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Abstract

The Murray-Darling Basin (MDB) has the second-most variable surface flows in the world. The unreliable nature of MDB surface water supply is expected to increase under climate change. To partially address this future problem, Australia's government released 927 gigalitres (GL = 1 billion litres) of groundwater rights to agricultural users in the basin under the Murray-Darling Basin Plan (2012-2026). A key argument for that action was the perception that groundwater resources in the basin are sustainable, and more reliable, than surface water resources. Access to more reliable water often transforms agricultural cropping choices.
This chapter uses an optimization model of the MDB to explore how basin agriculture may transform in response to reliable water access—particularly in the northern part of the MDB. We find that traditional opportunistic cropping systems (i.e., annuals) shift towards high-value systems (e.g., perennials) and change irrigation practices when access to groundwater resources is increased. We also examine the change in value for those new groundwater rights as climate change impacts take hold.

Keywords

Conjunctive water resources, risk and uncertainty, transformation, reliability of rights, water rights

01

The Murray-Darling Basin Plan

This chapter explores the implications from increased access by agricultural producers in Australia to groundwater resources. Increased access will change the both the production systems (i.e., irrigated commodities) and management systems (i.e., irrigation practices) and our objective is to model how production and management transformations occur in response to both increased groundwater resource access and future climate change impacts to surface water supply. Australia's Murray-Darling Basin (MDB) provides the context for our analysis.

Australia's MDB can be divided into two parts, the highly developed and connected southern basin (SMDB) and the underdeveloped northern basin (NMDB) as shown in Figure 6-1. Water flows through the NMDB into the SMDB, and then runs from the eastern mountain ranges across western plainlands where much of the agricultural production takes place. The terminal node for the Murray River is the Coorong wetlands, located in South Australia (south of Adelaide in Figure 6-1).

'Development and connectivity' describe the extensive capital works (i.e. dams, irrigation networks and other capital investments) that help to reduce the surface water supply variability. These are required because the MDB has the second most variable surface water runoff globally (Love, 2005), punctuated by periodic flood events and extensive severe droughts. Of the total 21,000 gigalitres (GL = one billion litres or 810.7 acre feet) of surface water storage in the MDB, around 77% is situated in the southern basin (MDBA, 2020a). Greater access to stored surface water means that southern agriculture enjoys higher supply reliability compared to growers located in the NMDB. As Loch *et al.* (2020a) discuss, reliability is important for determining crop choices because the ability to irrigate perennial crops annually is necessary to preserve the capital invested. Higher surface water reliability

Figure 6-1 *Location of key rivers, supply sources and critical identifiers for the MDB (Source: https://www.mdba.gov.au/sites/default/files/images/pubs/Murray-Darling_Basin_Boundary.jpg)*

Table 6-1 *2012 MDB Plan and Change in Water Resources (GL)*

k	Catchment	Trading Zone	Net Change in Volume	
			Ground water	Surface Water
k1	Condamine	NMDB	62.8	-60.0
k2	Border Rivers QLD	NMDB	47.8	-8.0
k3	Warrego Paroo	NMDB	132.0	-9.0
k4	Namoi	NMDB	0.0	-10.0
k5	Central West	NMDB	8.6	-65.0
k6	Maranoa Balonne	NMDB	41.9	-40.0
k7	Border Rivers Gwydir	NMDB	128.7	-49.0
k8	Western	NMDB	95.5	-6.0
k9	Lachlan	Unconnected	123.3	-48.0
k10	Murrumbidgee	Southern NSW	0.0	-320.0
k11	North East	Southern VIC	0.0	-32.9
k12	Murray 1	Southern NSW	0.1	-7.9
k13	Goulburn Broken	Southern VIC	32.3	-369.3
k14	Murray 2	Southern NSW	1.3	-131.0
k15	North Central	Southern VIC	0.0	-194.5
k16	Murray 3	Southern NSW	1.1	-117.9
k17	Mallee	Southern VIC	142.7	-30.4
k18	Lower Murray Darling	Southern NSW	0.1	-13.2
k19	SA MDB	Southern SA	111.3	-101.0
		TOTAL	**929.2**	**-1,613.0**
	Further Reduction of Surface water by Trading Zones			
	Northern			-143.0
	Southern NSW			-462.9
	Southern VIC			-425.3
	Southern SA			-82.8
	Southern All			-450.0
	Reduction in the Trading Zones			-1,564.0
	TOTAL Surface Water Reductions*			**-3,194.0**
	TOTAL Net Change (Ground + Surface)			**-2,265.0**

has also encouraged different irrigated agriculture producers to develop across the two basins.

The NMDB has developed opportunistic agricultural production comprised of annual crops produced only when water is available (e.g., cotton). Alternatively, SMDB agricultural production includes both annual and perennial cropping systems (e.g., almonds); where perennial producers often own surface water rights with high reliability that receive 95-100% of their full water allocation annually. Other surface water rights include general reliability (receive ~30% of their allocation on average), and supplementary/low reliability rights (receive water during river pulse flow events derived from high rainfall/flooding).

A threat to the future reliability characteristics of water supply in the MDB is climate change which is expected to reduce surface water runoff (Chiew *et al.*, 2008). Like many river basins globally, water rights in the MDB have also been over-allocated, reducing the reliability and value of water resources for all users, and resulting in net welfare losses where environmental assets are impacted (i.e. negative externalities). For example, a lack of surface flows may result in black-water events from deoxygenated water, increased salinity, blue-green algal outbreaks and soil acidification—where any one of these events will reduce species diversity, river system connectivity and morphology, and/or loss of key riverine habitat. In 2007 the Australian federal government sought to address all of these issues with the introduction of a Water Act (Commonwealth of Australia, 2008). The Water Act was created to ensure a single planning mechanism for the MDB focused on establishing, and achieving, sustainable levels of extraction.

