Feasibility assessment of managed aquifer recharge for cotton irrigation in the Murrumbidgee

Milestone 4.1 report for *Feasibility study of manager aquifer recharge for improved water productivity for Australian cotton production*

CRDC project ANU1901 (26 November 2020)

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NOTE: This case study technical report scopes the feasibility of managed aquifer recharge in the Coleambally Irrigation Area of Operations (CIAO). The intended outcomes are to increase knowledge for industry stakeholders around how MAR in the region might be designed to provide benefit to irrigators and their local community, and to provide recommendations on next steps towards implementing MAR. Feasibility is considered based on the level of demand for more irrigation water, the availability of suitable water to bank, recharge and aquifer characteristics, the circumstances under which MAR is financially viable, potential environmental gains and risks, the level of social acceptability of the scheme, and the institutional settings which might enable or constrain MAR in practice in the case study area. Three potential MAR scenarios and, for comparison, three alternate surface water management options are identified and evaluated against seven feasibility assessment criteria. These scenarios demonstrate that MAR should be investigated further as part of conjunctive surface water and groundwater management in the region. It is important to note that these scenarios do not constitute endorsement from either the Coleambally Irrigation Cooperative Limited (CICL) or the CRDC for a particular course of action. While every effort has been made to ensure the accuracy and completeness of this report, no guarantee is given nor responsibility taken by the Australian National University (ANU) for errors or omissions and the ANU does not accept responsibility in respect of any information or advice given in relation to or as a consequent of anything contained herein.

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Executive summary

Background

The project *'Feasibility study of managed aquifer recharge* [MAR] *for improved water productivity for Australian cotton production'* is investigating the potential to implement MAR at a regional scale in key irrigated cotton growing regions of Australia.

The first focus region was the Murrumbidgee River system, with particular focus on Coleambally Irrigation Area of Operations (CIAO). This case study aimed to evaluate whether MAR could be feasible for irrigated cotton production in the Murrumbidgee region, and if so, make recommendations on further work to evaluate local hydrogeological conditions, plan the necessary site-specific infrastructure, and establish the legal, social and organisational conditions for its implementation.

The broad approach taken was to draw on evidence from a holistic feasibility assessment to scope the most promising opportunities ("scenarios") for MAR, and to test and refine these scenarios with the local stakeholder working group.

Opportunities for MAR in the Coleambally Irrigation Area

Three MAR scenarios identified and evaluated in the case study highlight promising opportunities for MAR in the region. These were compared and contrasted with alternative scenarios without a MAR component. These scenarios are illustrative in nature; enacting any of the components of a scenario will need further investigation and any required approvals from CICL members and relevant authorities.

Don't miss a drop

This scenario focuses on the capture and banking of water during wet periods. For example, the main channel for the delivery of irrigation water has the theoretical capacity to take in supplementary entitlements already owned by CICL members even within a single supplementary event. Over time, investment in infrastructure (e.g. settling ponds, infiltrations basins, wells) and operational capabilities would gradually increase the current capture and storage capacity in the system. Initial use of Coleambally Irrigation Cooperative Limited (CICL) own water licence as part of a MAR pilot project would mean that the co-operative can implement measures to retain control over how water is distributed, managing risks as part of their existing operations and transparently considering and addressing potential equity issues as they arise.

An alternative method without MAR for capturing supplementary water is the scenario of *Multi-year surface storages* which is analogous to the substantial investment in dams being made by large private companies along the Murrumbidgee River. MAR can provide a gradual pathway for a broader community of irrigators to access a similar capability without a large initial capital outlay.

Storing water for community sustainability

Even without additional (e.g. supplementary) water, a MAR scheme could still be operated entirely with existing CICL water entitlements with the objective of storing and recovering sufficient water to ensure a minimum level of water security in drought or dry years. Implementation of MAR in this scenario is conditional on a clear understanding of community objectives, agreement on a trial water distribution policy, and clarity over who bears the cost of MAR scheme development in light of the anticipated benefits. Active management of water for community sustainability by CICL and other irrigation companies is a radical change that would likely require long term societal and regulatory change, including involvement of the wider irrigation community across the Murray Darling Basin.

Alternative methods without MAR for providing water for community sustainability are the *Community sustainability through high security entitlements* and *Survival water for drought through policy change* scenarios. The former effectively ties water back to land to prioritise community outcomes over gross financial value. The idea of providing survival water in drought times particularly relates to changes in the use of environmental water, a suggestion that has been raised in the political sphere. Both alternative scenarios are provided for comparison against MAR options rather than as an endorsement.

Integrated groundwater and surface water delivery

This scenario reconceptualises the role of the CICL as a custodian and active manager of both surface and groundwater for the CIA, whereby the CICL play a more active role in assisting members in planning and coordinating their groundwater pumping and surface delivery, and addressing concerns related to pumping rates, pumping costs, and water quality. Albeit without a MAR component, the CICL and Murrumbidgee Irrigation (MI) are already using both surface and groundwater, and to some extent monitoring both resources, so this option was of most interest to the Murrumbidgee stakeholder group. MAR would be deployed as one of several strategies to manage groundwater levels and pressure to maximise water availability and achieve business, social and environmental outcomes over the long term. Key to this scenario is a focus on building capacity to monitor and control groundwater levels and groundwater use, in both the shallow and deep aquifers, as a precursor to MAR use.

Recommendations

MAR has the potential to increase the in-house water storage capability of irrigation companies and regions. Proceeding with a MAR pilot in the CICL AO would be worthwhile, especially if it could be supported within the context of a research project designed to support MAR policy development. Irrigation companies, in collaboration with NSW DPIE and WaterNSW, would have an important role to play in the development of water management in this space. Core recommendations for both the CICL and CRDC are given below.

Recommendations for CICL

1. Develop low cost pilot projects for MAR using existing infrastructure to improve understanding and form partnerships for scaling up

2. Establish credible socio-economic monitoring, reporting and planning systems to inform the management of water in dry years to support long term sustainability of the co-operative and community

3. Integrate near real-time monitoring of groundwater pumping into channel operation planning, and integrate groundwater head monitoring into water availability assessments, to better understand the role of groundwater availability (which can be augmented by MAR) in irrigation water delivery

Recommendations for CRDC

1. Provide support for:

(a) site-specific feasibility assessments and site planning for MAR,

(b) coordination between cotton growers in irrigation areas to achieve critical mass to make investment in MAR viable, in collaboration with other agricultural R&D organisations

(c) engage with state government and the MDBA to ensure MAR policy that meets grower needs

2. Invest in development of socio-economic monitoring programmes, frameworks and/or guidelines to identify region-specific minimum water requirements needed to ensure sustainable local cotton supply chains and communities

3) Encourage monitoring and reporting of groundwater and surface water use for cotton irrigation alone, and changes in local groundwater head, to support research and development regarding use of groundwater as a complementary resource, the management of which can benefit from MAR.

Acronyms and Organisations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCC	Australian Competition and Consumer Commission
ACT	Australian Capital Territory
AIP	Aquifer Interference Policy
ANU	Australian National University
AO	Area of Operations
ASR	Aquifer Storage and Recovery
ASTR	Aquifer Storage Treatment and Recovery
AWD	Available Water Determination
BRS	Bureau of Rural Sciences
CEWH	Commonwealth Environmental Water Holder
CEWO	Commonwealth Environmental Water Office
CIAO	Coleambally Irrigation Area of Operations
CICL	Coleambally Irrigation Co-operative Limited
CMA	Catchment Management Authority
CRDC	Cotton Research and Development Corporation
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	Direct Current
DEWNR	Department for Environment, Water and Natural Resources
DPI	Department of Primary Industries
DPIE	Department of Planning, Industry and Environment
EM	Electromagnetic
EPA	Environment Protection Authority
EPHC	Environment Protection Heritage Council
GDE	Groundwater Dependent Ecosystems
GL	Gigalitre
GMA	Groundwater Management Area
GPS	Global Positioning System
GPWUI	Gross Production Water Use Index
IAH	International Association of Hydrogeologists

IAHS	International Association of Hydrological Sciences
IREC	Irrigation Research and Extension Committee
IWUI	Irrigation Water Use Index
LWMP	Land and Water Management Plan
MAR	Managed Aquifer Recharge
MARRO	Managed Aquifer Recharge and Recycling Options
MDB	Murray Darling Basin
MDBA	Murray Darling Basin Authority
MIA	Murrumbidgee Irrigation Area
ML	Megalitre
NHMRC	National Health Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
NSW	New South Wales
PWA	Prescribed Wells Area
QLD	Queensland
SA	South Australia
SDL	Sustainable Diversion Limits
TCC	Total Channel Control
TEM	Time-domain Electromagnetic
TSS	Total Suspended Solids
USA	United States of America
WA	Western Australia
WSP	Water Sharing Plan

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1. Introduction

1.1 The Australian cotton industry

Cotton production is an important industry in Australia's agricultural and rural landscape. Most cotton is grown in south-east Australia with established regions from Emerald in north Queensland, down to Griffith in southern NSW, with smaller and emerging regions across northern Australia in Western Australia, the Northern Territory and Queensland [1]. Most cotton (66%) is grown in NSW, and almost all cotton farms (90%) are family-owned and employ about 12,000 people. In the 2011-12 growing season, a record 583,000 ha of cotton was grown in Australia, with an estimated value of $3 billion, but a more typical value is $2 billion/year.

1.2 The implications of water reforms and climate variability on irrigated cotton production

Most cotton production (80%) is produced from irrigated systems. Historically, the Australian cotton industry was strongly criticised for its high water use, but now it is known as one of the most water efficient cotton industries in the world. Roth et al. (2014) report that from 2002 to 2012 the industry improved its water use efficiency by 40%, due to both increases in yields (from advances in plant breeding, adoption of genetically modified varieties and improved crop management practices) and more efficient use of water. The Australian Grown Cotton Sustainability Report 2014 (Cotton Australia, 2014) gives the following examples of farm management changes leading to this improved water use:

- 70% of farmers use soil moisture probes, up from 40 percent in 2006
- 96% of irrigators have improved their furrow irrigation system or changed to an alternate irrigation system
- 49% of irrigators had made changes to the flow or size of their siphons
- 35% have redesigned fields. For example, growers use laser-levelling to ensure uniform, well-drained fields using GPS guidance equipment and position storage dams closer to cotton fields to reduce evaporation losses
- Other practices include irrigating to deficits, using drip and overhead sprinkler systems, better accounting of soil variations, changed bed shapes, using irrigation scheduling probes, furrow irrigation system optimisation evaluations, pump optimisation and reducing distribution losses

Despite strong improvements in water use efficiency, irrigated cotton production varies considerably from year to year, strongly influenced by its reliance upon the availability of irrigation water (Figure 1; Cotton Australia, 2014). The value of cotton lint production closely matches the extent of irrigated crop production (Figure 2; Cotton Australia, 2014). With an increasingly uncertain future climate and the potential for further policy changes to water entitlements, water security has become a key limiting factor in the profitability of the industry.

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[1] https://cottonaustralia.com.au/industry-overview, accessed 13 March 2020

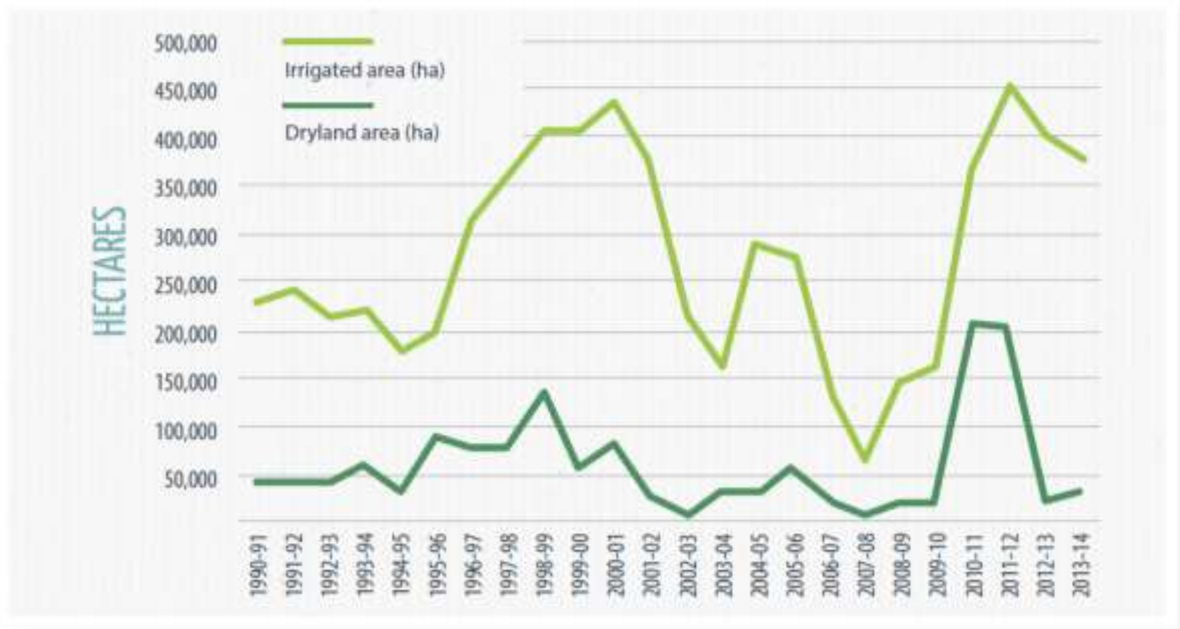

Figure 1 The area planted to irrigated and dryland cotton in Australia, 1990-2014 (Source: Figure 8 in Cotton Australia, 2014)

Figure 2 The gross value of cotton lint production, 1990-2014 (Source: Figure 15 in Cotton Australia, 2014)

Cotton Australia (2014) reported that about 15% of the water used for irrigated cotton production is sourced from groundwater, although in dry periods dependence upon groundwater resources increases. In this context, managed aquifer recharge (MAR) may be a strategy that could help irrigators manage their production risks in the face of future surface water scarcity.

1.3 A brief history of MAR schemes in Australia

MAR is the purposeful recharge of aquifers using surface water, which can be extracted when required. It has shown great potential to increase water security overseas, for example, in increasing options for water supply security in the USA, and interest in MAR is continuing to grow in Australia. MAR projects have been undertaken in Australia in some capacity since the 1960s (Dillon, 2009). The majority of the projects are based in South Australia (SA) and

Western Australia (WA), with the southeastern states having few systems (Dillon, 2009). Below is a brief overview of several MAR schemes operating in Australia.

Queensland's infiltration basin based MAR operation on the Burdekin Delta is Australia's longest running MAR project, which has for decades maintained groundwater levels in the area and prevented the intrusion of seawater (Dillon, 2009). Infiltration basins have also used been used in WA since the mid-1980s to recycle wastewater to be used to irrigate local playing fields and public spaces (Vanderzalm et al., 2015).

In SA, multiple areas inject stormwater into aquifers before recovery for irrigation and industry use (Barnett et al., 2000; Miotliński et al., 2014; Yuan et al., 2016). MAR sites around Adelaide at Andrews Farm, The Paddocks and Regent Gardens inject wetland treated stormwater into confined saline aquifers (Barnett et al., 2000). The recovered water quality is of reduced salinity compared to that of the native aquifer, but is not of potable standard, being used instead for irrigation (Barnett et al., 2000). Artificial wetland detention ponds are used as settling ponds to remove suspended solids and improve water quality before injection (Barnett et al., 2000). The Salisbury aquifer storage treatment and recovery (ASTR) MAR project uses spatially separated injection and recovery wells to 'treat' the water during residence in the aquifer (Miotliński et al., 2014; Yuan et al., 2016). Four injection wells inject stormwater during winter months, as this is when SA receives the majority of its rainfall, and recover it via two recovery wells during summer to be used for irrigation (Miotliński et al., 2014; Yuan et al., 2016). The stormwater injected at the Salisbury MAR site is also passed through constructed wetland settling basins to reduced total suspended solids, reducing clogging of the injection wells (Yuan et al., 2016).

The above examples show the success of well-planned MAR schemes in Australia. There is room to grow the presence of MAR projects throughout Australia to assist in increasing storage capacity, and therefore water security, in a way that is economically viable compared to traditional surface storages (Dillon, 2009; Khan et al., 2008a).

1.4 Feasibility study of managed aquifer recharge for improved water productivity for Australian cotton production

MAR systems offer an option to store surface water underground, therefore avoiding evaporative losses that can be experienced when storing water above ground. This 'banked' water supply can even out the peaks and troughs, leading to greater security and certainty in irrigated cropping. However, MAR systems can be expensive to implement and are also subject to technical and financial uncertainties such as aquifer recharge and recovery rates and costs. Therefore, there is a need for guidance as to when MAR might be a feasible option.

The *'Feasibility study of managed aquifer recharge for improved water productivity for Australian cotton production'* project was funded by the Cotton Research and Development Corporation (CRDC) to investigate the potential to utilise MAR at a regional scale in key irrigated cotton growing regions of Australia. More specifically, after several years of discussion about MAR in cotton regions, this research aims to investigate whether MAR shows potential as a more feasible option than the current or alternate surface water management options. If MAR does not show promise in relation to other options, then efforts should be directed to water management options that are more feasible or beneficial. In this project, the feasibility of MAR compared to existing water management systems is being investigated, using a case study approach, based on seven feasibility criteria of Ticehurst and Curtis (2017).

The case study regions proposed in consultation with the project steering committee were the Murrumbidgee region in southern NSW, the Namoi region in northern NSW and the Gilbert region in northern Queensland (Figure 3). The Murrumbidgee and Namoi regions were selected because, following group discussion around what was known about these systems across the criteria used for the feasibility assessment, they were believed to have the most likelihood of MAR being feasible. Therefore, if MAR is found to unfeasible in these regions, then it can be ruled out as a water management tool for the industry, and thus address the project aim. In the Gilbert region, a potential cotton production area which has attracted increasing interest from local farmers, MAR may be a solution that addresses the region's challenge that it is unable to build and utilise traditional surface water storage options.

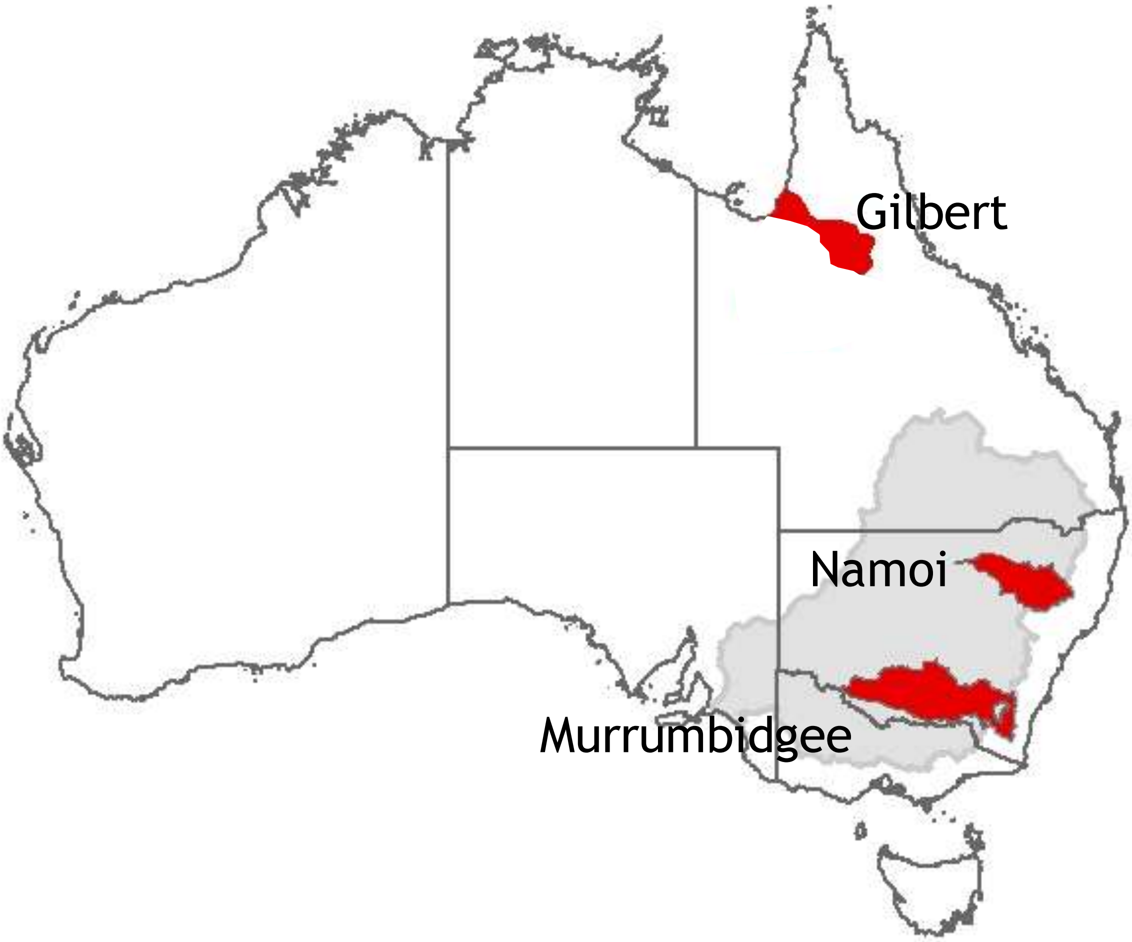

Figure 3 Location of the project's proposed case study areas. This report focuses on the Murrumbidgee case study, specifically the Coleambally Irrigation Area.

1.5 Structure of this report

This report focuses on the Murrumbidgee case study (Milestone 4.1 of the project) and the approach used to assess the feasibility of MAR is provided in Section 2. This is followed in Section 3 by a description of the Murrumbidgee system and the Coleambally Irrigation Area (CIA), which is the focus of the case study. Six scenarios representing MAR options or alternative surface water storage options are identified and evaluated in Section 4. The development and evaluation of these scenarios drew on the detailed results of the feasibility criteria assessment provided in Section 0. The report concludes in Section 6 with a statement of the potential for MAR in the region and recommendations for CICL and the CRDC going forward.

2. Approach

2.1 Overview

A schematic of the process and steps to undertake the feasibility assessment, develop water management scenarios and make recommendations for MAR pilots in the CIA is given in Figure 4. As mentioned, the project Steering Committee helped identify the broad case study regions. Upon selecting the Murrumbidgee as a case study, a stakeholder group for the catchment was established, and through workshops with this group, the CIA was chosen as the focus for a more intensive investigation of the potential feasibility of MAR. Analyses to assess the potential feasibility (based on the seven criteria of Ticehurst and Curtis, 2017; see Section 0) included local key informant interviews, desktop review of scientific, government and other literature, analysis of existing spatial data, financial analyses, discussions with the Steering Committee and the Murrumbidgee stakeholder group, and discussions with MDBA and NSW Government representatives. The feasibility assessment facilitated the identification and evaluation of three MAR scenarios and three alternate surface water management scenarios. Feedback on these scenarios was sought from the Murrumbidgee stakeholder group, which helped refine the feasibility assessments and to provide recommendations for MAR pilot(s) in the CIA or greater Murrumbidgee.

