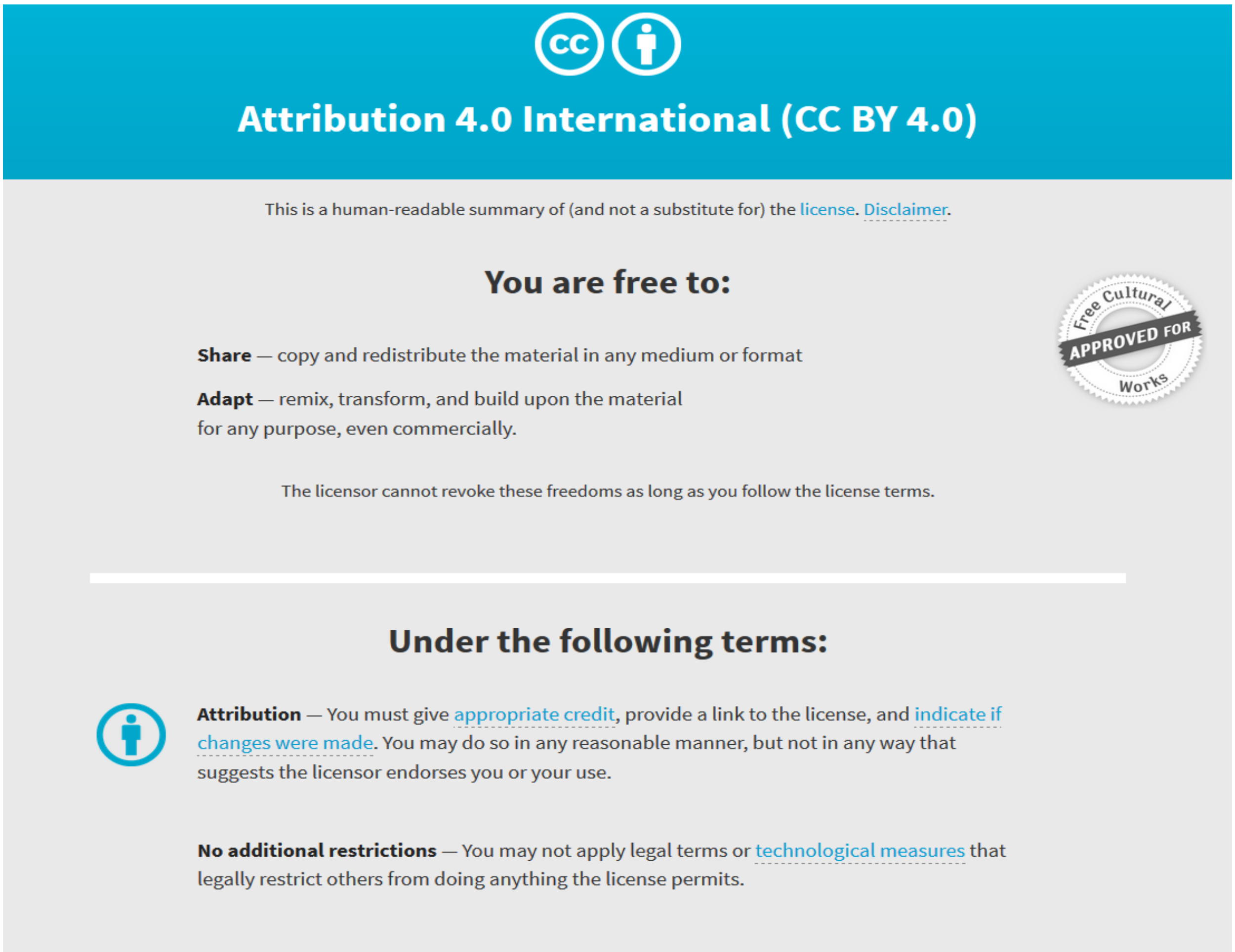
Ellen M. Douglas, Sarah Ann Wheeler, David J. Smith, Ian C. Overton, Steven A. Gray, Tanya M. Doody, Neville D. Crossman

Using mental-modelling to explore how irrigators in the Murray-Darling Basin make water-use decisions

Journal of Hydrology : Regional Studies, 2016; 6:1-12



Attribution 4.0 International (CC BY 4.0)

This is a human-readable summary of (and not a substitute for) the license. Disclaimer.

You are free to:

Share — copy and redistribute the material in any medium or format

Adapt — remix, transform, and build upon the material for any purpose, even commercially.

The licensor cannot revoke these freedoms as long as you follow the license terms.

Under the following terms:

Attribution — You must give appropriate credit, provide a link to the license, and indicate if changes were made. You may do so in any reasonable manner, but not in any way that suggests the licensor endorses you or your use.

No additional restrictions — You may not apply legal terms or technological measures that legally restrict others from doing anything the license permits.

Journal of Hydrology: Regional Studies 6 (2016) 1–12

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Using mental-modelling to explore how irrigators in the Murray–Darling Basin make water-use decisions

Ellen M. Douglas[a,*], Sarah Ann Wheeler[b,c], David J. Smith[d], Ian C. Overton[e], Steven A. Gray[g], Tanya M. Doody[e], Neville D. Crossman[f]

[a] *School for the Environment, University of Massachusetts, Boston, USA*
[b] *Global Food Studies, University of Adelaide, Adelaide, SA, Australia*
[c] *Adjunct, School of Commerce, University of South Australia, Adelaide, SA, Australia*
[d] *CSIRO, Agriculture Flagship, Griffith, NSW, Australia*
[e] *CSIRO, Land and Water, Waite Campus, Adelaide, SA, Australia*
[f] *CSIRO, Land and Water, Waite Campus, Adelaide, SA, Australia*
[g] *Department of Community Sustainability, Michigan State University, East Lansing, MI, USA*

ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 13 January 2016
Accepted 20 January 2016
Available online 18 February 2016

Keywords:
Irrigation
Water use
Farmer decisions
Mental model
Stakeholders

ABSTRACT

Study region: Water stress and over-allocation are at the forefront of water management and policy challenges in Australia, especially in the Murray–Darling Basin (MDB). Because irrigated agriculture is a major social and economic component of the MDB, farmer decision-making plays a major role in water sustainability in the region.
Study focus: This study used a fuzzy cognitive mapping methodology, 'mental modeling', to understand the perceived constraints of irrigator water-use decisions in the MDB, for two different types of irrigation: permanent and annual crops. The approach elicits and documents irrigator insights into the complex and networked nature of irrigation water use decisions in relation to farm-based dynamics.
New hydrological insights for the region: Results suggest support for greater local and irrigator involvement in water management decisions. Many, if not most, of the irrigators understood the need for, or at least the inevitability of, governmental policies and regulations. However, a lack of accountability, predictability, and transparency has added to the uncertainty in farm-based water decision-making. Irrigators supported the concept of environmental sustainability, although they might not always agree with how the concept is implemented. The mental modelling approach facilitated knowledge sharing among stakeholders and can be used to identify common goals. Future research utilizing the mental modelling approach may encourage co-management and knowledge partnerships between irrigators, water managers and government officials.

1. Introduction

As the driest inhabited continent on the planet (Vaze et al., 2011), Australia faces significant water stress and water allocation issues, and is at the forefront of water management and policy discussions. One of the most compelling examples is the Murray–Darling Basin (MDB) which covers more than one-seventh of the continent and is home to two million people

---

[*] Corresponding author at: 100 Morrissey Blvd, Boston, MA 02125, USA. Fax: +1 617 287 7474.
E-mail address: ellen.douglas@umb.edu (E.M. Douglas).

http://dx.doi.org/10.1016/j.ejrh.2016.01.035
2214-5818/

(including the capital city of Canberra). Even though the area is water-limited, farmland within the Basin generates 40% of Australia's total agricultural production and utilizes 60% of all irrigation water withdrawn nationally (CSIRO, 2008). The long-term average annual flow of the MDB has been reduced to less than 40% of the average pre-development flow (Wentworth Group, 2010). Australian society has reaped an enormous benefit from agriculture in the Basin, but this benefit has come at great cost to MDB flow regimes and river ecosystems (ibid). In addition to the development and population stresses, the MDB has experienced three major droughts over the approximately 120 year period of record (Chiew et al., 2011; Wheeler, 2014). Most recently, the so-called Millennium drought (1997–2010) was the worst by many measures (Kirby et al., 2014). As damaging as this drought was to agricultural, economic and ecologic systems, Wheeler (2014) notes that droughts have been critical in bringing about cooperation and driving institutional water reform in Australia. To help catalyze social reform, methods for structuring decision-making and promoting social learning (Pahl-Wostl et al., 2007) are necessary. This paper illustrates the use of one such method applied to water-use decisions made by irrigators in the MDB.

