HAC model; generalized spatial two-stage least squares (GS2SLS)	Distance decay function (<200km)	Access to production infrastructure/consumers/crops, local degree of urbanisation, regional share of non-hog farms	Local interaction effect among hog producers; land limitations do not limit the spatial concentration of hog production and may boost the role played by non-market spatial externalities in the agglomeration process	France
Broch et al. (2013)	Other (participation in conservation scheme)	Farm/region al level (postal codes)	Random parameter logit model		Groundwater availability, species/biodiversity richness, population density, forest cover, hunting	Spatial variations (e.g. in population density) need to be considered when designing conservation policies	Denmark
Garrett et al. (2013)	Land use decision (soybeans)	Regional level (county)	Spatial lag model	Three nearest neighbours	Transport cost, distance Sao Paolo, biophysical data (rainfall, temperature, latitude, longitude), cattle density	Regions with high cooperative membership increases soy planted area/yields; yields decline/planted area increases as transportation costs increase	Brazil
Genius et al. (2013)	Technology adoption (irrigation)	Farm level	Duration analysis (maximum likelihood)		Stock of adopters in the reference group, distance to nearest extension agency/stock of adopters in the reference group	Distance from extension service and stock of adopters have a negative effect; distance between adopters has a positive effect; dry weather induces adoption speed	Greece
Li et al. (2013)	Land use decision (farmland conversion)	10 km cell/ county level	Spatial multinomial logit model	Contiguity weight matrix	Land quality, slope, elevation, climate data, regional GDP, road density	Significant neighbouring land use effects; all other spatial variables had significant influences on farmland conversion	China
Läpple and Kelley (2014)	Land use decision (organic)	Farm level	Bayesian spatial Durbin probit model (SDM)	Inverse distance (20, 30, 40, and 50km)	Livestock density, distances to market and organic demonstration farm	Farmers located in close proximity have similar adoption behaviour; social norms and attitudes have spatial spill-over effects; livestock density negative effect	Ireland
Polyakov et al. (2014)	Agricultural land value	Farm level	Spatial fixed effects model, Manski model with spatio-temporal lags	25km	Slope, precipitation, tree cover, distances to national park, main road and river, Population Gravity Index (sum of the inverse squared distance weighted population of urban centres and localities within 700km radius from the property)	Population gravity index, proximity to rivers and roads increases property values; characteristics of neighbouring properties influence property values; sale price of a property is affected by the sale prices of properties in the neighbourhood	Australia
Mukherjee and Schwabe (2015)	Agricultural land value	Farm level	General spatial model (GSM)	Contiguity weight matrix	Distance to nearest city, population, degree days, precipitation, water access, groundwater well depth and salinity	Water quality, reliability and availability have a negative and access to a diverse water portfolio has a positive effect on farmland value	USA

Storm et al. (2015)	Land use decision (farmland abandon- ment)	Farm level	Probit model, spatially lagged explanatory variable model (SLX) and spatial Durbin error model (SDEM)	Median driving distance to the furthest field in each municipality (maximum number of neighbours is 20)	NA	Farm exit/survival is affected by neighbouring farmers' characteristics and their direct payments received	Norway
Ward and Pede (2015)	Land use decision (HYV rice)	Farm level	Spatial two-stage ARAR model (error and lag)	Same village membership; inverse distance	NA	Positive neighbourhood effect (based on distances)	Bangladesh
Dall'erba and Domínguez (2016)	Agricultural land value	Regional level (county)	OLS, SLX, 2SLS	240km	Population density, erosion, clay content, permeability, moisture capacity, climate data	Population density has a positive and soil conditions a negligible effect; there is a heterogeneous role of climate	USA
Niedermayr et al. (2016)	Land use decision (styrian oil pumpkin)	Regional level (muni- cipalities)	Tobit and SLX tobit models	Contiguity (municipalities)	Soil quality, distance from nearest washing/ drying facility, share of organic farms, share of farmers with higher agricultural education	Region-specific factors (e.g. marketing) and their spatial interdependence influence spatial variations in oil-pumpkin-cultivated areas	Austria

### Appendix E Supplementary tables: spatial data collection and description

Table E.1: Databases and search tools for national and state-level spatial data

Database/ Search tool	Address	Short Description
Australian Government - data.gov.au	http://data.gov.au/	Facilitates finding, accessing and reusing public datasets from the Australian Government, e.g. Geoscience, Federal and State Departments. Gives access to over 3,500 datasets (May 2014).
Australian Spatial Data Directory (ASDD)	http://asdd.ga.gov.au/ asdd/search.html	The ASDD was initiated by the ANZLIC - the Spatial Information Council to improve access to nationally consistent spatial datasets. The ASDD consolidates government and commercial nodes in each state/territory and spatial data agencies within the Australian Government incorporating information about datasets (metadata) from all jurisdictions. The ASDD has now been replaced by FIND the Australian Government's spatial data catalogue.
NSW Spatial Data Catalogue	http://www.sdi.nsw.g ov.au/GPT9/catalog/ main/home.page	The NSW Spatial Data Catalogue is the central source for metadata describing NSW Local and State Government spatial data.
NSW Government	http://www.data.nsw. gov.au/	data.NSW collates a list of NSW Government datasets available in one searchable website to make data more accessible to the public and to industry.
Victorian Government Data Directory	http://www.data.vic.g ov.au/	The Victorian Government Data Directory provides public access to Victorian Government generated or owned data.
DataSearch Victoria	http://services.land.vi c.gov.au/SpatialData mart/index.jsp	DataSearch Victoria is an online search and discovery tool that enables assessment of available spatial data resources from the Victorian Government.

Table E.2: Land use categories assessed in Chapter 6

Level 1	Level 2	Level 3
Production from	Grazing irrigated modified	Irrigated woody fodder plants
irrigated agriculture	pastures	Irrigated pasture legumes
and plantations		Irrigated legume/grass mixtures
		Irrigated sown grasses
	Irrigated cropping	Irrigated cereals
		Irrigated beverage & spice crops
		Irrigated hay & silage
		Irrigated oil seeds
		Irrigated sugar
		Irrigated cotton
		Irrigated alkaloid poppies
		Irrigated pulses
	Irrigated perennial	Irrigated tree fruits
	horticulture	Irrigated oleaginous fruits
		Irrigated tree nuts
		Irrigated vine fruits
		Irrigated shrub nuts, fruits & berries
		Irrigated perennial flowers & bulbs
		Irrigated perennial vegetables & herbs
		Irrigated citrus
		Irrigated grapes
	Irrigated seasonal	Irrigated seasonal fruits
	horticulture	Irrigated seasonal nuts
		Irrigated seasonal flowers & bulbs
		Irrigated seasonal vegetables & herbs
		Irrigated turf farming
	Irrigated land in transition	Degraded irrigated land
		Abandoned irrigated land
		Irrigated land under rehabilitation
		No defined use (irrigation)
		Abandoned irrigated perennial horticulture
Production from	Land in transition	Degraded land
dryland agriculture and plantations		Abandoned land
and plantations		Land under rehabilitation
		No defined use
		Abandoned perennial horticulture

Source: adapted from ABARES (2012)

# Appendix F GIS tools

Table F.1: Description of GIS tools used

GIS tool (toolbox)	Description (summary)	Chapter
Buffer (Analysis)	Creates buffer polygons around input features to a specified distance.	7
Calculate Distance Band from Neighbour Count (Spatial Statistics)	Returns the minimum, the maximum, and the average distance to the specified Nth nearest neighbour (N is an input parameter) for a set of features.	7
Cluster and Outlier Analysis (Anselin Local Moran's I) (Spatial Statistics)	Given a set of weighted features, identifies statistically significant hot spots, cold spots, and spatial outliers using the Anselin Local Moran's I statistic.	7
Create Fishnet (Data Management)	Creates a fishnet of rectangular cells.	7
Euclidean Distance (Spatial Analyst)	Calculates, for each cell, the Euclidean (straight-line) distance to the closest source.	7
Generate Near Table (Analysis)	Determines the distances from each feature in the input features dataset to one or more nearby features in the near features dataset, within the search radius.	7
Incremental Spatial Autocorrelation (Spatial Statistics)	Measures spatial autocorrelation (Global Moran's I statistic) for a series of distances and optionally creates a line graph of those distances and their corresponding z-scores. Z-scores reflect the intensity of spatial clustering, and statistically significant peak z-scores indicate distances where spatial processes promoting clustering are most pronounced. These peak distances are often appropriate values to use for tools with a Distance Band or Distance Radius parameter.	7
Int (Spatial Analyst)	Converts each cell value of a raster dataset to an integer dataset by truncation.	6, 7
Kernel Density (Spatial Analyst)	Calculates a magnitude per unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline.	6
Natural Neighbour (Spatial Analyst)	Interpolates a raster surface from points using a natural neighbour algorithm which finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas to interpolate a value. Its basic properties are that it's local, using only a subset of samples that surround a query point, and interpolated heights are guaranteed to be within the range of the samples used. It does not infer trends and will not produce peaks, pits, ridges, or valleys that are not already represented by the input samples. The surface passes through the input samples and is smooth everywhere except at locations of the input samples.	7
Point Density (Spatial Analyst)	Calculates a magnitude per unit area from point features that fall within a neighbourhood around each cell.	7
Raster Calculator (Spatial Analyst)	Builds and executes a single map algebra expression using Python syntax in a calculator-like interface (e.g. for calculating averages from several raster datasets (e.g. rainfall))	5, 6, 7
Spatial Join (Analysis)	Joins attributes from one feature dataset to another based on the spatial relationship. The target features and the joined attributes from the join features are written to the output feature class.	5, 6, 7
Tabulate Area (Spatial Analyst)	Calculates cross-tabulated areas between two datasets and outputs a table.	6
Zonal Statistics as Table (Spatial Analyst)	Summarises the values of a raster dataset within the zones of another dataset and reports the results to a table.	6

Source: ESRI (2012)

## **Appendix G Supplementary tables for the models in Chapter 6**

Table G.1: Collinearity for water entitlement selling model

Variables	VIF
Entitlement sales (In ML)	1.18
Soil texture (index)	3
Net rainfall previous 5 years (mm/d)	2.02
Dryland salinity (dummy)	1.35
Groundwater salinity (dummy)	2.26
Surface-water salinity (dummy)	1.8
Population growth previous 5 years (%)	2.07
Business income (PP; \$ in thousands)	1.08
Density cities	2.57
Entitlements owned (ln ML)	7.71
Groundwater use (In ML)	1.43
Allocation level previous 5 years (%)	3.94
Entitlement price previous year (ln \$/ML)	1.95
Allocation price (ln \$/ML)	2.03
Irrigated cropping (%)	2.08
Irrigated horticulture (perennial) (%)	1.53
Irrigated horticulture (seasonal) (%)	1.61
Irrigated grazing (%)	2.71
Land in transition (%)	1.6
Murrumbidgee (dummy)	5.74
VIC Murray (dummy)	6.29
Goulburn (dummy)	4.85
NSW Murray (dummy)	4.03
Loddon (dummy)	2.65
Mean VIF	2.81

Table G.2: Collinearity for water entitlement purchasing model

Variable	VIF
Entitlement purchases (In ML)	1.3
Soil texture (index)	5.15
Net rainfall previous 5 years (mm/d)	1.76
Dryland salinity (dummy)	1.4
Groundwater salinity (dummy)	2.14
Surface-water salinity (dummy)	1.63
Population growth previous 5 years (%)	2.69
Business income (PP; \$ in thousands)	1.1
Density cities	3.47
Entitlements owned (In ML)	9.46
Groundwater use (ln ML)	1.41
Allocation level previous 5 years (%)	4.61
Entitlement price previous year (ln \$/ML)	2.79
Allocation price (ln \$/ML)	2.03
Irrigated cropping (%)	2.16
Irrigated horticulture (perennial) (%)	1.52
Irrigated horticulture (seasonal) (%)	1.77
Irrigated grazing (%)	3.22
Land in transition (%)	1.63
Murrumbidgee (dummy)	7.76
VIC Murray (dummy)	12.62
Goulburn (dummy)	7.5
NSW Murray (dummy)	5.47
Loddon (dummy)	2.43
Mean VIF	3.63