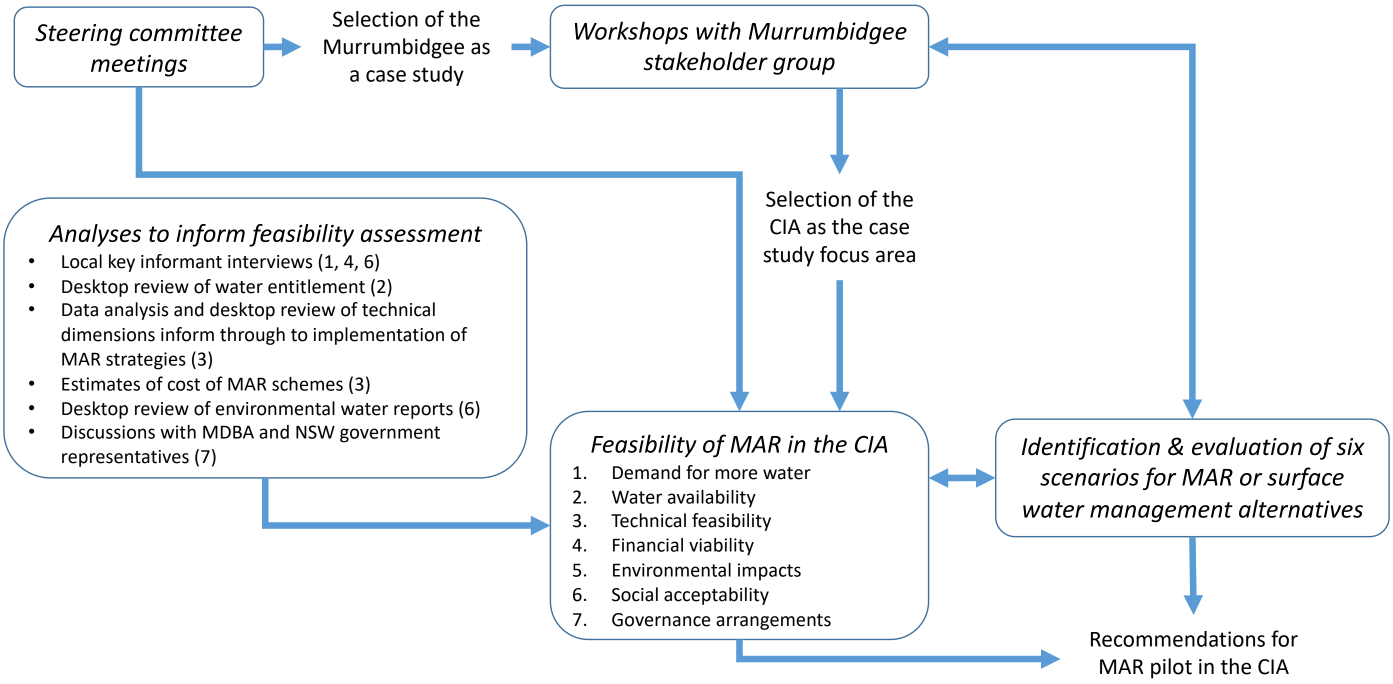

Figure 4 Process used to achieve Milestone 4.1 outcomes.

2.2 Stakeholder engagement

The stakeholder groups involved in this case study are listed in Table 1. Some groups were invited but did not ultimately participate in workshops or interviews, including cultural leaders, urban water managers, and community drought and financial representatives.

2.2.1 Murrumbidgee stakeholder group

Over a period of eight months, we conducted three workshops with a group of representatives of organisations who had a stake in the use and management of water in the case study region. The purpose of establishing the Murrumbidgee stakeholder group was to assist us in consolidating and assessing MAR options. The group was made up of representatives from the Murrumbidgee Food and Fibre association, Coleambally Irrigation Co-operative Limited (CICL), Murrumbidgee Irrigation Cotton Info, Irrigation Research and Extension Committee (IREC), Murrumbidgee Groundwater Inc, NSW DPIE, local irrigators, Murrumbidgee Food & Fibre Association, WaterNSW, NSW Irrigators Council, plus the research team.

The first stakeholder workshop was held at Griffith, NSW on the 5th August 2019. This workshop was run to introduce the project and research team, and then to have an open discussion on where the group thought that MAR would most likely work within the Murrumbidgee region. After an active discussion from the group on the performance of the Murrumbidgee region, and specific zones within it, across the seven feasibility criteria, the group decided this research should focus on investigating the feasibility of MAR in the CIA. The CIA was an appealing option because it had an existing irrigator co-operative, with the CICL already in charge of surface water delivery for its members.

Table 1 Diversity of stakeholders interviewed for feasibility assessment

	Number of Participants		
Stakeholder group representatives	**Interviews**	**Coleambally Workshops**	**Total [a]**
Irrigators	4	4	8
Industry representatives	5	3	7 (1)
Environmental managers	1	1	2
Water managers	2	7	8 (1)
Other [b]	2	3	4 (1)
TOTAL no. people	14	15 (3) [c]	29 people involved in project discussions

[a] The numbers in brackets are the number of people who had been interviewed and also had been invited to workshops.

[b] 'Other' include researchers, water brokers, and a representative from the NSW irrigators council.

[c] Some people invited to workshops were representing more than one stakeholder group (e.g. an irrigator who also sat on the NSW irrigators council).

The other two workshops were held with the stakeholder group to discuss the feasibility of MAR across the seven criteria in the Coleambally Irrigation Area of Operations (CIAO). In October 2019, the workshop participants provided feedback on the preliminary feasibility assessment and identified new data sources to support these analyses. The February 2020 workshop provided further feedback on the feasibility assessment (reported in Section 5), with a focus on refining and evaluating the scenarios documented in Section 4 (with feedback discussed in Section 5.6.3).

2.2.2 Key informant interviews

Targeted phone interviews with key stakeholders explored the feasibility of MAR using the seven evaluation criteria, but particularly focused on the demand for change from the existing water management options (criteria 1), the social acceptability of MAR (criteria 6), and the importance of a consistent water supply for irrigators and the cotton industry. Eight interviews were conducted as part of a prior project which also explored the feasibility of MAR in the Murrumbidgee region. Another six interviews directly focused on the potential for MAR in the CIAO.

3. Case Study Area

3.1 Murrumbidgee

3.1.1 Catchment background

The Murrumbidgee catchment (Figure 5) covers 87,348 km^2 in area [2], with the river extending about 1,485 km [3]. The average annual rainfall ranges from nearly 1600 mm in the alpine regions, down to about 350 mm near Hay on the Riverina Plains. The catchment covers a diverse range of geologies, which has resulted in a diverse range of soil types and properties (Usowicz et al., 2017). These range from shallow and poor quality soils on the sedimentary rock, to deeper more fertile soils on the granite, to fertile but stony basaltic soils, to the highly fertile alluvial soils generally confined to the river course. Figure 6 shows that the soil texture generally increases in clay further down the catchment (i.e. from east to west).

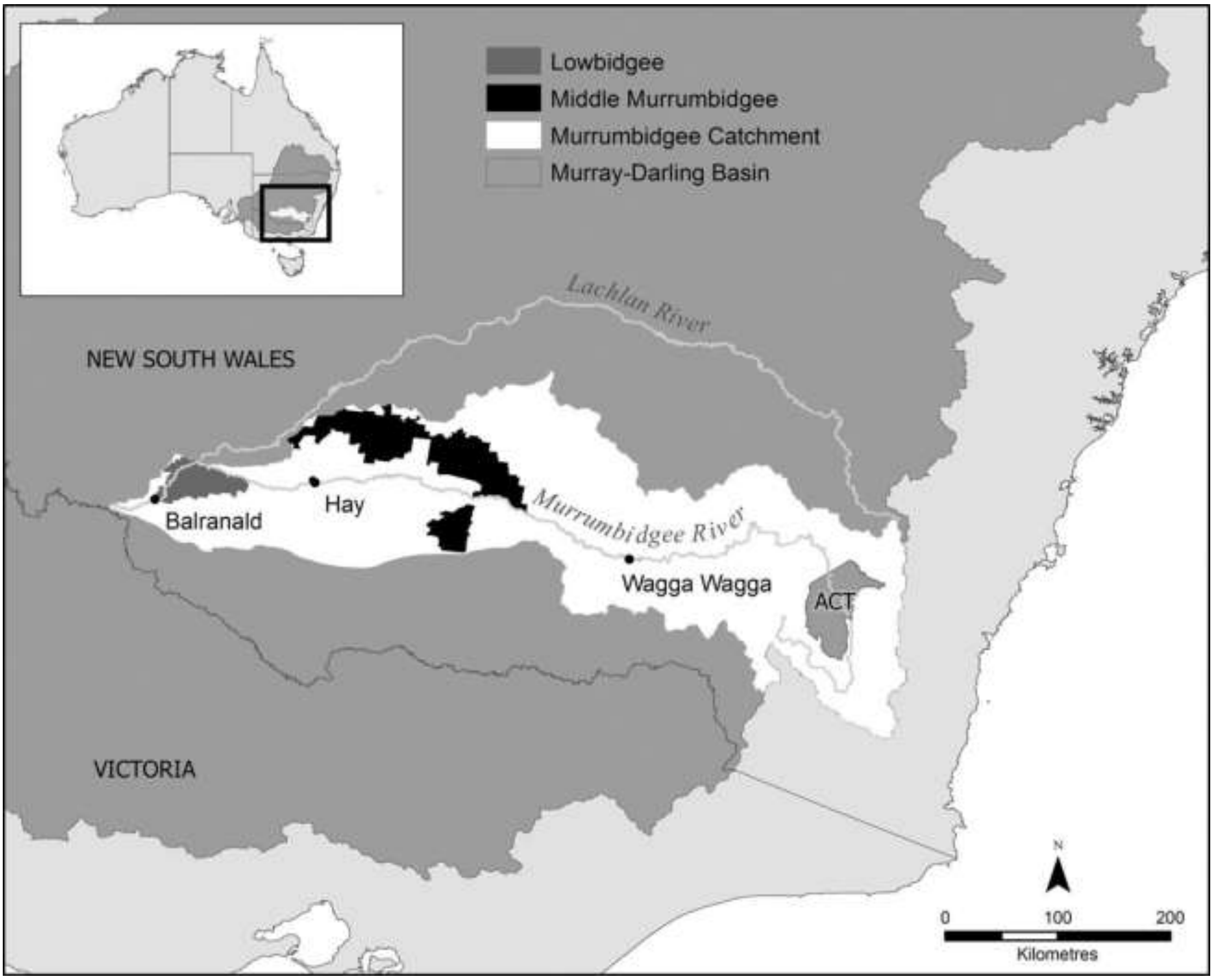

Figure 5 Murrumbidgee catchment (Source: Conroy et al. 2019)

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[2] http://www.clw.csiro.au/publications/waterforahealthycountry/mdbsy/pdf/Murrumbidgee-Report.pdf, accessed 23 April 2020
[3] https://www.mdba.gov.au/discover-basin/catchments/murrumbidgee, accessed 8 April 2020

The Murrumbidgee River flows through lands previously occupied by the Wiradjuri people, the largest Aboriginal nation in NSW. It also includes other smaller Aboriginal nations including Barapa Barapa, Muthi Muthi, Nari Nari, Nyeri Nyeri, Wadi Wadi, Wamba Wamba, Weki Weki, Wolgalu, Ngunawal and Ngarigo [3].

The Murrumbidgee catchment supports a population of ~550,000 people [3], most of whom live in Canberra (395,790 people based on 2016 census data [4]), Queanbeyan (36,348 people based on 2016 census data [5]) and Wagga Wagga, the largest inland city in NSW (62,385 people based on 2016 census data [6]). The catchment also supports numerous regional cities and larger towns including Cooma, Tumut, Narrandera, Griffith, Leeton, Hay and Balranald, and smaller towns such as Coleambally and Darlington Point, to take Murrumbidgee Council as an example.

In its natural state, the Murrumbidgee catchment supported a wide variety of natural ecosystems, some of which still remain today. The Tuckerbill and Fivebough Swamps are listed under the international Ramsar Agreement for their ecological importance [3] (Figure 7), with another 16 wetlands listed to have national significance. Tuckerbill is seasonal, shallow and brackish to saline, while Fivebough is permanent, shallow, and fresh to brackish. They provide important drought refuge. The Lowbidgee Wetland complex is over 2000 km^2 in areas and is significant for its River Red Gum (*Eucalyptus camaldulensis*) forest, black box (*Eucalyptus largiflorens*), lignum (*Duma florulenta*) and reed-bed communities. Part of this includes the Yanga National Park, which was gazetted in 2007 and covers 31,190 ha. The Sustainable Rivers Audit of 2012 concluded that the river condition was poor [3], which is most likely due to the land and water use of the catchment. Flow regulation has meant that the flow variability is poor and has severely impacted upon fish communities.

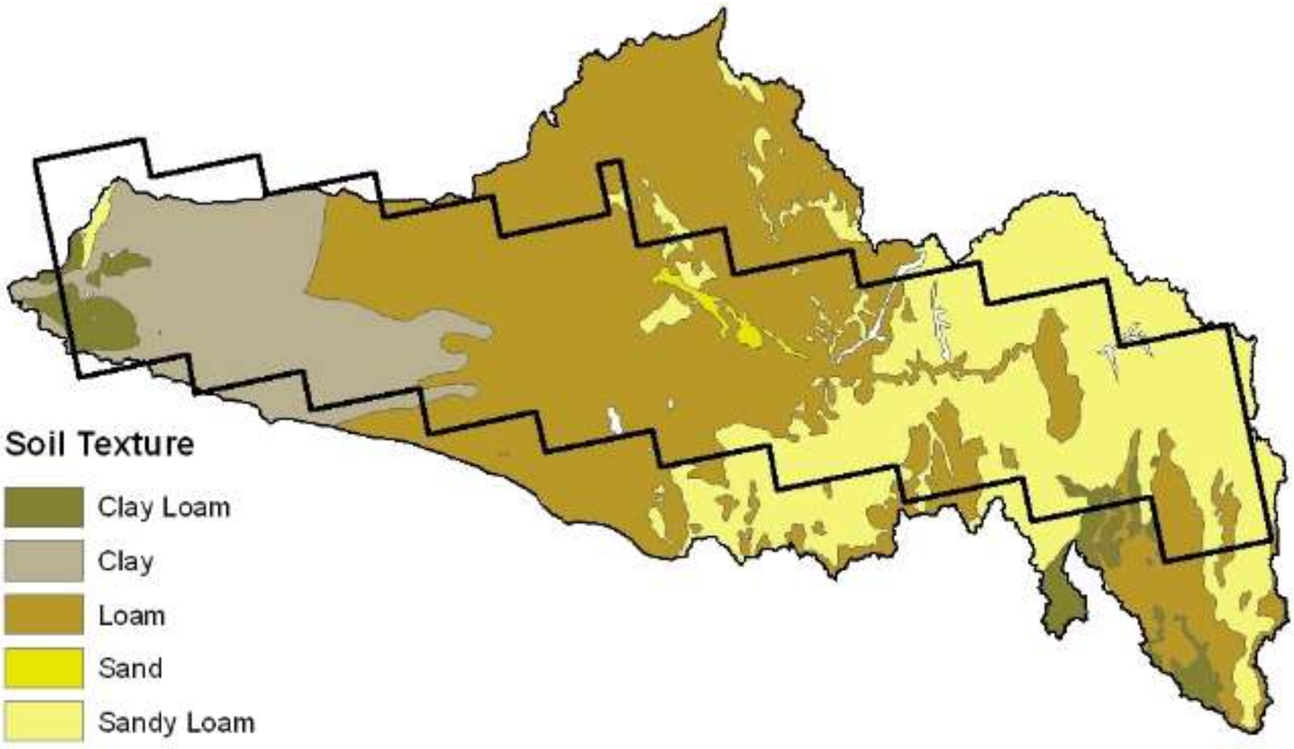

Figure 6 Soil texture across the Murrumbidgee catchment (Source: Usowicz et al. 2017)

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[4] https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/8001?opendocument, accessed 18 May 2020

[5] https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/UCL102001?opendocument, accessed 18 May 2020

[6] https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/LGA17750?opendocument, accessed 18 May 2020

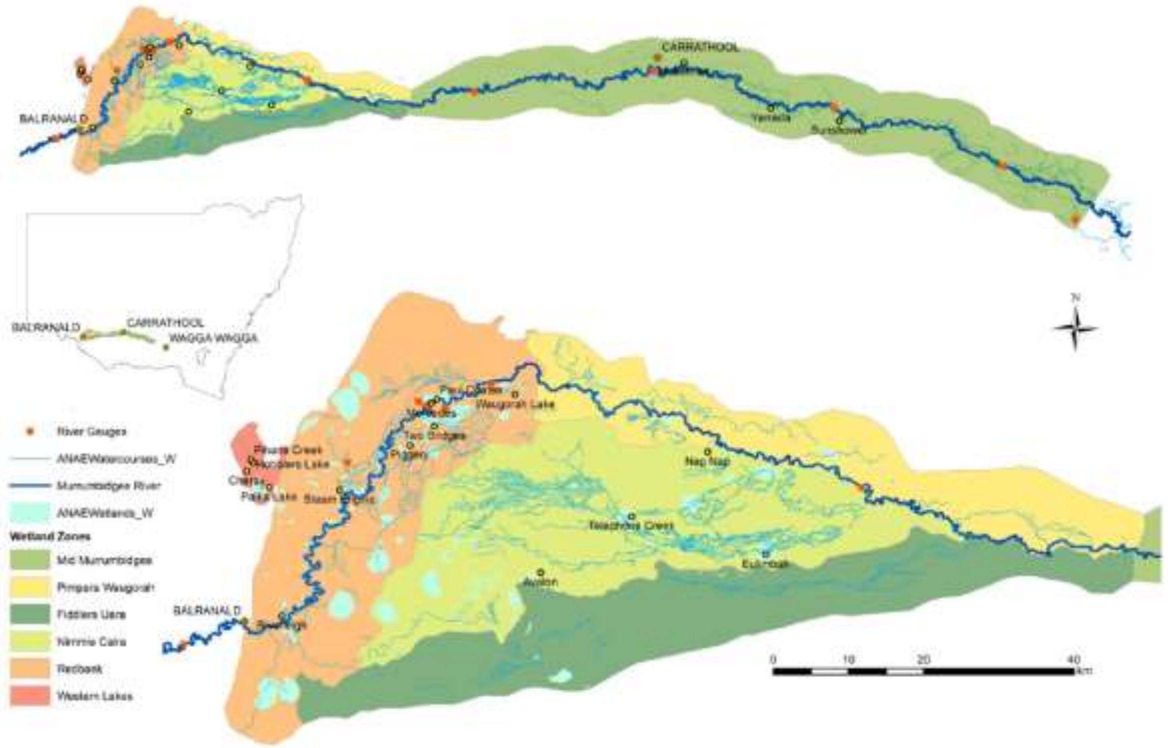


Figure 7 Distribution of wetland zones and location of key sites (Source: Wassens et al. 2014)

Due to the diversity in its environments (i.e. climate, soils and topography) the catchment also supports a wide variety of land uses (Figure 8). The trend is for forest and nature conservation in the upper catchment, dryland grazing and cropping mid-catchment, and the irrigation cropping and pastures in the mid to lower catchment (from map in ABS, ABARE & BRS, 2009), with the dominant land uses being 52% pasture, 21% arable land and 18% silviculture (in 2010). Irrigation occurs on about 5% of the region (ABS, ABARE & BRS, 2009). The main irrigated industries are fruit and vegetables, wine and rice, and more recently cotton and nuts.

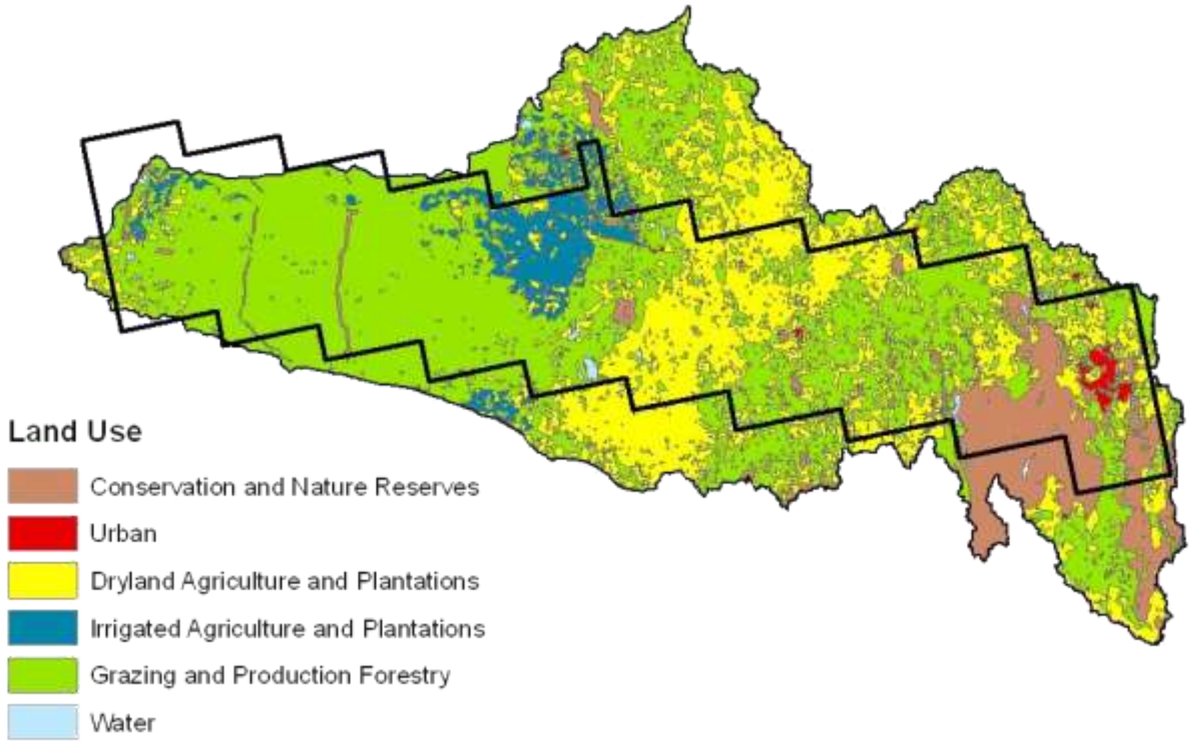
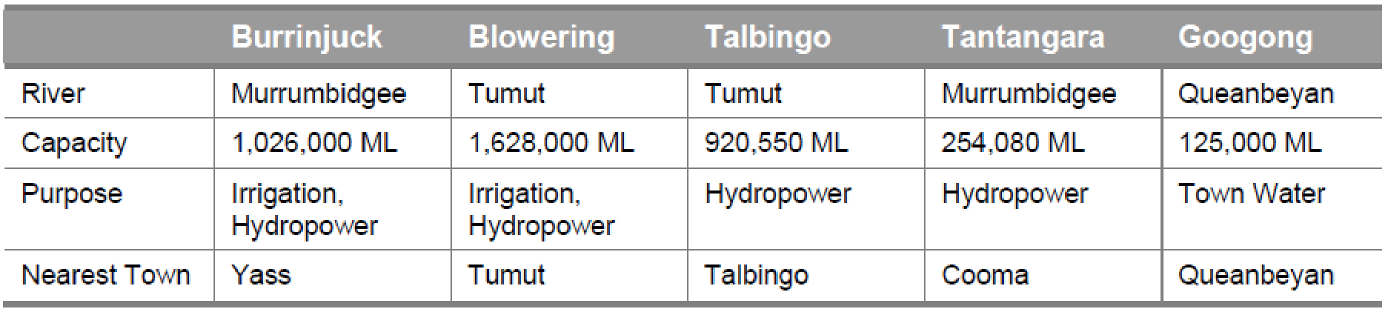


Figure 8 Land use of the Murrumbidgee Catchment 2010 (Source: Peischl et al. 2012)

3.1.2 Water management in the Murrumbidgee

The Murrumbidgee River is a highly regulated system with the major storages for irrigation being Burrinjuck Dam and Blowering Dam (Table 2). The highest flows are from October to March, correlated to the irrigation season.