Concerns over water availability and use in the MDB are not new. Various irrigation acts, commissions, caps, regulations and property rights have been implemented in the MDB over the past century to attempt to deal with water scarcity and quality issues. With the ratification of the MDB management plan (MDB Plan) in November 2012, Australia leads the world in integrated water management policy reforms, which, over the last two decades have moved Australia from strongly opposing the transfer of consumptive (irrigation) water to the environment to a large government-led, market-based environmental water buyback program (Lane-Miller et al., 2013). But, successful implementation of this policy depends critically on the involvement and willingness of irrigators to sell their water to the Commonwealth and on states cooperating with the Commonwealth on water policy. Given that irrigators' interests often drive states positions, it becomes critical to understand irrigator decision-making and to utilize tools that can capture and illustrate irrigator's complex water-use behavior. Much of the literature supports this stance: for example, Mooney et al. (2012) suggested that distributional equity (fair access to resources) and procedural equity (fair process in decision making) were most important to irrigators; while Whittenbury and Davidson (2009) argued that improvements in water-use efficiency by irrigators that can to lead to real environmental benefits require an understanding of both macro and structural influences on irrigator behavior. In this research, we portray (and illustrate) the wide range of influences on the decision-making process of two groups of irrigators in the MDB, which has not been shown fully in previous literature.

Although farmer water-use decision-making has been investigated previously (e.g., ABARES, 2014; Wheeler et al., 2012b; Ashton et al., 2009), often regression models and overview reports are limited in terms of their capacity to include attitudinal drivers and more qualitative factors in decision-making. Our approach incorporated a more individual-level analysis of water-use decision-making by farmers and deepens the understanding gained from previous studies. Specifically, our research objectives were to: (1) define and model how individual irrigators make water-use decisions, including the networked manner in which market, water authority, business, and environmental factors are related in the minds of irrigators; and (2) through this process, gain insight into how irrigator knowledge may be better incorporated into broad water decision-making within the Basin. This paper does so by implementing a fuzzy cognitive mapping methodology (known as mental modeling and explained further in Section 2.3) to allow us to highlight and discuss the range of influences on irrigators' water-use decisions. By doing so, we are investigating whether irrigators can provide a mental map of their farm as a system, and as such, how much do farmer mental maps differ between two very different forms of irrigation: permanent and annual cropping?

2. Understanding farmer behavior and decisions about irrigation water-use

2.1. Influences on farmer behavior in general

Edwards-Jones (2006) provides an overview of the literature on decision-making, and summarizes the six key influences on farmers: socio-demographics, psychological factors, farm household characteristics, farm business structure, the wider community and characteristics of the farming techniques. Within the Australia literature related to farmer behavior there is the adoption literature (e.g., Pannell et al., 2006); the sustainability and governance literature (e.g., Marshall, 2009); the systems literature (e.g., Wilson, 1995) and the psychological literature (e.g. Maybery et al., 2005). In relation to the application of cognitive mapping to farming decisions, Fairweather and Hunt (2011) and Fairweather (2010) found that farmers in New Zealand could map their farm systems, both as individuals and in groups, and concluded that cognitive mapping had the potential to contribute to knowledge, and other stakeholder management issues.

2.2. Influences on farmer water-use decision-making and behavior

Changes in water policy, in combination with stressed hydrological flows, have presented enormous uncertainty in irrigated agriculture in the MDB. Prior to the Millennium drought, irrigation water allocations were near or at 100% of entitlements meaning that farmers received their expected allotments of irrigation water. But, water allocations fell from approximately 12,000 GL in 2000–2001 to just below 4100 GL in 2008–2009 as a result of the Millennium drought; even so, irrigated production gross value declined by only 20% (on aggregate), largely due to irrigators adopting a suite of adaptation strategies that varied by farm type (Kirby et al., 2014). In addition to reduced physical water availability, the government has changed the way it announces seasonal allocations resulting in a shifting of uncertainty in cropping decisions from the water managers to the farmers. Prior to 1997, not only did irrigators receive 100%+ of their water entitlements, but final allocations were announced well before planting decisions had to be made, ostensibly allowing farm-based decision-making to coincide with water resource allotments. However, beginning in 1998, water managers began making water allocation announcements based solely on the current storage levels and minimum expected flows (Wheeler et al., 2014), which dramatically increased the level of uncertainty in planting decisions made by irrigators. Other changes faced by irrigators include irrigation infrastructure funding and changes to the water market.[1]

There are many influences on irrigator's water-use decisions. Cuddy et al. (2005) found that farmers often put more weight on natural indicators that were locally ecologically relevant (e.g., ant behavior) and their own "gut feelings" than in seasonal forecast information. Factors that may influence water trade decisions include debt or farm restructure (e.g., Wheeler and Cheesman, 2013); long-term goals and farm succession issues (Wheeler et al., 2012a); farmers adaptive capacity (Park et al., 2012); and age and health (Wheeler et al., 2013). We utilized cognitive mapping to capture these and other influences and how they relate to water-use decisions made by irrigators in the MDB.

2.3. *Cognitive mapping with mental modeler*

The successful management of complex social-ecological systems requires the coordination of actions which in turn requires a level of shared understanding of the system or situation; a shared or common mental model (Mathevet et al., 2011). A mental model describes how a person views the world and how those views affect their interactions. Mental models have been widely used in facilitating group decisions and consensus in public and private management settings (Giordano et al., 2005) as well as in risk analysis, education, natural resource management, and climate change adaptation (Biggs et al., 2011). An emerging participatory modeling approach that captures both individual and group mental models using a fuzzy-logic cognitive mapping (FCM) software is *Mental Modeler* (http://www.mentalmodeler.org/). Although there are a number of ways to present a mental model (Biggs et al., 2011), *Mental Modeler* uses an influence diagram to illustrate factors and relationships between factors. Both the factors and the relationships (including the direction and strength of the relationships) can be defined collectively as the group mental model is developed using this software. This software has been used to capture mental models held by individual or communities thought to influence decision-making (Gray et al., 2013, 2014). Although the term 'mental model' refers specifically to individually held internal beliefs about the external world (Johnson-Laird, 1983), such cognitive mapping approaches in group settings is argued to facilitate social-learning and problem structuring, reflecting the shared beliefs of the groups of people included in the modeling process (Henly-Shepard et al., 2015). Originally developed by Kosko (1986) as a semi-quantitative form of concept mapping, and popularized in environmental decision-making contexts by Ozesmi and Ozesmi (2004), the FCM approach is becoming an increasingly popular way to incorporate local or expert knowledge into ecological decision making (Nyaki et al., 2014; Halbrendt et al., 2014). Mental models are informed by social and cultural influences, and to understand the factors that influence the decision-making of cultural groups (Biggs et al., 2011) such as farmers (Halbrendt et al., 2014).