In 2012, the Murray-Darling Basin Plan (MDB Plan) was enacted and regulators estimated that between 2,750-3,200 GL of surface water would need to be recovered from irrigators and transferred to an environmental manger to achieve a sustainable diversion limit (SDL) going forward (MDBA, 2012). An SDL is a reduction in the total volume of water that was originally extracted for irrigated agriculture (i.e., the current diversion limit or CDL which sets a baseline for reduction assessments), with that reduction transferring to environmental uses. That is, the total volume of extraction does not lower, but the proportion of use between users is altered such that sustainable objectives can be achieved.

To achieve that water reduction, over AU$13 billion was allocated across two main programs. The first (Restoring the Balance) focused on buying back rights from willing sellers while the second (Sustainable Rural Water Use Infrastructure Program) invested in water efficient technology savings. Any water recovered under either of these programs enables actual resources to be transferred to an environment manager for national welfare gains (Adamson & Loch, 2018). These programs are well documented elsewhere (Mallawaarachchi *et al.*, 2020).

“Any increase in access to groundwater resources must stem from a belief they represent a highly reliable resource”

However, what is less known about the MDB Plan is that an additional 927 GL of groundwater reserves above previous extraction limits were released for agricultural use. Around 45% of these new groundwater resources are located in the NMDB (see Table 6-1), with an additional 13% in the Lachlan catchment—which for the purposes of this chapter we will consider part of the NMDB. Table 6-1 highlights the MDB Plan’s proposed net changes in water by all 19 catchments in the MDB (see section 3.2). As shown, these catchments are also categorized into NMDB, the unconnected Lachlan catchment, and SMDB catchments across the three state jurisdictions (called Trading Zones in Table 6-1, and where refer to individual catchments within the MDB across New South Wales (NSW), Victoria (VIC) and South Australia (SA)). Also provided is the additional surface water that needs to be recovered by trading region to achieve a net reduction of 3,194 GL in surface water.

Given the MDB Plan was created to achieve sustainable extractions under an expectation of highly variable water resources in future due to climate change impacts, we argue that any increase in access to groundwater resources must stem from a belief they represent a highly reliable resource. We base this on the counter-factual that, under any adoption of a precautionary principle approach, water regulators would not release these resources if there was any doubt as to their reliability both now and into the future. If we accept the assumption that groundwater is perceived by regulators in the MDB—and water users in agriculture—as a highly reliable resource, what might this mean for agricultural production and management transformation across the Basin? Further, what changes might we see in the value of surface and groundwater resources as climate change impacts increase, how could the risk profile surrounding cropping patterns change, and what also might this mean for future water resource management? To answer these questions, we first extend the discussion on groundwater and resource reliability. Next, the methodology and model used to explore these issues are presented. Finally, the results from the analysis are discussed before concluding comments are made.

02
Water Supply in the MDB

2.1. Overview of Resources

Prior to the MDB Plan, total average annual conjunctive water supply in the MDB was believed to be 26,418 GL. Runoff from rainfall is the largest contributor accounting for 22,925 GL (Mallawaarachchi *et al.*, 2010). Groundwater extractions account for 2,373 GL (MDBA, 2012) and 1,118 GL of water is transferred into the MDB from the Snowy River Hydro Scheme as shown in Figure 6-1 (Murray-Darling Basin Commission, 2006). In any given year, if supply exists, approximately 15,716 GL of water (13,344 GL of surface water and 2,372 GL of groundwater) can be allocated to irrigation/environmental users and for essential human water use (e.g., 206 GL for The City of Adelaide) in the MDB (Adamson *et al.*, 2011).

Table 6-2 CDL Entitlements by Catchment (K)

k	Entitlement Security (GL)				Total
	Ground	High	General	Supplementary	
k1	132			1,398	1,530
k2	24			587	611
k3	2			125	127
k4	224	5	286	255	770
k5	99	18	632	143	892
k6	88			932	1,020
k7	108	16	773	375	1,272
k8	79			196	275
k9	393	31	615	68	1,107
k10	355	377	1,888	697	3,317
k11	0	196	79	61	336
k12	6	6	50	20	82
k13	486	1,221	706	139	2,552
k14	96	96	834	334	1,360
k15	0	913	432	161	1,506
k16	87	86	750	301	1,224
k17	70	156	73	12	311
k18	4	11	111	275	401
k19	120	449	0	0	569
Total	**2,373**	**3,582**	**7,230**	**6,081**	**19,266**

However, due to its variability, the use of average numbers provides misleading estimations of water supply reliability in the MDB. Water resources in the MDB are allocated from the surface water storages (Young & McColl, 2009), and the classification of surface water rights into three classes (high, general and supplementary) means that water is only allocated when it is available. See Table 6-2 which shows where the three surface rights and one groundwater right are located.

As evident in Figure 6-2, surface water diversions from river systems for agricultural production have ranged from around 10,000 GL to only 3,000 GL in 2007-08 during the Millennium Drought; which occurred between 2001 and 2010 (Heberger, 2011). Demand for greater water withdrawal in the MDB is always present though, and under an expectation that climate change is expected to reduce future reliability of water, any additional access to reliable groundwater will provide opportunities for all advantaged users (e.g., urban and environmental users). However, for simplicity in this chapter we assume that all water is only used by irrigators for agricultural production.

2.2. Groundwater Resources

Groundwater reserves have the capacity to mitigate water supply variability due to the spatial disaggregation between recharge area and consumption (Kirby *et al.*, 2014). Provided that aquifers are managed carefully, groundwater is considered a renewable resource (Crosbie *et al.*, 2008; Loáiciga, 2003). However, unsuitable consumption will compromise the aquifer structure reducing its ability to recharge (Brunke & Gonser, 1997), the volume that can be stored (Scanlon *et al*., 2012), and water quality can also be degraded (Knapp & Baerenklau, 2006).