Table 2 Major storages in the Murrumbidgee Catchment (Source: Green et al., 2011).



	Burrinjuck	Blowering	Talbingo	Tantangara	Googong
River	Murrumbidgee	Tumut	Tumut	Murrumbidgee	Queanbeyan
Capacity	1,026,000 ML	1,628,000 ML	920,550 ML	254,080 ML	125,000 ML
Purpose	Irrigation, Hydropower	Irrigation, Hydropower	Hydropower	Hydropower	Town Water
Nearest Town	Yass	Tumut	Talbingo	Cooma	Queanbeyan

The two major irrigation districts in the mid to lower Murrumbidgee are the Murrumbidgee Irrigation Area (MIA) (3,624 km^2) and the 795 km^2 Coleambally Irrigation Area (CIA); the Lowbidgee Flood Control and Irrigation District is located further downstream and covers 1,400 km^2 of which 380 km^2 are irrigated (Figure 9; Figure 10). Water is delivered to the MIA through the main canal at *Berembed Weir* (Capacity 6,700 ML/day) while the Coleambally Canal services the CIA.

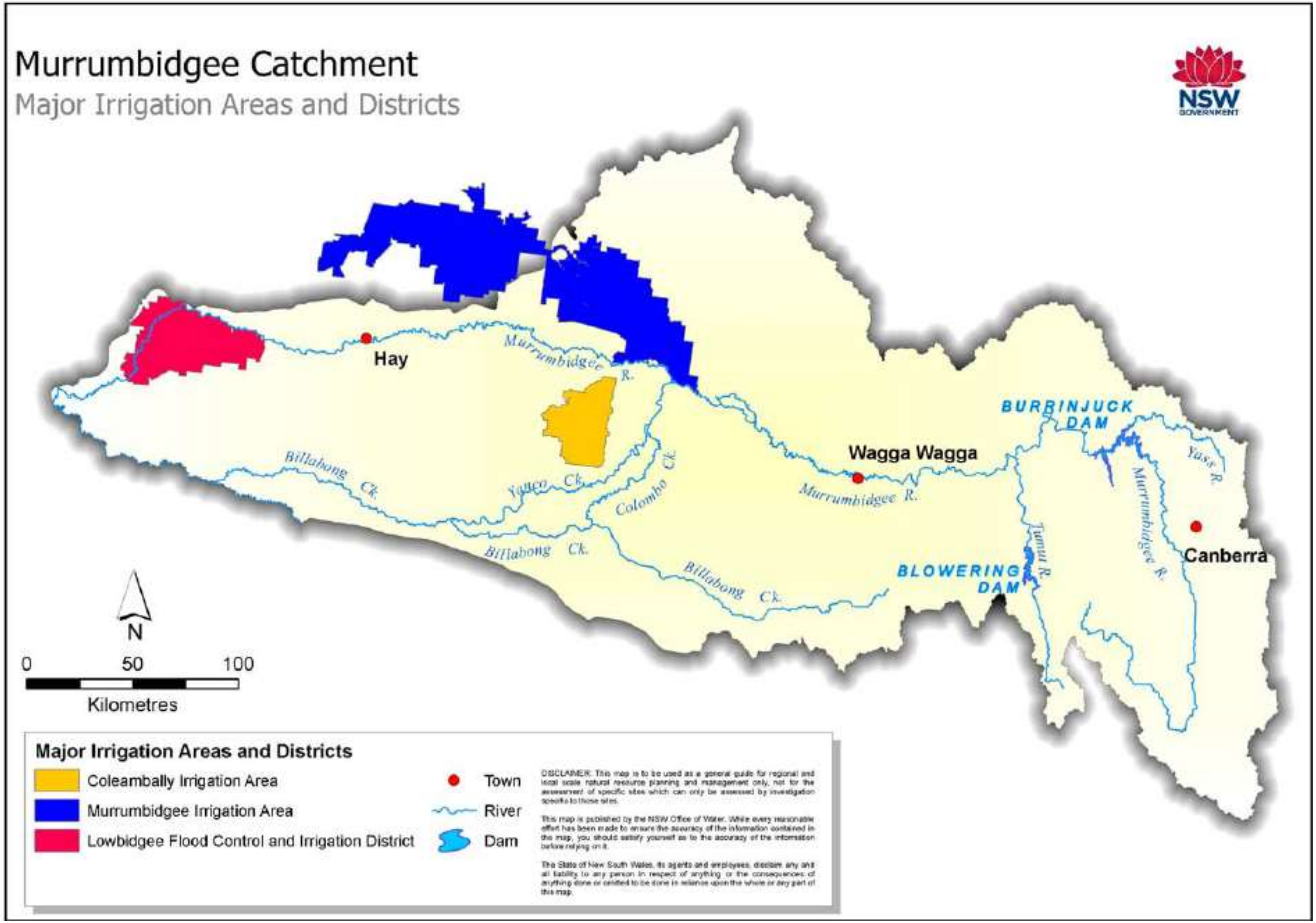
Recent water entitlements in the Murrumbidgee River are shown in Table 3. Murrumbidgee Irrigation and CICL have entitlement to 1,159 GL and 122 GL, respectively. The NSW Environmental Water Holder and the Commonwealth Environmental Water Holder have 158 GL and 771 GL, respectively.

Table 3 Water entitlements for the Murrumbidgee River.

	NSW environmental water holdings GL (1 July 2018)[a]	Commonwealth Environmental Water Holder GL (February 2020) [b]	Murrumbidgee Irrigation GL (Sep 2018) [c]	Coleambally Irrigation GL (June 2019) [d]
High Security	-	14.2	284	8.4
General Security	3.4	286.5	602	4.3
Conveyance		50.3	203	103
Supplementary allocation	6.7	22.0	36	0
Supplementary (Lowbidgee)	148	393.1	7	-
Groundwater aquifer	-	5.1	-	3
Groundwater supplementary	-	-	-	-
Stock & domestic, Towns	-	-	27	3.5

[a] Source: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Water/Water-for-the-environment/annual-environmental-watering-priorities-2018-19-murrumbidgee-180372.pdf, accessed 20 April 2020
[b] Source: https://www.environment.gov.au/water/cewo/about/water-holdings, accessed 20 April 2020
[c] Source MI Irrigation Industry fact sheet, https://www.mirrigation.com.au/ArticleDocuments/199/Fact%20Sheet%20Company%20Overview.pdf.aspx, accessed 20 April 2020
[d] Source: https://www.colyirr.com.au/annual-compliance-report?rq=annual, accessed 18 May 2020

The water entitlement is managed according to the water sharing plans. There are two water sharing plans for the surface water in the Murrumbidgee and three for the groundwater: Murrumbidgee unregulated and alluvial water sources (2012), Murrumbidgee regulated river (2014 but due to be updated), Lower Murrumbidgee Groundwater (2019), NSW Murray-Darling Basin Fractured Rock Groundwater, NSW Murray Darling Basin Porous Rock Groundwater.



DISCLAIMER: This map is to be used as a general guide for regional and local scale natural resource planning and management only, not for the assessment of specific sites which can only be assessed by investigation specific to those sites.

This map is published by the NSW Office of Water. While every reasonable effort has been made to ensure the accuracy of the information contained in the map, you should satisfy yourself as to the accuracy of the information before relying on it.

The State of New South Wales, its agents and employees, disclaim any and all liability to any person in respect of anything or the consequences of anything done or omitted to be done in reliance upon the whole or any part of this map.

Figure 9 Major irrigation areas and districts in the Murrumbidgee catchment (Source: Green et al., 2011).

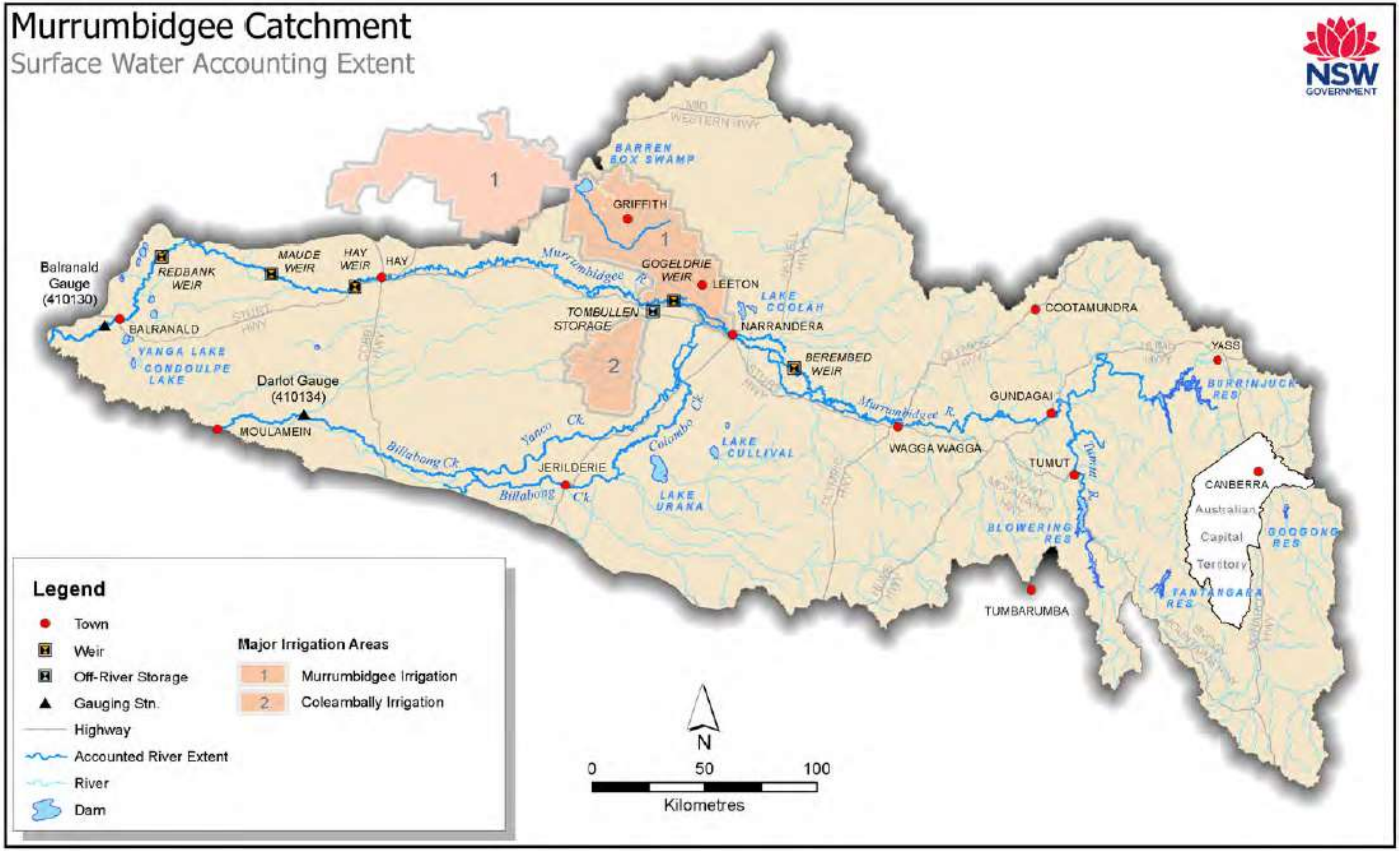


Figure 10 Surface water accounting extent in the Murrumbidgee (Source: Burrell et al. 2015).

The water year starts from 1st July each year (NSW DPI Water, 2015). An allocation is announced at the start of the year, and if it is not 100%, then it may be increased throughout the water year. Stock & domestic, and town water supplies are 'generally' given 100% unless it is very dry, similarly, the high security water is usually very high (i.e. 95% unless the general security allocation is 100%, then it matches the general security). Conveyance is also generally high and 'commensurate' to other allocations. General security allocations typically start low (as there will never be enough water in storage at the beginning of the water year for a 100% allocation at the start) and increase throughout the water year depending on the rainfall and runoff.

Water is allocated in the following sequence. Firstly, the volume of water required to run the river (i.e. end of system flows, transmission losses = conveyance entitlements + evaporation losses) is allocated, then the required environmental water is set. If the general security water reaches 95% allocation, then both the general and the high security water are increased equally until they both reach 100%. However, once general security allocation plus the average carry-over have reached 80% allocation, then water is proportionately set aside for commencing allocations for the next water year. The dam inflows and allocations are assessed monthly, and NSW DPIE makes an allocation announcement mid-monthly.

High reliability water cannot be carried over, but 30% of general security water can be carried over from one year to the next. However, a general license holder cannot use more than 100% of their entitlement in any given water year. This includes allocation plus water traded out plus carry over plus any diverted supplementary flow. If, with their carry-over, they exceed 100% of their entitlement, then the additional carry-over is forfeited back to the store allocation (NSW DPI Water, 2015).

Supplementary water is uncontrolled flow which cannot be regulated or stored for future use (i.e. floods etc). Once a supplementary event is declared it is 'opportunistic water' for those with supplementary licenses or general security license holders who have <70% of their allocation, and <100% of their share considering allocation plus carry over.

There are limits on stream flow at various locations throughout the catchment, above which flooding may occur (NSW DPI Water, 2015). The limits on the flows have been set at:

- 9,000 ML/day in Tumut River at Oddys Bridge
- 9,300 ML/day in Tumut River at Tumut
- 32,000 ML/day in Murrumbidgee River at Gundagai
- 1,400 ML/day in Yanco Creek at the off-take.

Other constraints are for the maximum release when a dam is full, being 29,100 ML/day for Burrinjuck Dam and 21, 300 ML/day from Blowering Dam (State Water Corporation 2014 in CEWO, 2014). This is important for the peak summer demand, which could be as high as 20,000ML/day, so it means that Burrinjuck Dam may need to supply over half of this due to the Tumut River limitations. These restrictions in flow can impact the ability to deliver water when irrigators most need it. Burrinjuck Dam relies on rainfall for its storage while Blowering Dam gets regular inflow from the Snowy-Hydro Scheme. This can result in the Blowering Dam having water available, but it is unable to deliver it to the irrigators at the desired volumes because of the restriction in the Tumut River, while Burrinjuck does not have the water to contribute. Another constraint is if the Snowy-Hydro has a release late in the irrigation season, this water may not be useful to include in the allocations for the current water year so they are counted in the allocations for the next season, or they are allocated and carried over by the irrigators themselves, rather than being a useful resource for the current season.

3.2 Coleambally Irrigation Area of Operations

Irrigation in the region, located south of Griffith in the middle of the Murrumbidgee Valley, was established by the NSW Government from the late 1960's with the township gazette in 1968. The late 1990's saw a shift towards privatisation and local ownership, and in June 2000 the Coleambally Irrigation Co-operative Limited (CICL) came into being [7]. As of June 2020, the CICL has 236 voting members and 283 shareholders (CICL, 2020a). Irrigation and drainage services to 497 farms (CICL, 2020a) is achieved through a network of 516 km of supply channels and 711 km of drainage channels. CICL irrigators who tend to be opportunistic croppers producing a mix of summer and winter crops, with the main summer crops being cotton and corn [8]. The 4,568 km^2 CICL Area of Operations, shown in Figure 11, services the CIA (795 km^2 of irrigable land), the Kerarbury scheme (120 km^2 of grazing and irrigation land) and the West Coleambally Channel (WCC) region which covers about 3,135 km^2 of land. On the latter, grazing is the dominant use along with some opportunistic irrigation development. Historically it encompasses the least intensively irrigated farmland within the CIAO; in contrast, the CIA has been (and remains) the most intensively irrigated zone. CICL (2020b) report that 70% of irrigation water used within the area encompassing the CIA, the WCC and a section of land adjacent to Coleambally (that is not serviced by CICL) is used within the CIA compared with 7% in the WCC.

In the early 1990s, rising water tables and increasing soil salinity were issues across the district. This led to joint government and community investment in improved land and water management in the district, under the Coleambally Land and Water Management (LWMP) [9]. The main elements of the LWMP were whole farm planning, landforming, construction of farm water recycle systems, land use change, and associated education, research and development. In 2001, the CICL commenced the modernization of its gravity supply infrastructure by trialling Total Channel Control (TCC) technology, with implementation partially funded through environmental water recovery programs[10]. This greatly improved the efficiency of water delivery to member irrigators and, since 2005/06, an average of 90% water delivery efficiency has been achieved (up from a baseline efficiency of 75-80%). The solar powered and fully automated TCC system allows water orders to be filled within two hours and typically, excluding the impacts of trade, most farms have access to a minimum daily flow rate of 14 ML/day; supply is during the irrigation season (mid-August to mid-May) although a small number of channels in high security zones had access to winter supply [11].

CICL holds high security, general security, supplementary and conveyance surface water access licenses, as well as groundwater licenses (see Table 3). Of these, only the conveyance license is not a contractual right to members [12]. CICL, with water savings derived from infrastructure investment in the TCC, channel lining and storage, provides members with access to a member benefit and additional water offers. Member benefits and additional water offers are distributed in proportion to the delivery entitlements (DE [13]) held by members. The eligibility requirements to be a CICL member or customer are that the person(s) owns or leases a farm in the CIAO which is connected to CICL's channel network and which has an outlet through which water can be delivered; members need to own 10 DE, 10 shares and the use or trade of a minimum of 10 ML each year [14]. Given that they are tradeable, farms in the CIAO can hold different volumes of water and delivery entitlements and shares are tradeable [15].

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[7] https://www.colyirr.com.au/brief-overview, accessed 16 March 2020

[8] https://www.colyirr.com.au/brief-overview, accessed 17 November 2020

[9] https://www.colyirr.com.au/our-story, accessed 16 March 2020

[10] https://www.colyirr.com.au/coleambally-irrigation-area?rq=member%20benefits, accessed 17 November 2020

[11] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 18 November 2020

[12] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 18 November 2020

[13] A Delivery Entitlement (DE) is an entitlement to have water delivered to land in Coleambally Irrigation Co-operative Limited (CICL) areas of operation (https://www.colyirr.com.au/s/FACT-SHEET-CICL-Delivery-Entitlement.pdf, accessed 18 November 2020).

[14] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 18 November 2020

[15] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 18 November 2020

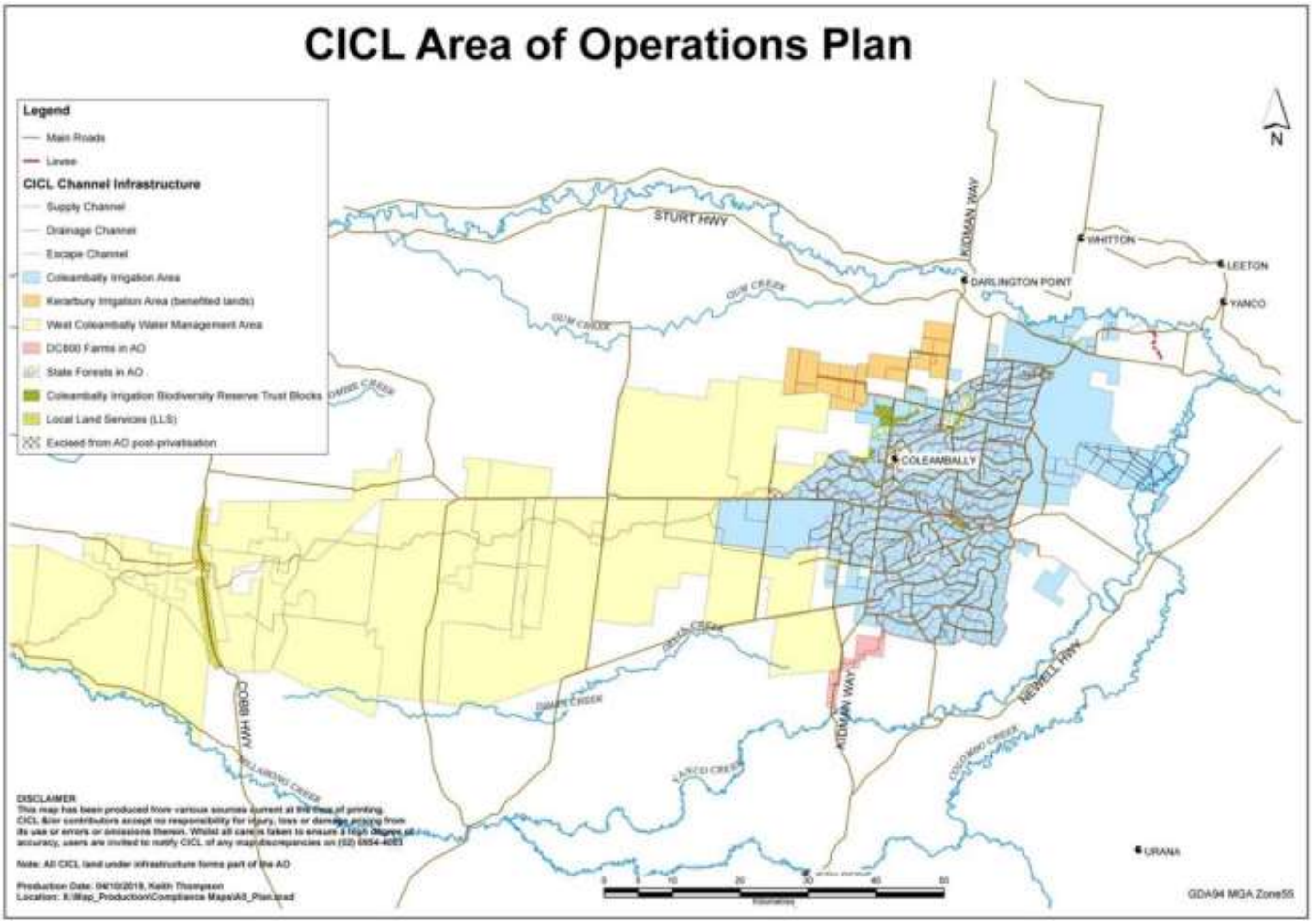

Figure 11 CICL area of operations (Source: Figure 7.1 in CICL, 2020b).