Table G.3: Pairwise correlations for water entitlement trading models

	Entitlement sales (In ML)	Entitlement purchases (ln ML)	Soil texture (index)	Net rainfall previous 5 years (mm/d)	Dryland salinity (dummy)	Groundwater salinity (dummy)
Entitlement purchases (ln ML)	0.321	1.000			(uullilly)	(ddiffiny)
Soil texture (index)	0.099	0.137	1.000			
Net rainfall previous 5 years (mm/d)	-0.175	-0.165	-0.227	1.000		
Dryland salinity (dummy)	0.067	-0.119	-0.085	0.072	1.000	
Groundwater salinity (dummy)	0.111	0.087	0.036	-0.448	0.046	1.000
Surface-water salinity (dummy)	-0.120	0.032	-0.001	-0.018	-0.008	-0.124
Population growth previous 5 years (%)	-0.091	-0.130	-0.178	0.119	-0.030	-0.241
Business income (PP; \$ in thousands)	0.065	0.078	0.029	-0.058	0.044	0.117
Density cities	-0.170	-0.183	-0.266	0.404	-0.048	-0.454
Entitlements owned (ln ML)	0.088	0.096	0.223	-0.105	-0.226	-0.064
Groundwater use (ln ML)	0.124	0.124	0.035	0.038	-0.031	-0.035
Allocation level previous 5 years (%)	-0.042	0.097	-0.046	0.124	-0.172	-0.062
Entitlement price previous year (ln \$/ML)	0.027	-0.117	0.002	0.015	-0.068	-0.027
Allocation price (ln \$/ML)	-0.034	0.239	0.032	0.060	0.009	-0.009
Irrigated cropping (%)	0.174	0.136	0.523	-0.304	-0.100	0.116
Irrigated horticulture (perennial) (%)	-0.027	-0.010	-0.108	-0.161	-0.082	0.241
Irrigated horticulture (seasonal) (%)	-0.005	-0.060	0.062	-0.203	0.067	0.324
Irrigated grazing (%)	0.016	0.044	0.422	-0.176	-0.196	-0.049
Land in transition (%)	0.095	0.153	-0.073	-0.109	0.003	0.213
Murrumbidgee (dummy)	0.093	0.078	0.146	0.062	-0.061	-0.223
VIC Murray (dummy)	-0.026	-0.042	0.288	-0.034	-0.140	0.102
Goulburn (dummy)	-0.042	0.063	0.103	0.061	-0.023	-0.101
NSW Murray (dummy)	0.078	-0.026	0.211	-0.101	0.089	-0.023
Loddon (dummy)	-0.057	-0.045	0.038	0.085	0.087	-0.065

**Table G.3 Continued** 

	Surface- water salinity (dummy)	Population growth previous 5 years (%)	Business income (PP; \$ in thousands)	Density cities	Entitlements owned (ln ML)	Groundwater use (ln ML)	Allocation level previous 5 years (%)	Entitlement price previous year (ln \$/ML)	Allocation price (ln \$/ML)
Population growth previous 5 years (%)	-0.001	1.000							
Business income (PP; \$ in thousands)	0.042	-0.049	1.000						
Density cities	0.173	0.303	-0.177	1.000					
Entitlements owned (ln ML)	-0.186	-0.041	-0.047	-0.046	1.000				
Groundwater use (ln ML)	0.155	-0.102	0.003	0.073	0.367	1.000			
Allocation level previous 5 years (%)	-0.228	0.135	-0.056	0.108	0.157	-0.060	1.000		
Entitlement price previous year (ln \$/ML)	-0.323	-0.032	-0.089	0.167	0.162	-0.175	-0.032	1.000	
Allocation price (ln \$/ML)	0.219	-0.011	0.098	-0.012	-0.006	0.030	0.411	-0.322	1.000
Irrigated cropping (%)	-0.030	-0.166	-0.056	-0.186	0.199	0.078	0.056	0.111	0.028
Irrigated horticulture (perennial) (%)	-0.126	-0.025	-0.047	-0.063	0.046	-0.011	0.086	0.037	-0.024
Irrigated horticulture (seasonal) (%)	-0.194	-0.104	0.033	-0.181	0.073	0.019	0.030	0.057	0.002
Irrigated grazing (%)	0.041	-0.087	-0.102	0.036	0.248	0.099	0.175	0.115	0.029
Land in transition (%)	-0.118	-0.093	0.006	-0.229	-0.031	-0.095	0.068	-0.128	-0.020
Murrumbidgee (dummy)	-0.190	0.014	0.075	-0.188	0.389	0.007	-0.132	0.174	-0.036
VIC Murray (dummy)	-0.114	-0.099	0.007	-0.139	0.318	0.084	0.379	0.071	0.049
Goulburn (dummy)	-0.068	0.013	-0.173	0.151	0.351	0.078	0.222	0.111	0.028
NSW Murray (dummy)	-0.140	-0.036	0.025	-0.039	0.225	0.137	-0.225	0.136	-0.042
Loddon (dummy)	0.403	-0.027	0.032	0.035	-0.385	0.041	-0.271	-0.012	0.026

**Table G.3 Continued** 

	Irrigated cropping (%)	Irrigated horticulture (perennial) (%)	Irrigated horticulture (seasonal) (%)	Irrigated grazing (%)	Land in transition (%)	Murrumbidgee (dummy)	VIC Murray (dummy)	Goulburn (dummy)	NSW Murray (dummy)
Irrigated horticulture (perennial) (%)	-0.059	1.000							
Irrigated horticulture (seasonal) (%)	0.282	0.306	1.000						
Irrigated grazing (%)	0.559	-0.117	-0.037	1.000					
Land in transition (%)	-0.162	0.396	0.027	-0.148	1.000				
Murrumbidgee (dummy)	0.031	-0.070	-0.066	-0.168	-0.003	1.000			
VIC Murray (dummy)	0.330	0.052	0.291	0.210	-0.107	-0.125	1.000		
Goulburn (dummy)	0.172	-0.097	-0.124	0.480	-0.120	-0.140	-0.122	1.000	
NSW Murray (dummy)	0.018	-0.076	0.016	0.079	-0.067	-0.094	-0.082	-0.092	1.000
Loddon (dummy)	0.024	-0.131	-0.114	-0.077	-0.110	-0.128	-0.112	-0.125	-0.084

Table G.4: Collinearity for the water allocation selling model

Variable	VIF
Allocation sales (In ML)	1.45
Soil texture (index)	2.79
Net rainfall (mm/d)	2.07
Dryland salinity (dummy)	1.21
Groundwater salinity (dummy)	1.93
Surface-water salinity (dummy)	1.78
Population growth (%)	1.59
Business income (PP; \$ in thousands)	1.11
Density cities	2.17
Entitlements owned (ln ML)	5.19
Groundwater use (ln ML)	1.75
Allocation level (%)	2.06
Entitlement price (ln \$/ML)	2.72
Allocation price previous year (ln \$/ML)	14.98
Irrigated cropping (%)	2.3
Irrigated horticulture (perennial) (%)	1.53
Irrigated horticulture (seasonal) (%)	1.6
Irrigated grazing (%)	2.33
Land in transition (%)	1.56
Murrumbidgee (dummy)	5.39
VIC Murray (dummy)	4.07
Goulburn (dummy)	3.9
NSW Murray (dummy)	3.37
Loddon (dummy)	1.9
2010/11 (dummy)	7.19
2011/12 (dummy)	2.44
2012/13 (dummy)	5.33
Mean VIF	3.17

Table G.5: Collinearity for the water allocation purchasing model

Variable	VIF
Allocation purchases (ln ML)	1.52
Soil texture (index)	3.8
Net rainfall (mm/d)	1.84
Dryland salinity (dummy)	1.39
Groundwater salinity (dummy)	1.92
Surface-water salinity (dummy)	1.56
Population growth (%)	1.75
Business income (PP; \$ in thousands)	1.12
Density cities	2.61
Entitlements owned (ln ML)	8.28
Groundwater use (ln ML)	1.55
Allocation level (%)	2.33
Entitlement price (ln \$/ML)	2.67
Allocation price previous year (ln \$/ML)	18.69
Irrigated cropping (%)	2.12
Irrigated horticulture (perennial) (%)	1.37
Irrigated horticulture (seasonal) (%)	1.52
Irrigated grazing (%)	2.83
Land in transition (%)	1.61
Murrumbidgee (dummy)	7.21
VIC Murray (dummy)	7.68
Goulburn (dummy)	7.6
NSW Murray (dummy)	5.33
Loddon (dummy)	1.9
2010/11 (dummy)	8.48
2011/12 (dummy)	2.73
2012/13 (dummy)	6.51
Mean VIF	4

Table G.6: Pairwise correlations for water allocation trading models

	Allocation sales (ln ML)	Allocation purchases (ln ML)	Soil texture (index)	Net rainfall (mm/d)	Dryland salinity (dummy)
Allocation purchases (ln ML)	0.400	1.000			
Soil texture (index)	0.112	0.177	1.000		
Net rainfall (mm/d)	-0.327	-0.308	-0.194	1.000	
Dryland salinity (dummy)	0.005	-0.044	-0.085	0.054	1.000
Groundwater salinity (dummy)	0.068	-0.052	0.036	-0.392	0.046
Surface-water salinity (dummy)	-0.080	0.027	-0.001	-0.025	-0.008
Population growth (%)	-0.068	-0.033	-0.168	0.097	-0.027
Business income (PP; \$ in thousands)	0.039	0.005	0.029	-0.035	0.044
Density cities	-0.174	-0.191	-0.266	0.370	-0.048
Entitlements owned (In ML)	0.155	0.124	0.223	-0.085	-0.226
Groundwater use (ln ML)	0.136	0.128	0.035	-0.136	-0.031
Allocation level (%)	-0.131	-0.091	-0.020	0.049	-0.024
Entitlement price (ln \$/ML)	-0.158	-0.065	-0.016	0.189	-0.074
Allocation price previous year (ln \$/ML)	-0.218	-0.178	0.017	0.303	-0.004
Irrigated cropping (%)	0.101	0.168	0.523	-0.244	-0.100
Irrigated horticulture (perennial) (%)	-0.013	-0.050	-0.108	-0.130	-0.082
Irrigated horticulture (seasonal) (%)	0.057	-0.088	0.062	-0.170	0.067
Irrigated grazing (%)	0.012	0.143	0.422	-0.122	-0.196
Land in transition (%)	0.151	0.107	-0.073	-0.102	0.003
Murrumbidgee (dummy)	0.124	0.169	0.146	0.040	-0.061
VIC Murray (dummy)	0.016	0.011	0.288	0.001	-0.140
Goulburn (dummy)	-0.107	-0.064	0.103	0.063	-0.023
NSW Murray (dummy)	0.089	0.064	0.211	-0.077	0.089
Loddon (dummy)	-0.190	-0.036	0.038	0.043	0.087
2010/11 (dummy)	-0.254	-0.222	0.000	0.340	0.000
2011/12 (dummy)	-0.135	-0.073	0.000	-0.090	0.000
2012/13 (dummy)	0.167	0.072	0.000	-0.129	0.000

**Table G.6 Continued** 

	Groundwater salinity (dummy)	Surface-water salinity (dummy)	Population growth (%)	Business income (PP; \$ in thousands)	Density cities	Entitlements owned (ln ML)	Groundwater use (ln ML)
Surface-water salinity (dummy)	-0.124	1.000					
Population growth (%)	-0.224	0.004	1.000				
Business income (PP; \$ in thousands)	0.117	0.042	-0.057	1.000			
Density cities	-0.454	0.173	0.254	-0.177	1.000		
Entitlements owned (ln ML)	-0.064	-0.186	-0.005	-0.047	-0.046	1.000	
Groundwater use (ln ML)	-0.035	0.155	-0.080	0.003	0.073	0.367	1.000
Allocation level (%)	0.079	0.111	-0.065	-0.040	0.115	-0.187	-0.094
Entitlement price (ln \$/ML)	0.017	-0.322	-0.134	-0.069	0.148	0.139	-0.221
Allocation price previous year (ln \$/ML)	0.009	-0.105	-0.003	0.078	-0.006	-0.014	-0.443
Irrigated cropping (%)	0.116	-0.030	-0.168	-0.056	-0.186	0.199	0.078
Irrigated horticulture (perennial) (%)	0.241	-0.126	0.001	-0.047	-0.063	0.046	-0.011
Irrigated horticulture (seasonal) (%)	0.324	-0.194	-0.105	0.033	-0.181	0.073	0.019
Irrigated grazing (%)	-0.049	0.041	-0.110	-0.102	0.036	0.248	0.099
Land in transition (%)	0.213	-0.118	-0.061	0.006	-0.229	-0.031	-0.095
Murrumbidgee (dummy)	-0.223	-0.190	0.038	0.075	-0.188	0.389	0.007
VIC Murray (dummy)	0.102	-0.114	-0.107	0.007	-0.139	0.318	0.084
Goulburn (dummy)	-0.101	-0.068	0.011	-0.173	0.151	0.351	0.078
NSW Murray (dummy)	-0.023	-0.140	-0.023	0.025	-0.039	0.225	0.137
Loddon (dummy)	-0.065	0.403	-0.031	0.032	0.035	-0.385	0.041
2010/11 (dummy)	0.000	-0.089	0.030	0.005	0.000	0.040	-0.305
2011/12 (dummy)	0.000	-0.089	-0.075	-0.053	0.000	-0.017	0.079
2012/13 (dummy)	0.000	0.089	0.047	-0.143	0.000	-0.009	0.119

**Table G.6 Continued** 

	Allocation level (%)	Entitlement price (ln \$/ML)	Allocation price previous year (ln \$/ML)	Irrigated cropping (%)	Irrigated horticulture (perennial) (%)	Irrigated horticulture (seasonal) (%)
Entitlement price (ln \$/ML)	0.299	1.000				
Allocation price previous year (ln \$/ML)	-0.142	0.224	1.000			
Irrigated cropping (%)	0.090	0.093	0.016	1.000		
Irrigated horticulture (perennial) (%)	0.020	0.076	0.010	-0.059	1.000	
Irrigated horticulture (seasonal) (%)	0.047	0.071	0.005	0.282	0.306	1.000
Irrigated grazing (%)	0.130	0.093	0.010	0.559	-0.117	-0.037
Land in transition (%)	-0.061	-0.094	0.003	-0.162	0.396	0.027
Murrumbidgee (dummy)	-0.287	0.170	0.025	0.031	-0.070	-0.066
VIC Murray (dummy)	0.148	0.071	0.023	0.330	0.052	0.291
Goulburn (dummy)	0.166	0.091	0.016	0.172	-0.097	-0.124
NSW Murray (dummy)	-0.255	0.113	-0.047	0.018	-0.076	0.016
Loddon (dummy)	0.152	-0.036	0.014	0.024	-0.131	-0.114
2010/11 (dummy)	-0.091	0.247	0.866	0.000	0.000	0.000
2011/12 (dummy)	0.130	0.173	-0.249	0.000	0.000	0.000
2012/13 (dummy)	-0.043	-0.130	-0.634	0.000	0.000	0.000