Elsawah et al. (2015) and Jones et al. (2011) note numerous strengths in the use of mental models including the benefits of mixed methodologies, model clarity and transparency and ease of explanation. Documenting mental models can highlight both consensus and lack thereof, among stakeholders, which can be useful in improving coordination and social learning in resource management (Abel et al., 1998; Biggs et al., 2011; Mathevet et al., 2011). However, weaknesses include the necessity for the researcher to have a good understanding of the decisions to be mapped and the ability to discern details that may or may not be applicable to a particular mapping outcome. Jones et al. (2014) found that mental models can be greatly affected by the location of the interviews used in their development. Despite these shortcomings, perhaps one of the most important characteristics of this approach is that it affords transparency to information gathering and can be used to transfer knowledge between science and policy (Kolkman et al., 2005).

2.4. *Application of mental modeling to water-use and farming decisions*

Mental models have been used to identify the issues underlying water conflict and to evaluate alternative strategies in order to overcome obstacles to sustainable water management (Giordano et al., 2005; Mouratiadou and Moran, 2007). They have also been used to translate the results of scientific experiments in support of improving crop management (Papageorgiou et al., 2009) and to better understand individual farmer decisions (Isaac et al., 2009; Fairweather and Hunt, 2011). Fairweather (2010) demonstrated that mental models from individual farmers in different locations could be aggregated to develop a broader model of the farming-ecological system in a region. In Australia, mental models have been used characterize short-term and long-term water use decisions made primarily by viticulturists (Whittenbury and Davidson, 2009; Elsawah et al., 2015).

We sought to test whether the *Mental Modeler* software could be used to translate irrigator expert knowledge into a networked model of irrigation water-use decision-making. This was done through a series of workshops with irrigators

---

[1] In the MDB, there are well-developed water markets in both permanent and temporary trade. A water entitlement (permanent water) represents exclusive access to a specific share of water within a water resource plan area. A water allocation (temporary water or lease water) is annual access to a portion of that entitlement based on current and projected hydrologic conditions.

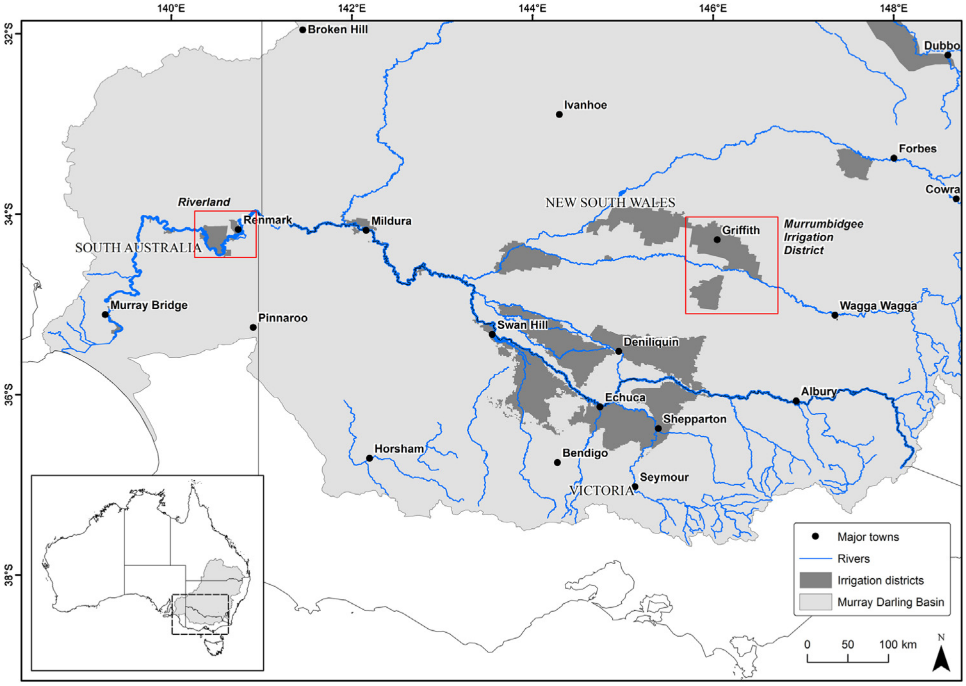


Fig. 1. Irrigation districts in the southern portion of the Murray–Darling Basin (MDB) in southeastern Australia. Our workshops were focused in two irrigation districts (red boxes): Riverland in South Australia and Riverina in New South Wales.

in two regions in the MDB, where individual and group beliefs were discussed and debated, and the model revised until consensus was reached. Model factors and the relationships between factors (including direction and strength) were defined by the irrigator groups. Such group-level mental modeling practices have recently been found to be important in terms of communicating complex systems into easily understood form or concept mapping (Gray et al., 2012). The following section describes the areas and methods specifically applied to our research.

3. Study areas and methods

3.1. Case study areas

We held workshops with two communities of irrigators in the MDB: the Riverina and the Riverland, each characterized by different irrigation, agricultural and environmental conditions. Our first study site was located within the Murrumbidgee Irrigation Area (MIA, a.k.a, Riverina; Fig. 1) in New South Wales. The Murrumbidgee River basin, a sub-basin within the MDB comprises 27% of the MDB's population. Sources of irrigation water include the Murrumbidgee River and its tributaries, the Snowy Hydro Scheme and its associated storages, aquifers and wetlands. Irrigated agriculture is the predominant economic driver within the region with farm types ranging from broadacre (annual) crops (rice, corn, vegetables, soybeans, cotton, winter cereal grains and pasture) to horticulture (permanent) crops (grapes, citrus, sugar plums). Rice and horticulture producers make up around 90% of farms and have a very high dependency on irrigation (MDBA, 2010).

Murrumbidgee Irrigation Ltd. (MI) is one of the largest private irrigation companies in Australia serving over 3200 landholdings owned by over 2500 customers within an area of 660,000 ha. MI manages irrigation water for MIA farmers, holding a water license of 1416GL, including 314GL of High Security (water that farmers will receive full water allocations 95 years out of 100, typically used by permanent crop farmers) and 815GL of General Security (implying irrigators receive full water allocations up to 70 years out of 100; typically used by annual crop farmers) water entitlements. Private diverters in the region hold 625GL general security water entitlements and 21GL high security water entitlements. Over 90% of the irrigation water in MIA is applied using gravity-fed surface irrigation systems (typically flood or flood-furrow), with distribution efficiency reported around 80% (MDBA, 2010).

The Millennium Drought considerably influenced the gross value of irrigated agriculture production in the region (MDBA, 2010). Broadacre farms in the MI network saw the biggest drop in water allocations (from nearly 100% prior to 2000 to a low of 10% in 2006) while their high security water allocations remained nearly constant at 90–95% during this time. This is reflected in the agricultural productivity of the region. From 1997 to 2002, the region produced over 500,000 t of rice annually, as compared to an average of less than 187,000 t annually from 2004 through 2009. Less than 13,000 and 52,000 t of rice were produced in 2007–08 and 2008–09 respectively. In comparison there were 148,000 t of wine grapes produced in 2000 and 256,000 t in 2008, a 73% increase over the eight-year period (MDBA, 2010). However, water trading (such as selling their available water on the temporary market at prices around AUD$1000 per megalitre (ML)) brought in a much-needed source of farm income for rice farmers during the peak of the drought (Wheeler, 2014).

Our second study area was the Riverland irrigation area straddling the lower Murray River in South Australia (see Fig. 1), growing more than 50% of South Australia's wine grapes and also well known for its production of citrus, stone fruit, almonds and vegetables. Riverland population is around 33,500, including approximately 3000 growers. The regional economy of around AUD$2.2 billion is highly dependent on high security irrigation water and permanent crops, with wineries, packing sheds and other food processing reliant on a consistent supply of irrigated crops (MDBA, 2010). Water-based recreation is also an important contributor to the regional economy in the form of houseboat accommodations, canoeing, kayaking, fishing, swimming and tourism.