Irrigators in the NMDB access groundwater from the Great Artesian Basin (GAB), whose recharge zone includes the Gulf of Carpentaria in northern Queensland (Smerdon *et al.*, 2012). The NMDB is thus largely comprised of fractured or fissured aquifers of low to moderate productivity. The SMDB enjoys relatively higher productivity aquifers as shown in Figure 6-3.

In general, groundwater quality in the MDB is mixed but total resource suitability for irrigation is generally considered to be

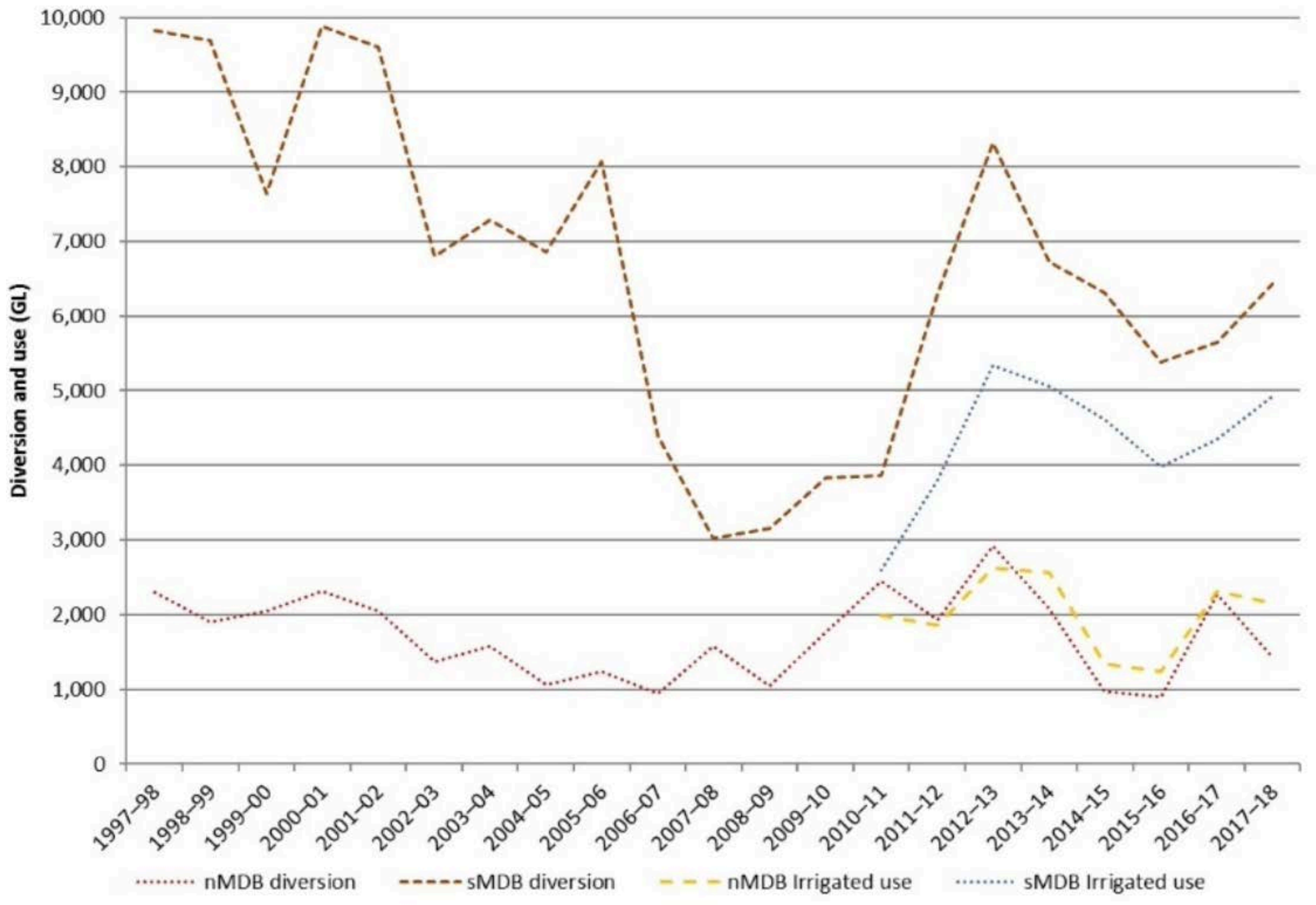

Figure 6-2 *Annual Diversions and Water use on Farm (Source: Authors' own based on MDBA 2019b and ABS 2018)*

good (MDBC, 1999). However, groundwater in the SMDB can be highly saline (Smitt *et al.*, 2002) making it less attractive for irrigated agriculture. To deal with SMDB salinity, and the salinity mobilized from overirrigation, Salinity Interception Schemes (SIS) have been developed to extract highly saline water before it enters the river system (Telfer *et al.*, 2012), but such systems are not needed in the NMDB. For this analysis we therefore assume that groundwater resources are of suitable quality in the NMDB to produce any agricultural commodity. This is important, as we are interested here in the transformation of irrigated agriculture production and management choices as a consequence of being able to access reliable resources in the face of future supply uncertainty (i.e., where extensive water storage and other infrastructure is not available).

2.3. Groundwater Use and the Murray-Darling Basin Plan

Groundwater use in the MDB is conservative compared to both the old baseline current diversion limit (CDL) and the new sustainable diversion limit (SDL) (see Figure 6-4). While groundwater use has been increasing since 2012-13 to 2017-18 due to increasing drought conditions, it is still far less than can theoretically be extracted (i.e., the SDL level as indicated). However, the value of groundwater for all users will increase during drought, and dependency on groundwater reserves in the MDB is expected to increase as the severity and frequency of droughts increase under future change climate (MDBA, 2019a).