As is the case across the Murrumbidgee Valley, drought, water reforms and increased demand for water (particularly from the horticultural sector) means there is little un-utilised consumptive water within the CIAO, and surface water entitlements in the CICL licence have been decreasing since the mid-2000’s. In times of low allocation, and without the capacity to invest in on-farm infrastructure or purchase high-cost water, CICL members may choose to use the water market to sell their remaining water allocation when . In this context, the interest of CICL in MAR, expressed at the local stakeholder working group workshops for this project, is whether it can offer some value to members in terms of making more water available during times of low allocation; as an irrigation corporation it is likely better placed to invest in MAR than individual members.

4. Scenarios

The following scenarios were initially developed from discussions at the local stakeholder workshop in October 2019 and preliminary feasibility analyses. They were refined based on feedback from the local stakeholder workshop in February 2020 and further assessment of potential feasibility. Note that these scenarios do not constitute an endorsement for a particular course of action by either the CICL or the CRDC. Rather, they highlight promising opportunities for MAR in the CIA and contrasting alternative scenarios without a MAR component, and are used to develop recommendations for CICL and the CRDC on how to proceed with MAR, and conjunctive use of water more broadly, should either party wish to invest further in investigating MAR. Operationalising any component of the proposed scenarios will need the cooperation and collaboration of CICL (with formal support from members) and government.

4.1 Don't miss a drop

Using managed aquifer recharge (MAR) to capture and bank water during wet periods could potentially provide water at prices competitive with water trading in dry years, ranging from estimates of $95 and $845/ML depending on the situation [16]. Previous work and a new suitability analysis both suggest MAR should be technically feasible within the Coleambally region [17].

Implementation of MAR would start with a pilot project that keeps costs low while building experience and confidence [18]. The pilot would be structured as a research project with co-funding from industry, and sites in multiple irrigation districts. Collaboration with researchers and consultants would build local capacity, e.g. regarding evaluation of water quality, and sediment removal to mitigate clogging [19], and developing monitoring required to understand impact of MAR water recharge and recovery, e.g. with placement of new piezometers and soil water monitoring[20]. Collaboration with government would work towards establishing appropriate MAR policy for NSW, and support development of necessary project approvals, particularly regarding rules for recovery of water. The need for MAR policy is already recognised by NSW Government and the Water Sharing Plan, and there are two active MAR schemes within the Murray Darling Basin, demonstrating that MAR is already compatible with the Basin Plan [21].

The pilot in Coleambally could be managed by CICL, using water entitlements on CICL's bulk water license, and with accounting rules developed for distribution of recovered water and voted for by CICL members. Multiple recharge sites would be developed to increase capacity and to test characteristics of multiple promising locations and multiple technologies. Infiltration tests could be performed with conveyance water in an old sand quarry, or drainage canal coinciding with a highly permeable prior streambed [22]. Existing piezometers could be used to monitor responses from groundwater levels and evaluate the potential to store freshwater as a lens in saline areas [23]. Promising existing bores could be selected for injection, likely in collaboration with irrigators [24].

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[16] Levelised cost of MAR water (Section 5.4.3)
[17] How much water can be recharged? (Section 5.3.1), Suitability assessment (Section 5.3.3), Managed recharge strategies (Section 5.3.4)
[18] 'How a pilot would work' in Responses to scenarios (Section 5.6.3)
[19] Managed recharge strategies (Section 5.3.4), Water quality risks (Section 5.5.3)
[20] Monitoring design to manage effects (Section 5.3.6)
[21] The MDBA and MAR (Section 5.7.1), The NSW Water Policy context (Section 5.7.2), Potential MAR project assessment process (Section 5.7.3)
[22] 'Infiltration into low salinity areas of shallow aquifer' in Managed recharge strategies (Section 5.3.4)
[23] 'Infiltration/injection as freshwater lens into shallow aquifer' in Managed recharge strategies (Section 5.3.4)
[24] 'Injection into deep aquifer' in Managed recharge strategies (Section 5.3.4)

The pilot would start with small volumes and scale up over time. Experimentation to improve water management, treatment, and recharge rates would gradually increase the capacity of the scheme, ultimately aiming to fully capture a 20 GL supplementary allocation. The main channel intake capacity should be sufficient [25], but substantial operational challenges remain in getting the water sufficiently quickly into infiltration basins and settling ponds. General entitlements in excess of carryover limits [26] would also be banked. While the largest recharge volumes would therefore occur in flood events and in wet years, the CICL could experiment with using MAR of conveyance water to support operations. The CICL would control water recovery, including through bores at the same location for local use or distribution through the existing irrigation channel network, or through bores at different locations if the hydrogeology and project approvals allow it [27].

4.2 Multi-year surface storage

MAR is primarily a water storage technology, conceptually offering an option to increase the 'carryover' capacity over one or more years. Therefore, an alternative to MAR is investment in large dams able to capture floods and potentially store water over multiple years. Following the lead of other irrigated agricultural companies, this could take the form of additional large scale turkey nest dams.

There are substantial similarities to the requirements of infiltration basins and settling ponds used for MAR, in terms of need for land adjacent to main canals, need to fill the dam by gravity, cost of earthworks, and need to address issues associated with shallow water tables.

The primary differences to MAR relate to the nature of a dam versus MAR as a water cycle intervention. MAR moves surface water underground, replenishing groundwater and reducing evaporation, and can be scaled up gradually, with increasing infiltration area and number of injection sites increasing capacity over time. MAR sites are used for transfer of water, not storage. A dam, on the other hand, retains water above ground, potentially increasing evaporation, and its capacity is limited by its physical storage dimensions, which are in turn limited by landscape and operational constraints. It is likely that dams would need to be large individual projects, with upfront investments that can more easily be afforded by large privateers who have the financial capacity to invest in the dams and the supporting infrastructure to capture large volumes of water quickly, while other farmers do not. MAR may ultimately provide similar capabilities at lower upfront costs. Construction of such dams, however, is an established technology with fewer legal barriers.

Further investigation of dam construction as an alternative to MAR was out of the scope of this project but may be of interest in future.

4.3 Storing water for community sustainability

MAR may be worthwhile even if it cannot provide additional water (e.g. if supplementary water is not available). The idea would be to store and recover enough CICL conveyance water and general security entitlements to ensure a minimum level of water security in drought or dry years [28].

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[25] Surface water infrastructure' in How much water can be recharged? (Section 5.3.1), 'Feasibility of capturing large supplementary events' in Responses to scenarios (Section 5.6.3)

[26] General security entitlements (Section 5.2.1)

[27] Recovery efficiency (Section 5.3.5), Monitoring design to manage effects (Section 5.3.6)

[28] Industry and community perspective (5.1.3), General security entitlements (5.2.1), CICL water budget (Conveyance, Channel seepage and evaporative losses) (5.2.4)

It is generally considered that irrigating annual crops such as cotton allows farmers to ride the booms and busts rather than being reliant on high security water as for perennials. However, evening out peaks and troughs in water supply would still have advantages [29]. Lack of security inhibits capital investment in supply chains and infrastructure, increases the risks of signing forward contracts, and increases the costs of accessing necessary labour for harvest. More generally, in dry years farmers may be unable to farm, requiring them to sell their remaining water allocations on the temporary market, diversify their income, or wait till the next year. Flow-on effects for the community tend to reduce expenditure for agribusinesses, including cotton gins, and decrease the attractiveness of the town, reducing demand in other local businesses [30].

Banking water reduces the area planted in wetter years when the water is recharged, but this is likely to be compensated by the increased area that can be planted in a dry year (depending on changes in crop prices). While MAR in this scenario does not provide additional water, and may not provide additional crop production overall, it may be worth investing in order to support the long term viability of the co-operative and social sustainability of the community, and co-investment by government may therefore be warranted [31].

This use of MAR, however, would rely on strict control by CICL of how recovered MAR water is used by farmers, which would need to be approved by members, and in turn a strong understanding of how water distribution affects outcomes for the co-operative, its infrastructure, crop supply chains and the community. This represents a substantial departure from current arrangements and identifying institutional and legal arrangements, and building social license, for such water distribution would be major issue. CICL, however, is well placed to tackle such issues [32] as a co-operative that has a mandate to look after its members, with an existing emphasis on innovation. A first step could involve research collaborations to help assess how much production and water is needed to keep supply chain businesses active and maintain community activity through droughts. Facilitated discussions with CICL members, community and other stakeholders would gradually achieve a clear understanding of community objectives, a proposed water distribution policy with expected outcomes, and clarity over who bears the cost of MAR scheme development in light of the anticipated benefits.

There is value in such research collaborations even without committing to MAR as described in this scenario. A strong understanding of water needs for community sustainability would allow the community to make the case for MAR to be approached as one part of a broader trailblazing partnership between CICL and government, to reinforce the sustainability of the town of Coleambally and of the Murrumbidgee Council more generally. Such a project would build on Coleambally's track record of innovation to position it as a leader in the Australian water sector at the cutting edge of socially as well as environmentally responsible irrigation.

4.4 Alternatives for providing water for community sustainability

4.4.1 Community sustainability through high security entitlements

Existing water storages already provide a mechanism to support water security in dry years, namely high security water entitlements. Inflows and storage from Burrinjuck and Blowering dams are used to provide 284 GL of entitlements available to the Murrumbidgee (Table 3; 8.4 GL in the Coleambally in 2018/19) [33], which could in principle be used to support community sustainability instead of resorting to MAR.

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[29] Irrigators' perspective (5.1.2)

[30] Industry and community perspective (5.1.3)

[31] Enablers for MAR adoption in the Coleambally Irrigation Area (5.6.1), Industry and community perspective (5.1.3)

[32] Enablers for MAR adoption in the Coleambally Irrigation Area (Section 5.6.1)

[33] Costs of purchasing high security water entitlements (Section 5.4.4)

High security entitlements are currently limited and high cost ($1,950 to 8,500/ML), such that they are more likely to be used for higher value crops such as nuts, rather than specifically to ensure supply chain and community sustainability. If by some means, high security "community sustainability entitlements" were made available, major decisions would still need to be made around the distribution and use of those entitlements. Water use is large compared to the capacity of the reservoirs, such that only a limited demand could still be met. The storage capacity and reliable inflows of existing dams may not be sufficient to meet the dry year water requirements of all irrigation-dependent towns [34]; MAR would help increase this capacity.

In terms of providing water security, the primary difference between the MAR scenarios and existing reservoirs lies in more direct control over the storage itself because the CICL can manage the MAR schemes, compared to WaterNSW management of the regional storages. However, this depends on regulations on the recovery of recharged water, which still need to be established.

Further investigation into the role of high security surface water entitlements for community sustainability was out of the scope of this project but may be of interest in future research.

4.4.2 Survival water for drought through policy change

More generally, other arrangements for water sharing in times of drought could also be revisited. In particular, it has been argued that environmental water could be used differently, as the priority in drought times is on provision of refuges and maintaining water quality rather than flood flows. To provide one example of this line of thought, NSW Nationals Senator Perin Davey has discussed potential rules requiring the Commonwealth Environmental Water Holder (CEWH) to sell half of the water held in a region on the water market when it is affected by severe drought, which in turn provides income for CEWH to use in other periods [35].

This scenario would need to be revisited once specific policies are put forward, but again, water availability would be limited by dam storage, and the effects of distribution of water on community sustainability would need to be examined. In particular, if water were made available on the open water market, then like high security entitlements they would likely be used for higher value crops rather than to maintain community sustainability more generally.

4.5 Integrated groundwater and surface water delivery

Perhaps the simplest argument for MAR is that it makes sense to manage groundwater and surface water together, and that MAR is one available technique to do so that involves transferring surface water into aquifers. CICL could strengthen their water management role to become the custodian and active manager of both surface and groundwater for the region.

Given the ubiquity of water use metering in Australia, it makes sense to think of MAR in terms of volumes of water recharged and recovered. MAR is, however, already common around the world in contexts where the volume of water is not known, or is a lesser concern. In India, the USA, and the lower Burdekin in Queensland, MAR is used above all as a way of replenishing the aquifer rather than making water available for a later time [36].

In the context of Coleambally and CIA area of operations, it is important to recognise that groundwater use is already widespread, with 92 GL used in 2019/20 from 137 wells [37]. "Conjunctive" use of surface water and groundwater is

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[34] Water management in the Murrumbidgee (Section 3.1.2)

[35] Water management in the Murrumbidgee (Section 3.1.2), https://www.damiandrum.com.au/19-12-05/

[36] A brief history of MAR schemes in Australia (Section 1.3)

[37] Conjunctive use of groundwater and surface water (Section 5.2.5)

already common [38]. Total surface and groundwater volumes are reported together in CICL annual compliance reports, with WaterNSW providing groundwater use data.

The next step in the integration of groundwater and surface water use is to track them with near-real-time monitoring in order to better account for groundwater use in planning of surface water delivery [39]. CICL already has a strong interest in groundwater through its extensive network of piezometers used to track the water table and risks associated with groundwater salinity. Closer tracking of groundwater use helps to complete this picture and would also enhance the ability to avoid shallow water tables in wet periods. Understanding of conjunctive use over time could allow CICL to play a more active role in assisting members in planning and coordinating their groundwater pumping and surface delivery, and addressing concerns related to pumping rates, pumping costs, and water quality[40].

In dry years, when low demand for water deliveries and high evaporation reduces the efficiency of surface water delivery, it is already the case that sections of channels are kept empty. In a context in which CICL has developed expertise in supporting access to groundwater, it becomes conceivable that member orders for water are delivered entirely through groundwater pumping, potentially dramatically reducing the volume of conveyance water needed [41]. Conveyance water not used for surface water delivery could instead be utilised through MAR, allowing the scheme to run even in dry years [42].

Careful management of groundwater levels across the region may allow changes to the WSP to allow existing rules for available water determinations to be revised. Rather than being limited directly by long-term average annual extraction limits, minimum and maximum groundwater levels could be specified across the region, with the aquifer operated like a reservoir. During a drought, the aquifer would be pumped to the limit, and in wet years, the aquifer would be gradually refilled until full storage is available. This is a natural extension of the recent NSW policy to allow greater pumping in dry years, and less in wet years. While the policy change for this scenario is a more radical change, strengthening the technical and institutional capacity to manage groundwater is a logical first step.

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[38] Conjunctive use of groundwater and surface water (Section 5.2.5), Enablers for MAR adoption in the Coleambally Irrigation Area (Section 5.6.1)

[39] 'Integrated groundwater-surface water delivery' in Responses to scenarios (Section 5.6.3)

[40] 'Potential space in the aquifer' and 'Aquifer Pumping Rates' in How much water can be recharged? (Section 5.3.1), Levelised cost of MAR water (Section 5.4.3), Water quality risks (Section 5.5.3)

[41] Water management in the Murrumbidgee (Section 3.1.2), Variability of water allocations (Section 5.1.1), CICL water budget (Conveyance, Channel seepage and evaporative losses) (Section 5.2.4)

[42] Water management in the Murrumbidgee (Section 3.1.2), Variability of water allocations (Section 5.1.1), CICL water budget (Conveyance, Channel seepage and evaporative losses) (Section 5.2.4)

5. Feasibility Criteria Analysis

This section presents the data, information, analysis and assumptions that have been made in order to inform the potential feasibility of the six scenarios presented in Section 4 across the seven criteria outlined in Table 4. An overview of key points for each scenario and feasibility criteria is given in Table 5.

Table 4 The seven feasibility criteria of Ticehurst and Curtis (2017).

Criteria	Example questions and considerations
Demand for Water	• Is there demand for more water, or a greater water security? • Who wants the water and when?
Water availability	• Is water available to be banked underground (e.g. unused surface water shares, surface water traded in when prices are low)?
Technical feasibility	• Is there space in the aquifer systems to store surface water for drier times? • How can the water be recharged, stored and extracted?
Financial viability	• Financial viability and profitability of MAR schemes are influenced by many factors including the MAR type, water source, infiltration and recovery rates, groundwater depth, water markets, crop prices and yields, groundwater pumping costs
Environmental risks	• Are there any significant effects on water quality & quantity (positive or negative)? • What are the consequential impacts of any change on farm land and ecosystems?
Social acceptability	• Is it a socially acceptable option to irrigators, stakeholders and the wider community? • What are people's values, knowledge and beliefs about MAR? • Do they perceive risks about its implementation in their region?
Governance arrangement	• Are the legislative and policy settings appropriate to support a MAR system? • If not, how would they need to be changed?

Table 5 Summary of the scenario feasibility (for further detail refer to the section headings in parentheses).

Scenario	Don't miss a drop	Multi-year Surface Storage	Storing water for community sustainability	Community sustainability through high security entitlements	Survival water for drought through policy change	Integrated groundwater and surface water delivery
1. Effective demand for products	Variable and low allocations mean that water is valuable and fully using entitlements is worthwhile (5.1.1)		While cotton is an opportunistic crop, evening out peaks and troughs could allow greater investment in supply chains, infrastructure, justify cost of pickers, and take-up of forward contracts, allowing farmers to farm and the community to endure extended dry period (5.1.1, 5.1.2, 5.1.3)			Irrigators use both groundwater and surface water entitlements. Increased groundwater use in drought is limited by long term SDL and MAR could allow increases (5.1.2)
2. Water availability	During long events with wet antecedent conditions, supplementary allocations that would otherwise be forgone by members could be banked (5.2.2) Water entitlements that cannot be carried over could also be banked (3.1.2, 5.2.1, 5.2.3)		Long term storage of part of conveyance and general security allocations (487 GL held in 2019) (5.2.1, 5.2.4)	Current high security surface water entitlements for Coleambally are approximately 8.4 GL (5.4.4). More would likely need to be acquired in some way	Requires a serious change in how water is allocated during times of drought, for example, allowing environmental water allocations (3.1.2) to be sold on market	Managing surface and groundwater conjunctively means that the focus is on balancing reservoir and aquifer levels. Only using groundwater in dry years may free up conveyance water (5.2.4, 5.2.5)
3. Technical feasibility	High flows capture is limited by main channel intake and recharge rate across multiple infiltration and injection sites (5.3.1 5.3.2, 5.3.4)	To allow interannual storage, large dams, likely with high evaporation would be needed. (Box C)	Preliminary suitability analysis suggests it is possible. However, further testing would identify best locations and mechanisms for long term recharge (5.3.3, 5.3.4)	Existing reservoirs would be used, change is only in allocation and governance	Existing reservoirs would be used, change is only in allocation and governance	Focus on managing drawdown rather than recharge volumes reduces barriers to operation (5.1.3, 5.3.3)
4. Financial viability	Levelised cost of MAR water is competitive with market value of water in dry years (5.4.3)	Large corporations in the region have found it viable, with government subsidies (5.4.2)	Benefits for viability of co-operative and sustainability of community can warrant additional co-investment (5.4.4)	Expense of high security water entitlements would require support for market purchases or reallocation (5.4.4)	The freed (environmental) water would be available on the water market, and likely to attract high prices similar to high security entitlements	Investment would be shared between MAR and delivery infrastructure, as well as improved groundwater monitoring
5. Environmental risk	Capture of full supplementary water allocations may affect environmental flows, and be further regulated (5.5.1, 5.5.2)		Artificial recharge does come with potential risks for water quality (5.5.3)	Negligible – little change from current reservoir operations, greater water in dry years in the irrigation district	Environmental risk managed by the Commonwealth Environmental Water Holder to meet dry and wet year objectives, subject to best available knowledge, prior to releasing water.	Explicit management of groundwater levels benefits from understanding of effects of drawdown on dependent ecosystems. (5.5.4)

Table 5 (continued) Summary of the scenario feasibility (for further detail refer to the section headings in parentheses).

Scenario	Don’t miss a drop	Multi-year Surface Storage	Storing water for community sustainability	Community sustainability through high security entitlements	Survival water for drought through policy change	Integrated groundwater and surface water delivery
6. Social acceptability	Multi-stage pilot projects can resolve community concerns and minimise initial investment risk (5.6.1, 5.6.3)	There has been public opposition to other large dams built in the region	Coleambally is an innovative co-operative and district with potential to lead the way in management of district-scale water resources(5.6.1)	Not all communities could use this strategy. High security would need to be seen as community entitlements rather than high value entitlements, otherwise there would be pressure to sell water	Not all communities could use this strategy. Freed (environmental) water would need to be seen as community entitlements; likely to be contentious within and outside the Murrumbidgee	Long term transition would involve greater understanding of current groundwater use and availability, integration into surface water delivery operations, and coordination of water sources before integrating managed aquifer recharge (5.6.1, 5.6.3)
7. Governance arrangements	Injection is subject to NSW Aquifer Intervention Policy, any project will require project assessment process or new water recovery rules (5.7.2, 5.7.3, 5.7.4)	Other large dams have been successfully completed and audited	Large scale community projects can be developed collaboratively with local, state and/or national government with project-specific assessment processes (5.7.1, 5.7.2)	Possible now within water market mechanisms	Current water sharing arrangement would need to be revised, for example, to allow for the sale of environmental water when deemed necessary and when critical environmental needs are met.	Possible now with approval through NSW Aquifer Intervention Policy, but decisions on groundwater use restrictions would need to account for drawdown to guarantee access in drought periods (5.7.2)

5.1 Effective demand for products

The feasibility of a ‘new’ water management option requires some level of ‘demand’ for change, as this will enable the adoption of new practices. In this case, we are considering either:

- increasing the volume of water available for consumptive use, and/or
- evening out the peaks and troughs in water supply to create greater water security from one year to the next.