**Table G.6 Continued** 

	Irrigated grazing (%)	Land in transition (%)	Murrumbidgee (dummy)	VIC Murray (dummy)	Goulburn (dummy)	NSW Murray (dummy)	Loddon (dummy)	2010/11 (dummy)	2011/12 (dummy)
Land in transition (%)	-0.148	1.000							
Murrumbidgee (dummy)	-0.168	-0.003	1.000						
VIC Murray (dummy)	0.210	-0.107	-0.125	1.000					
Goulburn (dummy)	0.480	-0.120	-0.140	-0.122	1.000				
NSW Murray (dummy)	0.079	-0.067	-0.094	-0.082	-0.092	1.000			
Loddon (dummy)	-0.077	-0.110	-0.128	-0.112	-0.125	-0.084	1.000		
2010/11 (dummy)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	
2011/12 (dummy)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.333	1.000
2012/13 (dummy)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.333	-0.333

Table G.7: Tobit random-effects panel models for water entitlement trading

	Entitlement	sales (ln ML)		purchases (In L)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	-0.309 (0.352)		1.301** (0.514)	1.417*** (0.434)
Net rainfall previous 5 years (mm/d)	-2.910* (1.646)	-3.583*** (1.344)	-2.026 (2.004)	
Dryland salinity (dummy)	1.190** (0.497)	1.214*** (0.427)	-0.139 (0.646)	
Groundwater salinity (dummy)	0.216 (0.670)	(34 4)	1.178 (0.789)	1.212** (0.615)
Surface-water salinity (dummy)	-0.751 (0.589)	-1.297*** (0.461)	0.187 (0.663)	(00000)
Population growth previous 5 years (%)	0.255 (0.293)	(01.01)	0.233 (0.380)	
Business income (PP; \$ in thousands)	0.016 (0.012)		0.010 (0.010)	
Density cities	-0.060 (0.038)	-0.052* (0.026)	-0.047 (0.054)	
Other regional variables:	(0.030)	(0.020)	(0.054)	
Entitlements owned (ln ML)	0.264 (0.434)		1.672** (0.723)	1.811*** (0.515)
Groundwater use (ln ML)	0.281**	0.256*** (0.077)	0.078 (0.139)	(0.010)
Allocation level previous 5 years (%)	0.020 (0.021)	(0.077)	0.065** (0.029)	0.060** (0.024)
Entitlement price previous year (ln \$/ML)	0.881 (1.194)		0.701 (1.340)	(0.021)
Allocation price (ln \$/ML)	-0.299 (0.556)		1.690** (0.718)	1.827*** (0.611)
Irrigated cropping (%)	0.105*** (0.027)	0.052** (0.020)	0.063** (0.030)	0.065** (0.029)
Irrigated horticulture (perennial) (%)	-0.026 (0.027)	(0.020)	0.005 (0.035)	(0.02)
Irrigated horticulture (seasonal) (%)	-0.438 (0.304)	-0.615*** (0.238)	-0.874 (0.595)	
Irrigated grazing (%)	-0.018 (0.026)	(0.200)	0.007 (0.029)	
Land in transition (%)	0.485 (0.375)		0.500 (0.392)	0.605* (0.345)
Murrumbidgee (dummy)	-0.374 (1.428)		-4.465** (2.162)	-4.527*** (1.682)
VIC Murray (dummy)	-1.515 (1.549)		-8.433*** (2.611)	-8.861*** (2.103)
Goulburn (dummy)	-0.895 (1.478)		-5.452** (2.441)	-5.491*** (1.882)
NSW Murray (dummy)	0.079 (1.468)		-4.457** (2.220)	-4.872*** (1.690)
Loddon (dummy)	-0.036 (1.060)		-0.507 (1.570)	(1.070)
Constant	-10.11 (11.85)	-0.573 (0.854)	-39.59** (17.08)	-36.88*** (7.564)
Sigma u constant	0.734 (0.527)	0.881** (0.423)	0.000 (1.207)	0.284 (1.656)
Sigma e constant	4.054*** (0.224)	4.098*** (0.213)	4.090*** (0.264)	4.155***
Observations Left-censored observations	484	548	319 164	320 164
Len-censored observations	<i>LL</i> I	239	104	104

Uncensored observations	257	289	155	156
Right-censored observations	0	0	0	0
Log likelihood	-897.05	-1017.87	-544.14	-551.66
Wald chi2	60.44***	48.22***	70.46***	61.62***
AIC	1846.12	2055.74	1140.28	1131.32
BIC	1954.84	2098.80	1238.18	1184.08

Notes: standard errors in parentheses; \*p<0.10, \*\*p<0.05, \*\*\*p<0.01

Table G.8: Marginal effects (dy/dx) of the tobit random-effects panel models for water entitlement trading

	Entitlement sales (In ML)		Entitlement purc	chases (ln ML)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	-0.184		0.695	0.759
Net rainfall previous 5 years (mm/d)	-1.726	-2.110	-1.082	
Dryland salinity (dummy)	0.706	0.715	-0.074	
Groundwater salinity (dummy)	0.128		0.629	0.649
Surface-water salinity (dummy)	-0.445	-0.764	0.100	
Population growth previous 5 years (%)	0.151		0.124	
Business income (PP; \$ in thousands)	0.009		0.005	
Density cities	-0.035	-0.030	-0.025	
Other regional variables:		1		<u>'</u>
Entitlements owned (ln ML)	0.157		0.893	0.969
Groundwater use (ln ML)	0.166	0.151	0.042	
Allocation level previous 5 years (%)	0.012		0.035	0.032
Entitlement price previous year (ln \$/ML)	0.522		0.375	
Allocation price (ln \$/ML)	-0.177		0.903	0.978
Irrigated cropping (%)	0.062	0.030	0.034	0.035
Irrigated horticulture (perennial) (%)	-0.015		0.003	
Irrigated horticulture (seasonal) (%)	-0.260	-0.362	-0.467	
Irrigated grazing (%)	-0.011		0.004	
Land in transition (%)	0.288		0.267	0.324
Murrumbidgee (dummy)	-0.222		-2.385	-2.424
VIC Murray (dummy)	-0.898		-4.505	-4.744
Goulburn (dummy)	-0.531		-2.913	-2.940
NSW Murray (dummy)	0.047		-2.381	-2.608
Loddon (dummy)	-0.022		-0.271	

Table G.9: Tobit random-effects panel models for water allocation trading

	Allocation sales (In ML)		Allocation p M	urchases (ln L)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	0.312 (0.349)		0.402 (0.476)	
Net rainfall (mm/d)	-2.629*** (0.878)	-3.290*** (0.713)	-3.454*** (1.205)	-4.030*** (1.143)
Dryland salinity (dummy)	0.814* (0.485)		1.259** (0.630)	
Groundwater salinity (dummy)	-0.981 (0.630)		-1.524** (0.730)	-1.208* (0.645)
Surface-water salinity (dummy)	-1.084** (0.507)		0.366 (0.594)	
Population growth (%)	0.018 (0.194)		0.122 (0.235)	
Business income (PP; \$ in thousands)	0.001 (0.005)		-0.001 (0.006)	
Density cities	-0.032 (0.036)		-0.125*** (0.048)	-0.106*** (0.037)
Other regional variables:				
Entitlements owned (ln ML)	1.120*** (0.305)	0.465*** (0.152)	1.220** (0.534)	0.525** (0.227)
Groundwater use (ln ML)	-0.052 (0.077)		-0.044 (0.097)	
Allocation level (%)	0.001 (0.009)		-0.018 (0.013)	
Entitlement price (ln \$/ML)	0.178 (1.035)		2.568* (1.373)	
Allocation price previous year (ln \$/ML)	-0.092 (0.655)		-0.688 (0.889)	
Irrigated cropping (%)	0.055* (0.030)		0.048 (0.032)	
Irrigated horticulture (perennial) (%)	-0.056* (0.029)	-0.061** (0.026)	0.031 (0.037)	
Irrigated horticulture (seasonal) (%)	0.031 (0.336)		-0.604 (0.384)	
Irrigated grazing (%)	-0.001 (0.024)		0.085*** (0.026)	0.089*** (0.023)
Land in transition (%)	0.947** (0.419)	0.923*** (0.349)	0.519 (0.463)	
Murrumbidgee (dummy)	-3.036** (1.322)	,	-2.503 (1.928)	
VIC Murray (dummy)	-3.520*** (1.294)		-4.372** (1.873)	-2.428** (0.969)
Goulburn (dummy)	-4.752*** (1.205)	-2.117*** (0.702)	-5.836*** (1.797)	-3.857*** (1.141)
NSW Murray (dummy)	-2.750** (1.374)	( · · · · · · · · · · · · · · · · · · ·	-3.668* (1.925)	\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \
Loddon (dummy)	-2.104** (0.885)	-2.327*** (0.766)	-0.725 (1.291)	
2010/11 (dummy)	-3.751*** (0.874)	-3.162*** (0.386)	-3.385*** (1.149)	-3.431*** (0.500)
2011/12 (dummy)	-3.278*** (0.513)	-2.882*** (0.330)	-3.268*** (0.662)	-2.823*** (0.432)
2012/13 (dummy)	-0.688 (0.731)	(0.000)	-2.354** (0.985)	-1.571*** (0.423)
Constant	-8.428 (8.538)	-0.203 (2.025)	-24.01* (12.70)	0.244 (3.097)

Sigma u constant	2.142***	2.168***	2.184***	2.443***
	(0.211)	(0.198)	(0.258)	(0.239)
Sigma e constant	3.184***	3.295***	3.226***	3.226***
	(0.140)	(0.134)	(0.168)	(0.155)
Observations	623	709	442	506
Left-censored observations	213	240	148	171
Uncensored observations	410	469	294	335
Right-censored observations	0	0	0	0
Log likelihood	-1285.18	-1486.70	-924.85	-1064.12
Wald chi2	217.46	217.84	143.44	140.11
AIC	2628.37	2995.39	1907.70	2154.23
BIC	2756.97	3045.59	2026.34	2209.18

Notes: standard errors in parentheses; \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Table G.10: Marginal effects (dy/dx) of the tobit random-effects panel models for water allocation trading

	Allocation sales (ln ML)		Allocation p	urchases (ln ML)
	Full model	Reduced model	Full model	Reduced model
Spatial variables:				
Soil texture (index)	0.237		0.312	
Net rainfall (mm/d)	-2.003	-2.512	-2.679	-3.111
Dryland salinity (dummy)	0.620		0.976	
Groundwater salinity (dummy)	-0.747		-1.182	-0.933
Surface-water salinity (dummy)	-0.826		0.284	
Population growth (%)	0.013		0.095	
Business income (PP; \$ in thousands)	0.001		-0.001	
Density cities	-0.024		-0.097	-0.082
Other regional variables:	1			
Entitlements owned (ln ML)	0.854	0.355	0.946	0.405
Groundwater use (ln ML)	-0.039		-0.034	
Allocation level (%)	0.001		-0.014	
Entitlement price (ln \$/ML)	0.136		1.992	
Allocation price previous year (ln \$/ML)	-0.070		-0.534	
Irrigated cropping (%)	0.042		0.038	
Irrigated horticulture (perennial) (%)	-0.043	-0.047	0.024	
Irrigated horticulture (seasonal) (%)	0.023		-0.469	
Irrigated grazing (%)	-0.001		0.066	0.069
Land in transition (%)	0.721	0.705	0.403	
Murrumbidgee (dummy)	-2.313		-1.941	
VIC Murray (dummy)	-2.681		-3.391	-1.874
Goulburn (dummy)	-3.620	-1.616	-4.526	-2.978
NSW Murray (dummy)	-2.095		-2.845	
Loddon (dummy)	-1.603	-1.777	-0.563	
2010/11 (dummy)	-2.858	-2.414	-2.625	-2.649
2011/12 (dummy)	-2.497	-2.201	-2.535	-2.180
2012/13 (dummy)	-0.524	_	-1.826	-1.213

Table G.11: Comparison fixed-effects and random-effects models for entitlement sales (ln ML)

	Entitlement sales (ln ML)		
	Fixed-effects model	Random-effects model	
Net rainfall previous 5 years (mm/d)	2.385 (1.921)	-1.928** (0.797)	
Population growth previous 5 years (%)	1.099* (0.614)	-0.155 (0.141)	
Business income (PP; \$ in thousands)	0.011*** (0.004)	0.007* (0.004)	
Entitlements owned (ln ML)	0.586 (0.662)	0.062 (0.113)	
Groundwater use (ln ML)	0.118* (0.061)	0.150*** (0.055)	
Allocation level previous 5 years (%)	-0.025 (0.020)	-0.001 (0.008)	
Entitlement price previous year (ln \$/ML)	-1.134 (1.147)	0.147 (0.646)	
Allocation price (ln \$/ML)	-0.062 (0.329)	-0.161 (0.258)	
Constant	3.349 (11.95)	0.063 (5.397)	
Observations	484	484	
$\mathbb{R}^2$	0.06 (within)	0.06 (overall)	
Wald chi <sup>2</sup>		24.92***	
F-statistic	2.59***		
Hausman test (Prob > chi <sup>2</sup> )	0.037**		