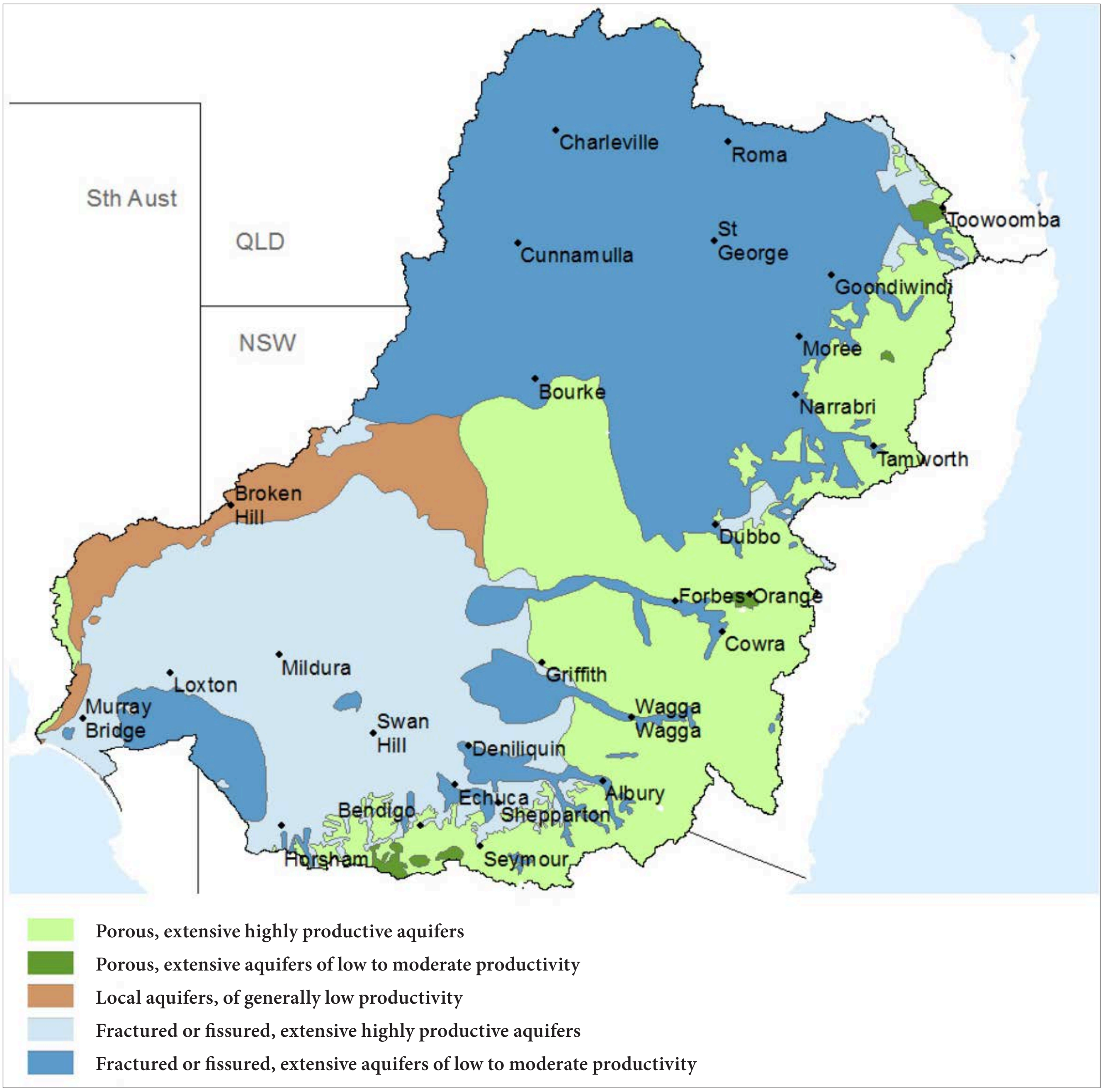

Figure 6-3 Groundwater Resources (Source: Author's own GIS mapping)

However, ultimately groundwater extraction may remain lower than the SDL for two reasons. First it may cost more to access groundwater than surface water depending on the conditions in place. Second the water resource plans that need to be developed by state governments to bring the new SDL extractions into law may be incomplete (MDBA, 2019a). As of December 2020 many of the 19 state-based plans for groundwater use submitted to the Murray–Darling Basin Authority (MDBA) who manage the Basin as an entity were still under review (MDBA, 2020b). This is a complex process. MDBA reports (2019a, 2020b) detail the complexity involved which includes how water is to be used to provide economic, cultural, social and environmental gains; the connectivity between surface and groundwater resources; the integrity of the aquifer and its hydrological relationships; and the risk posed to the groundwater system from over extraction. State governments have subsequently been monitoring and evaluating these resources to ensure that any new extractions do not pose a long-term risk to the system. Many users may be waiting for greater certainty before committing significant capital to groundwater extraction and use.

However, we anticipate that, once resources can be accessed, groundwater consumption will increase as the future becomes drier and hotter. In anticipation of this increased resource use, scientific debate has centered around alternative methodologies for quantifying and monitoring available groundwater resources (e.g. Chen *et al.*, 2016a; Chen *et al.* 2016b). Other work has focused on the current and future reliability of the resource (Schumacher *et al.*, 2018), the quality of the resource (Hart *et al.*, 2020), the connectivity of groundwater resources (Lamontagne *et al.*, 2014); and the role of groundwater in conjunctive water management (Ticehurst & Curtis, 2019). However, little to no economic analysis has been conducted on how access to more groundwater under a changing climate will change the value of that resource over time. The few examples which do exist include an MDBA commissioned work on the groundwater SDL which failed to quantify the economic benefits from higher access to groundwater (Deloitte Access Economics, 2015), and another study which only assessed the value of current groundwater in markets for a single catchment (de Bonviller *et al.*, 2020). Our chapter aims to address this deficiency in the literature.