The Central Irrigation Trust (CIT), located in Barmera, South Australia (SA), manages water for twelve irrigation districts in the Riverland and conveys water from the Murray River through large-diameter pipeline systems. Irrigated agriculture is predominantly grapes (55%), fruits (25%) and citrus (15%) with the remaining area in vegetables and pasture. Irrigation has progressed from flooded furrow systems (as late as the mid-1990s) to piped sprinklers and drip irrigation infrastructure, all but eliminating conveyance losses and creating highly water-efficient, albeit more energy-intensive, irrigation systems. CIT farmers do not have the luxury of adjusting irrigated area in response to reduced water allocations; permanent crops such as grapes must be watered to preserve the productive potential for future years and to meet contractual obligations; indeed, Riverland agriculture was developed based on the expectation of full allocations. The Millennium drought resulted in several years of exceptionally low water allocations for SA (60, 32 and 18% in 2006–07, 2007–08 and 2008–09; MDBA, 2010), forcing many irrigators to purchase temporary water at high prices to maintain their crops. The price of permanent water also increased during this time, but at a slower rate and remained above $2,000/ML until 2010–11 (Wheeler and Cheesman, 2013). Combined with an approximately 20% drop in grape prices during that time, rising farm debt became a pressing issue in the Basin.

Traditionally (and especially so in wet years) irrigators have not used all the water allocations that have been allocated to them. MDBA (2012) suggests that the water utilization average over the past fifteen years is around 60–80%, with generally SA irrigators utilizing a higher percentage of their water allocations received than NSW irrigators.

3.2. *Fuzzy cognitive modelling (FCM) methodology and workshop design*

A workshop was held in each of our case study areas in 2014 to develop a model representation of irrigator water-use decision-making using the *Mental Modeler* FCM-based software. Ten irrigators participated in the MIA workshop and 13 in the CIT workshop. The premise of our workshops was that irrigators would elucidate important variables that would not typically be identified or quantified in academic research, thereby allowing a more cultural group analysis of water-use decision-making. Though more qualitative in nature, we believed that this local or expert knowledge could be used to augment the academic and governmental-level decision models since farmers hold important expertise at the local-scale in which irrigation decisions are made.

At the beginning of the workshops, the goal of building a group mental model of irrigation water-use decisions was explained and that we were interested in both the quantifiable (i.e., water allocations, farm size, etc.) and the non-quantifiable (risk appetite, information sources, etc.) variables—borrowing from methods developed by Ozesmi and Ozesmi (2004). Rather than starting with a pre-defined list (see Gray et al., 2015a), we asked the irrigators to list the variables via free association (Gray et al., 2014) that were important to water decision-making from their perspective. Once an initial list of variables was compiled, the networked structure and degree of influence (represented by the direction and thickness of the arrows in the software) that one variable is perceived to have on another; either positively or negatively, was defined by the irrigators. The variables were listed on a white board and the *Mental Modeler* was projected on a screen. An independent facilitator developed the model in real-time while another researcher facilitated the conversations and discussions during the workshops. Both workshops continued (about three hours at each site) until there was agreement within the group that the mental model accurately represented their perceptions of the interaction between market, water authority, business, environmental and any other factors perceived to be relevant as defined by the irrigators. Notes were also taken (by the workshop facilitator) to capture the model building process and document our justification for the variables and relationships ultimately represented in the model.

4. Results and discussion

4.1. *MIA workshop: a group mental model for annual crop water-use decisions*

Seven of the ten participants from the MIA were broadacre irrigators (growing annual crops such as rice, corn, wheat, vegetables); the other three were permanent crop (grapes and citrus) irrigators. Because the majority of participants grew annual crops (namely rice), we focused on building a mental model of irrigation water-use for a rice farm. The outcome of interest was "irrigated area", which was considered to be the direct proxy for irrigation water used on a rice farm. We first asked the irrigators to list the variables that were most related to irrigation area; and 35 variables were identified (Table 1). The quantifiable variables are listed in the left hand column and the non-quantifiable variables are listed in the right hand column.

Table 1
List of variables that are considered in making irrigation water use decisions.

Quantitative factors	Non-quantitative factors
Type of water license (high vs. general security)	Unpredictability of government decisions Policy stability
Type of crop (permanent vs. annual)	Layers of bureaucracy
Environmental water storage	Decision-maker accountability
Farm size	Communication
Water level in dams	Water sharing rules
Farm equity	Water entitlement priorities
Selling water	Timing of allocation announcements
Forward contracts for produce	Water budget year
Opening water allocation	Anticipating peer behavior
Water carry over	Whole farm plan/agronomic plan
Return on investment	Farmer characteristics (age, risk appetite, succession plan)
Input costs	
Weather	Farming practices
Seasonal rainfall forecasts	Water trade signals
Autumn break (excess soil moisture in fall)	Water activation
Water trade	Security of water delivery
Crop price guarantees	Delivery entitlements
Current commodity prices	

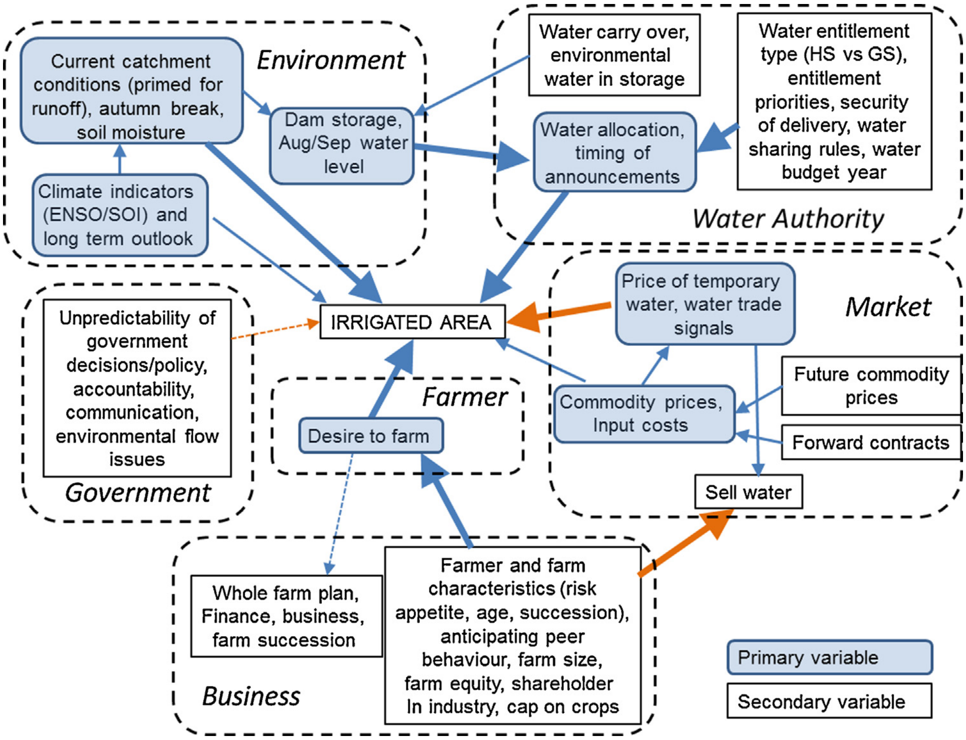


Fig. 2. Group mental model of water use decisions for broadacre (annual) rice cropping. Blue boxes are primary variables that directly influence water use decisions. Blue lines represent positive relationships, orange lines represent negative relationships. Line thickness represents strength of relationship (thick = strong, thin = moderate, dashed = weak).

Interestingly, most of the discussion for the first hour or so centered on the non-quantifiable variables, especially those related to government decisions and policy making. Many farmers often felt “at the whim” of changes that they could not predict. It should be noted that many of these changes relate to previous government policy changes, and not necessarily current government policies. Following on from this, in the end, while these variables were identified as the things that “keep me up at night”, they were not directly linked to irrigated area. By the end of the workshop, the irrigators had developed the so-called “simplified” model of irrigation water-use decisions (shown as blue boxes in Fig. 2).

The seven variables that were useful in determining the amount of irrigated area on a rice farm were: opening allocations, water levels in the Blowering and Burrunjick dams in late winter (August/September), current catchment conditions (whether is it wet or dry), the price of temporary water, large-scale climate indicators (ENSO, SOI) and long-term seasonal rainfall outlook, commodity prices and the “desire to farm”.