Notes: standard errors in parentheses; \*p<0.10, \*\*p<0.05, \*\*\*p<0.01

Table G.12: Comparison fixed-effects and random-effects models for entitlement purchases ( $\ln$  ML)

	Entitlement purchases (ln ML)		
	Fixed-effects model	Random-effects model	
Net rainfall previous 5 years (mm/d)	1.049 (2.459)	-1.680 (1.088)	
Population growth previous 5 years (%)	-0.172 (0.641)	-0.299* (0.157)	
Business income (PP; \$ in thousands)	0.008* (0.004)	0.005 (0.004)	
Entitlements owned (ln ML)	-0.195 (0.927)	0.097 (0.160)	
Groundwater use (ln ML)	-0.019 (0.074)	0.056 (0.067)	
Allocation level previous 5 years (%)	0.035* (0.021)	0.007 (0.009)	
Entitlement price previous year (ln \$/ML)	-2.145 (1.334)	-1.089* (0.599)	
Allocation price (ln \$/ML)	0.377 (0.366)	0.896*** (0.307)	
Constant	17.73 (14.69)	5.061 (5.346)	
Observations	319	319	
$\mathbb{R}^2$	0.15 (within)	0.12 (overall)	
Wald chi <sup>2</sup>		41.91***	
F-statistic	5.07***		
Hausman test (Prob > chi <sup>2</sup> )	0.14		

Notes: standard errors in parentheses; p<0.10, p<0.05, p<0.01

Table G.13: Comparison fixed-effects and random-effects models for allocation sales (ln ML)

	Allocation sales (ln ML)		
	Fixed-effects model	Random-effects model	
Net rainfall (mm/d)	0.006 (0.780)	-2.012*** (0.537)	
Population growth (%)	0.078 (0.164)	-0.073 (0.125)	
Business income (PP; \$ in thousands)	-0.0004 (0.004)	0.001 (0.004)	
Entitlements owned (ln ML)	2.302*** (0.529)	0.386*** (0.123)	
Groundwater use (ln ML)	0.043 (0.053)	-0.001 (0.048)	
Allocation level (%)	0.003 (0.007)	-0.007 (0.006)	
Entitlement price (ln \$/ML)	-2.743 (1.700)	-0.493 (0.644)	
Allocation price previous year (ln \$/ML)	-0.116 (0.429)	-0.319 (0.419)	
2010/11 (dummy)	-1.639** (0.740)	-1.612*** (0.552)	
2011/12 (dummy)	-1.232** (0.480)	-1.965*** (0.333)	
2012/13 (dummy)	-0.341 (0.500)	-0.642 (0.473)	
Constant	-5.737 (14.03)	6.000 (4.620)	
Observations	623	623	
$\mathbb{R}^2$	0.29 (within)	0.21 (overall)	
Wald chi <sup>2</sup>		189.12***	
F-statistic	16.53***		
Hausman test (Prob > chi <sup>2</sup> )	0.001***		

Notes: standard errors in parentheses; \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Table G.14: Comparison fixed-effects and random-effects models for allocation purchases ( $\ln$  ML)

	Allocation purchases (ln ML)		
	Fixed-effects model	Random-effects model	
Net rainfall (mm/d)	0.198 (1.084)	-2.162*** (0.788)	
Population growth (%)	0.013 (0.186)	-0.128 (0.151)	
Business income (PP; \$ in thousands)	0.003 (0.004)	0.0009 (0.004)	
Entitlements owned (ln ML)	-0.524 (0.765)	0.157 (0.193)	
Groundwater use (ln ML)	0.059 (0.067)	-0.007 (0.063)	
Allocation level (%)	-0.004 (0.010)	-0.017** (0.008)	
Entitlement price (ln \$/ML)	-3.849* (2.160)	0.885 (0.906)	
Allocation price previous year (ln \$/ML)	-0.470 (0.571)	-0.514 (0.553)	
2010/11 (dummy)	-0.835 (0.906)	-1.890*** (0.717)	
2011/12 (dummy)	-0.947 (0.629)	-2.089*** (0.434)	
2012/13 (dummy)	-0.934 (0.665)	-1.401** (0.622)	
Constant	42.27** (18.53)	0.926 (6.310)	
Observations	442	442	
$\mathbb{R}^2$	0.22 (within)	0.17 (overall)	
Wald chi <sup>2</sup>		100.21***	
F-statistic	8.15***		
Hausman test (Prob > chi <sup>2</sup> )	0.029**		

Notes: standard errors in parentheses; \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

## Appendix H Survey excerpts for the dependent variables

1.1 We would like you to think entitlements and trading history in		high security water
In 2010-11, did you consider selling environmental purposes?	permanent entitlements to the Fe	ederal government for
Not interested at all in selling I slightly considered selling I seriously considered selling I submitted a tender (which was either unsuccessful Yes, I sold water	l or is unconfirmed at this point in	time)
Figure H.2: Excerpt from the 2010 sur Q.20 Have you considered selling water purposes?		
Not interested at all in selling I have slightly considered it I have seriously considered it I have submitted a tender Yes, I have sold	☐ (Go to Q.24) ☐ (Go to Q.21) ☐ (Go to Q.21) ☐ (Go to Q.22) ☐ (Go to Q.22)	

Figure H.3: Excerpt from the 2011 survey: price choices for WTP for water entitlements

#### AT WHAT PRICE WOULD YOU BUY PERMANENT WATER?

6. We would now like you to think about different high security and low/general security permanent water entitlement prices in your region and your participation in the water market today. Below we will present you with a range of \$/ML. For each price we would like you to indicate how many ML of each type of PERMANENT WATER ENTITLEMENTS you would buy today for your farm (or do nothing). If you do not want to buy, please write a "0" in each space. A worked example is provided below.

#### **WORKED EXAMPLE FOR Question 6**

At different prices, would you buy, sell or do nothing? Please remember that you must be able to afford (or be able to borrow) to buy more water. Also, if you sell water, you will not have that water to use in irrigation.

High Security Price (\$ per ML)	Number of high security ML you would Buy
\$500	15
\$1,000	10
\$1,500	8
\$2,000	0
\$2,500	0
\$3,000	0
\$3,500	0

At \$1,500/ML today, I would buy 8 ML of water

NOW, at these prices, would you buy or do nothing?

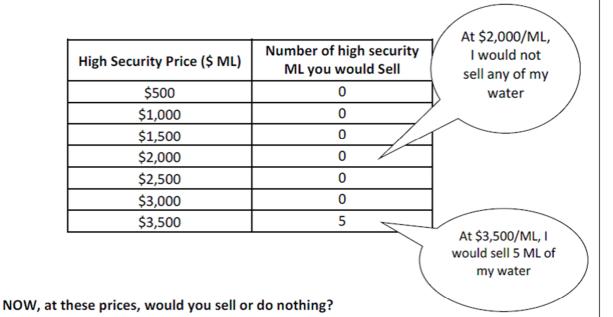
High Security Price (\$ per ML)	Volume: Number of High Security ML you would Buy	Low/general Security Price (\$ per ML)	Volume: Number of low/general Security ML you would Buy
\$500		\$300	
\$1,000		\$600	
\$1,500		\$900	
\$2,000		\$1,200	
\$2,500		\$1,500	
\$3,000		\$1,800	
\$3,500		\$2,100	
\$4,000		\$2,400	
\$4,500		\$2,700	
\$5,000		\$3,000	

Figure H.4: Excerpt from the 2011 survey: price choices for WTA for water entitlements

#### AT WHAT PRICE WOULD YOU SELL WATER?

7. We would now like you to think about different high security and low/general security permanent water entitlement prices in your region and your participation in the water market today. Below we will present you with a range of \$/ML. For each price we would like you to indicate how many ML of each type of permanent entitlements you would sell today (or do nothing). If you wish not to sell (or you do not have high security or low security water) please write a "0" in each space. A worked example is provided below.

#### **WORKED EXAMPLE FOR Question 7**



High Security Price (\$ per ML)	Volume: Number of High Security ML you would Sell	Low/general Security Price (\$ per ML)	Volume: Number of Low/general Security ML you would Sell
\$500		\$300	
\$1,000		\$600	
\$1,500		\$900	
\$2,000		\$1,200	
\$2,500		\$1,500	
\$3,000		\$1,800	
\$3,500		\$2,100	
\$4,000		\$2,400	
\$4,500		\$2,700	
\$5,000		\$3,000	

### Appendix I Geocoding process and providers

Choosing a method for geocoding is a crucial process, since the quality of the reference address data (in addition to the quality of the input address data) and the settings for the geocoding process (e.g. accuracy levels, multiple address locator in use) of the geocoding provider contribute substantially to the quality of the analysis (Duncan et al. 2011; Zandbergen 2008). For this chapter, various geocoding provider and address reference data were considered. Pre-installed address locators in ArcGIS were not applicable for detailed address geocoding of Australian addresses. Creating a new address locator by loading detailed reference address data may be costly as they may not be publicly available (the most detailed national dataset of address points in Australia is the Geocoded National Address File (G-NAF), which was made publicly available in 2016, initiated by the government to create a national dataset for address mapping through merging state address datasets (Christen et al. 2004; PSMA 2013)). Some states maintain their own address dataset, which can be highly accurate, such as 'VICmap address' (DSE 2012). Other street data can be sourced from Geoscience Australia or via the open source initiative OpenStreetMap; however, those sources have not been studied and do not seem to be sufficient especially in a rural context. Thus, other geocoding providers needed to be considered, such as free online (Table I.1) or commercial (Table I.2) geocoding services. The accuracy of online geocoding services has not been tested widely (compared to commercial services). Most of the online services use street centreline reference datasets with interpolation processes that may not meet a high geocoding accuracy level depending on the study area. But some studies have shown that the geocoding results of these services (e.g. Yahoo, Google) are not significantly different compared to other services (e.g. Kumar et al. 2012). However, care must be taken regarding the terms of use of each service, as they may not allow storing and displaying results within other applications.

To summarise, geocoding in rural areas is a challenging process, however this is expected to improve in future as address reference databases are constantly being updated, and a consistent rural addressing system is being implemented in Australia. Geocoding is easily and freely accessible through online geocoding services, providing it is not needed to store or visualise coordinates in another internal application. If data is to be analysed further, detailed address databases need to be acquired or commercial geocoding services hired. If the geocoding process is the foundation for detailed micro-scale analysis, it is advisable to use and compare multiple geocoding services (and reference databases). For example, it was found during this chapter's geocoding process that reference databases vary for Australian

rural addresses and that different geocoding providers use different algorithms (e.g. the *StreetName* locator may produce locations at the beginning or middle of the street depending on the provider (Figure I.2).

Table I.1: Selection of free online geocoding services

Service	Reference Data	Web address	Terms of use	Batch geo- coding
Google Geocoding API	TIGER (US) + others, own address data	https://developers.go ogle.com/maps/docu mentation/javascript/	No permission to store the data; the Geocoding API may only be used in conjunction with a Google map	Yes
Yahoo's Geocoding API	HERE and TomTom	http://developer.yaho o.com/boss/geo/	No permission to store the data; the Geocoding API may only be used in conjunction with a Yahoo map	Yes
iTouchMap	Google	http://itouchmap.com /latlong.html	see Google's policy	No
TravelGIS	Google	http://www.travelgis. com/geocode/	see Google's policy	No
Batchgeo	Google	http://batchgeo.com/	see Google's policy	Yes
GPS Visualizer	Google or Yahoo	http://www.gpsvisual izer.com/geocoder/	see Google's and Yahoo's policy	Yes
Gisgraphy	OSM	http://services.gisgrap hy.com/public/geoco ding.html		No
Mapquest	HERE	http://www.mapquest .com/	Not to be used in conjunction with any commercial application or to process or generate data for any third party.	Yes
Geohash	uses Google, OSM	http://geohash.org/	see Google's policy	No
Cloudmate API	OSM + other	http://cloudmade.com /products/geocoding		Yes
Bing Maps Geocode Service (Microsoft)	HERE	http://msdn.microsoft .com/en- us/library/ff701713.a spx	Data may be stored locally and only for use within the user's company applications.	Yes
Mapsys	Bing, Google	http://mapsys.info/ge ocoding-tool/	see Google's and Microsoft's policy	No
GeocodeFarm	Google	http://www.geocodef arm.com/index.html	see Google's policy	Yes

**Table I.2: List of commercial geocoding services (for Australia)** 

Commercial services	Reference data	Web address	Costs (AUD\$)	Free trial version
ArcGIS Online World Address Locator	HERE and TomTom	http://www.esri.com/so ftware/arcgis/arcgisonli ne/	Depending on the plan, approx. \$500 per year per user, min. of five users (80 credits per 1,000 geocodes)	Yes (2,500 free geocodes)
TomTom Global Geocoder  Pitney Bowes Spectrum	TomTom (no address points for Australia) G-NAF for Australia	https://geocoder.tomto m.com/app/view/index www.pitneybowes.com .au	Unspecified  min. \$2,500 + GST (\$0.06 per geocode up to 100,000)	Yes (2,500 free geocodes) Yes (100 free geocodes)
Callpoint Spatial Pty Ltd decarta devzone	G-NAF for Australia HERE, TomTom, OSM	http://www.callpointspa tial.com.au/geocoding/ http://developer.decarta .com/	\$400 + GST for 1,000 geocodes Unspecified	Yes (100 free geocodes) Unspecified
TerraPages Geocoder (LISAsoft)	G-NAF for Australia	http://www.terrapages.c om/TerraPages/Product s-and-Solutions.html	approx. \$1,100 annual subscription (monthly cap - 1,000 geocodes)	Unspecified