Figure 6-4 *Groundwater Use in the MDB (Source: MDBA, 2019b)*

2.4. Summary

Surface water supply in the MDB is highly variable, and in the absence of storage systems to help mitigate that variability in the NMDB, increased access to reliable sources of groundwater has the capacity to positively transform agricultural production and management systems in economic and social terms—and environmentally if groundwater is used to achieve ecological objectives (e.g., wetland inundation). As climate change is anticipated to increase the severity and longevity of droughts, we seek to explore the value groundwater may have for agricultural producers. To understand how the value of highly reliable groundwater changes in response to droughts and floods we also need to deal with risk and uncertainty. For that we turn to the state-contingent approach, as discussed in the next section.

> *"The economic value of groundwater is not constant, we have to understand how the price elasticity of water is altered by the state of nature and alternative production systems such as annual and perennial crops"*

03

Valuing Groundwater Resources under Uncertainty

3.1. Risk, Uncertainty and the Value of Water

Economics has two major approaches for dealing with uncertainty. The first approach, which is the dominant approach, utilizes mean and variance (e.g., stochastic functions) to explore inherent variability in systems. The second approach divides uncertainty into mutually exclusive alternative states of nature (e.g., drought, flood, normal) to represent the inherent variability in systems and to then explore how individuals respond to those states of nature. This is known as the State-Contingent Approach (SCA).

This difference is important as the first approach models a passive decision maker. In that case, once the event occurs, a decision maker continues on as before, failing to reallocate resources in response. This is akin to standing on a railway line and not stepping off the line when a train is approaching. Despite constant discussion about the limitations of this approach (Just & Pope, 1979; Rothschild & Stiglitz, 1971) it persists in the literature.

By contrast, a key feature of SCA is that it separates the uncertainty signal (i.e., in this case water supply uncertainty) from the producers' response to that realized uncertainty (Chambers & Quiggin, 2000) so that both may be examined. This distinction is important because the economic value of groundwater is not constant (de Bonviller *et al.*, 2020; MDBA, 2019a). Consequently, we have to understand how the price elasticity of water is altered by the state of nature and alternative production systems such as annual and perennial crops (Adamson *et al.*, 2017; Loch *et al.*, 2020a). A key driving force behind the value of water is the role it plays in each production system, and SCA helps us to explain this. Perennial production systems must always apply water in every state of nature to protect their capital base. The failure to irrigate can lead to crop death and expose the irrigators' investment to unacceptable levels of risk. Consequently, perennial producers have a strong incentive to outbid annual producers in water markets—particularly if supply is short. This threat to long run capital investments and the options available to producers is provided in more detail by Adamson and Loch (Accepted 26 May 2020).

While the above work helps illustrate perennial agricultural producer behavior and simulate any outcomes in response, it does not optimize total resource use within a basin. To do that, we expand an SCA model for the MDB originally developed by Adamson *et al.* (2007). This forms the basis of our analysis.

3.2. An Overview of the Optimization Model

Reallocating water within a closed basin like the MDB is a complex issue. We have to understand the drivers of change (water supply, social, economic, environmental), the policy instruments and incentives that are used to drive the transformation, and how risk and uncertainty alter the drivers and behavioral responses to that uncertainty signal (Gómez Gómez *et al.*, 2018).

Building on past work (e.g. Adamson *et al.*, 2007; Adamson *et al.*, 2009; Quiggin *et al.*, 2010), Adamson (2015) transformed the SCA MDB optimization model into one that explored net welfare changes from implementation of the MDB Plan. Detailed methodological notes, all data sets and assumptions underpinning the model can be found in Adamson (2015). The following material summarizes the model and the adaption required for this analysis

3.2.1. Introduction to the Model

The model was built to explore what value SCA (Chambers & Quiggin, 2000) has in allocating water resources under uncertainty. The model was subsequently used to provide input into The Garnaut Climate Change Review which was a critical report for Australia that examined the impacts of climate change on the Australian economy, the costs of adaptation and mitigation, and the international context in which climate change is experienced and negotiated (Quiggin *et al.*, 2008), the MDB Plan (Adamson *et al.*, 2011; Mallawaarachchi *et al.*, 2010), and a number of journal chapters already listed.

“We have to understand the drivers of change, the policy instruments and incentives that are used to drive the transformation, and how risk and uncertainty alter the drivers and behavioral responses to that uncertainty signal”

In simple terms, the model utilizes the conjunctive water resource data presented in Section 2.1 to characterize water supply arrangements in a normal year. Based on this, a drought year will only provide 60% of that normal supply while wet years will supply 120%. The frequency of those states of nature (i.e., normal, drought and wet) have a probability of 50%, 20% and 30% respectively.

So defined, the model then utilizes a constrained optimization approach to allocate water at a catchment scale to maximize economic return from irrigation. It utilizes a directed flow structure (19 agricultural catchments, mandated demand from the City of Adelaide, and environmental flow requirements at the rivers' terminal node in the Coorong), salinity targets to replicate water quality, bio-physical reality and institutional setting constraints to replicate policy incentives. The model then helps understand the opportunity cost (economic return and changes to water quality) of using water across space (i.e., catchments) and time (three states of nature: dry, wet and normal, that occur with a given frequency).

The model is set up with a single individual as decision-maker with the capacity to play a game against nature by allocating irrigation resources across the 19 catchments to produce alternative commodities. As such it is forward looking and determines the optimal choice of production systems to maximize income. Finally, specific input and output sets for all states of nature highlight the production system requirements and outputs they generate. This way producer behavior can be modelled to reallocate resources between alternative SCA described production systems.

3.2.2. SCA Production Systems

Critical to the model is the representation of alternative production systems. Here care is needed to model how producers allocate inputs (land, water, variable costs, fixed costs and labor) between production choices by state of nature (i.e., normal, drought, wet year). Care is needed to reflect reality. If a producer engages in the choice to produce perennials, then that perennial crop must be present in all states of nature. Alternatively, an annual producer may choose to irrigate every year and/or be opportunistic in irrigation and only irrigate in one or two states of nature (i.e., normal and wet), while defaulting to a dryland or fallow crop in dry states of nature. This approach helps represent how decision makers alter their production systems in response to uncertainty where they can.