To assess the effective demand for either of these, we first explore the variability in water available for the water delivery company (CICL) and irrigators themselves (Section 5.1.1), and then present findings and feedback from the interviews and stakeholder workshops on the demand for change in water management from irrigators at a farm level (Section 5.1.2), and the cotton industry as a whole (Section 5.1.3).

5.1.1 Variability of water allocations

As shown in Section 5.2, CICL conveyance water is a reasonably secure supply of water (although not classified as such). Figure 12 shows that CICL is allocated above 85% each year shown. Assuming a full CICL entitlement of 130 GL and the allocation for that water year, from 2013/14 to 2018/19 (i.e. over the last five years), a total of 69.1 GL was foregone allocation due to the dry conditions (Figure 12).

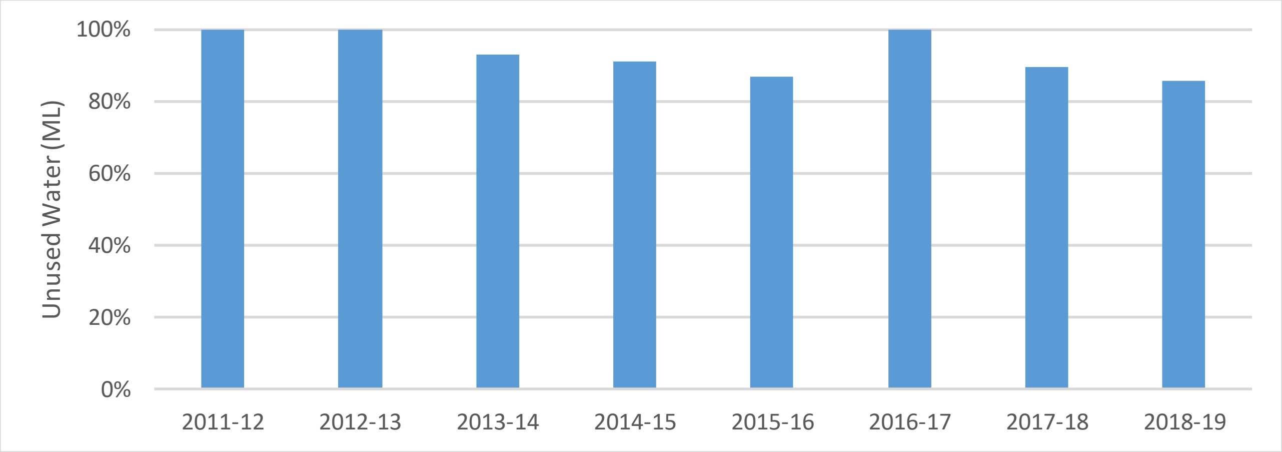

Figure 12 End of season allocation for Coleambally for conveyance for each water year (Source: Murrumbidgee allocation data from NSW water register)

Looking at irrigators’ general security entitlement in the CIA (which is the same as for the wider Murrumbidgee Regulated River Source), in only four of the last 14 years allocation was 100% (Figure 13). This means that 71% of the time general security allocation is below 100%. If these allocations were averaged over this period, it gives an allocation of 55%.

Figure 13 End of year percentage allocation for general security (GS) licenses on the Murrumbidgee regulated source (Source: Murrumbidgee allocation data from NSW water register)

The timing of cumulative allocation announcements over the duration of a water year has been identified as a potential reason for ‘underuse’ of water (RMCG, 2019). In years where initial announcement in early July are low, irrigators may choose not to plant a crop on some or all of their available land. MAR might provide irrigators some confidence to commence planting if they believe they can recover sufficient volumes of water at the required time, to establish crops.

MAR could potentially improve delivery efficiency by providing a means of capturing rain rejection flows, and so may be a strategy of interest beyond irrigators (e.g. environmental water managers, river operators).

5.1.2 Irrigators’ perspective

Talking to irrigators, it is clear that some local cotton growers view cotton as an opportunistic crop, only planting when the surface water is freely available (“*I’m happy to ride the booms and busts in water supply*”; *“The beauty of annual crops is that you can turn them on and off with the water* supply”). If the allocation is too low to support a crop, then farmers sell their available water, at a premium price given the dry conditions (“*13% of people haven’t done anything with their water this year because there isn’t enough water to grow anything, and you can get $300/ML on the market.*”). Trading their surface and groundwater enabled one irrigator to keep up the lease repayments and focus their activities on preparing their ground for next year by bringing in manure. Others have also diversified to other products that are not as strongly dependent upon irrigation water supply.

However, the majority of cotton growers would prefer a more secure supply of water that allows them to continue their irrigated crop production over other activities, even if it may be less profitable. One irrigator said that although irrigators could make money by selling their water entitlement in dry years, they would preferentially grow a crop to make money because *“farmers want to farm ... we’re here to farm”*. This irrigator said that *“I’d rather be growing cotton than doing the washing”*, highlighting the non-financial benefits that they get from their production activities. On a similar vein, another irrigator noted they would ‘*rather be producing a crop from the water rather than just selling the water because of depression’*. This irrigators said his neighbour has not grown a crop for three years and instead he *“does nothing”*.

Less variable water supply is particularly beneficial to irrigators who are locked into contracts for cotton supply, and/or have investment in on-farm capital which requires a more consistent supply of product in order to pay off loans and keep machines in good working order. With an increasingly uncertain climate, less variable water supply is a growing concern. One irrigator who stressed the need for a consistent supply of water said that “*The idea of banking water never seemed needed in the region, but with climate change, more big rainfall years and drought [it does now]*”. This same irrigator highlighted the challenge for irrigators dependent on general security licenses, saying “*I would like to think that we can use it to decrease the economic impact of general security licences. General security licence holders will suffer most from climate change*.”

5.1.3 Industry and community perspective

The area of cotton production in the Murrumbidgee area fluctuates with available water. Cotton in the region is highly dependent on irrigation water, more so than in other cotton growing regions in Australia, given the rainfall pattern is not well suited to cotton growth. For example, irrigation water requirements in the Murrumbidgee are 10-11.5 ML/ha, while in the Gwydir and Namoi its 4-5 ML/ha. In dry periods the area planted to cotton in the Murrumbidgee is 10,000 to 15,000 ha while in peak seasons 90,000 ha is produced.

Evening out the peaks and troughs in water supply so that a more consistent area of cotton could be grown each year is preferred by the two local gin operators spoken to for this research. While one gin operator spoke of ‘coping’ with the peaks and troughs in water and therefore cotton supply, another said that *“More consistent water would absolutely be better”*. In the 2019-20 season, one of the local gins will see a 60% drop in cotton bales [43] being

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[43] 1 bale is 227 kg (Roth et al., 2014)

delivered for processing from the previous season, with cotton being processed by only 36% of growers who produced in 2018-19.

The impact on the gin's processing season and the flow-on impact for employment in the local community is pronounced. For example, this poor water season has halved the number of staff that the gin can employ from a typical year, and the period of time that they can employ them (i.e. 10 weeks rather than 5 months). The production efficiency is also reduced, as in a typical season the processing machinery will be kept running for 24 hours a day 7 days a week until the end of the processing season. In this season, the machinery will only be run for 18 hours a day in off-peak periods (9 pm to 5 pm) to reduce costs. Consequently, the machinery has to be warmed up each day. As the machinery has had less use throughout the season, the level of maintenance required at the end of the season is also reduced, so fewer staff are required to stay and carry out the maintenance. Consequently, local staff have been finding work in cotton growing regions overseas, including the USA. The fear is that you "*can only find alternative duties* [for staff in low production years] *for so long, so if next year's low again I don't know what will happen*".

For this gin, an ideal number of cotton bales to process each year would be 120,000 to 150,000. With that volume of bales, the blades would not have to be replaced during the processing season, but it would provide enough work that you could maintain people in local employment. The aim is for a rotation through local agricultural industries with some of the winter crops such as grapes, and therefore maintain employment throughout the year. *"You get better staff if you offer better conditions"*, and it reduces the need to retrain people if they can come back again the next year. An estimate of the volume of water needed to produce this range is in Box A.

Other community impacts of the 2019-20 dry season water were identified with one cotton grower saying that they had not employed anyone this year whereas they would *"normally employ up to two backpackers in a fully blown season"*. Another irrigator, interviewed in early November, said that the Coleambally Newsagency closed last week and the population has declined [in response to the water scarcity and pressures placed on the irrigation-dependent community]. However, this irrigator also felt that *"Selling water is just as good to the community"* as is using it to grow crops.

BOX A An estimate of the amount of water needed to produce 120,000 to 150,000 bales

An estimate of the potential water needed in the CIA to achieve this ideal production has been calculated using some numbers provided in Roth et al. (2014). These authors described the upward trend in the Irrigation water use index (IWUI)[a] between 2001 and 2012; by 2012 this had increased 97% from 1.10 bales/ML in 2001 to 2.17 bales/ML. Assuming an irrigation water index of 2.17 bales/ML (the 2012 value), the volume of water needed to reach the ideal range is 55,300-69,124 ML.

An alternative measure of water use in irrigated cotton is Gross Production Water Use Index (GPWUI) [a]. As a worst-case scenario, if all water inputs for irrigated cotton were to come from irrigation alone, then the water requirements would be larger. For example, based on the 2010/11 average GPWUI of 0.94 bales/ML, 127,659 ML and 159,574 ML would be required to produce 120,000 to 150,000 bales, respectively.

During dry years the extraction of previously banked MAR water at a lower cost than purchasing on the water market could be used to help growers reach these targets, ultimately softening peaks and troughs in water availability in the area.

[a] The Gross production water use index (GPWUI) is the gross amount of lint produced per unit volume of total water input. The total water input includes irrigation, rainfall, and total soil moisture used. The IWUI is similar to the GPWUI but relates cotton production only to the amount of irrigation water used (Roth et al., 2014)

5.2 Water availability

The trend in Coleambally entitlements for surface water are shown in Figure 14. In 2018, there was 487 GL of entitlement on CICL's license, most of which is irrigators' general security licenses (73%, 357 GL) and CICL conveyance (24%, 117 GL).

5.2.1 General security entitlements

In years when 100% general security allocation was made (i.e. 2010-11, 2011-12, 2012-13 and 2016-17; blue row in Table 6) the percent of general security entitlement used ranged between 37% (2010-11) and 75% (2012-13), on average being 56%. The range in use is influenced by the timing of the rainfall that contributed to the surface water volumes in storage and thus the allocation volumes. If there is a dry start to the season, then a smaller area of irrigated crop would be planted, and this would contribute to a lower use of irrigation water for the season, regardless of the final volume of water available. Also, a large volume of rainfall during the main irrigation period (i.e. December to February) would increase total allocations, but also decrease the need for irrigation water because crop needs can be met by rainfall. This would also then result in a lower than expected use of water such as in 2010-11. Conversely, 2012-13 began with a high initial allocation of 64%, so the area planted to irrigated crop was higher, and the total percent of general security used was also high (75%).

In the case when a large volume of general security allocation is not used in a season, any allocation exceeding the 30% allowable limit for carryover will be returned to the 'common pool' of water stored in the surface water stores. Thus the irrigator loses their direct entitlement to that water. In the case of 2010-11 only 37% of general security allocation was used by the end of the season, leaving 30% to be carried over, and 33% foregone back to the 'common pool' for reallocation. Therefore, MAR could increase total water available by one of three means: 1) store excess carryover that cannot be stored in the reservoirs (a rare occurrence); 2) store excess carryover that the license holder would otherwise lose to the common pool - at the expense of other license holders who would have benefited from that water in the subsequent year; 3) store carryover in such a way that total evaporation losses are reduced while maximizing the proportion of MAR water that can be recovered.

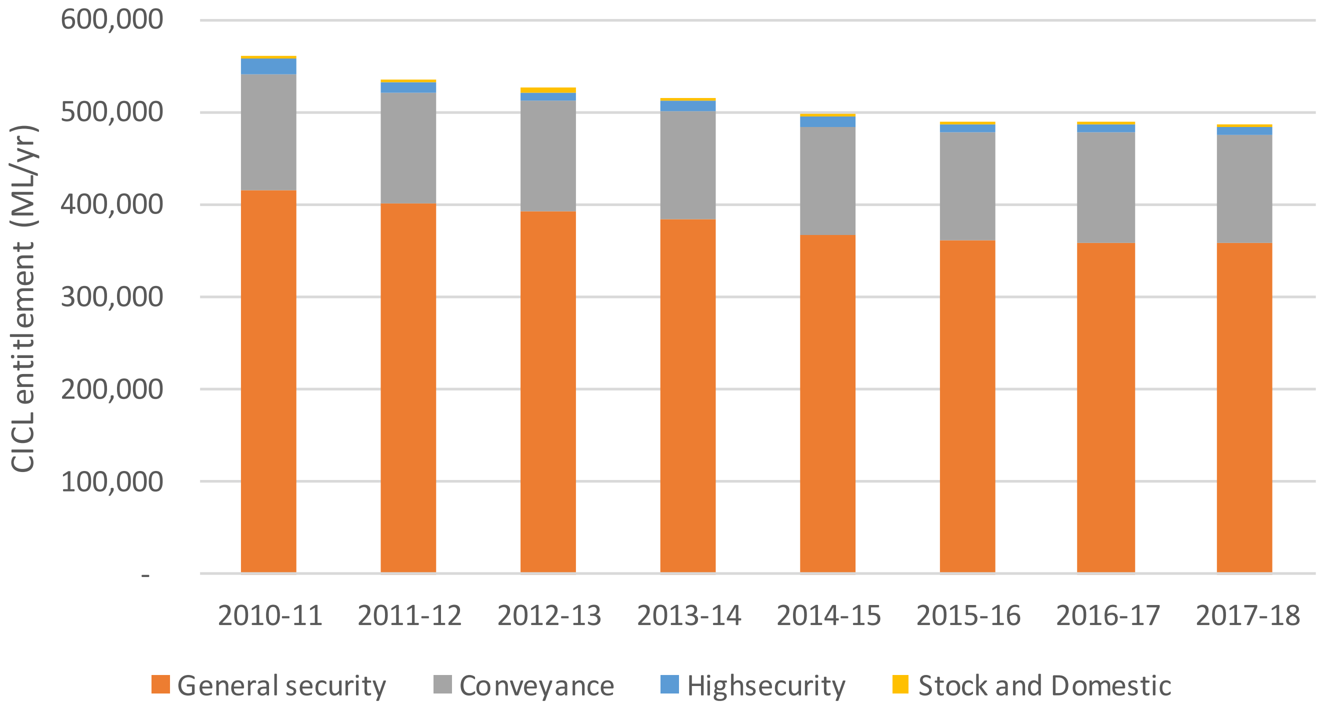


Figure 14 Water entitlement on CICL's license (Source: Murrumbidgee allocation excel file, CICL annual reports).

Table 6 Available water under the general security license for the Murrumbidgee Regulated River source. Years with 100% allocation are highlighted in blue.

Year	Total Share Component (ML/share)	Cumulative AWD Unit (Allocation)	Water made Available (ML)	Usage (ML)	General Security usage (%)
2004-05	2,029,465.7	0.4	812057.5	865890.6	107
2005-06	2,033,284.7	0.54	1095939.7	1267312.3	116
2006-07	2,033,284.7	0.15	304996.3	357015.7	117
2007-08	1,918,405.7	0.13	264334.7	75216.2	28
2008-09	1,892,021.7	0.21	401712.7	195261.1	49
2009-10	1,891,994.7	0.27	510863.3	272756.5	53
2010-11	1,891,994.7	1	1892019.7	698932.6	37
2011-12	1,891,994.7	1	1892009.7	1022492.9	54
2012-13	1,891,994.7	1	1891993.9	1417269	75
2013-14	1,891,994.7	0.63	1191998.2	959067.5	80
2014-15	1,891,994.7	0.53	1002770.1	1104998.9	110
2015-16	1,891,994.7	0.37	700062.3	643994.3	92
2016-17	1,891,994.7	1	1892019.3	1130707.1	60
2017-18	1,891,994.7	0.45	851421.2	1128720.8	133
2018-19	1,891,994.7	0.07	132446.4	400712.8	303

Surface water trade

The CICL do not partake in the surface water trade market so it has not been included as a potential source of water for the current project. However, in the event that pilot studies in the CIA take hold, and MAR becomes active in the region, local irrigators could buy-in allocation when water is cheap, and bank that to add to their general security allocation.

In this case, the Murrumbidgee has an active trade market moving 514,201 ML within and 150,739 ML into the region in 1,533 transactions in 2017/18 (Aither Pty Ltd, 2017). Over this period Aither Pty Ltd (2017) reported that the price of water varied between $20/ML and $300/ML (Table 7). One irrigator felt that *"The water market works very well, despite what you see in the media"* and considered water trading to be a 'big part of the program'.

Table 7 Water markets in New South Wales 2017-18

Region	Lowest Price	Highest Price	Lowest volume	Highest volume
Murrumbidgee	$20/ML	$300/ML	20 GL	190 GL
Lachlan	$20/ML	$450/ML	4 GL	124 GL
Macquarie	$30/ML	$510/ML	2 GL	84 GL
Upper Namoi	$40/ML	$200/ML	0 GL	2 GL
Border rivers (NSW)	$40/ML	$210/ML	0 GL	3 GL
Peel	$40/ML	$430/ML	0 GL	4 GL
Lower Namoi	$80/ML	$300/ML	5 GL	22 GL
Gwydir	$120/ML	$300/ML	1 GL	30 GL

Source: reading off plots given in Aither (2017)

5.2.2 Supplementary entitlements

The supplementary entitlement for the Murrumbidgee Regulated River Source is 198.78 GL. The full supplementary entitlement has never been used to date (Figure 15), although it is unclear whether that is because irrigators were unable to extract the water quickly enough from the supplementary event to take their full entitlement, or whether it is because they were limited by the volume of storage that they had available to hold any take.

CICL members have access to a maximum of 20,407 ML of supplementary water. Extraction depends upon pump capacity, storage capacity and length of the event. In 2017/18 only 25% of supplementary water was used because there was not the storage capacity to take the remaining 15,663 ML (Figure 16). Other years, due to timing and location of rainfall, all supplementary water is used.

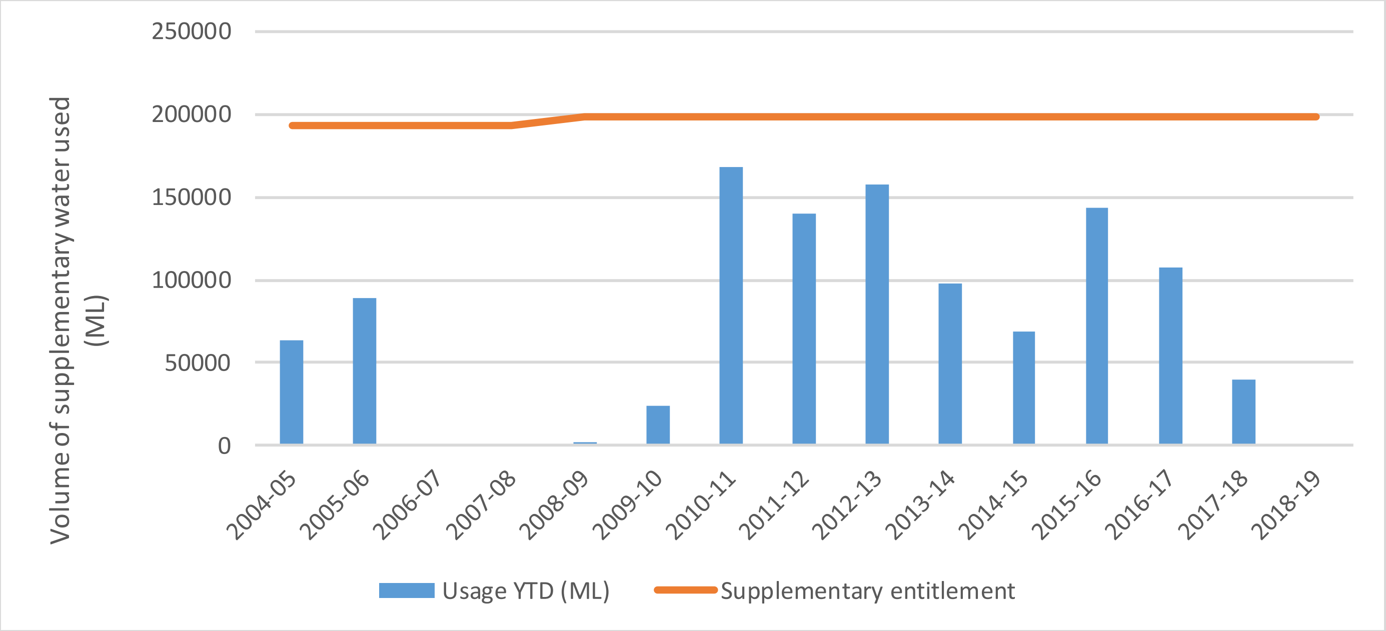


Figure 15 The volume of supplementary flow taken each water year from the Murrumbidgee Regulated River source.

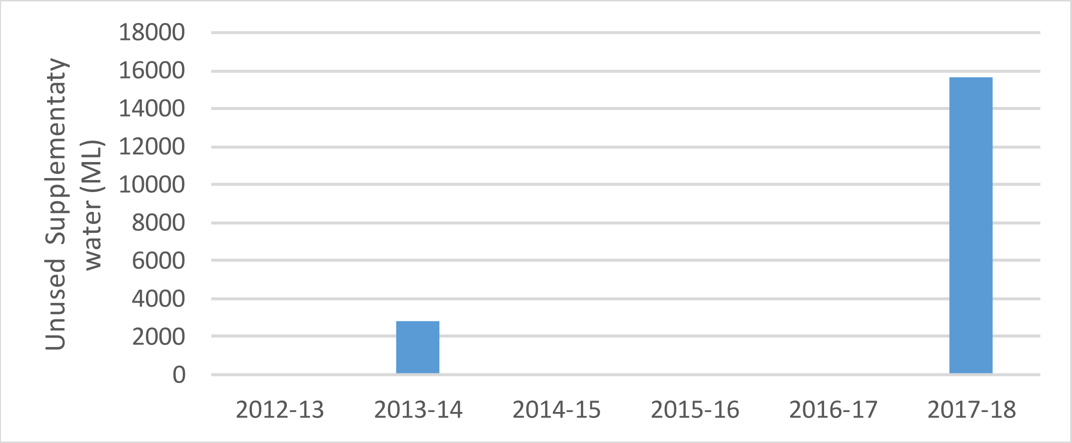


Figure 16 Unused CICL supplementary water since the 2012-13 water year (Source: Murrumbidgee allocation excel spreadsheet)

5.2.3 High security water

Less than 2% of irrigators have high security licenses. It is unlikely that stock and domestic or high security licenses would be banked, because their current supply is already very secure, but, given that high security licenses cannot be carried over, MAR would offer an opportunity for high security water to effectively be carried over.