Figure I.1: Process of checking and rematching geocoding results in ArcGIS 10.1

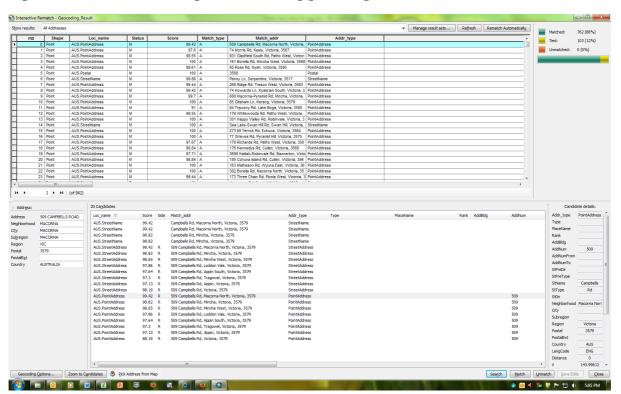
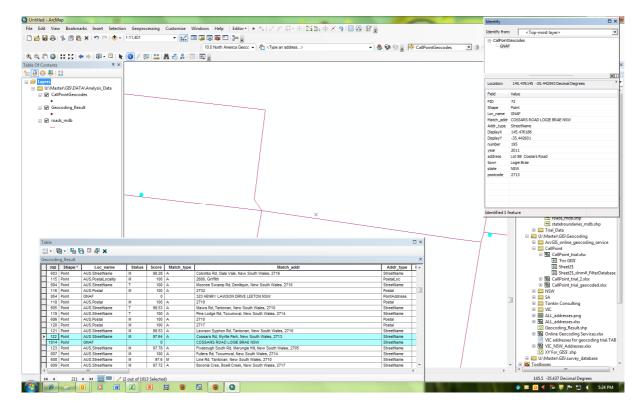


Figure I.2: Example for different geocoding results depending on the geocoding provider for the *StreetName* locator



# Appendix J Supplementary tables and figures for the probit model of water entitlement sales to the government

Table J.1; Marginal effects of the probit models of water entitlements sold to the government (reduced form)

	Surveys combined (2010 &	2009/10 (2010	2010/11 (2011
	2011)	survey)	survey)
Age	-0.027	-0.034	
Low education (dummy)	0.045	0.063	
Farm plan (dummy)	0.048		0.091
Government agency (dummy)	-0.048	-0.057	
Water entitlements owned (ln)	0.034	0.049	0.022
Carry-over (ln)	-0.007	-0.013	
Allocation trade (dummy)	0.048	0.065	
Farm size (ha)	-0.000	-0.000	-0.000
Risk type	0.012		
Health		0.019	
Gender (dummy)			-0.069
Net rainfall		0.951	
Dryland salinity (dummy)	0.051	0.060	
Population growth (%)	-0.004	-0.005	-0.007
Neighbours sold (SA2)	0.0009	0.002	
Distance to downstream area (km)	-0.0002	-0.0003	-0.0001
Allocation percent	-0.002		-0.002

Notes: For a continuous variable, the marginal effect is the change in probability of selling water entitlements to the government when the variable varies one unit in real value from its sample mean.

For a dummy variable, the marginal effect is the change in probability of selling water entitlements to the government when the variable varies from 0 to 1.

Table J.2: Full probit models of water entitlements sold to the government

	Surveys combined	2009/10 (2010	2010/11 (2011
	(2010 & 2011)	survey)	survey)
Survey variables:		T	T
Age	-0.117 (0.086)	-0.207* (0.110)	-0.092 (0.131)
Age squared	1.611 (1.248)	2.760* (1.584)	1.564 (1.923)
Low education (dummy)	0.343** (0.150)	0.548*** (0.178)	0.111 (0.287)
Farm plan (dummy)	0.364** (0.144)	0.195 (0.168)	1.197*** (0.284)
Government agency (dummy)	-0.575** (0.256)	-1.079** (0.475)	-0.198 (0.362)
Water entitlements owned (ln)	0.294*** (0.064)	0.486*** (0.086)	0.211*** (0.081)
Groundwater entitlements owned (ln)	-0.008 (0.036)	0.01 (0.043)	-0.075 (0.074)
Annual crops (%)	-0.001 (0.002)	-0.002 (0.002)	-0.001 (0.003)
Operating surplus (ln)	0.024 (0.015)	0.009 (0.022)	0.044* (0.022)
Children	0.037 (0.046)	0.055 (0.057)	-0.054 (0.084)
Allocation trade (dummy)	0.135 (0.126)	0.324** (0.162)	-0.365 (0.276)
Entitlement sale private market	0.020 (0.194)	0.239 (0.238)	0.032 (0.299)
(dummy)			
Gender (dummy)	-0.218 (0.158)	0.045 (0.195)	-0.566** (0.279)
Successor (dummy)	-0.217* (0.124)	-0.241 (0.152)	-0.325* (0.193)
Employees	-0.003 (0.023)	-0.025 (0.033)	0.037 (0.026)
Farm size (ha)	-0.0002*** (0.00009)	-0.0003** (0.0001)	-0.0003** (0.0001)
Horticulture (%)	-0.0009 (0.002)	0.002 (0.002)	-0.002 (0.003)
Off-farm income (%)	0.001 (0.001)	0.003* (0.002)	-0.002 (0.003)
Debt	-0.07 (0.165)	-0.206 (0.180)	1.272** (0.617)
Productivity change	-0.003 (0.047)	-0.027 (0.058)	0.064 (0.075)
Health	0.081 (0.055)	0.134** (0.067)	0.048 (0.093)
Organic grower (dummy)	0.194 (0.215)	0.321 (0.267)	-0.235 (0.511)
Diverse	-0.063 (0.081)	-0.03 (0.110)	-0.069 (0.129)
Risk type	0.101** (0.049)	0.05 (0.066)	0.077 (0.081)
Carry-over (ln)	-0.05** (0.026)	-0.109*** (0.032)	0.003 (0.053)
Survey year 2010 (dummy)	0.289 (0.223)		
Spatial variables:			
Net rainfall	5.385* (2.945)	10.16** (4.150)	2.697 (5.880)
Soil texture	0.1 (0.103)	0.161 (0.137)	0.009 (0.168)
Dryland salinity (dummy)	0.172 (0.131)	0.396** (0.164)	0.038 (0.228)
Groundwater salinity (dummy)	-0.076 (0.220)	0.058 (0.288)	-0.509 (0.399)
Surface-water salinity (dummy)	0.174 (0.129)	0.1 (0.168)	0.122 (0.264)
Regional population growth (%)	-0.031 (0.021)	-0.042 (0.026)	-0.05 (0.038)
Distance to cities (km)	0.003 (0.003)	0.003 (0.003)	0.001 (0.004)
Neighbours sold (SA2)	0.004 (0.004)	0.009 (0.005)	0.003 (0.006)
Distance to downstream area (km)	-0.002*** (0.0006)	-0.003*** (0.0008)	-0.003 (0.001)
Other regional variables:			
IIO charges (ln)	-0.003 (0.06)	-0.1 (0.072)	0.113 (0.1)
Allocation percent	-0.012*** (0.004)	-0.005 (0.004)	-0.024*** (0.008)
Water entitlement price (ln)	-0.018 (0.378)	-0.231 (0.494)	-0.264 (0.729)
Constant	-8.676 (5.750)	-11.69 (7.314)	-6.680 (9.985)
Observations	1146	732	414
$x^2$ (Wald)	112.94***	106.9***	88.15***
Pseudo R <sup>2</sup>	0.14	0.21	0.22
McKelvey and Zavoina's R <sup>2</sup>	0.32	0.43	0.51
% correctly predicted	0.88	0.89	0.89
AIC	0.69	0.68	0.74
BIC	-7084.73	-4153.71	-2034.28
Log pseudo-likelihood	-356.51	-211.88	-115.72

Notes: clustered robust standard errors in parentheses; \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Table J.3: Pairwise correlations for the full probit model of water entitlements sold to the government (both surveys, n=1,146)

	Buyback	Net	Soil texture	Dryland salinity	Groundwater	Surface-water	Population	Distance to	Neighbours
	(dummy)	rainfall		(dummy)	salinity (dummy)	salinity (dummy)	growth (%)	cities (km)	sold (SA2)
Net rainfall	-0.03	1.00							
Soil texture	0.00	-0.15	1.00						
Dryland salinity (dummy)	0.09	0.09	-0.08	1.00					
Groundwater salinity (dummy)	-0.02	0.03	-0.23	0.07	1.00				
Surface-water salinity (dummy)	0.04	0.09	0.11	0.03	-0.07	1.00			
Population growth (%)	-0.09	0.35	-0.14	0.16	0.08	0.15	1.00		
Distance to cities (km)	0.08	-0.18	-0.52	0.10	0.16	-0.36	-0.43	1.00	
Neighbours sold (SA2)	0.10	0.01	0.17	0.03	0.12	-0.02	-0.48	0.26	1.00
Distance to downstream area (km)	-0.07	-0.09	0.77	-0.27	-0.27	0.12	-0.03	-0.59	-0.07
Age	-0.01	0.05	-0.01	0.02	0.04	-0.02	-0.02	0.00	0.04
Age squared	0.00	0.05	-0.01	0.02	0.04	-0.02	-0.02	0.01	0.04
Low education (dummy)	0.04	-0.04	0.01	0.00	0.04	0.02	-0.04	0.02	0.09
Farm plan (dummy)	0.09	0.03	0.19	0.03	-0.09	0.04	0.04	-0.10	0.00
Government agency (dummy)	-0.06	0.00	-0.04	-0.07	0.04	-0.04	-0.06	0.06	0.01
Water entitlements owned (ln)	0.10	-0.16	0.37	-0.14	-0.12	0.06	-0.08	-0.23	-0.05
Groundwater entitlements owned (ln)	-0.02	0.07	0.14	-0.05	-0.19	0.11	0.19	-0.22	-0.08
IIO charges (ln)	0.00	-0.07	-0.09	0.07	0.08	-0.03	-0.06	0.10	0.09
Annual crops (%)	-0.02	-0.06	0.40	-0.11	-0.17	0.05	0.03	-0.31	-0.07
Operating surplus (ln)	0.02	-0.10	0.09	-0.07	0.01	0.05	0.00	-0.08	-0.05
Children	0.05	-0.01	0.10	-0.01	-0.07	0.06	0.02	-0.09	-0.03
Allocation trade (dummy)	0.05	-0.18	0.11	-0.08	-0.06	0.04	-0.05	-0.13	-0.12
Allocation percent	-0.11	0.00	-0.21	0.00	0.09	0.00	0.06	0.00	-0.21
Water entitlement price (ln)	0.00	0.25	-0.09	-0.18	-0.22	-0.18	-0.01	0.14	-0.03
Entitlement sale private market (dummy)	0.00	0.04	0.01	0.05	0.04	0.06	0.02	-0.04	-0.02
Gender (dummy)	-0.04	0.01	-0.01	0.02	0.00	0.01	0.03	0.01	0.00
Successor (dummy)	-0.02	-0.02	0.02	-0.05	-0.03	-0.08	-0.03	-0.02	0.00
Employees	0.05	0.04	-0.03	0.00	0.02	0.01	0.03	0.01	-0.01
Farm size (ha)	-0.03	0.01	0.20	-0.14	-0.05	-0.01	-0.06	-0.05	-0.05
Horticulture (%)	0.00	-0.01	-0.65	0.10	0.12	-0.22	-0.05	0.52	-0.04
Off-farm income (%)	-0.01	-0.05	-0.08	0.01	-0.01	-0.02	-0.02	0.06	-0.03
Debt	0.01	-0.33	0.01	0.00	-0.01	0.03	-0.03	0.02	-0.09
Productivity change	-0.04	0.07	-0.07	0.00	0.08	0.00	0.11	0.00	-0.02

Health	0.02	0.00	0.06	-0.05	-0.01	0.00	0.03	-0.05	0.03
Organic grower (dummy)	0.03	0.03	-0.08	-0.01	0.02	-0.01	0.05	-0.03	-0.05
Diverse	0.00	0.02	0.20	-0.04	-0.03	0.17	0.04	-0.15	0.06
Risk type	0.05	0.04	0.11	-0.01	-0.11	-0.03	0.04	-0.07	0.00
Carry-over (ln)	0.00	0.01	0.32	-0.08	-0.08	0.04	-0.07	-0.15	0.08
Survey year 2010 (dummy)	0.00	-0.73	0.01	-0.01	-0.03	0.10	0.03	-0.01	-0.31