Critical to any analysis is the inclusion of all inputs listed in Table 6-1 above, which allows the model to deal with capital investments. Capital is treated as an annual fixed cost payment over a 20-year repayment period. This then allows for the economic return (i.e., farm income from alternative agricultural crop investments less total production costs) to be explored across all states of nature.

3.2.3. Water Use

Prior versions of the model allowed producers to grow production systems with either ground or surface water. However, to represent the net change in total water resources (decreased surface water and increased groundwater), the production systems were doubled so that output could come from either groundwater or surface water, but not both. While this may not be fully representative of realistic options, it provides clarity on the value of each water resource. To facilitate this analysis, a new set of inputs and outputs was also required to reflect changes in production costs. Note that for ease of analysis, the cost to purchase any new groundwater releases was not included.

The separation of water into ground and surface resources allowed two major advances. First the model can now explore the reliability of those rights by catchment, across time. For this analysis we assume all new water is always available due to the institutional rigor that is being applied in state water resource plans (as described above) to ensure that access is possible. Second the model can represent the change in the SDL from any existing entitlements (see Table 6-1). Our ability to utilize the directed flow network and trading rules listed in Table 6-1 allowed the SDL to be obtained at least cost to production. This then incorporates the institutional objectives of the MDB Plan.

3.2.4. Incorporating Climate Change into the Model

Perhaps one of the greatest contributions to water economics by this model was achieved in Adamson *et al*. (2009). Here, the capacity for SCA to describe what happens by state of nature (to water supply), and the frequency with which each state occurs, allows climate change to be more accurately represented and modeled. Consequently, the way water supply changes can be described for each state of nature (e.g., more severe droughts) and the frequency with which each state occurs (e.g., increased drought events). This description allows for an exploration of the impacts i) that changes in water supply have by a mean reduction in water supply (i.e., proportional change of agricultural production in each state), ii) when water supply by states do not change but the frequency of each state does, or iii) from a combination of both. Thus, we can predict that a new and reliable source of groundwater will increase production choices and be more valuable in the future.

The combination of a water flow network (i.e., a representation of the river system), biophysical limits (i.e., water volumes, salinity and choke points that constrain delivery) and institutional objectives (i.e., flow targets to the Coorong), then help restrict water use under a changing climate, even if the existing reliability of rights are not altered—where alteration of water right reliability is not possible within the Australian system.

Our analysis thus explores climate change in two ways. First the expected change in water supply out to 2050 and 2100 have been explored based on new climate change scenarios where CO_2 emissions stabilize at 450 parts-per-million (ppm) (Quiggin *et al*., 2008). The model produces results for combinations of atmospheric CO_2 concentrations and year, such as 450 ppm and 2050, and this data has been used to align with other studies (e.g., the Garnaut Review). The reduction in normal state surface water supply is assumed to be 10% and 20% for the year 2050 and 2100 respectively. Assumed supply under drought (i.e., 60% of normal) and wet states (i.e., 120% of normal) remain constant. These scenarios are described as “450 ppm, year 2050” and “450 ppm, year 2100”.

To model increasing drought states we change the probability of each of the states of nature occurring, where the new climate occurs with the following frequencies: normal (50%), drought (30%), and wet state (20%). Under these new state outcomes we leave the water supply descriptions as per the base model (i.e., the CDL scenario) and label this scenario as Drought states where it reports economic returns across all three states.

Ultimately, for all scenarios we assume that groundwater access does not reduce. As per the discussion above, the groundwater SDL should not have increased, since decisions to allow increased access were made in light of climate change expectations.

3.3. Summary

This has been a brief description of the model used and highlights the major changes that occurred to model the current and future value of groundwater. While Adamson (2015) includes a wider discussion on what happens to surface rights, this version extends the findings on the value of groundwater. The next section outlines the results of our analysis.

04

Welfare Changes from Increased Groundwater

4.1. Moving to the Sustainable Diversion Limits

In the model outputs the first noticeable thing is that, under the transition from the CDL to the new SDL, economic return (welfare) increases, while the total consumption of water reduces. Economic return in the model is the net return from producing an agricultural crop (e.g., cotton). However, while total water (surface and groundwater) use has reduced, augmented access to reliable groundwater transforms agricultural production and management systems to increase economic returns (Table 6-3). For the CDL, a total of 15,049 GL of surface and groundwater resources produced a total of $3 billion of economic returns in the NMDB ($241 million from groundwater use and $967 million from surface water) and

Table 6-3 *Economic Return (Welfare) Changes from the MDB Plan, by scenario*

		NMDB		SMDB		TOTAL
		GW	SW	GW	SW	
Welfare ($'m)	CDL	$241.3	$967.3	$399.3	$1,473.9	**$3,081.8**
	SDL	$340.2	$957.4	$636.3	$1,360.3	**$3,294.2**
	450ppm, year 2050	$390.4	$762.8	$645.6	$1,338.3	**$3,137.1**
	450ppm, year 2100	$413.4	$728.7	$645.6	$1,337.5	**$3,125.2**
	Drought States	$406.1	$820.2	$582.3	$1,020.8	$2,829.5
Water Used (ML)	CDL	1,149.4	3,899.1	1,223.3	8,777.0	15,048.7
	SDL	1,789.8	3,709.9	1,512.0	6,478.3	13,490.1
	450, 2050	1,789.9	3,083.4	1,512.0	6,480.5	12,865.8
	450, 2100	1,789.9	3,044.7	1,512.0	6,480.5	12,827.1
	Drought States	1,789.9	3,563.8	1,512.0	6,488.0	13,353.7

Table 6-4 *Area irrigated (1,000 Ha)*

	NMDB		SMDB		TOTAL
	GW	SW	GW	SW	
CDL	254	1,151	221	1,079	**2,705**
SDL	408	1,100	247	817	**2,571**
450, 2050	477	845	243	760	**2,326**
450, 2100	481	829	243	761	**2,313**
Drought States	377	1,052	234	555	**2,218**

SMDB ($399 million from groundwater use and $1,474 million from surface water use). By contrast, under the SDL a total of 13,490GL of water use produces $3.3 billion in economic returns following the transformation. This arises from new NMDB ($340 million from groundwater, and $957 million from surface water) and SMDB production and management systems ($636 million from groundwater and $1,360 million from surface water).