5.2.4 CICL water budget (conveyance, channel seepage and evaporative losses)

CICL conveyance entitlement is 130 GL, but due to decreased water availability, it has recently been less than this such as 103.2 GL in 2018/19 (Table 3; Water entitlements for the Murrumbidgee River.) The CICL use about 90% of their conveyance allocation each year (Figure 17). Leaving about 10 GL each year left unused. In wet years of full allocation such as 2011-12, only 79% was used (leaving about 41 GL unused).

Of the water that is 'used' it is estimated that about 10.5 GL is lost to evaporation from the channel system (Table 8), and 3.7 GL is deemed lost to seepage because there are not the means in place to currently account for this water as recoverable aquifer recharge.

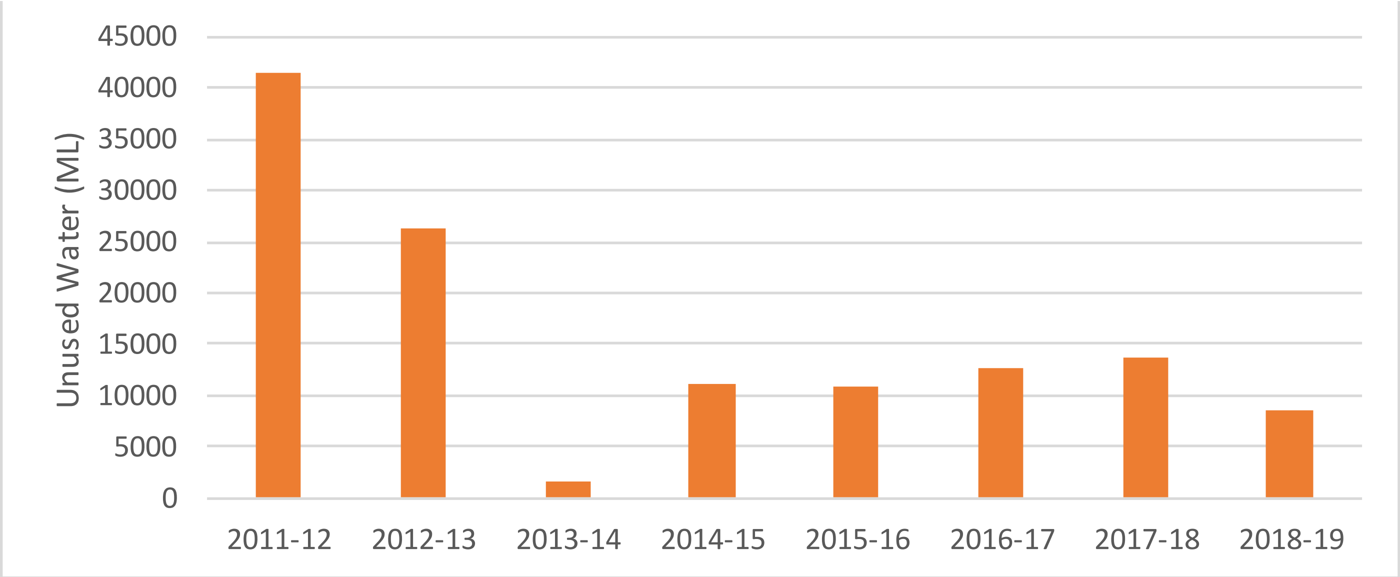
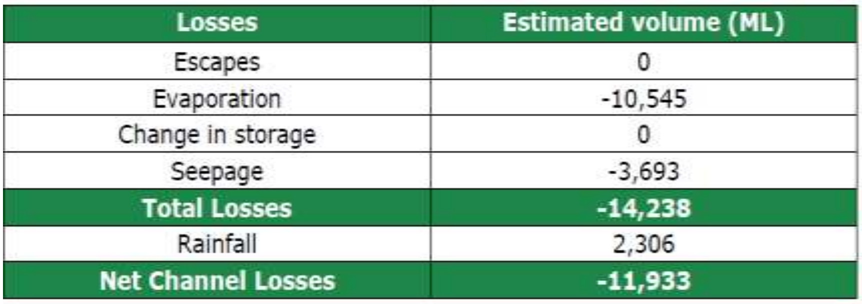


Figure 17 Unused CICL conveyance water (Source: Murrumbidgee allocation excel spreadsheet).

Table 8 Net channel loss accounting (Source: Table 4.3 in CICL compliance report 2017-18)



Losses	Estimated volume (ML)
Escapes	0
Evaporation	-10,545
Change in storage	0
Seepage	-3,693
Total Losses	**-14,238**
Rainfall	2,306
Net Channel Losses	**-11,933**

5.2.5 Conjunctive use of groundwater and surface water

In addition to surface water entitlements, CICL also has access to groundwater, through a Lower Murrumbidgee Groundwater aquifer licence [44]. This is used to supplement surface water, particularly CICL's conveyance licence water and winter water supply [45]. A substantial number of members also hold their own groundwater licenses. In the 2019/20 water year, 92,204 ML of groundwater was used across the CIA, WCC and Coleambally External reporting area, extracted from 137 bores, which was a decrease compared to 2018/19 (110,978) and 2017/18 water years (102,991 ML) (CICL, 2020b). Overall groundwater extraction from both the Lower Murrumbidgee shallow and deep aquifer in recent years is shown below (Figure 18 and Figure 19).

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[44] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 15 April 2020

[45] https://www.accc.gov.au/system/files/Water%20inquiry%20-%20Submission%20-%20Coleambally%20Irrigation%20Co-operative%20Ltd%20-%2029%20November%202019.pdf, accessed 15 April 2020

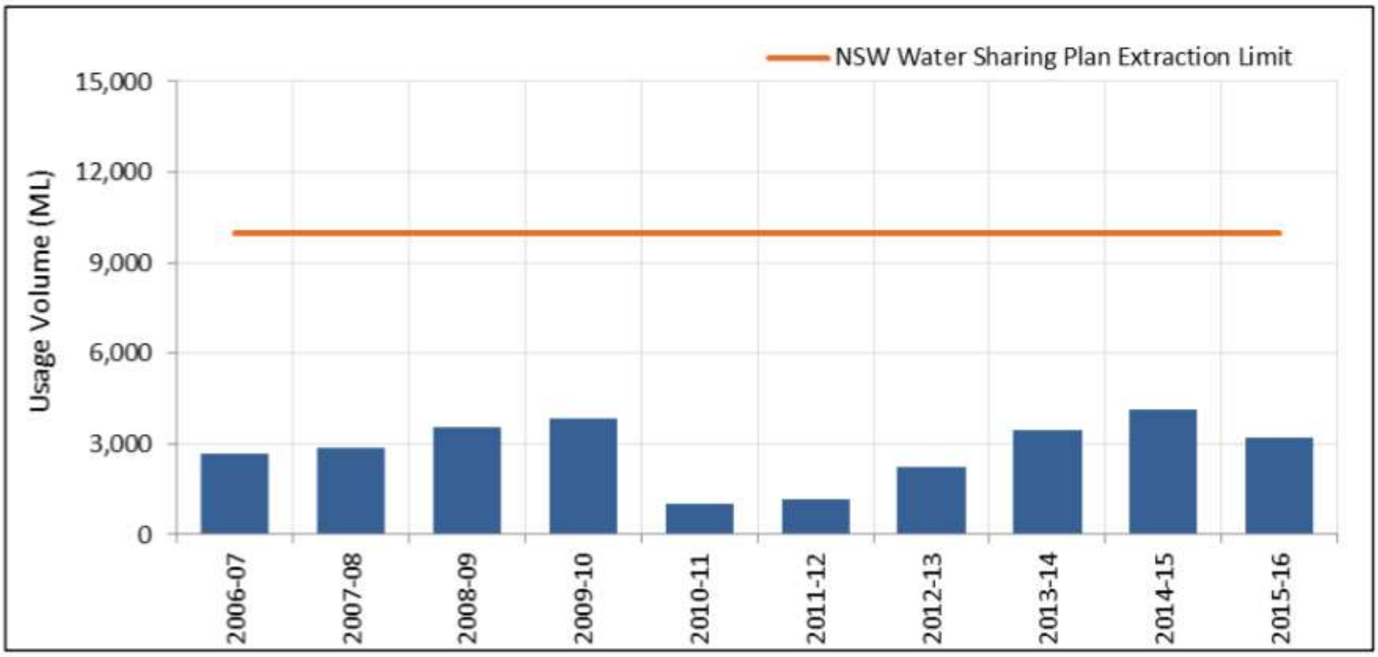

Figure 18 Groundwater extraction from the Lower Murrumbidgee shallow aquifer (Source: https://www.industry.nsw.gov.au/__data/assets/pdf_file/0011/157358/Murrumbidgee-GW-WRP-SIP.pdf, accessed 15 April 2020)

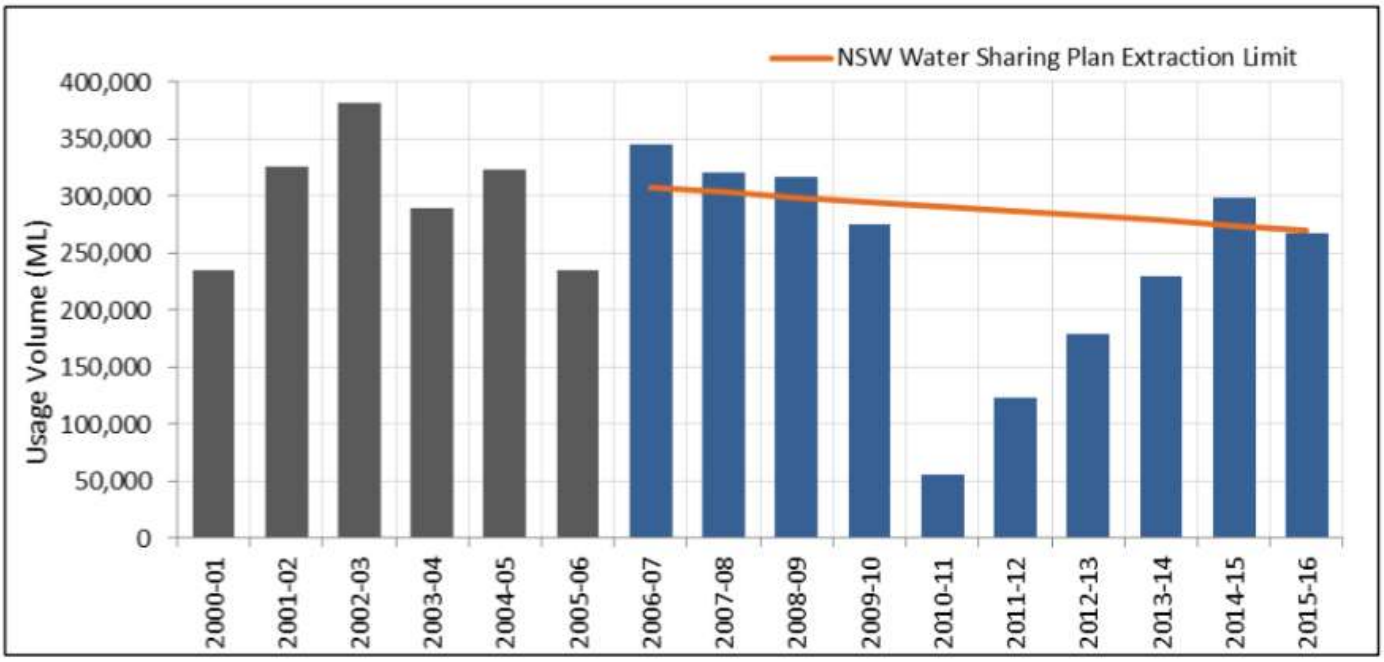

Figure 19 Groundwater extraction from the Lower Murrumbidgee deep aquifer (Source: https://www.industry.nsw.gov.au/__data/assets/pdf_file/0011/157358/Murrumbidgee-GW-WRP-SIP.pdf, accessed 15 April 2020)

5.3 Technical feasibility

This section is structured to provide information on aquifer and soil characteristics (Section 5.3.1 and Section 5.3.2) and then to inform the design, planning and implementation of MAR strategies (Sections 5.3.3 to 5.3.6).

5.3.1 How much water can be recharged and extracted?

Aquifer characteristics

In the Lower Murrumbidgee, the Shepparton Formation overlies the deeper Calvil/Renmark Group (Kumar, 2009). The recharge of the Shepparton Formation and the Calvil/Renmark Group is 65,000 ML/year and 335,000 ML/year, respectively (Kumar, 2009). The Shepparton Formation averages 65 m thick (Kumar, 2010). The semi-confined to confined Calvil and the confined Renmark Formations have a maximum thickness of 90 m and 366 m, respectively (Kumar, 2010). Further aquifer characteristics for the Shepparton, Calvil and Renmark Formations are presented in Table 9. The volume of freshwater reported by Khan (2009) in Table 9 may be error, possibly being underreported by a factor of ten. Unfortunately, further clarification was unable to be found. It should also be noted that the freshwater volumes reported in the Table 9 are not an indication of the amount of water that can extracted from the formations, as this is limited based on the specific yield and, more importantly, adverse impacts associated with over extraction/excessive drawdowns (e.g. significant subsidence).

Table 9 Characteristics of the aquifers in the lower Murrumbidgee reported in Kumar (2010).

Description	Shallow (Shepparton)	Deep (Calivil/Renmark)
Age of water (years)	up to 3,000	2,000-20,000
Water Quality (mg/L)	Variable, generally 1,500-7,000, fresher quality closer to river and within irrigation areas.	Generally less than 1,000 in eastern parts, approximately over 40% of Groundwater Management Area (GMA).
Yields (L/s)	Variable, generally between 0.1 – 10, occasionally >10.	Variable, generally 50 - 350 occasionally >350.
Groundwater flow direction	generally east to west	generally east to west
Hydraulic gradient	1:4,300 (eastern part of GMA) 1:5,000 (western part of GMA)	1:1,900 (eastern part of GMA) 1:7,200 (western part of GMA)
Estimated rate of flow (m/yr)	0.04-0.20	0.1-11.5
Hydraulic conductivity (m/d)	0.5-2.0 (groundwater model)	2.0-60.0 (groundwater model)
Specific Yield/Storage Coefficient	0.10-0.25 (groundwater model)	1.00E-05 to 5.00E-03 (groundwater model)
Average thickness	65 m	100 in the eastern parts, >100 in the west
Volume of groundwater in storage (x1,000 GL)	532.5 (assuming a porosity of 0.25)	1,515.6 (assuming a porosity of 0.25)
Recharge to storage ratio	1:1,400	1:6,000
Volume of fresh groundwater in storage (x1,000 GL)*	19.8 (assuming 37% of aquifer only)	330.0 (assuming average aquifer thickness of 100 m in recharge areas and 40% of aquifer only)

* Note the potential error in this table noted in the previous paragraph.

The groundwater quality, particularly salinity, in the above aquifers varies spatially, with areas of low salinity associated with freshwater recharge (Khan et al., 2008a).

Potential space in the aquifer

Vertical flows from the Shepparton to the deep aquifers were estimated to be 31.0 GL in the 1999-2000 water year (Khan *et al.*, 2008b; Chen *et al.*, 2012). This value is greater than older estimates due to the decline in deep aquifer pressure as a result of increased groundwater pumping (Khan et al., 2008b). That is, increased deep aquifer extraction leads to increased vertical flows between the shallow and deep aquifers in the region.

Generally, groundwater storage in the CIA has shifted down in depth (i.e. there is less groundwater stored in the 4 m below the surface than in the past)[46]. During dry conditions, it is common for the combination of higher groundwater pumping and limited recharge to cause declines in the shallow aquifer under the CIA (Khan et al., 2008b). During one year (March 2002 – March 2003), these declines varied spatially between 0.5 – 2 m (Figure 20; Khan et al., 2008b). The area with the greatest decline (northeast region of CIA, near the main intake canal; Figure 20) is associated with higher vertical flow between the Shepparton and deeper aquifers (Khan et al., 2008b). Therefore, this area may be highlighted as a target area for a pilot infiltration scheme, to quicken the time taken for water to get from the shallow to the deep aquifer.

Based on calculations using the area of CIA (Khan et al., 2008b), the storage coefficient reported by Kumar (2010) and an average drawdown of 0.5 m in the Shepparton shallow aquifer, a total of 40 GL could be stored. Drawdowns in excess of 12 m have been recorded in the deeper aquifers under CIA (Figure 21; Khan et al., 2008a), which reduces the pressures in the deeper aquifer and means that "space" is available. Injection schemes have been suggested in the CIA area that would target the deeper aquifers directly, with the injection of 90 GL per year (Khan et al., 2008a).

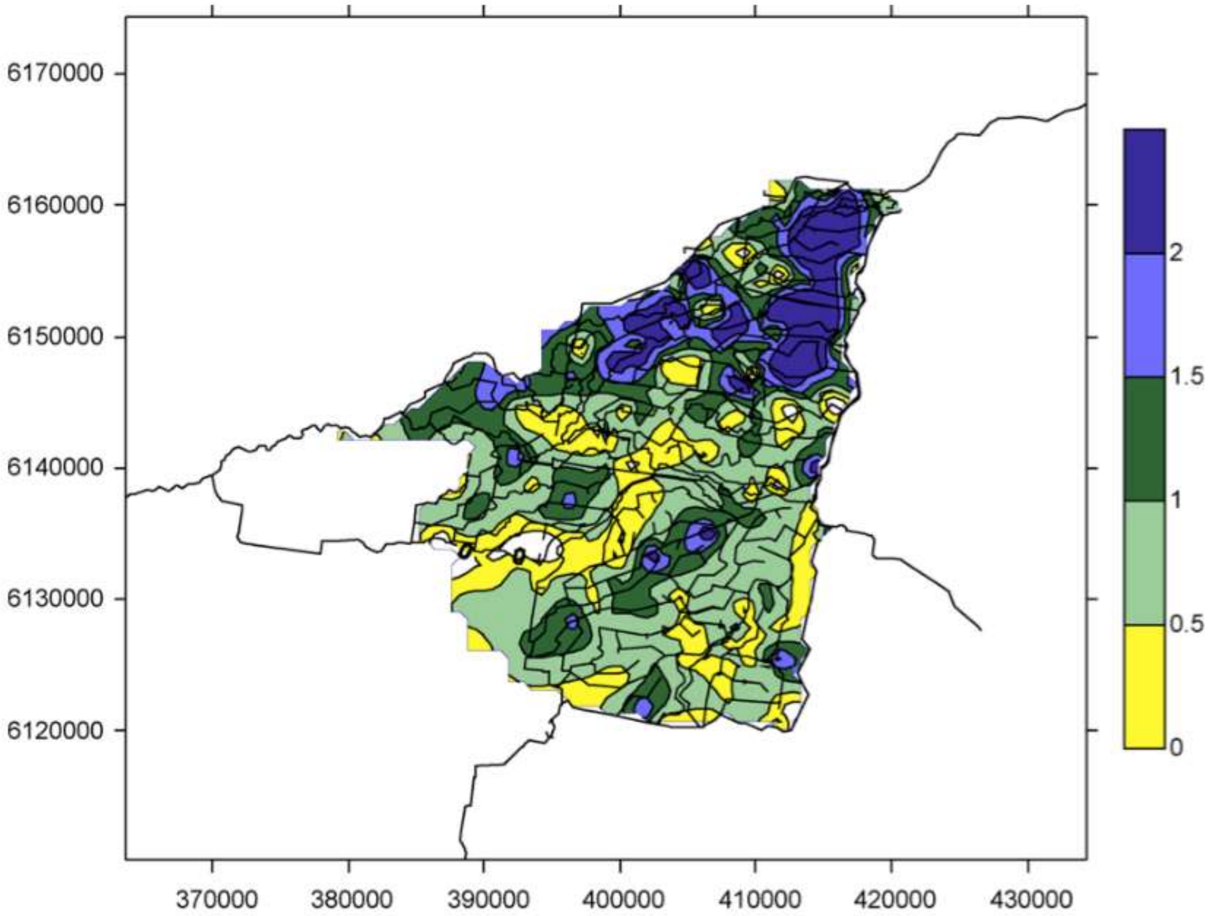

Figure 20 Groundwater decline (m) between March 2002 and March 2003 in CIA (Source: Khan et al. (2008b)

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[46] https://www.colyirr.com.au/annual-compliance-report, accessed 21 April 2020

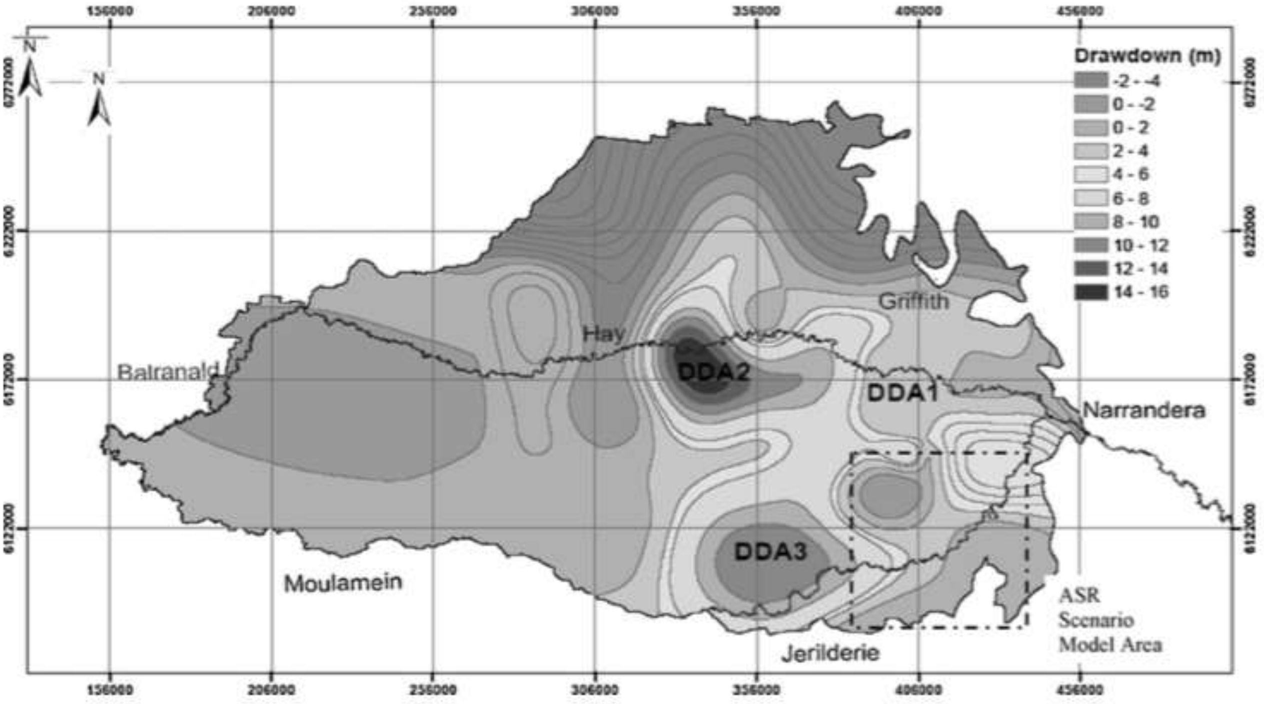

Figure 21 Groundwater level changes in the Renmark/Calivil Formations between 1990–2000 (Source: Khan et al., 2008a).