**Table J.3 Continued** 

	Distance to downstream area (km)	Age	Age squared	Low education (dummy)	Farm plan (dummy	Government agency (dummy)	Entitlements owned (ln)	Groundwater entitlements owned (ln)	IIO charges (ln)
Age	-0.01	1.00							
Age squared	-0.02	1.00	1.00						
Low education (dummy)	0.00	0.26	0.26	1.00					
Farm plan (dummy)	0.14	-0.05	-0.05	-0.06	1.00				
Government agency (dummy)	-0.03	-0.05	-0.05	-0.03	-0.03	1.00			
Water entitlements owned (ln)	0.37	-0.06	-0.05	-0.02	0.18	-0.05	1.00		
Groundwater entitlements owned (ln)	0.20	-0.14	-0.14	-0.05	0.10	-0.05	0.06	1.00	
IIO charges (ln)	-0.06	-0.01	-0.01	0.03	-0.10	0.03	-0.08	-0.05	1.00
Annual crops (%)	0.35	-0.13	-0.13	-0.05	0.11	-0.08	0.28	0.14	-0.11
Operating surplus (ln)	0.11	-0.07	-0.07	-0.01	0.05	0.04	0.12	0.03	0.02
Children	0.10	0.16	0.17	0.04	0.03	-0.06	0.09	0.06	-0.07
Allocation trade (dummy)	0.16	0.02	0.02	-0.04	-0.04	0.04	0.09	-0.06	0.02
Allocation percent	-0.05	0.02	0.02	0.02	-0.08	0.06	-0.17	-0.09	0.10
Water entitlement price (ln)	-0.01	-0.01	-0.01	-0.08	0.04	-0.02	0.02	-0.01	-0.04
Entitlement sale private market (dummy)	0.00	0.01	0.01	0.00	-0.03	0.05	-0.03	-0.03	-0.01
Gender (dummy)	0.00	0.03	0.02	0.06	0.03	-0.02	0.04	0.02	0.03
Successor (dummy)	0.00	0.07	0.06	0.03	0.04	-0.02	0.12	0.06	-0.07
Employees	-0.05	-0.09	-0.09	-0.05	0.09	-0.05	0.18	0.16	-0.15
Farm size (ha)	0.14	-0.05	-0.06	-0.03	0.00	-0.05	0.20	0.11	-0.14
Horticulture (%)	-0.55	0.03	0.03	0.00	-0.13	0.06	-0.27	-0.18	0.12
Off-farm income (%)	-0.04	0.00	-0.01	0.02	-0.07	0.03	-0.14	-0.07	0.00
Debt	-0.01	-0.19	-0.19	-0.03	0.03	0.01	0.04	0.02	0.03

Productivity change	-0.07	-0.08	-0.09	0.01	0.01	-0.01	-0.11	0.03	0.00
Health	0.07	-0.11	-0.12	-0.08	0.03	0.00	0.03	0.05	-0.02
Organic grower (dummy)	-0.08	-0.01	0.00	-0.07	0.01	-0.01	-0.11	-0.02	-0.16
Diverse	0.16	-0.10	-0.10	0.01	0.14	-0.08	0.18	0.16	0.03
Risk type	0.09	-0.02	-0.02	0.02	0.12	-0.06	0.09	0.09	-0.05
Carry-over (ln)	0.27	-0.01	0.00	-0.03	0.14	-0.07	0.38	0.10	-0.08
Survey year 2010 (dummy)	0.01	-0.07	-0.07	0.02	-0.02	-0.01	0.04	0.03	0.03

**Table J.3 Continued** 

	Annual crops (%)	Operating surplus (ln)	Children	Allocation trade (dummy)	Allocation percent	Water entitlement price (ln)	Entitlement sale private market (dummy)	Gender (dummy)	Successor (dummy)	Employees
Operating surplus (ln)	0.09	1.00								
Children	0.10	0.04	1.00							
Allocation trade (dummy)	0.09	0.05	0.07	1.00						
Allocation percent	-0.26	0.00	-0.06	0.06	1.00					
Water entitlement price (ln)	0.05	-0.05	0.01	-0.06	-0.20	1.00				
Entitlement sale private market (dummy)	-0.01	-0.01	0.04	0.07	0.07	-0.07	1.00			
Gender (dummy)	0.05	0.11	0.04	-0.02	0.03	0.01	-0.01	1.00		
Successor (dummy)	0.10	-0.01	0.06	-0.04	-0.07	0.04	-0.02	-0.05	1.00	
Employees	0.03	0.03	0.00	-0.04	0.01	0.00	-0.02	-0.04	0.08	1.00
Farm size (ha)	0.23	0.07	0.04	-0.01	-0.13	-0.03	-0.04	-0.02	0.09	0.18
Horticulture (%)	-0.46	-0.07	-0.10	-0.10	0.28	0.11	-0.08	0.02	-0.06	0.05
Off-farm income (%)	-0.07	-0.02	-0.04	0.01	0.01	0.03	0.08	-0.04	-0.07	-0.07
Debt	0.05	-0.01	0.04	0.09	0.05	-0.16	-0.04	-0.03	0.03	0.04
Productivity change	-0.08	0.03	-0.07	-0.08	0.16	-0.06	-0.04	0.06	0.04	0.09
Health	0.05	0.02	-0.01	0.01	-0.11	0.04	0.00	0.08	0.04	-0.01
Organic grower (dummy)	-0.13	-0.07	0.01	0.02	0.08	-0.07	0.07	-0.04	0.01	0.04
Diverse	0.23	0.08	0.09	-0.01	-0.08	-0.08	-0.03	0.06	0.06	0.14
Risk type	0.09	0.00	0.07	-0.04	-0.02	0.02	0.05	0.02	0.07	0.07
Carry-over (ln)	0.22	0.08	0.08	-0.01	-0.16	0.06	-0.04	0.07	0.07	0.10
Survey year 2010 (dummy)	0.04	0.12	0.01	0.20	0.10	-0.29	-0.06	-0.01	0.01	0.00

**Table J.3 Continued** 

	Farm size (ha)	Horticulture (%)	Off-farm income (%)	Debt	Productivity change	Health	Organic grower (dummy)	Diverse	Risk type	Carry- over (ln)
Horticulture (%)	-0.22	1.00								
Off-farm income (%)	-0.12	0.07	1.00							
Debt	-0.01	0.02	0.03	1.00						
Productivity change	-0.04	0.09	-0.05	0.02	1.00					
Health	0.05	-0.07	0.03	-0.02	0.02	1.00				
Organic grower (dummy)	-0.05	-0.02	-0.04	-0.04	0.06	-0.01	1.00			
Diverse	0.08	-0.22	-0.07	0.01	0.05	0.04	-0.12	1.00		
Risk type	0.05	-0.09	-0.01	0.04	0.04	0.00	0.02	0.09	1.00	
Carry-over (ln)	0.19	-0.26	-0.12	-0.04	-0.05	0.08	-0.07	0.13	0.11	1.00
Survey year 2010 (dummy)	-0.05	0.06	0.07	0.41	0.00	0.00	0.00	-0.02	0.00	-0.04

Table J.4: Collinearity diagnostics for the full probit model of water entitlements sold to the government (both surveys, n=1,146)

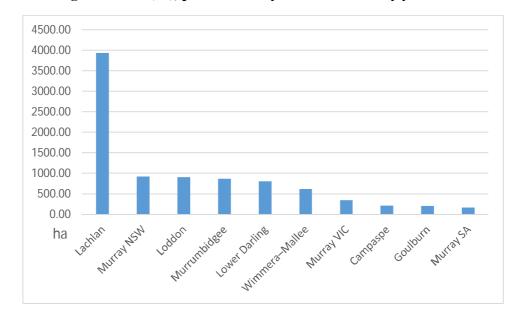
Variable	VIF
Buyback (dummy)	1.09
Net rainfall	3.96
Soil texture	4.85
Dryland salinity (dummy)	1.36
Groundwater salinity (dummy)	1.29
Surface-water salinity (dummy)	1.35
Regional population growth (%)	2.17
Distance to cities (km)	3.54
Neighbours sold (SA2)	2.08
Distance to downstream area (km)	4.04
Age	271.52
Age squared	270.88
Low education (dummy)	1.15
Farm plan (dummy)	1.16
Government agency (dummy)	1.07
Water entitlements owned (ln)	1.92
Groundwater entitlements owned (ln)	1.18
IIO charges (ln)	1.18
Annual crops (%)	1.55
Operating surplus (ln)	1.09
Children	1.1
Allocation trade (dummy)	1.14
Allocation percent	1.37
Water entitlement price (ln)	1.56
Entitlement sale private market (dummy)	1.07
Gender (dummy)	1.08
Successor (dummy)	1.12
Employees	1.18
Farm size (ha)	1.3
Horticulture (%)	2.39
Off-farm income (%)	1.07
Debt	1.3
Productivity change	1.11
Health	1.07
Organic grower (dummy)	1.18
Diverse	1.21
Risk type	1.08
Carry-over (ln)	1.35
Survey year 2010 (dummy)	3.85
Mean VIF	15.51

Table J.5: Probit models of water entitlements sold to the government for observations with high/medium geocoding quality (reduced form)

	Surveys combined (2010 & 2011)	2009/10 (2010 survey)	2010/11 (2011 survey)
Survey variables:			
Age		-0.248* (0.140)	0.025** (0.011)
Age squared		3.549* (2.034)	
Low education (dummy)	0.459*** (0.166)	0.622*** (0.189)	
Farm plan (dummy)			0.585* (0.319)
Government agency (dummy)		-0.878* (0.498)	
Water entitlements owned (ln)	0.289*** (0.072)	0.362*** (0.068)	0.170** (0.081)
Carry-over (ln)		-0.079** (0.034)	
Operating surplus (ln)	0.033* (0.019)		
Children			-0.203* (0.115)
Allocation trade (dummy)	0.335** (0.143)	0.498*** (0.163)	
Successor (dummy)	-0.318** (0.140)	-0.282* (0.159)	-0.500* (0.256)
Employees			0.084** (0.037)
Farm size (ha)	-0.0002* (0.0001)		-0.0002** (0.0001)
Debt			1.916** (0.853)
Productivity change			0.176* (0.102)
Health		0.168** (0.072)	
Organic (dummy)	0.404* (0.228)	0.460* (0.244)	
Risk type	0.105* (0.057)		
Survey 2010 (dummy)	0.575** (0.254)		
Spatial/regional variables:			
Net rainfall	8.059*** (3.117)	9.120** (4.036)	
Dryland salinity (dummy)	0.422*** (0.153)	0.537*** (0.169)	
Population growth (%)	-0.070*** (0.023)	-0.066*** (0.025)	-0.144*** (0.049)
Neighbours sold (SA2)	0.008* (0.004)	0.014*** (0.005)	
Distance to downstream area (km)	-0.002*** (0.0005)	-0.002*** (0.0005)	
Allocation percent	-0.010*** (0.004)		-0.020*** (0.007)
Constant	-3.417*** (0.708)	-16.41** (7.394)	-3.761*** (1.175)
Observations	864	651	282
$x^2$ (Wald)	79.31***	79.19***	30.07***
Pseudo R <sup>2</sup>	0.17	0.21	0.22
McKelvey and Zavoina's R <sup>2</sup>	0.35	0.44	0.47
% correctly predicted	0.89	0.88	0.90
AIC	0.62	0.64	0.60
BIC	-5227.30	-3731.70	-1380.20
Log pseudo-likelihood	-253.26	-191.08	-71.56

Notes: clustered robust standard errors in parentheses; \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

Figure J.1: Average farm size (ha), per river valley across both survey years



Own figure (data source: Surveys 2010 and 2011)

Figure J.2: Sensitivity analysis of spatial autocorrelation by distance of irrigators' decision to sell water entitlements to the government in the 2010 survey (n=599)

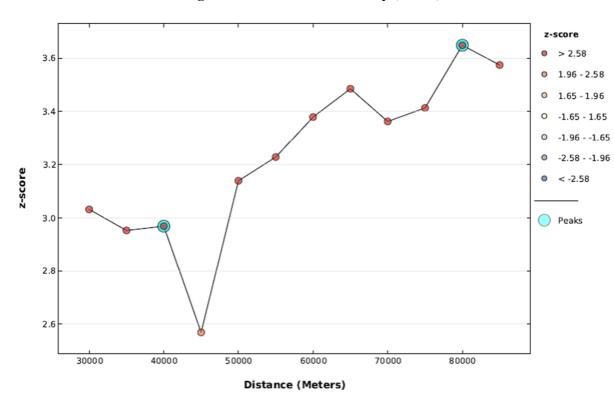


Table J.6: Comparison between a traditional economic model of water entitlement sales from Wheeler et al. (2012b) and this chapter's 2009/10 water sales model

Buyback	2009/10: Wheeler et al.	2009/10: this chapter's
	(2012b) model (excluding spatial variables)	model (including spatial variables)
Survey variables:		
Age	-0.013** (0.007)	-0.262** (0.103)
Age squared		3.714** (1.488)
Low education (dummy)	0.4** (0.172)	0.401** (0.158)
Farm plan (dummy)	0.306* (0.165)	
Government agency (dummy)	-0.58 (0.361)	-0.691** (0.348)
Water entitlements owned (ln)	0.209*** (0.056)	0.381*** (0.058)
Allocation trade (dummy)	0.458*** (0.15)	0.448*** (0.133)
Farm size (ha)		-0.0002* (0.00008)
Carry-over (ln)		-0.0980*** (0.03)
Health		0.148** (0.058)
Annual crops (%)	-0.004* (0.002)	
Operating surplus (ln)	-0.026** (0.013)	
Tradition (attitude)	-0.131** (0.065)	
Children	0.078* (0.045)	
Spatial variables:		
Net rainfall		6.331* (3.802)
Dryland salinity (dummy)		0.495*** (0.133)
Regional population growth (%)		-0.038* (0.023)
Neighbours sold (SA2)		0.012*** (0.004)
Distance to downstream area (km)		-0.002*** (0.0004)
Other regional variables:		
Allocation percent	-0.01*** (0.003)	
VIC (state dummy)	0.585*** (0.162)	
SA (state dummy)	0.993*** (0.211)	
Constant	-2.167*** (0.586)	-16.83*** (5.401)
Observations	734	925
x <sup>2</sup> (Wald)	57.66	95.22
Prob. $> X^2$	0.00	0.00
Pseudo R <sup>2</sup>	0.12	0.16
% correctly predicted	0.89	0.88
AIC	0.67	0.63
BIC	-4284.59	-5666.71
BIC'	21.82	-6.39