The change in land use by scenario is presented in Table 6-4 and Figure 6-5. We can see from Figure 6-5 that access to extra groundwater allows for an increase of over 150,000 hectares (Ha) of land (CDL versus SDL) in the NMDB. While there is a slight increase in perennial area, most land is utilized to produce cotton and grains. At the same time, we see an increase in the SMDB area irrigated by groundwater (6,000 Ha). The reason why economic returns are so great in the SMDB as a consequence of increased groundwater use (i.e., $636 million under the SDL versus $399 million under the CDL) is that there is a reallocation of land towards higher-valued perennials (increase of over 40,000 Ha) from the increased access to reliable water.

A frequent observation for Australia is that land is not a binding constraint; only water. In the NMDB, the development of an additional 150,000 Ha of land irrigated in all states (i.e., perennial cropping supported by groundwater resources) will create second round benefits that may help negate the drought shocks that occur in regional communities—although at the expense of increased capital exposure risk in the face of uncertain future climate outcomes. Logically as access to surface water reduces, the dairy industry is the biggest looser with over 200,000 Ha of land removed. However, the recent Millennium drought highlighted the ability for dairy producers to adapt a SCA production mentality as they were able sell water and purchase fodder to continue production (Mallawaarachchi *et al.*, 2017).

> *"The recent Millennium drought highlighted the ability for dairy producers to adapt a SCA production mentality as they were able sell water and purchase fodder to continue production"*

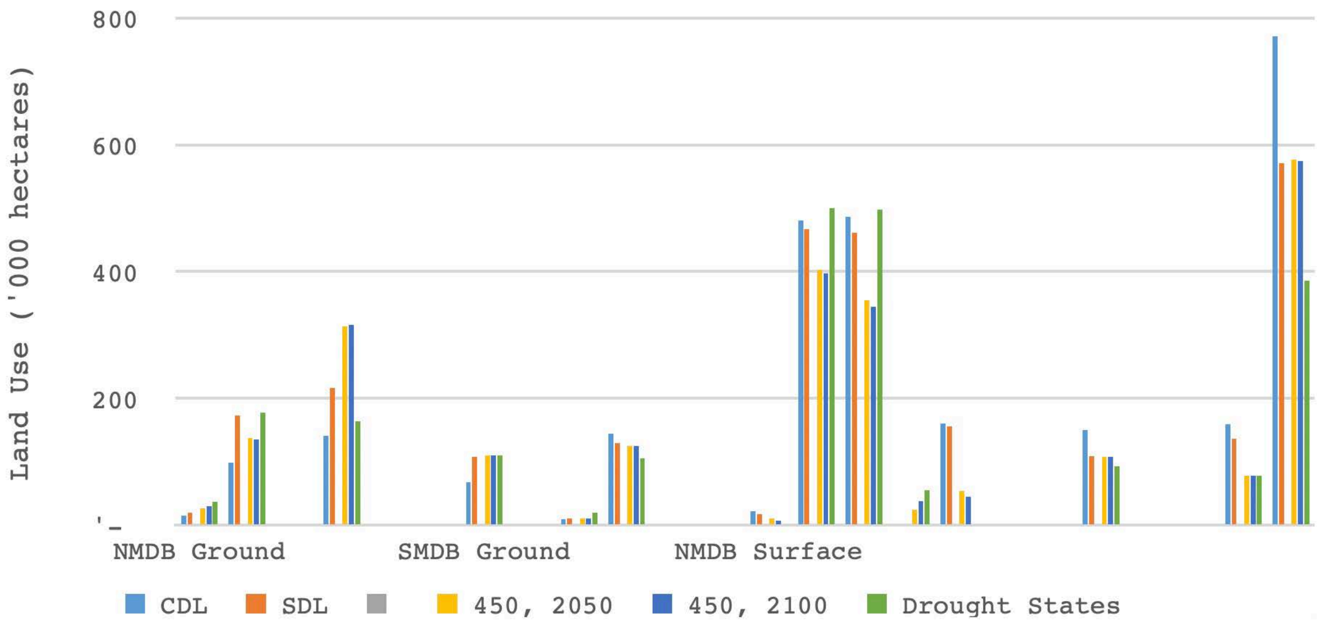

Figure 6-5 *Land Use Production Systems by Scenario, Location and Water Source*

4.2. Climate Change Impacts on Welfare

The two climate change impacts: 450;2050 and 450;2100 and increased drought states highlight the benefits of highly reliable groundwater under a changing climate. The economic return from groundwater continues to increase as water becomes scarcer (Table 6-5). For both 450 ppm scenarios, extra groundwater offsets reductions in surface water despite a total reduction in water supply between 10% and 20%. However, if droughts become more frequent, the extra groundwater may not offset the total loss of surface water via a changing climate.

We can see the impact that increased droughts have on production in Figure 6-5 where in the NDMB all surface water basically is used to grow cotton (i.e., in normal and wet years only) and Opportunistic Cotton (Opp Cotton) that is only grown in wet years. Again, the dairy industry loses approximately another 200,000 Ha of production seriously threatening its future viability. While this may be seen as unrealistic in countries where government intervention is the norm, Australian farmers are largely left to make their own investment decisions as food security is not a concern.