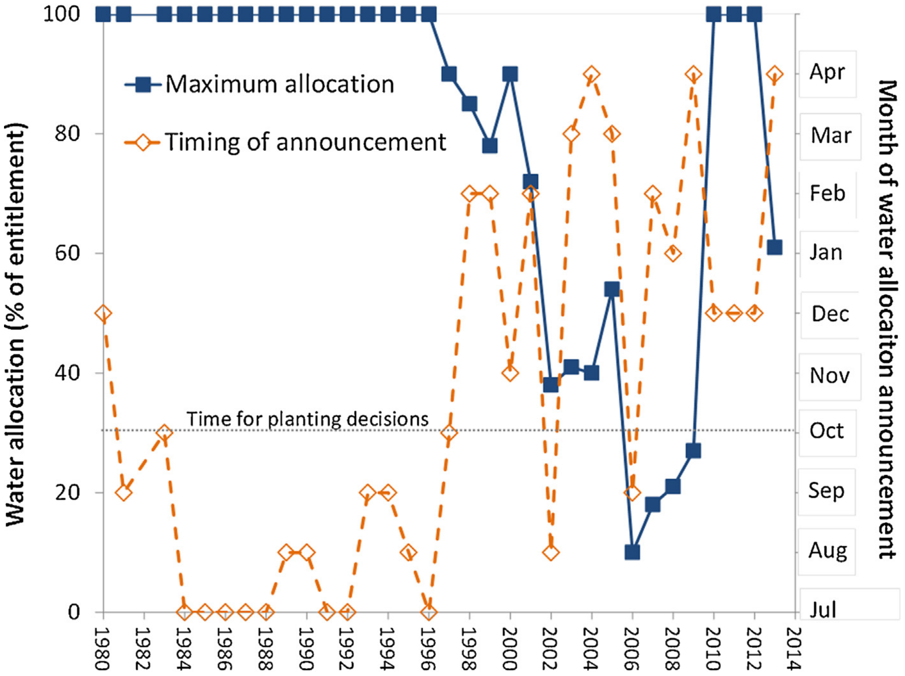


Fig. 3. Increased uncertainty in planting decisions due to a combined shift in water allocation amounts and timing in Riverina. Blue symbols are the seasonal maximum water allocations (capped at 100% for graphing purposes) and the orange symbols are the month in which that the maximum allocation announcement was made. Below the dotted line represents the time within which irrigators must make planting decisions for the upcoming season (July 1–October 1).

The last variable was perhaps the most unexpected and interesting. Several farmers stated that, despite the risks and uncertainty inherent in all the other decision variables, they would choose to plant because "*we are farmers, this is what we do*." This was a desire to always farm. The "final" mental model that was developed and agreed to by the irrigatos is shown in Fig. 2. As recommended by the farmers during the workshop, many of the non-quantifiable (and less emphasized) variables listed in Table 1 (right-hand side) were lumped into single boxes that represented farmer/farm characteristics (age, risk appetite, farm size, whole farm plan, etc.) and unpredictability of government decisions (policy stability, layers of bureaucracy, accountability, etc.) and were linked to the "desire to farm" variable. After the workshop, researchers grouped the decision variables into broad categories of environment, market, business, water authority (in this case, MI), government (state and federal) and farmer characteristics. This illustrates the broad range of factor types as well as scales that have to be considered in making water-use decisions. A couple of times, one of the farmers commented that "*we need to figure all these things out before 5am!*".

The "desire to farm" was one of the enlightening outcomes of this exercise. From the discussion, it became quite clear that given positive indicators in the farm/farmer characteristics variable (for example, age, farm equity, reasonably high appetite for risk), and a reasonable understanding of near-term government policy decisions, a farmer wants to choose to farm even in the face of negative environmental indicators such as a low rainfall outlook or low dam levels. Selling temporary water on the market was perceived by the irrigators as a failure. This as a pertinent and telling observation; political uncertainty added to the other uncertainties inherent in farming (e.g., weather, market prices, etc.) could be the factor that tips the balance from willingness to farm (in spite of other risks) to selling water and finding other means to make a living. However, the irrigatos also generally agreed that if water allocations were too low (exact threshold was not identified) and/or water prices were too high (suggestions of water prices >$80/ML), then they would be more likely to sell water than plant crops. One irrigator quipped, "*But as food producers, its really sad to have to say that were not going to grow food this year, we're going to sell water,*" suggesting that this choice would be made only under fairly high level of duress, at least for some irrigators.

Water allocations received was deemed a primary, and obvious, variable in water-use decisions. The more water allocated in a season, the more irrigated planting that can potentially occur. What is not so obvious is the effect of the timing of allocation announcements by a water manager, in this case, MI. Planting decisions for rice generally must be made by early October and for other summer cereal crops, by mid-November. Uncertainty in water availability has increased dramatically in the Murrumbidgee region through both reduced seasonal water allocations and later allocation announcements (Fig. 3). After record low storage levels were experienced in 1998 (storage dropped to 8.5% of capacity in the Burrinjuck by May 1998 and to <5% in the Blowering dam by April 1998), water managers began making seasonal water allocations announcements based solely on current storage levels and the minimum projected inflows to the system. Hence, the announcement of the maximum allocation that irrigators could expect for a season came much later and usually well after planting decision time.

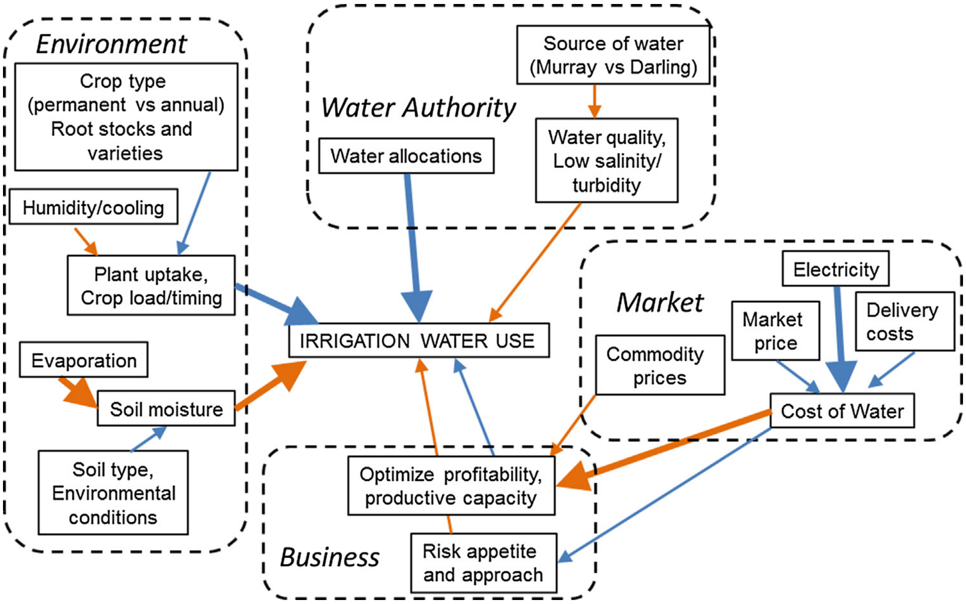


Fig. 4. Group mental model of short-term (annual) irrigation water use decision for permanent crop growers in the CIT area. Blue lines represent positive relationships, orange lines represent negative relationships. Line thickness represents strength of relationship (thick = strong, thin = moderate, dashed = weak).

Prior to 1997, the maximum allocation averaged >100% and announcement generally occurred within a month of July 1 (start of the water year). Since 1997, the average maximum seasonal allocation has dropped to 60% and the announcement is made, on average, in January of the next calendar year. Even during 2010–2012, when the maximum allocation was again 100%, the timing of this allocation was in December (see Fig. 3). The effect has been a dramatic shift of risk from water managers to irrigators, and this was clearly reflected in the mental model.