Notes: clustered robust standard errors in parentheses, \*p<0.10, \*\*p<0.05, \*\*\*p<0.01

Table J.7: Global Moran's I results for the independent survey variables (i.e. farmers' socioeconomic and farm data) at different distances ( $2010\ survey$ )

Socio-economic and farm data (2010 survey)	Significant peak(s) of clustering at the following distances (spatial autocorrelation/Global Moran's I)
Age	None
Low education (dummy)	40km and 70km
Farm plan (dummy)	40km and 70km
Government agency (dummy)	None
Water entitlements owned (ln)	50km
Groundwater entitlements owned (ln)	45km
Annual crops (%)	None
Operating surplus (ln)	45km and 75km
Children	40km and 65km
Allocation trade (dummy)	None
Entitlement sale private market (dummy)	None
Gender (dummy)	None
Successor (dummy)	None
Employees	None
Farm size (ha)	40km and 90km
Horticulture (%)	None
Off-farm income (%)	35km
Debt (debt to equity ratio)	None
Productivity change	40km
Health	None
Organic grower (dummy)	60km and 90km
Risk type	50km
Carry-over (ln)	35km

Table J.8: Examples of additional spatial data available and collected

Data description	Source
Soil type according to the Australian Soil Classification (ASC)	CSIRO
Soil properties (e.g. chemical/physical limitations)	ABARES
Level of phosphorus, nitrogen and carbon in the soil	CSIRO
Soil pH-level	CSIRO
Bulk density	CSIRO
Water holding capacity in the soil	CSIRO
Soil moisture	CSIRO (AWAP)
Elevation	CSIRO
Slope	ABARES
Soil erosion	CSIRO
Land cover/vegetation/extent of native vegetation	DAFF/ABARES
Bare soil/green cover	ABARES
Indicators for Catchment Conditions (e.g. Water Condition, Biota, Land index)	DAFF
Assessment of River Condition Indexes	DSEWPaC
Temperature	CSIRO (AWAP)
Solar radiation	CSIRO (AWAP)
Run-off	CSIRO (AWAP)
Hydrologic Indicator Sites	MDBA
Index of Relative Socioeconomic Advantage and Disadvantage	ABARES
Distance to roads	Geoscience
Accessibility/Remoteness Index of Australia (2001)	ABARES
Population by age (SA2)	ABS
Depth to water table	MDBA
Water course lines/areas, channels and dams	Geoscience
Sustainable Rivers Audit (by river valley)	MDBA

## Appendix K Supplementary tables and figures for the tobit models of irrigators' price choices for WTP and WTA for water entitlements in 2010/11

Table K.1: Full tobit models of irrigators' price choices for WTP and WTA for water entitlements in 2010/11

	Price selling (WTA; ln)	Price buying (WTP; ln)
Survey variables:		
Age	0.007 (0.043)	-0.143** (0.070)
Age squared	-0.040 (0.627)	1.911* (1.027)
Low education (dummy)	0.102 (0.078)	-0.285** (0.143)
Farm plan (dummy)	0.011 (0.063)	0.114 (0.113)
Government agency (dummy)	0.116 (0.088)	-0.186 (0.180)
Water entitlements owned (ln)	-0.061** (0.028)	-0.0009 (0.037)
Groundwater entitlements owned (ln)	-0.050** (0.019)	-0.040 (0.027)
Carry-over (ln)	-0.024* (0.013)	0.006 (0.024)
Entitlement sale private market (dummy)	-0.245*** (0.072)	0.046 (0.128)
Allocation trade (dummy)	-0.176** (0.073)	0.040 (0.133)
Operating surplus (ln)	-0.002 (0.006)	0.024** (0.012)
Off-farm income (%)	-0.002** (0.0007)	0.0007 (0.001)
Debt 2010/11 (ln)	-0.0004 (0.006)	0.023* (0.012)
Diverse	-0.028 (0.036)	0.164*** (0.061)
Farm size (ha)	-0.000007 (0.00001)	0.00002 (0.00003)
Employees	-0.006 (0.008)	0.026*** (0.010)
Annual crops (%)	0.001 (0.0008)	0.0002 (0.001)
Horticulture (%)	0.0004 (0.0008)	-0.0004 (0.001)
Organic (dummy)	0.156 (0.122)	0.083 (0.211)
Children	-0.019 (0.022)	-0.002 (0.040)
Gender (dummy)	-0.100 (0.093)	0.079 (0.153)
Successor (dummy)	0.182*** (0.061)	0.070 (0.100)
Health	0.021 (0.030)	0.032 (0.048)
Risk type	0.044* (0.026)	-0.001 (0.045)
Productivity change	0.003 (0.024)	0.040 (0.039)
Spatial variables:		. ,
Net rainfall	-1.503 (1.476)	-1.176 (2.413)
Soil texture	0.030 (0.051)	-0.072 (0.089)
Dryland salinity (dummy)	0.073 (0.066)	0.201* (0.108)
Groundwater salinity (dummy)	-0.243* (0.138)	0.189 (0.209)
Surface-water salinity (dummy)	-0.096 (0.080)	-0.124 (0.126)
Population growth (%)	0.007 (0.009)	0.006 (0.016)
Distance to cities (population >1000)	0.003 (0.002)	0.004 (0.004)
Distance to cities (population >5000)	-0.002 (0.001)	-0.001 (0.002)
Distance to cities (population >10000)	0.0005 (0.001)	-0.002 (0.002)
Neighbours sold (SA2)	-0.004*** (0.001)	0.005* (0.003)
Distance to downstream area (km)	0.0006** (0.0003)	-0.00003 (0.0005)
Other regional variables:	•	
IIO charges (ln)	0.005 (0.026)	-0.013 (0.043)
Allocation percent	-0.009*** (0.001)	-0.0006 (0.003)
Water entitlement price (ln)	0.317* (0.187)	-0.485 (0.317)
Constant	6.819*** (2.627)	2.914 (4.700)
Sigma Constant	0.472*** (0.023)	0.821*** (0.036)
Observations	439	447
left-censored observations	0	217 (at ln(500))
uncensored observations	266	230
right-censored observations	173 (at ln(5000))	0
Log pseudo likelihood	-283.10	-425.52
F-statistic	5.88***	3.23***

McKelvey & Zavoina's R <sup>2</sup>	0.36	0.21
AIC	648.21	933.05
BIC	815.67	1101.25

Notes: robust standard errors in parentheses; \*p<0.10, \*\*p<0.05, \*\*\*\* p<0.01

Table K.2: Pairwise correlations for the full tobit models of irrigators' price choices for WTP and WTA for water entitlements in 2010/11 (n=531)

	Price selling (WTA; ln)	Price buying (WTP; ln)	Age	Age squared	Low education (dummy)	Farm plan (dummy)	Government agency (dummy)
Price buying (WTP; ln)	-0.169	1.000					
Age	0.106	-0.232	1.000				
Age squared	0.103	-0.231	0.998	1.000			
Low education (dummy)	0.067	-0.129	0.261	0.256	1.000		
Farm plan (dummy)	0.039	0.132	-0.053	-0.051	-0.063	1.000	
Government agency (dummy)	0.002	-0.021	-0.052	-0.049	-0.025	-0.033	1.000
Water entitlements owned (ln)	-0.049	0.065	-0.057	-0.054	-0.019	0.181	-0.048
Groundwater entitlements owned (ln)	-0.053	0.001	-0.136	-0.137	-0.046	0.101	-0.053
Carry-over (ln)	-0.053	0.112	-0.005	-0.001	-0.028	0.141	-0.071
Entitlement sale private market (dummy)	-0.107	0.015	0.010	0.010	0.004	-0.030	0.053
Allocation trade (dummy)	-0.188	0.006	0.016	0.020	-0.036	-0.038	0.042
Operating surplus (ln)	-0.009	0.158	-0.072	-0.073	-0.014	0.053	0.035
Off-farm income (%)	-0.083	-0.006	-0.004	-0.005	0.018	-0.073	0.034
Debt 2010/11 (ln)	-0.026	0.208	-0.347	-0.343	-0.194	0.171	-0.030
Diverse	-0.049	0.131	-0.098	-0.102	0.006	0.144	-0.082
Farm size (ha)	-0.016	0.044	-0.053	-0.055	-0.033	0.000	-0.050
Employees	-0.101	0.136	-0.090	-0.089	-0.052	0.086	-0.053
Annual crops (%)	0.121	0.111	-0.126	-0.130	-0.045	0.113	-0.082
Horticulture (%)	-0.063	-0.050	0.027	0.033	0.000	-0.133	0.065
Organic (dummy)	0.045	-0.004	-0.011	-0.005	-0.066	0.013	-0.007
Children	-0.010	-0.030	0.164	0.167	0.044	0.025	-0.061
Gender (dummy)	-0.085	0.057	0.026	0.020	0.064	0.033	-0.022
Successor (dummy)	0.183	0.011	0.067	0.061	0.028	0.041	-0.018
Health	0.010	0.084	-0.109	-0.115	-0.083	0.032	0.003
Risk type	0.078	0.042	-0.022	-0.023	0.022	0.123	-0.058
Productivity change	0.012	0.105	-0.082	-0.087	0.009	0.006	-0.006
Net rainfall	-0.020	0.054	0.052	0.047	-0.042	0.027	-0.003
Soil texture	0.072	0.052	-0.013	-0.014	0.009	0.186	-0.036
Dryland salinity (dummy)	-0.043	0.034	0.015	0.015	-0.004	0.030	-0.066
Groundwater salinity (dummy)	-0.099	0.041	0.038	0.039	0.038	-0.087	0.040
Surface-water salinity (dummy)	-0.092	0.002	-0.022	-0.023	0.022	0.040	-0.037
Population growth (%)	0.114	0.027	-0.019	-0.023	-0.037	0.038	-0.060

Distance to cities (population >1,000)	0.037	0.043	0.018	0.019	-0.019	0.048	-0.017
Distance to cities (population >5,000)	-0.148	-0.058	0.002	0.006	0.024	-0.102	0.062
Distance to cities (population >10,000)	-0.066	-0.050	-0.052	-0.047	-0.039	-0.131	0.043
Neighbours sold (SA2)	-0.130	0.030	0.035	0.036	0.089	0.002	0.010
Distance to downstream area (km)	0.091	0.003	-0.015	-0.018	0.004	0.140	-0.035
IIO charges (ln)	-0.033	-0.062	-0.007	-0.005	0.031	-0.100	0.029
Allocation percent	-0.171	0.004	0.019	0.021	0.022	-0.079	0.065
Water entitlement price (ln)	0.195	-0.048	-0.010	-0.012	-0.076	0.043	-0.020

**Table K.2 Continued** 

	Water entitlements owned (ln)	Groundwater entitlements owned (ln)	Carry- over (ln)	Entitlement sale private market	Allocation trade (dummy)	Operating surplus (ln)
Groundwater entitlements owned (ln)	0.060	1.000		-		_
Carry-over (ln)	0.381	0.097	1.000			
Entitlement sale private market (dummy)	-0.029	-0.032	-0.036	1.000		
Allocation trade (dummy)	0.094	-0.055	-0.006	0.070	1.000	
Operating surplus (ln)	0.123	0.028	0.077	-0.011	0.046	1.000
Off-farm income (%)	-0.141	-0.075	-0.123	0.082	0.008	-0.018
Debt 2010/11 (ln)	0.125	0.145	0.153	-0.008	-0.040	0.047
Diverse	0.175	0.165	0.131	-0.028	-0.014	0.077
Farm size (ha)	0.201	0.114	0.188	-0.041	-0.011	0.067
Employees	0.179	0.159	0.099	-0.021	-0.044	0.031
Annual crops (%)	0.280	0.144	0.218	-0.014	0.085	0.092
Horticulture (%)	-0.267	-0.177	-0.260	-0.075	-0.099	-0.069
Organic (dummy)	-0.108	-0.019	-0.075	0.066	0.025	-0.072
Children	0.089	0.062	0.084	0.037	0.070	0.043
Gender (dummy)	0.036	0.024	0.066	-0.013	-0.020	0.107
Successor (dummy)	0.123	0.059	0.066	-0.017	-0.037	-0.007
Health	0.030	0.048	0.083	-0.005	0.007	0.019
Risk type	0.087	0.091	0.111	0.050	-0.038	-0.003
Productivity change	-0.106	0.028	-0.054	-0.043	-0.084	0.031
Net rainfall	-0.161	0.074	0.011	0.044	-0.183	-0.104
Soil texture	0.368	0.142	0.319	0.009	0.112	0.091
Dryland salinity (dummy)	-0.142	-0.048	-0.080	0.047	-0.084	-0.070
Groundwater salinity (dummy)	-0.120	-0.188	-0.076	0.044	-0.055	0.013
Surface-water salinity (dummy)	0.056	0.108	0.036	0.062	0.036	0.051
Population growth (%)	-0.083	0.191	-0.074	0.018	-0.050	-0.001
Distance to cities (population >1,000)	0.162	0.068	0.190	0.034	0.114	0.043
Distance to cities (population >5,000)	-0.230	-0.217	-0.152	-0.044	-0.126	-0.076
Distance to cities (population >10,000)	-0.184	-0.201	-0.104	-0.075	-0.081	-0.072
Neighbours sold (SA2)	-0.051	-0.080	0.078	-0.015	-0.124	-0.048
Distance to downstream area (km)	0.372	0.196	0.272	0.000	0.156	0.112
IIO charges (ln)	-0.076	-0.048	-0.077	-0.012	0.019	0.016