The converse is true for surface water where a reduction in total supply reallocates water towards high returns (e.g., in the SMDB away from dairy). However, the influence of climate change is reflected by increased economic returns per ML for groundwater. This is most notable in the SMDB where economic returns increase by over 30% from increased groundwater access (CDL versus the 450 scenarios). Under these access improvements, groundwater becomes akin to gold; that is, compared to highly variable surface water rights, groundwater provides more certainty and economic value. Finally, while not as evident in the SMDB, the economic returns from surface water decrease. Any reduction in economic returns from surface water in the NMDB is likely due to the absence of large capital infrastructure to help mitigate supply variability.

Therefore, as the economic returns from water use diverge between surface water and groundwater, the implementation of the MDB Plan will create wealth for owners—or gifted recipients—of groundwater property rights. As these new groundwater rights become available it will be interesting to see how they transition into private hands as a result of that increased value.

4.3. Value of Groundwater Under a Changing Climate

The economic return from the alternative water sources is also shown in Table 6-5. Here we see basic economics working; that is, how scarcity and reliability alter economic return. Initially the increased supply of groundwater devalues the return that can be made by access to increased groundwater and transformations under the shift from CDL to SDL in the NMDB. In the SMDB, increased groundwater allows new greenfield sites to emerge and for the production of more annual crops. As the SMDB already has extensive investments in support infrastructure (e.g., packing sheds, transportation hubs, proximity to markets, labour supplies etc.) an increase in perennial production systems is both logical and straightforward.

4.4. Summary

The MDB Plan has the capacity to create wealth by increasing the overall reliability of total conjunctive water supplies. However, the gains are not uniform by catchment nor between the SMDB and the NMDB. This wealth gain may offset come losses associated with climate change (admittedly the scenario here is very optimistic as it now appears that the world hopes to stop at around 550 ppm). And as the reliability of surface water deteriorates, surface water rights will continue to be worth less and less, but highly reliable rights (surface or groundwater) will appreciate.

Table 6-5 Economic Return by Water Supply ($/ML)

	NMDB		SMDB	
	GW	SW	GW	SW
CDL	$210	$222	$326	$168
SDL	$190	$244	$421	$225
450, 2050	$218	$194	$427	$222
450, 2100	$231	$186	$427	$222
Drought States	$227	$209	$385	$222

05

Concluding Comments

While water infrastructure (dams, channels) is often promoted as a prime mechanism for drought-proofing a nation, the reality is we cannot make it rain and existing/new water infrastructure may prove to be in the wrong place if rainfall patterns alter under climate change. Additionally, there are very few places left in the MDB that are suitable for developing new dams (Loch *et al.*, 2020b).

Groundwater aquifers thus provide several advantages for future water resource and irrigation opportunities to help offset the effects of climate change. First, these resources require minimal costs to develop when compared to large scale dams and distribution networks. Second, they allow greater opportunities for greenfield sites that are not constrained by the existing engineering infrastructure yet to be developed.

However, this natural capital (aquifer system) must be maintained and preserved via sustainable use. As discussed in Section 2.3, current scientific evidence suggests the groundwater SDL will in fact be sustainable. As climate change realities set in, access to a highly reliable and sustainable source of groundwater will provide golden (consistent income) returns for its owners and those who by association provide production inputs. Therefore, we expect significant future pressure to increase groundwater extractions. If this occurs, we may simply be creating another legacy for future generations to deal with where we degrade the natural capital (i.e., the storage system, the volume stored and its quality).

“Any new groundwater resources will need a process of careful allocation, constant monitoring and periodic evaluation for sustainability”

Therefore, perhaps the best way forward is to adopt a precautionary approach where the amount utilized is less than what is suggested as sustainable until the future has been revealed. To be truly sustainable, understanding the risk to future supply, the risks to the reliability of water percolation back into groundwater, and the risks to aquifer integrity from over consumption must be understood. This may involve regulatory restrictions on the development of new perennial production sites, but in our view that is unlikely in the current political climate. Further, while increased access to groundwater provides the capacity for the development of an expanded perennial industry, other considerations such as access to transport, markets, labor and the large-scale capital investment (packing sheds, refrigeration equipment, etc.) may be equally important as the access to water. This is especially true for Australia where food security is not a priority, and approximately 70% of agricultural product is exported to close neighbors (e.g., SE Asian countries).

As we have shown, in the short run, access to reliable groundwater may make it more likely that irrigators will transition to perennial commodities in the NMDB; particularly if export returns are high as explained above. Profitable commodities (e.g., almonds) will require capital systems to change—which in turn may increase both community viability and capital risk. Only time will tell. In the SMDB where the associated capital already exists, agricultural producers are far more likely to also transition toward greenfield perennial systems under any capacity to access and utilize secure reliable groundwater.

Regardless of the industry that develops (including non-agricultural sectors such as mining) access to more highly reliable groundwater provides economic growth for a region in all states of nature. To maximize net social welfare, including capacity to address positive externalities for environmental right holders who can have improved access to (previously) constrained rights, reallocation should occur through the existing market infrastructure—that admittedly is unique to Australia. Australia has a highly developed water market system that has the capacity to achieve such resource reallocation objectives. (de Bonviller *et al.*, 2020; Gómez Gómez *et al.*, 2018). The rights should also be sold off slowly, over time, to maximize the income from sales and our capacity to halt sales if new information concerning their reliability is revealed. This may help negate the current impact of droughts where shocks to agricultural income place a break on regional economic activity (PC, 2009). It must also be said that it is equally possible that, depending on the structure of rights held by an individual irrigator, groundwater resources may not be utilized due to cost differences in using surface water.

As stated above, government reports on groundwater resources, SDL constraints and utilisation are still largely being finalized and delivered. As such, this analysis is a timely exploration of the economic value of groundwater. However, our analysis does not explore the future reliability of groundwater with respect to recharge rates, depletion, and/or aquifer stability—that is the domain of scientific investigations. Whatever happens, any new groundwater resources will need a process of careful allocation, constant monitoring and periodic evaluation for sustainability.

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