4.2. CIT Wworkshop: a group mental model for permanent crop water-use decisions

As nearly all the participants in the CIT workshop were permanent crop growers (meaning irrigated area remained fairly constant), the decision outcome that we asked irrigators to focus upon was "irrigation water-use". Irrigators were asked to list the variables that were most related to irrigation water on a typical farm in the CIT. The list was very similar to that shown in Table 1, with the following exceptions: environmental water storage, dam levels and carryover were not listed; while water profile strategy, productive efficiencies, emotional drivers, critical human needs, source water quality and evaporative cooling were added. The phrase "*desire to farm*" from MIA growers was roughly synonymous with "*farming enjoyment*" in CIT. Whereas MIA farmers viewed two different levels of water-use decision variables (primary and secondary, see Fig. 2), the CIT irrigators noted two distinct time-frames in water-use decision-making: irrigation water decisions in the short-term (immediate) and water-use decisions over the medium-term (approximately 3–5 years). These two models are shown in Figs. 4 and 5.

As in Fig. 2 (for annual crop irrigators), the decision variables could be broadly categorized into those that represented environment, water authority (in this case, CIT), market, government and farmer characteristics, although not all categories were present in both models. Interestingly, CIT farmers considered risk appetite to be a primary driver of irrigation water-use in the area, which was highly influenced by the cost of water (a combination of the market price of water as well as energy and delivery costs). There was a lot of discussion about emotional and well-being factors, but in this case, the irrigators considered this as an influence that keeps them in farming over the long-term rather than an immediate influence on water-use decisions. This differed from the MI model.

A new factor in the permanent crops water-use model was evaporative cooling, which is unique to viticulture. During extreme heat, it is necessary to irrigate grapes in excess of plant water demand in order to keep the vineyard cool and to prevent grape vine sunburn. This is accomplished by spraying the vines directly with sprinklers and/or by irrigating the ground cover maintained between the rows of vines, and serves two purposes: (1) the ground cover maintains a more uniform soil moisture profile under the vineyard; and (2) evapotranspiration from the ground cover cools the surrounding vines. Although the proportion of irrigation water used for this purpose was not discussed, it is an adaptation to more frequent extreme heat days.

Water quality is another consideration in the CIT model that is not in the MI model. Irrigation water in the Riverland comes either from the Murray River or the Darling River. Murray River water tends to be higher in salt and turbidity than Darling River water, meaning that in order to prevent soil salinization and pore clogging, additional water needs to be applied to the

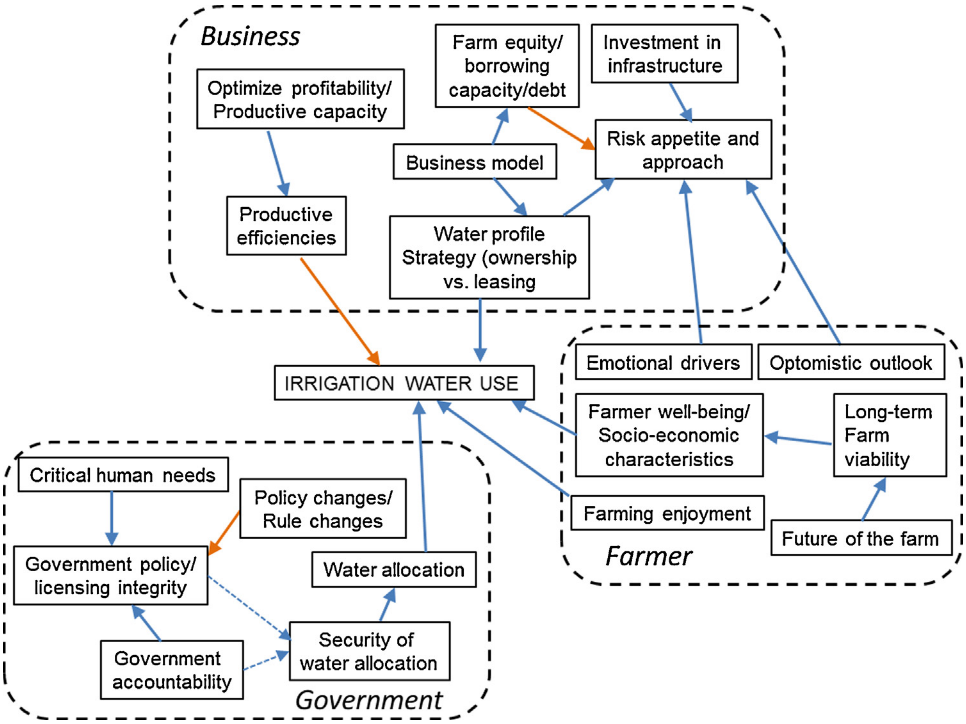


Fig. 5. Group mental model of medium-term (3–5 years) irrigation water use decision for permanent crop growers in the CIT area. Blue lines represent positive relationships, orange lines represent negative relationships. Line thickness represents strength of relationship (thick = strong, thin = moderate, dashed = weak).

crops when the source is the Murray. The CIT announces the source of irrigation water, which is why this was categorized as a water authority variable rather than environmental. In addition, the soils in the Riverland area naturally have a higher amount of salinity due to a shallow, naturally saline groundwater table (Jolly et al., 1993; MDBA, 2013) and farmers generally flush their soils with irrigation water at the end of every season to prevent buildup of salt in the root zone (Biswas et al., 2006).

An interesting observation can be made when comparing Figs. 4 and 5 in the differing factors influencing risk. In annual water-use decisions (Fig. 4), risk is almost completely defined by the cost of water. As cost increases (be it through market price, or energy and delivery costs), farming risk increases. In the medium-term decisions (Fig. 5), financial considerations such as farm equity and infrastructure investment also drive the farmer's appetite for risk (as would be expected), but so does emotional well-being. Again, "*farming enjoyment*" (similar to "*desire to farm*") was a key factor in water-use decisions and the socio-economic well-being was affected by the long-term viability of the farm. In the MI, the desire to farm was one factor that made farmers choose to plant in a year where other indicators would suggest selling their water instead of planting. The long-term viability of the farm (representing farm succession) was considered by the CIT farmers to be a medium-term decision factor and was included as part of farmer well-being. This is supported by Wheeler et al. (2012b) who found the presence of a farm succession plan to be a positive factor in long-term farm management decisions and in the ability of agriculture to adapt to changing conditions. Interestingly, increased uncertainty in water security was also found to have a negative impact on farm succession, suggesting that the relationship between water security and long-term farm viability could be considered a feedback loop.

The "farmer" category did not show up in the short-term CIT model; there was a lot of discussion about emotional factors, but they were considered to play a role in the longer-term outlook rather than in annual water-use decisions. In CIT, farming enjoyment is what kept farmers in agriculture over the long-term. There was a lot of discussion about how farmers make short-term decisions based on emotional factors as well, which they agreed may not always be the best decisions, but was often unavoidable. One of the participants is director of a collaborative farming operation, a collective of several farms in which the farmers own title to their land but work as employees of the collaborative enterprise. This irrigator argued strongly that one of the benefits of the collaboration is that farm decisions and operations are run by the collaborative (a type of corporation) and not individual farmers, hence taking the emotions out of farming decisions.

Environment, water authority and market factors were key ingredients in the short-term water decision model, but were absent in the longer-term model, where risk was defined as a combination of irrigator characteristics and business considerations. The main role of the government focused on the security of water allocations. Because CIT farmers are dependent on high security water, they feel vulnerable to government decisions that affect water security. Additionally, the farmers understood their role as water users upstream of major urban areas like Adelaide and agreed that they were part of a larger governmental scheme to ensure that critical human needs (household water-use as well as agricultural) were met. In contrast to MIA, where the role of government was mostly seen as a hindrance (multiple layers of bureaucracy, changing policy, lack of accountability for decisions), in CIT, the role of the government was seen as critical in ensuring water security for irrigators and urban dwellers, with a key role in ensuring the integrity of the water licensing scheme.