Allocation percent	-0.174	-0.092	-0.157	0.067	0.060	0.003
Water entitlement price (ln)	0.022	-0.007	0.063	-0.066	-0.057	-0.051

## **Table K.2 Continued**

	Off-farm income (%)	Debt 2010/11 (ln)	Diverse	Farm size (ha)	Employees	Annual crops (%)	Horticulture (%)	Organic (dummy)
Debt 2010/11 (ln)	-0.088	1.000						
Diverse	-0.069	0.112	1.000					
Farm size (ha)	-0.123	0.147	0.084	1.000				
Employees	-0.074	0.135	0.139	0.181	1.000			
Annual crops (%)	-0.068	0.149	0.232	0.234	0.030	1.000		
Horticulture (%)	0.072	-0.002	-0.221	-0.223	0.050	-0.463	1.000	
Organic (dummy)	-0.037	-0.029	-0.116	-0.045	0.039	-0.134	-0.019	1.000
Children	-0.039	0.115	0.086	0.043	0.003	0.098	-0.103	0.009
Gender (dummy)	-0.041	0.049	0.063	-0.023	-0.036	0.049	0.023	-0.035
Successor (dummy)	-0.069	0.174	0.059	0.089	0.079	0.099	-0.058	0.010
Health	0.030	-0.023	0.044	0.047	-0.009	0.050	-0.073	-0.014
Risk type	-0.010	0.182	0.095	0.049	0.072	0.088	-0.090	0.024
Productivity change	-0.047	0.102	0.048	-0.037	0.088	-0.083	0.087	0.063
Net rainfall	-0.048	0.085	0.024	0.009	0.040	-0.060	-0.014	0.030
Soil texture	-0.083	0.022	0.198	0.198	-0.032	0.403	-0.648	-0.084
Dryland salinity (dummy)	0.006	-0.024	-0.037	-0.140	-0.002	-0.105	0.099	-0.006
Groundwater salinity (dummy)	-0.005	-0.063	-0.027	-0.052	0.024	-0.167	0.125	0.022
Surface-water salinity (dummy)	-0.020	-0.067	0.167	-0.006	0.012	0.050	-0.222	-0.010
Population growth (%)	-0.015	0.089	0.042	-0.060	0.035	0.031	-0.054	0.049
Distance to cities (population >1,000)	-0.071	0.020	0.014	0.243	0.027	0.218	-0.278	0.061
Distance to cities (population >5,000)	0.056	-0.028	-0.152	-0.046	0.014	-0.309	0.523	-0.034
Distance to cities (population >10,000)	0.021	-0.043	-0.143	0.041	-0.002	-0.194	0.397	0.014
Neighbours sold (SA2)	-0.033	-0.106	0.057	-0.047	-0.013	-0.071	-0.040	-0.048
Distance to downstream area (km)	-0.037	0.015	0.158	0.140	-0.052	0.352	-0.553	-0.076
IIO charges (ln)	0.001	-0.068	0.028	-0.143	-0.145	-0.109	0.119	-0.159
Allocation percent	0.015	-0.073	-0.080	-0.130	0.013	-0.260	0.284	0.075
Water entitlement price (ln)	0.028	0.045	-0.078	-0.030	0.003	0.046	0.107	-0.073

**Table K.2 Continued** 

	Children	Gender (dummy)	Successo	Health	Risk type	Productivity change	Net rainfall	Soil texture	Dryland salinity (dummy)	Groundwater salinity (dummy)
		(uummy)	(dummy		турс	change	Taman	texture	(ddiffiny)	samily (duminy)
Gender (dummy)	0.041	1.000								
Successor (dummy)	0.055	-0.054	1.000							
Health	-0.013	0.078	0.041	1.000						
Risk type	0.065	0.019	0.066	0.004	1.000					
Productivity change	-0.070	0.056	0.045	0.016	0.045	1.000				
Net rainfall	-0.005	0.012	-0.024	-0.004	0.035	0.070	1.000			
Soil texture	0.101	-0.010	0.022	0.061	0.108	-0.073	-0.148	1.000		
Dryland salinity (dummy)	-0.010	0.025	-0.049	-0.052	-0.014	0.004	0.095	-0.075	1.000	
Groundwater salinity (dummy)	-0.070	-0.001	-0.026	-0.013	-0.106	0.084	0.032	-0.228	0.068	1.000
Surface-water salinity (dummy)	0.064	0.010	-0.084	-0.001	-0.034	0.000	0.093	0.113	0.034	-0.066
Population growth (%)	0.020	0.033	-0.026	0.032	0.038	0.107	0.347	-0.140	0.157	0.078
Distance to cities (population >1,000)	-0.006	-0.002	0.082	-0.003	0.065	-0.058	-0.084	0.240	-0.251	-0.168
Distance to cities (population >5,000)	-0.090	0.011	-0.016	-0.045	-0.073	-0.002	-0.180	-0.519	0.104	0.161
Distance to cities (population >10,000)	-0.119	-0.035	-0.008	-0.035	-0.038	-0.026	-0.229	-0.303	0.109	0.104
Neighbours sold (SA2)	-0.029	-0.002	0.002	0.029	0.003	-0.025	0.012	0.175	0.030	0.116
Distance to downstream area (km)	0.096	0.004	0.003	0.067	0.092	-0.067	-0.092	0.774	-0.268	-0.272
IIO charges (ln)	-0.069	0.028	-0.070	-0.023	-0.047	0.002	-0.075	-0.087	0.066	0.079
Allocation percent	-0.063	0.026	-0.069	-0.109	-0.018	0.157	0.004	-0.206	-0.004	0.092
Water entitlement price (ln)	0.013	0.009	0.042	0.036	0.021	-0.062	0.250	-0.091	-0.175	-0.223

**Table K.2 Continued** 

	Surface- water salinity (dummy)	Population growth (%)	Distance to cities (population >1,000)	Distance to cities (population >5,000)	Distance to cities (population >10,000)	Neighbours sold (SA2)	Distance to downstream area	IIO charges (ln)	Allocation percent
Population growth (%)	0.151	1.000							
Distance to cities (population >1,000)	-0.052	-0.202	1.000						
Distance to cities (population >5,000)	-0.359	-0.433	-0.003	1.000					
Distance to cities (population >10,000)	-0.479	-0.467	0.059	0.791	1.000				
Neighbours sold (SA2)	-0.019	-0.484	-0.040	0.265	0.254	1.000			
Distance to downstream area (km)	0.119	-0.033	0.215	-0.594	-0.466	-0.074	1.000		
IIO charges (ln)	-0.030	-0.055	-0.148	0.097	0.084	0.092	-0.057	1.000	
Allocation percent	-0.001	0.065	-0.068	-0.002	-0.087	-0.206	-0.050	0.098	1.000
Water entitlement price (ln)	-0.179	-0.013	-0.025	0.135	0.175	-0.035	-0.007	-0.041	-0.198

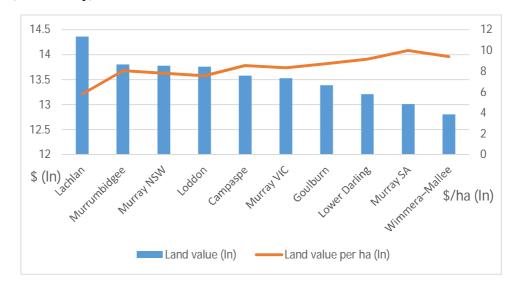
 $\label{eq:continuous} \textbf{Table K.3: Collinearity diagnostics for the full tobit model of irrigators' price choices for WTA for water entitlements$ 

Variable	VIF
Price selling (WTA; ln)	1.31
Age	307.57
Age squared	304.98
Low education (dummy)	1.24
Farm plan (dummy)	1.15
Government agency (dummy)	1.13
Water entitlements owned (ln)	2.35
Groundwater entitlements owned (ln)	1.24
Carry-over (ln)	2.48
Entitlement sale private market (dummy)	1.17
Allocation trade (dummy)	1.16
Operating surplus (ln)	1.26
Off-farm income (%)	1.18
Debt 2010/11 (ln)	1.45
Diverse	1.26
Farm size (ha)	1.47
Employees	1.25
Annual crops (%)	1.72
Horticulture (%)	2.28
Organic (dummy)	1.3
Children	1.12
Gender (dummy)	1.18
Successor (dummy)	1.21
Health	1.19
Risk type	1.16
Productivity change	1.18
Net rainfall	2.19
Soil texture	5.25
Dryland salinity (dummy)	1.55
Groundwater salinity (dummy)	1.31
Surface-water salinity (dummy)	1.76
Population growth (%)	2.63
Distance to cities (population >1000)	1.52
Distance to cities (population >5000)	5.41
Distance to cities (population >10000)	4.73
Neighbours sold (SA2)	2.02
Distance to downstream area (km)	4.43
IIO charges (ln)	1.31
Allocation percent	1.74
Water entitlement price (ln)	1.58
Mean VIF	17.09

 $\label{thm:continuous} \textbf{Table K.4: Collinearity diagnostics for the full tobit model of irrigators' price choices for WTP for water entitlements}$ 

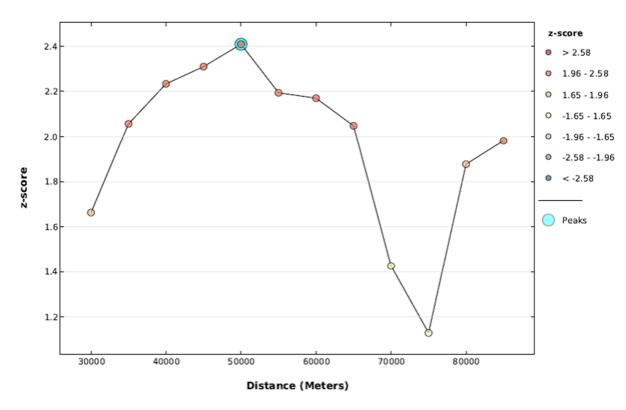
Variable	VIF
Price buying (WTP; ln)	1.19
Age	307.53
Age squared	304.66
Low education (dummy)	1.25
Farm plan (dummy)	1.15
Government agency (dummy)	1.12
Water entitlements owned (ln)	1.81
Groundwater entitlements owned (ln)	1.23
Carry-over (ln)	2.36
Entitlement sale private market (dummy)	1.15
Allocation trade (dummy)	1.14
Operating surplus (ln)	1.25
Off-farm income (%)	1.17
Debt 2010/11 (ln)	1.44
Diverse	1.29
Farm size (ha)	1.48
Employees	1.24
Annual crops (%)	1.72
Horticulture (%)	2.24
Organic (dummy)	1.27
Children	1.12
Gender (dummy)	1.17
Successor (dummy)	1.18
Health	1.17
Risk type	1.15
Productivity change	1.18
Net rainfall	2.15
Soil texture	5.34
Dryland salinity (dummy)	1.55
Groundwater salinity (dummy)	1.31
Surface-water salinity (dummy)	1.76
Population growth (%)	2.62
Distance to cities (population >1000)	1.53
Distance to cities (population >5000)	5.15
Distance to cities (population >10000)	4.7
Neighbours sold (SA2)	2
Distance to downstream area (km)	4.42
IIO charges (ln)	1.32
Allocation percent	1.62
Water entitlement price (ln)	1.57
Mean VIF	17.04

Figure K.1: Average farm land values (ln) and farm land values per ha (ln), per river valley in 2010/11 (2011 survey)



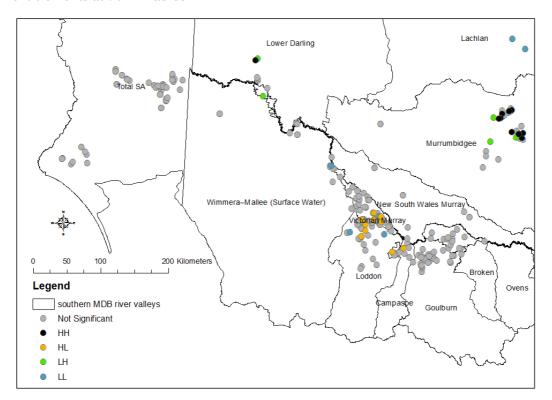
Own figure (data source: 2011 survey)

Figure K.2: Spatial autocorrelation by distance of irrigators' price choices for WTA for water entitlements in 2010/11



Notes: Only willing sellers and excluding irrigators with no neighbours below 30km.

Figure K.3: Cluster (HH, LL) and outlier (HL, LH) of irrigators' price choices for WTA for water entitlements at 50 km radius



Notes: Only willing sellers and excluding irrigators with no neighbours below 30km. Own map (base map source: MDBA (2013a))

## References

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