Aquifer Pumping Rates

Yields for shallow Shepparton Formation have been reported as between 0.1 L/s to 10 L/s (Table 9), which equates to 0.0864 ML/day to 0.864 ML/day. The deeper Calvil/Renmark Group is more productive, with reported yields of 50 L/s to 350 L/s 1 (Table 9), equating to 4.32 ML/day to 30.24 ML/day. Khan et al. (2008a) reports average yields of 28.5 ML/day. There are likely to be areas with higher yields.

As CICL's irrigation infrastructure is a gravity-fed network [47], there is the ability to use multiple bores to feed into channels for distribution to irrigators. This means the pumping rates of single bores are less of a limiting factor to meeting demand if multiple extraction wells are used, possibly associated with a distributed MAR system.

Surface water infrastructure

There are 516 km of supply channels and 711 km of drainage channels in the Coleambally area, established and operated by Coleambally Irrigation Co-operative Limited [48] (Figure 22). The main supply channel draws water from the Murrumbidgee River to the north of Coleambally (Figure 22), with an estimated maximum intake of 6,000 ML/day (Shahidi, Smith & Gillies, 2012).

5.3.2 Suitability of soils in the CIA for MAR

Soils suitable for MAR

When looking to use infiltration basins in or as part of an MAR scheme it is common to focus on areas with soils sandy in texture (Beganskas and Fisher, 2017; Smith and Pollock, 2012). Soils of this texture are most likely to be highly permeable with high infiltration rates (Rahman et al., 2012; Russo et al., 2015), supporting the quick infiltration of recharge water.

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[47] https://www.colyirr.com.au/coleambally-irrigation-area, accessed 21 April 2020
[48] https://www.colyirr.com.au/brief-overview, accessed 19 May 2020

Injection-based MAR projects are less dependent on the soils in the area, with the focus instead being placed on the characteristics of the aquifer into which the injection is to occur (Yuan et al., 2016). Usually confined or semi-confined aquifers are better suited to direct injection wells (Yuan et al., 2016).

Soil characteristics of the Coleambally

The CIA lies on the alluvial Riverine Plain, boarded to the north by the Murrumbidgee River (Hornbuckle et al., 2008). Soils of the area range from clay dominant to deep sands (Hornbuckle et al., 2008). The latter would be the most plausible place to begin searching for MAR infiltration sites. Such areas often present as high and low dunes (Hornbuckle et al., 2008). Although some profiles are sand to great depths, it is not uncommon for these profiles to contain clay layers (Hornbuckle et al., 2008), which could slow infiltration.

The hydraulic conductivity of deep sandy soil in the area ranged from 713 mm/day at depths of 0.5-0.9 m to 113 mm/day at depths of 1.4-1.9 m (Hornbuckle et al., 2008). This is considerably higher than those found under other more clay dominant soil types in the region (Hornbuckle et al., 2008), suggesting improved infiltration may be observed at these sites.

A map of the percentage sand for the area was developed based on the data available from the Soil and Landscape Grid of Australia (https://www.clw.csiro.au/aclep/soillandscapegrid/index.html) (Figure 22). As the data from the Soil and Landscape Grid of Australia is in several layers down to a depth of 200 cm, these layers were overlaid, and the minimum sand percentage taken for any given area displayed. This meant that sandy topsoils with deeper layers of low sand percentages were displayed as such (i.e. the most limiting layer was acknowledged). To identify areas of high clay percentage the inverse operation was undertaken (maximum clay percentage from any layer displayed), to further identify areas unsuitable for infiltration-based MAR schemes (Figure 23). The two soil properties are opposite (e.g. high clay associated with low sand) (Figure 22, Figure 23).

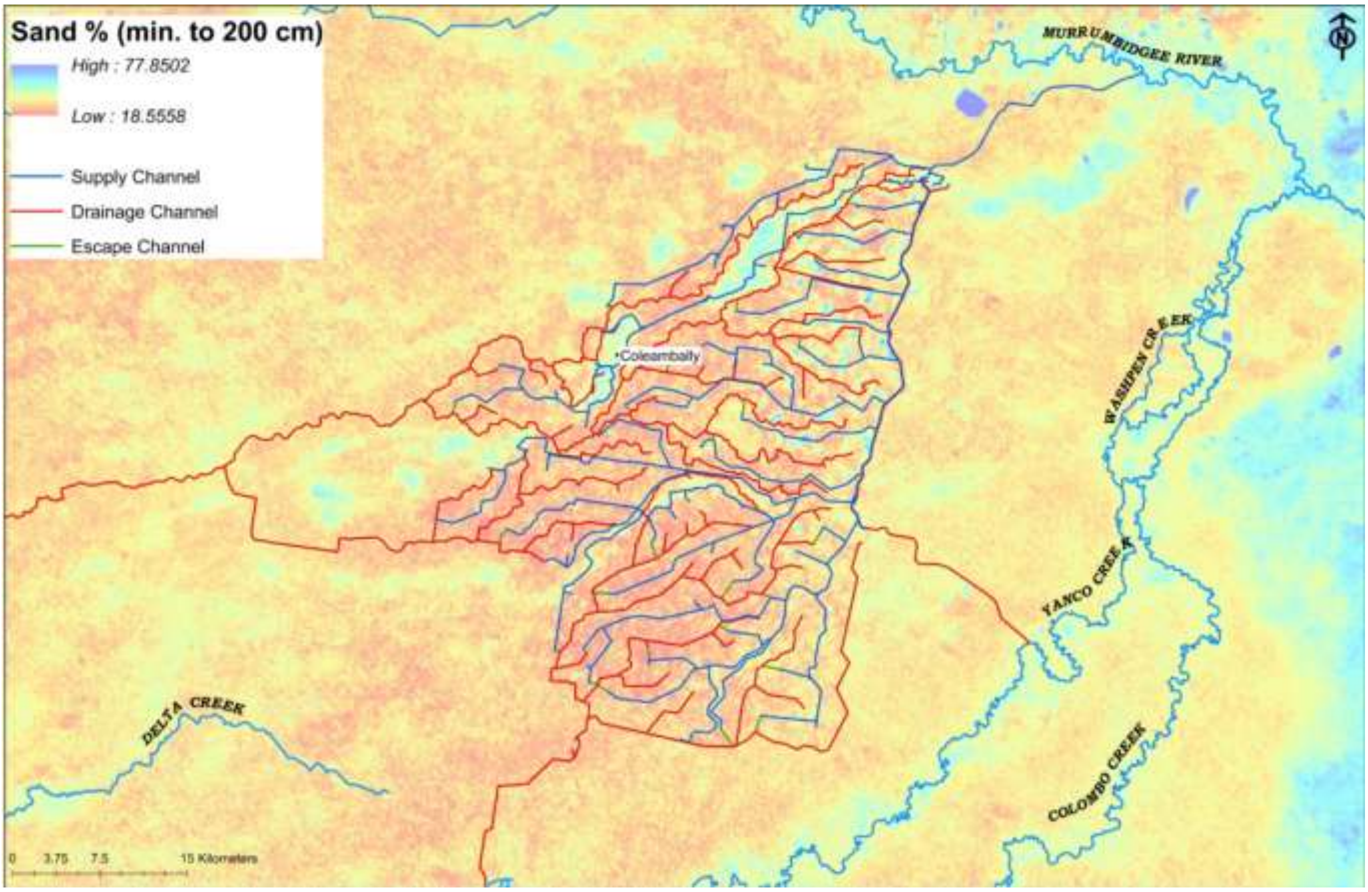


Figure 22 Minimum percentage (%) sand soil map for the Coleambally area, including major rivers of the region and the CICL channels.

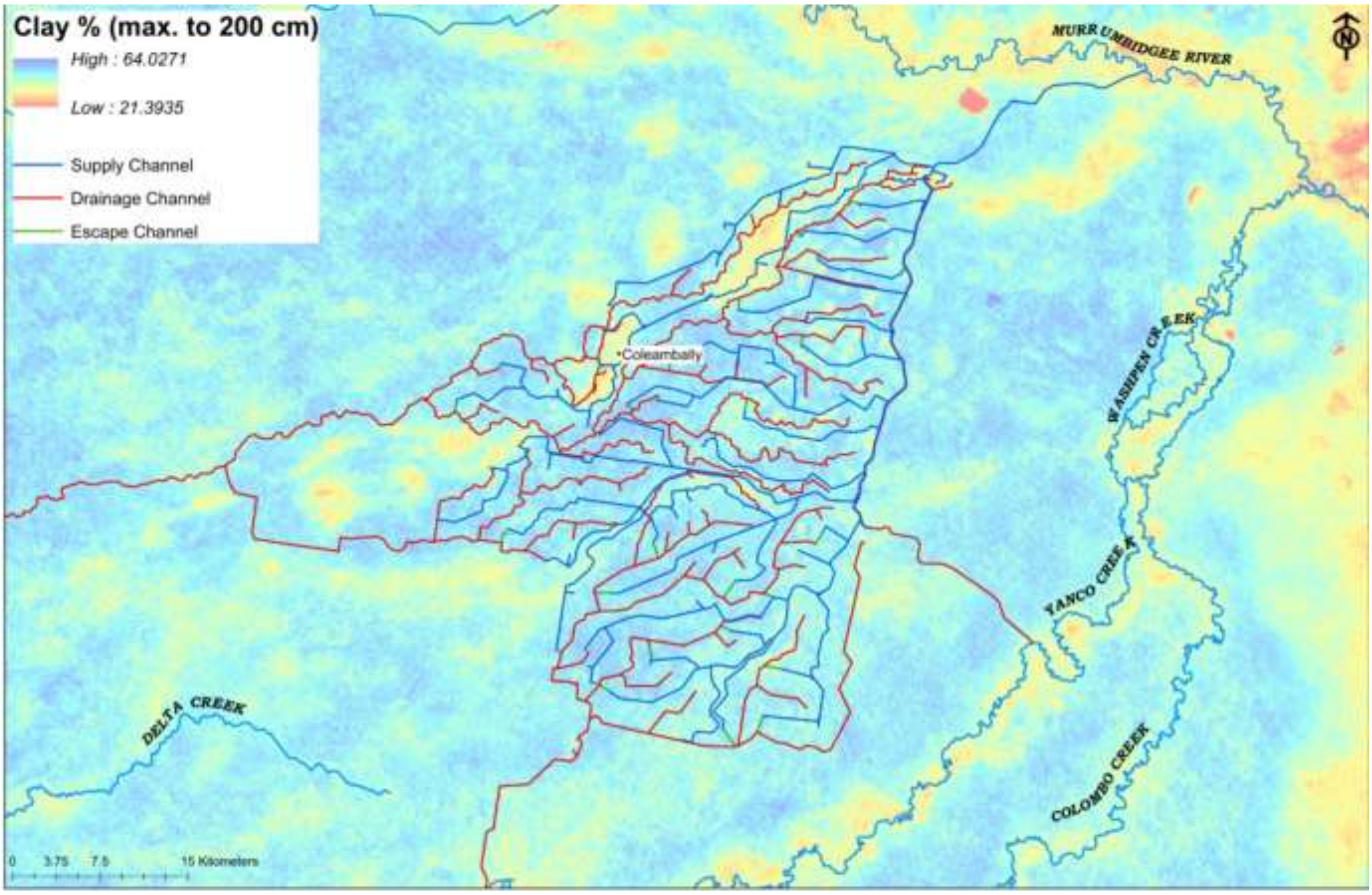


Figure 23 Maximum percentage (%) clay soil map for the Coleambally area, including major rivers of the region and the CICL channels.

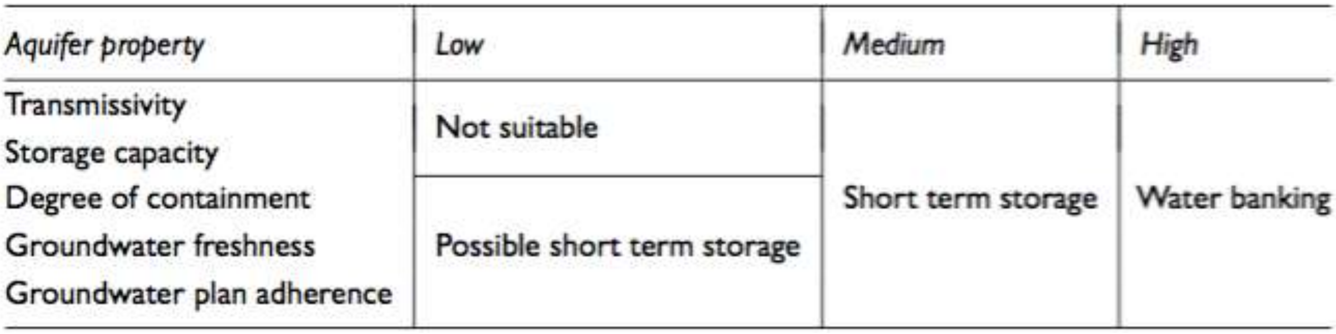
5.3.3 Suitability assessment

Approaches to assess suitability of a site for MAR

Prior to the implementation of any MAR project, feasibility testing is undertaken to locate suitable sites for the project (Fuentes and Vervoort, 2020; Ringleb et al., 2016). This testing is tailored based on an area's characteristics and the type(s) of MAR system being investigated. In Coleambally, evidence suggests that sites exist that may be suitable for MAR.

There are two approaches to assess the suitability of an area to support a MAR scheme: one based on limited data availability where decisions are based on general statements about an area accompanied by a table, flow chart or similar decision-making rubric and another data heavy method where suitability maps, often scaled or ranked, are produced. Examples of the former are shown below (Table 10 and Figure 24), taken from the work of Dillon (2016) and Yuan et al. (2016). Examples of the latter are explored in the following text.

Table 10 A generic guide to suitability of aquifers for MAR. Seasonal storage requires less onerous conditions for inter-year storage, or water banking, intended to increase drought resilience and security of water supplies in a variable climate (Source: Dillon 2016)



Aquifer property	*Low*	*Medium*	*High*
Transmissivity	Not suitable	Short term storage	Water banking
Storage capacity			
Degree of containment	Possible short term storage		
Groundwater freshness			
Groundwater plan adherence			

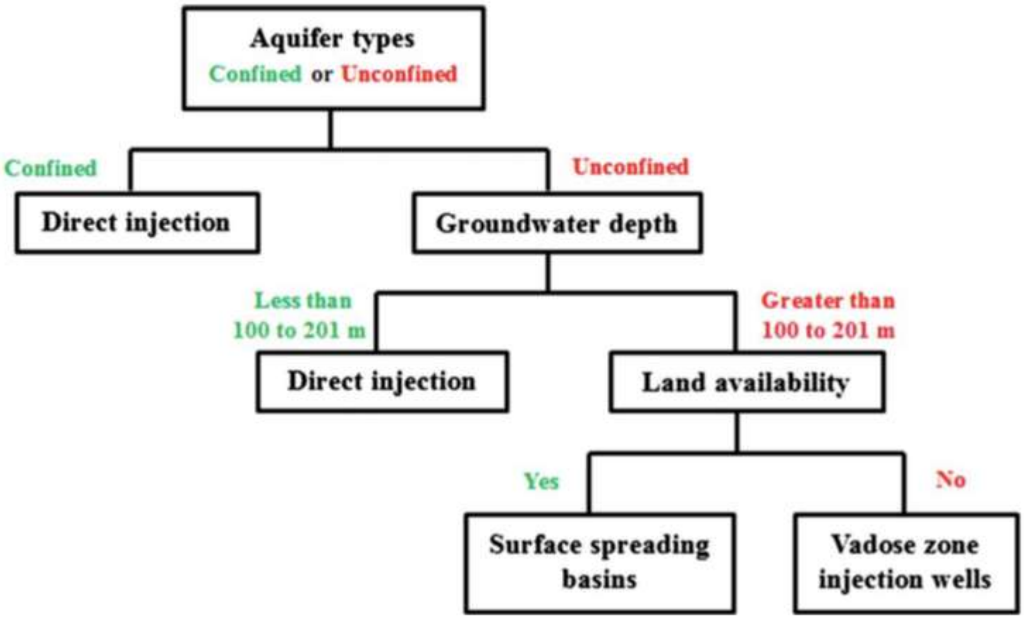


Figure 24 Decision tree to inform site suitability for MAR (Source: Yuan et al. 2016)

Spatial analysis of site suitability in the Coleambally

Site suitability for MAR has previously been undertaken in the Murrumbidgee region, based on a combined hydrological and cost modelling effort (Khan et al., 2008a). The hydrological modelling component identified areas that lacked adequate groundwater recovery in response to extraction, and therefore were associated with reduced groundwater pressure (drawdowns) and the potential for artificial recharge. Low salinity areas were also focused on. The cost modelling showed that MAR was associated with reduced costs compared to the development of new surface storage facilities and eliminated evaporative losses. Based on the undertaken feasibility analysis, Khan et al. (2008a) identified two possible MAR sites in the Coleambally region, both using injection well technology, one north of Yanco Creek and the other on the Murrumbidgee River.

More recently, MAR site suitability analysis was undertaken in the Namoi region (Fuentes and Vervoort, 2020) but the methods employed are transferable and have been used to create the maps in Figure 25 and Figure 26.

This assessment used multicriteria decision analysis combined with sensitivity analysis to identify the most suitable areas for an infiltration MAR project. Multiple datasets were reclassified into 5 sections and ranked, with the section ranked 5 corresponding to very high suitability for the MAR project. For example, the slope dataset was reclassified based on degrees, with areas with slope between 0 to 2 degrees ranked 5 (most suitable) to support an infiltration MAR project. These datasets can be visualised without further manipulation in their most basic form before being overlaid and the most suitable areas identified (Figure 25). However, the priority of the datasets is not equivalent, so a hierarchical approach was employed to ensure that important data sets were weighted as such. Based on the Namoi case study, the highest priority was placed on the slope data as the ability to pool and infiltrate water is paramount to the success of the project. A weighted suitability map can then be produced (Figure 26). To further refine the most suitable area, a sensitivity analysis was undertaken, where the datasets were grouped into three categories (surface, aquifer and underground), with these three categories being allocated different weights to highlight areas that were insensitive. These areas were deemed suitable to establish MAR projects, as regardless of data used, they were consistently highlighted.

The degree of input required by the user in terms of reclassifying the data may be problematic, needing to be revised by region and based on the MAR project type being focused on. For example, if an injection well MAR scheme was being assessed for suitability in an area, the focus on slope would be lessened, and therefore the definition of an optimal slope range could be broadened, but this would need be done on a case by case basis. It is therefore likely that more appropriate suitability maps could be produced with revisions to the reclassification to better fit the Coleambally region.