4.3. *Insights gained from mental models*

This research used cognitive mapping to visualize the influences on irrigator water-use decisions in order to understand the relationships between institutional, environmental, market and farm-based factors from the farmer perspective. Ultimately the models presented herein could be refined further and used by decision makers to better understand the effects of some types of water management and policy changes on stakeholder activities (for examples, see Nyaki et al., 2014; Halbrendt et al., 2014; Gray et al., 2013; Gray et al., 2015b; Vanwindekens et al., 2013; Lorance et al., 2011). Nevertheless, there are a number of key insights gained from this research that may prove useful to decision-makers. First, this research supports the concepts of co-management and knowledge partnerships between irrigators in the MDB and water managers and government officials. In particular, Berkes (2009) outlined many strategies that can improve co-management, which could be a valuable next step in MDB plan implementation. Second, irrigators in the MDB may have been misperceived when it comes to accepting policy change. Many, if not most, of the irrigators we talked to understood the need for, or at least the inevitability of, governmental policies and regulations. But a lack of accountability and predictability has added to the uncertainty in farming decisions. “Downward accountability”, a mechanism for making agencies responsible to users (Berkes, 2009), could improve this in the MDB. Irrigators are able, and in most cases willing, to adjust to policy changes when given enough lead time and input into the process. Finally, irrigators in the MDB subscribe to the concept of environmental sustainability, although they might not always agree with how the concept is implemented. Irrigators believe they should be recognized for their significant investments in the long-term sustainability of their farms and their communities and appreciated for their role in the sustainability of the Basin. The mental-modeling approach used in this research could be used to educate all stakeholders in commonalities and differences in perspectives and help to advance the implementation of sustainable management practices.

5. Conclusions

This research solicited the input of irrigators in two important, yet quite different, agricultural areas of the MDB: broadacre, annual crop (mostly rice) irrigators in Riverina with flood and furrow irrigation and permanent crop (mostly viticulture and citrus) irrigators with pressurized drip or sprinkler technologies in the Riverland. Both types of irrigators have been substantially impacted by the Millennium drought and by MDB water reform within the last decade. Uncertainty in end-of-season water allocations, drought and uncertainty about governmental water policy changes have all increased the difficulties in irrigators making water-use decisions. As would be expected, the variables that influence irrigation water-use decisions were similar, but there were some key differences. The “desire to farm” (the driving force that makes a farmer choose to plant despite the risk) is influenced by the constraints to the farming system (farmer characteristics, business model, environmental and market conditions) and governmental decisions and policy changes, which are mostly viewed as negative influences out of their control. In the Riverland, permanent crops such as grapes and citrus must be watered to maintain the long-term health of the crop, regardless of the environmental conditions or water availability. Unlike Riverina irrigators, risk and uncertainty for the Riverland irrigators was, in the short-term, predominantly driven by the cost of water, which includes market price and cost of delivery (energy and infrastructure maintenance). In the longer-term, risk (uncertainty) was seen to be influenced by the irrigator’s water profile strategy (whether they owned water entitlements or leased water each year) and well-being. Whereas in Riverina governmental policy was seen mostly as a hindrance to farming, in the Riverland the role of the government was seen as critical in ensuring water security for irrigators, with a key role in ensuring the integrity of the water-licensing scheme. Future research utilizing the mental modelling approach may prove fruitful in providing a methodology to encourage co-management and knowledge partnerships between irrigators, water managers and government officials.

Acknowledgements

Lead author Douglas was funded by a scholarship from the Australian-American Fulbright Commission and was hosted by the CSIRO in Canberra, ACT and Adelaide, SA. Travel and workshop expenses were shared by CSIRO Water Values and Benefits project and by the University of South Australia, and this project was supported by an ARC Future Fellowship FT140100773. We gratefully acknowledge the enthusiastic participation of the following irrigators in this research: Vince Vitucci, Keith Pickmere, Debbie Buller, Helen Dalton, David Cattanach, Hayden Cudmore, John Bonetti, Brian Grandi, Ian Blight and Frank Dalbon of Riverina; Rob Smyth, Leon Rosenzweig, Joe Gropler, Jack Papageorgiou, Anthony Fulwood, Peter Szabo, Lindsay Dowley, Darren Kennedy, Brett Proud, Caren Martin, Ashley Ratcliff, Cathryn Strachan and James Butler of Riverland. We also thank Deb Jansen of MI and Greg McCarron of CIT for their assistance in irrigator recruitment and workshop logistics.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ejrh.2016.01.035.

References

Abel, N., Ross, H., Walker, P., 1998. Mental models in rangeland research, communication and management. Rangel. J. 20, 77–91.

Ashton, D., Oliver, M., Hooper, S., Mackinnon, D., Mallawaarachchi, T., 2009. Irrigated agriculture in the Murray–Darling Basin: a farm level analysis by region and industry, Outlook 09 Issues and Insights, Australian Bureau of Agricultural and Resource Economics, Canberra, ACT.

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), 2014. Irrigation technology and water use on farms in the Murray–Darling Basin, 2006–07 to 2011–12 ABARES Research Report 14.3, Department of Agriculture and Water Resources, Canberra, ACT.

Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manag. 90, 1692–1702.

Biggs, D., Abel, Ni., Knight, A.T., Leitch, A., Langston, A., Ban, N.C., 2011. Theimplementation crisis in conservation planning: could mental models help? Conserv. Lett. 4, 169–183.

Biswas, T.K., Schrale, G., Strzaker, R., 2006. New tools and methodologies for in-situ monitoring of root zone salinity and leaching efficiency under drip and sprinkler irrigation. Acta Hortic. 792, 115–122.

Chiew, F.H.S., Young, W.J., Cai, W., Teng, J., 2011. Current drought and future hydroclimate projections in southeast Australia and implications for water resources management. Stoch. Environ. Res. Risk Assess. 25, 601–612.

CSIRO, 2008. Water availability in the Murray–Darling Basin. Summary of a report from CSIRO to the Australian Government, from the CSIRO Murray–Darling Basin Sustainable Yield Project, Australia, 12 pp.

Cuddy, S.M., Letcher, R.A., Chiew, F.H.S., Nancarrow, B.A., Jakeman, A.J., 2005. A role for streamflow forecasting in managing risk associated with drought and other water crises. In: Wilhite, D.A. (Ed.), Drought and Water Crises: Science, Technology, and Management Issues. Taylor & Francis Books, Florida, pp. 345–366 (Chapter 13).

Edwards-Jones, G., 2006. Modelling farmer decision-making: concepts, progress and challenges. Anim. Sci. 82, 783–790, http://dx.doi.org/10.1017/ASC2006112.

Elsawah, S., Guillaume, J.H.A., Filatova, T., Rook, J., Jakeman, A.J., 2015. A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: from cognitive maps to agent-based models. J. Environ. Manag. 151, 500–516.

Fairweather, J., 2010. Farmer models of socio-ecologic systems: application of causal mapping across multiple locations. Ecol. Model. 221, 555–562.

Fairweather, J., Hunt, L., 2011. Can farmers map their farm system? Causal mapping and the sustainability of sheep/beef farms in New Zealand. Agric. Hum. Values 28, 55–66.

Giordano, R., Passarella, G., Uricchio, V.F., Vurro, M., 2005. Fuzzy cognitive maps for issue identification in a water resources conflict resolution system. Phys. Chem. Earth 30, 463–469.

Gray, S., Chan, A., Clark, D., Jordan, R.C., 2012. Modeling the integration of stakeholder knowledge in social-ecological system decision-making: benefits and limitations to knowledge diversity. Ecol. Model. 229, 88–96.

Gray, S.A., Gray, S., Cox, L., Henly-Shepard, S., 2013. Mental modeler: a fuzzy-logic cognitive mapping modeling tool for adaptive environmental management, Proceedings of the 46th International Conference on Complex Systems, 963–973.

Gray, S.A., Gray, S., Zanre, E., 2014. Fuzzy cognitive maps as representations of mental models and group beliefs: theoretical and technical issues. In: Elpiniki, I. (Ed.), Fuzzy Cognitive Maps for Applied Sciences and Engineering, from Fundamentals to Extensions and Learning Algorithms. Papageorgiou, Springer Publishing, pp. 29–48.

Gray, S., McFall, A., Hilsberg, J., Arlinghaus, R., 2015a. The impact of specialization and target species choice on the structure of mental models about fish population dynamics. J. Outdoor Recreat. Tourism 12, 1–13.

Gray, S.A., Gray, S., O'Dwyer, B., Jordan, R., Nyaki, A., 2015b. Using fuzzy-logic cognitive mapping as a participatory approach to measure resilience, change, and preferred states of social-ecological systems. Ecol. Soc. 20 (2), 11.

Halbrendt, J., Gray, S.A., Radovich, T., Crow, S., Kimura, A., 2014. Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. Global Environ. Change 28, 50–62.

Henly-Shepard, S., Gray, S., Cox, L., 2015. Facilitating community adaptation through participatory modeling and social learning. Environ. Sci. Policy 45, 109–122.

Isaac, M.E., Dawoe, E., Sieciechowicz, K., 2009. Assessing local knowledge use in agroforestry management with cognitive maps. Environ. Manag. 43, 1321–1329.

Johnson-Laird, P.N., 1983. Mental Models: Towards a Cognitive Science of Language Inference and Consciousness. Harvard University Press, Cambridge, MA.

Jolly, I.D., Walker, G.R., Thorburn, P.J., 1993. Salt accumulation in semi-arid floodplain soils with implications for forest health. J. Hydrol. 150, 589–614.

Jones, N.A., Ross, H., Lynam, T., Perez, P., Leitch, A., 2011. Mental models: an interdisciplinary synthesis of theory and methods. Ecol. Soc. 16 (1), 46.

Jones, N.A., Ross, H., Lynam, T., Perez, P., 2014. Eliciting mental models: a comparison of interview procedures in the context of natural resource management. Ecol. Soc. 19 (1), 13.

Kirby, M., Bark, R., Connor, J., Qureshi, M.E., Keyworth, S., 2014. Sustainable irrigation: how did irrigated agriculture in Australia's Murray–Darling Basin adapt in the Millenium drought? Agric. Water Manag., http://dx.doi.org/10.1016/j.agwat.2014.02.013.

Kolkman, M.J., Kok, M., van der Veen, A., 2005. Mental model mapping as a new tool to analyse the use of information in decision-making in integrated water management. Phys. Chem. Earth 30, 317–332.

Kosko, B., 1986. Fuzzy cognitive maps. Int. J. Man Mach. Stud. 24, 65–75.

Lane-Miller, C.C., Wheeler, S., Bjornlund, H., Connor, J., 2013. Acquiring water for the environment: lessons from natural resources management. J. Environ. Policy Plan. 15 (4), 513–532.

Lorance, P.S., Agnarsson, S., Damalas, D., Des Clers, S., Figueiredo, I., Gil, J., Trenkel, V., 2011. Using qualitative and quantitative stakeholder knowledge: examples from European deep-water fisheries. ICES J. Mar. Sci. 68 (8), 1815–1824.

Marshall, G., 2009. Polycentricity, reciprocity, and farmer adoption of conservation practices under community-based governance. Ecol. Econ. 68, 1507–1520.

Mathevet, R., Etienne, M., Lynam, T., Calvet, C., 2011. Water management in the Camargue Biosphere Reserve: insights from comparative mental models analysis. Ecol. Soc. 16 (1), 43.

Maybery, D., Crase, L., Gullifer, C., 2005. Categorising farming values as economic, conservation and lifestyle. Econ. Psychol. 26, 59–72.

Mooney, C., Baldwin, C., Tan, P.L., Mackenzie, J., 2012. Transparency and trade-offs in water planning. J. Hydrol. 474, 66–73.

Mouratiadou, I., Moran, D., 2007. Mapping public participation in the water framework directive: a case study of the Pinios River Basin, Greece. Ecol. Econ. 62, 66–76.

MDBA, 2010. Appendix C of Guide to the Proposed Basin Plan: overview, Murray–Darling Basin Authority, Canberra accessed on-line on Aug 8, 2014: <http://www.mdba.gov.au/kid/guide/index.php/>.

MDBA 2012. Water Audit Monitoring Report 2010–11, Report of the Murray–Darling Basin Authority on the Cap on Diversions. Canberra: Murray–Darling Basin Authority (MDBA).

MDBA, 2013. Report of the independent audit group for salinity 2011–12. Canberra: Murray–Darling Basin Authority (MDBA).

Nyaki, A., Gray, S.A., Lepczyk, C.A., Skibins, J.C., Rentsch, D., 2014. Local-scale dynamics and local drivers of bushmeat trade. Conserv. Biol. 28, 1403–1414.

Ozesmi, U., Ozesmi, S.L., 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecol. Model. 176, 43–64.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., Taillieu, T., 2007. Social learning and water resources management. Ecol. Soc. 12 (2), 5 http://www.ecologyandsociety.org/vol12/iss2/art5/.

Pannell, D., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Aust. J. Exp. Agric. 46, 1407–1424.

Papageorgiou, E.I., Markinos, A., Gemptos, T., 2009. Application of fuzzy cognitive maps for cotton yield management in precision farming. Expert Syst. Appl. 36, 12399–12413.

Park, S., Marshall, N., Jakku, E., Dowd, A., Howden, S., Mendham, E., Fleming, A., 2012. Informing adaptation responses to climate change through theories of transformation. Global Environ. Change 22, 115–126.

Vanwindekens, F.M., Stilmant, D., Baret, P.V., 2013. Development of a broadened cognitive mapping approach for analysing systems of practices in social—ecological systems. Ecol. Model. 250, 352–362.

Vaze, J., Davidson, A., Teng, J., Podger, G., 2011. Impact of climate change on water availability in the Macquarie–Castlereagh River Basin in Australia. Hydrol. Process. 25, 2597–2612.

Wentworth Group, 2010. Sustainable diversions in the Murray–Darling Basin: an analysis of the options for achieving a sustainable diversion limit in the Murray–Darling Basin, Wentworth Group of Concerned Scientists, accessed on-line on April 14, 2014: <http://wentworthgroup.org/wp-content/uploads/2013/10/Sustainable-Diversions-in-the-Basin.pdf/>.

Wheeler, S., 2014. Insights, lessons and benefits from improved regional water security and integration in Australia. Water Resour. Econ. 8, 57–78.

Wheeler, S.A., Cheesman, J., 2013. Key findings from a survey of sellers to the restoring the balance programme. Econ. Pap. 32 (3), 340–352.

Wheeler, S., Bjornlund, H., Zuo, A., Edwards, J., 2012a. Handing down the farm? The increasing uncertainty of irrigated farm succession in Australia. J. Rural Stud. 28, 266–275.

Wheeler, S., Zuo, A., Bjornlund, H., Lane-Miller, C., 2012b. Selling the farm silver? Understanding water sales to the Australian Government. Environ. Resour. Econ. 52, 133–154.

Wheeler, S., Zuo, A., Bjornlund, H., 2013. Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. Global Environ. Change 23, 537–547.

Wheeler, S.A., Zuo, A., Bjornlund, H., 2014. Australian irrigators recognition of the need for more environmental water flows and intentions to donate water allocations. J. Environ. Plan. Manag. 57 (1), 104–122.

Whittenbury, K., Davidson, P., 2009. Beyond adoption: the need for a broad understanding of factors that influence irrigators' decision-making. Rural Soc. 19 (1), 4–16.

Wilson, J., 1995. An Introduction to Systems Thinking: Changing Agriculture, Second edition. Kangaroo Press, Kenthurst.