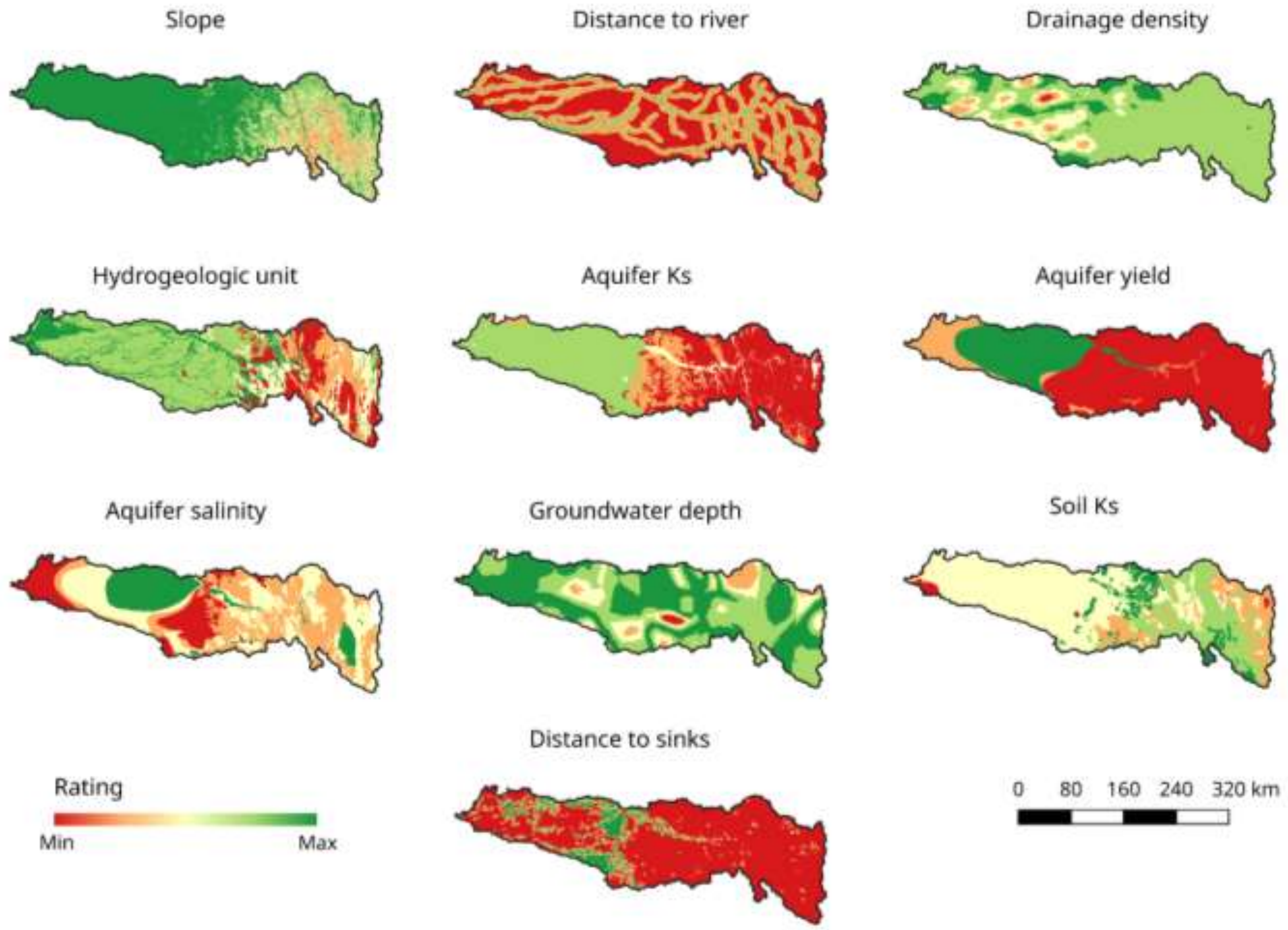


Figure 25 Multiple datasets ranked in terms of suitability for the MAR project (Fuentes, I., 2020, Unpublished raw data)

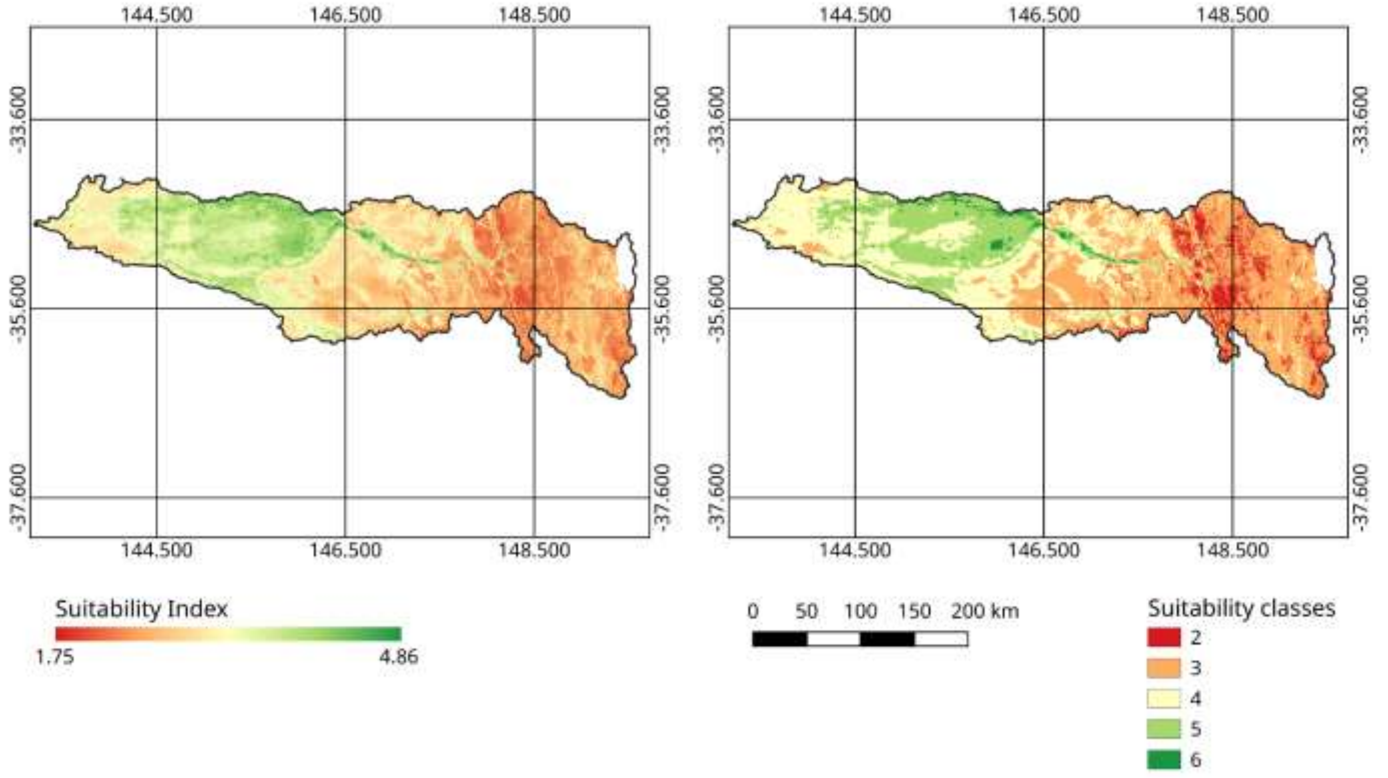


Figure 26 Weighted suitability map presented as (left) a suitability index or (right) in suitability classes (Fuentes, I., 2020, Unpublished raw data)

5.3.4 Managed recharge strategies

Three recharge strategies are considered in this subsection involving either infiltration or injection. An assessment of the chemistry of both the water in the aquifer and the water to be recharged should identify if treatments (e.g. deoxygenation) are needed to ensure that the chemistry of the aquifer water is not adversely changed by MAR.

Infiltration into low salinity areas of shallow aquifer

The efficiency of infiltration into low salinity shallow aquifers depends on the permeability of the soil between the infiltration basin and the target aquifer. This is shown by the calculations below (Box B), with conductivity values based on those reported in the Coleambally region by Hornbuckle et al. (2008), see Section 5.3.2. It is for this reason that sandy soils with high infiltration rates are preferred (Beganskas and Fisher, 2017; Rahman et al., 2012; Russo et al., 2015). It has been estimated that approximately 12% of the CIA is classified as sand (Xevi et al., 2010), with these areas being of highest interest in the initial feasibility search. Areas such as old riverbeds and abandoned quarries are considered ideal areas to begin the search for sandy soils suitable to support infiltration MAR schemes (Fuentes and Vervoort, 2020; Severi et al., 2016; Werner and Laattoe, 2016).

The use of discontinued quarry sites as MAR sites has been observed in Italy (Severi et al., 2016). River water was conveyed through established channels to an artificial lake that was once a quarry site. The sediment of the area was coarse, being mainly gravel, which allowed for effective infiltration into the semi-confined aquifers of the region. The increase in water flowing into the quarry lake resulted in an increase in groundwater levels in the region, with the effects being the greatest closest to the quarry lakes and more buffered at greater distances. This was measured using piezometric readings at varying differences from the lake. Electrical conductivity was also measured at these well sites, which could be applied in the CIA, to monitor the salinity of the rising aquifer. If there is possible contamination in and around a quarry site (Castagna et al., 2015; Hobbs and Gunn, 1998), investigations should be first made to ensure that MAR would not have negative impacts on the groundwater quality.

During the stakeholder consultations and area visits, there were multiple areas suggested as potential locations for infiltration-based MAR projects.

Two sections of the extensive CICL channel system, drainage channel (DC) 400 and 500 (Figure 27), were identified as areas of interest. DC 400 is a losing reach above a deep water table, which helps to mitigate the risk of water logging. The area was unable to support rice cropping due to large amounts of percolation. Although these properties are encouraging, the groundwater in the area is saline. This means that either the creation of the freshwater lens or a decrease in groundwater salinity would be the aim in this area.

Three specific locations were also highlighted (Figure 28):

- A sandy reach (Figure 28 and Figure 29) along a CICL channel required clay lining to prevent percolation. However, this area has an elevated water table which may cause water logging issues in the area, as well as in neighbouring fields.
- An old sand quarry (Figure 28 and Figure 30) close to the CICL's main channel.
- A dog leg (Figure 28 and Figure 31) off the main channel, which was sandy and required clay lining. This location is very close to the river, so return flows into the Murrumbidgee River could be problematic.

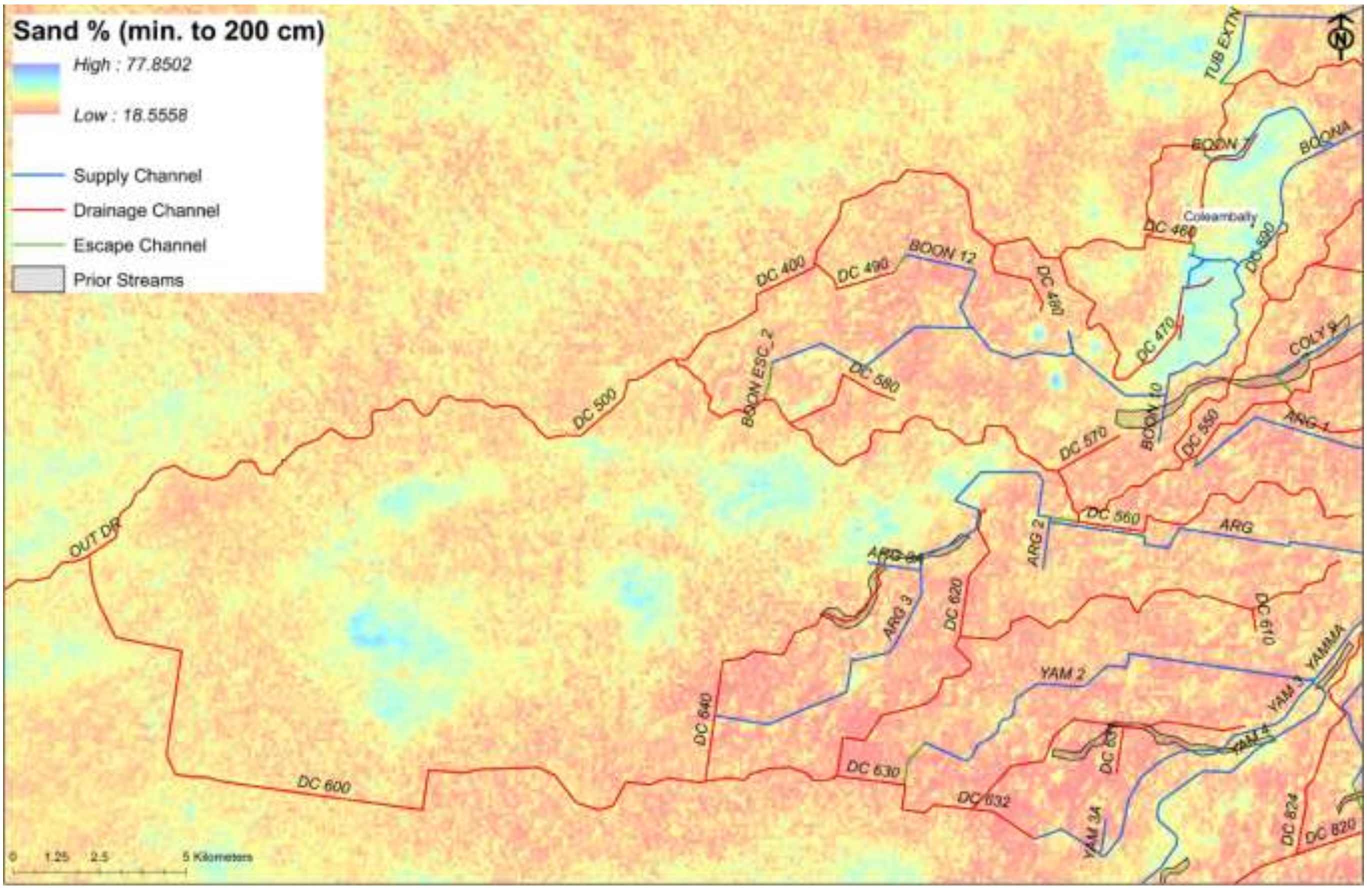


Figure 27 Prior streams and minimum percentage (%) sand soil map for the Coleambally area, including major rivers of the region.

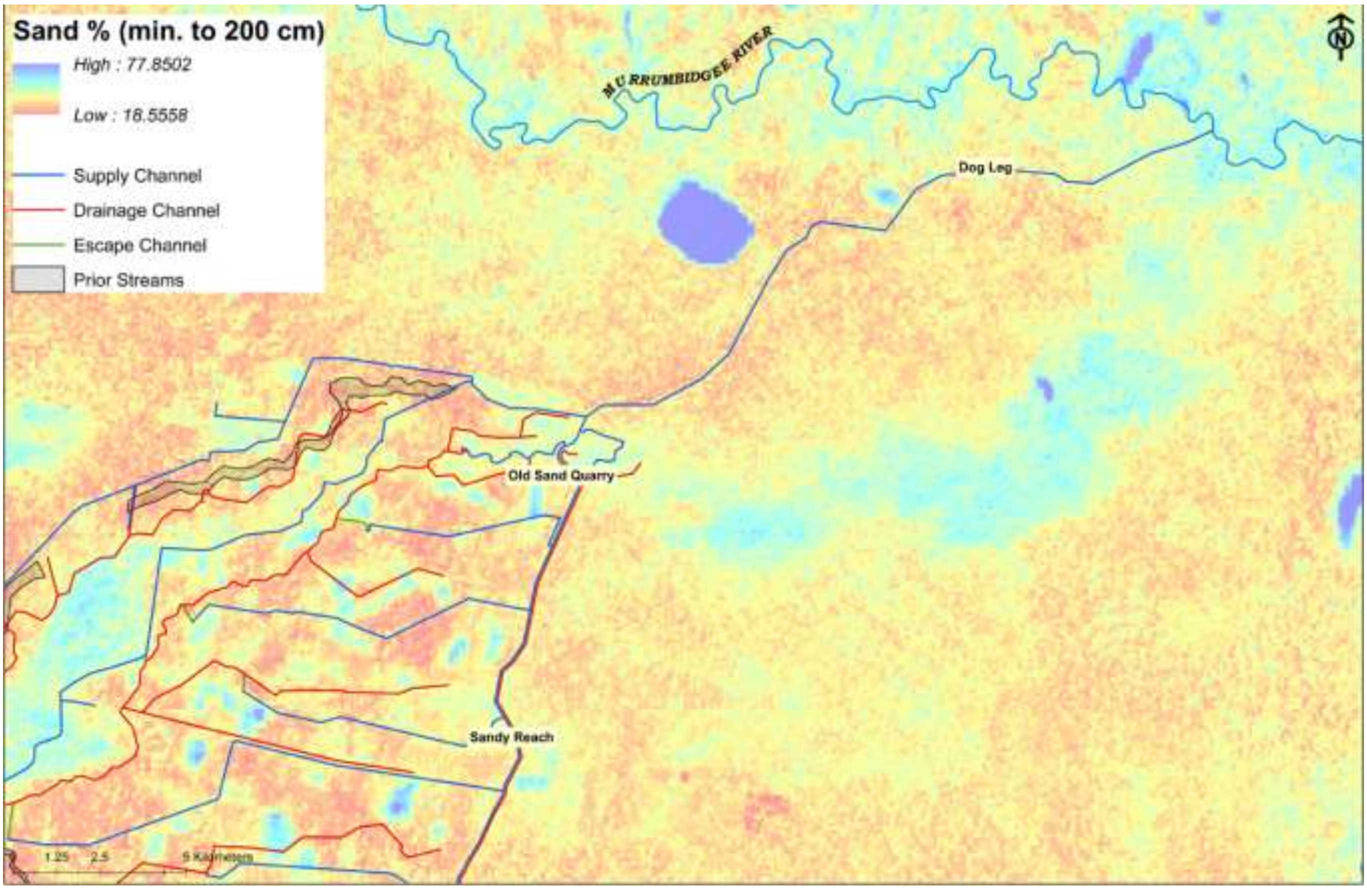


Figure 28 Areas of interest with close proximity to the Murrumbidgee River and the main channel.

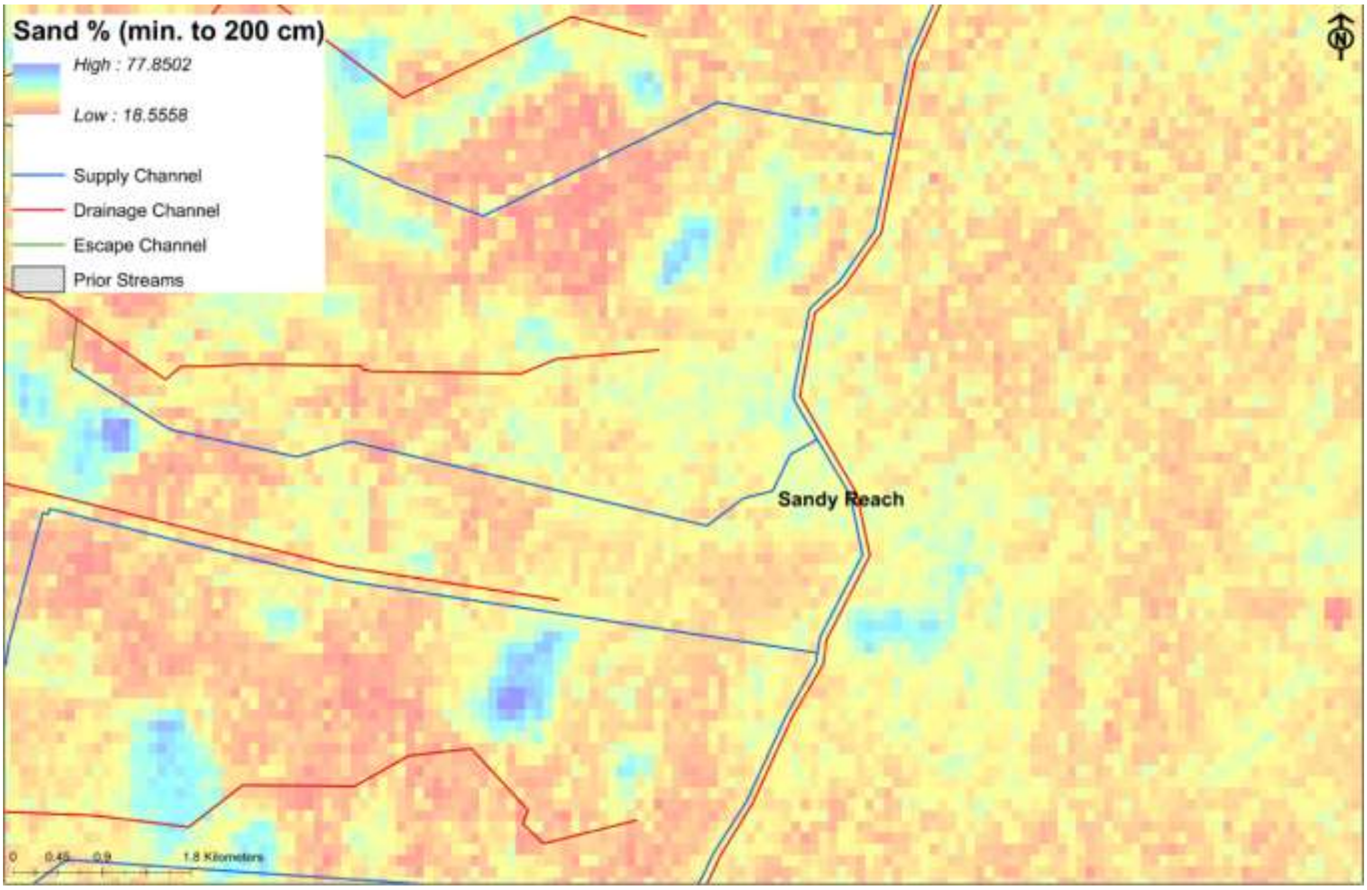


Figure 29 Sandy reach

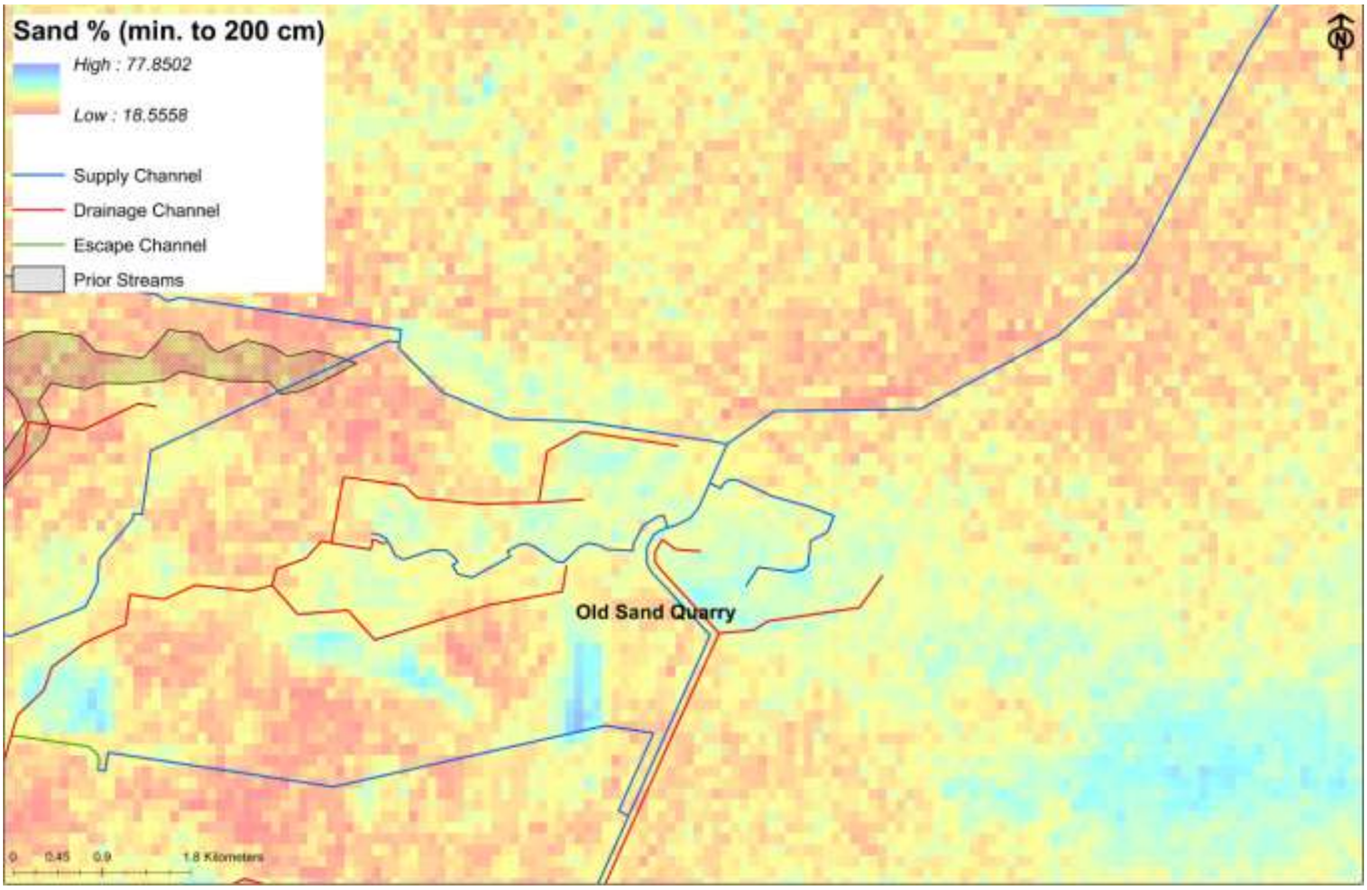


Figure 30 Old sand quarry

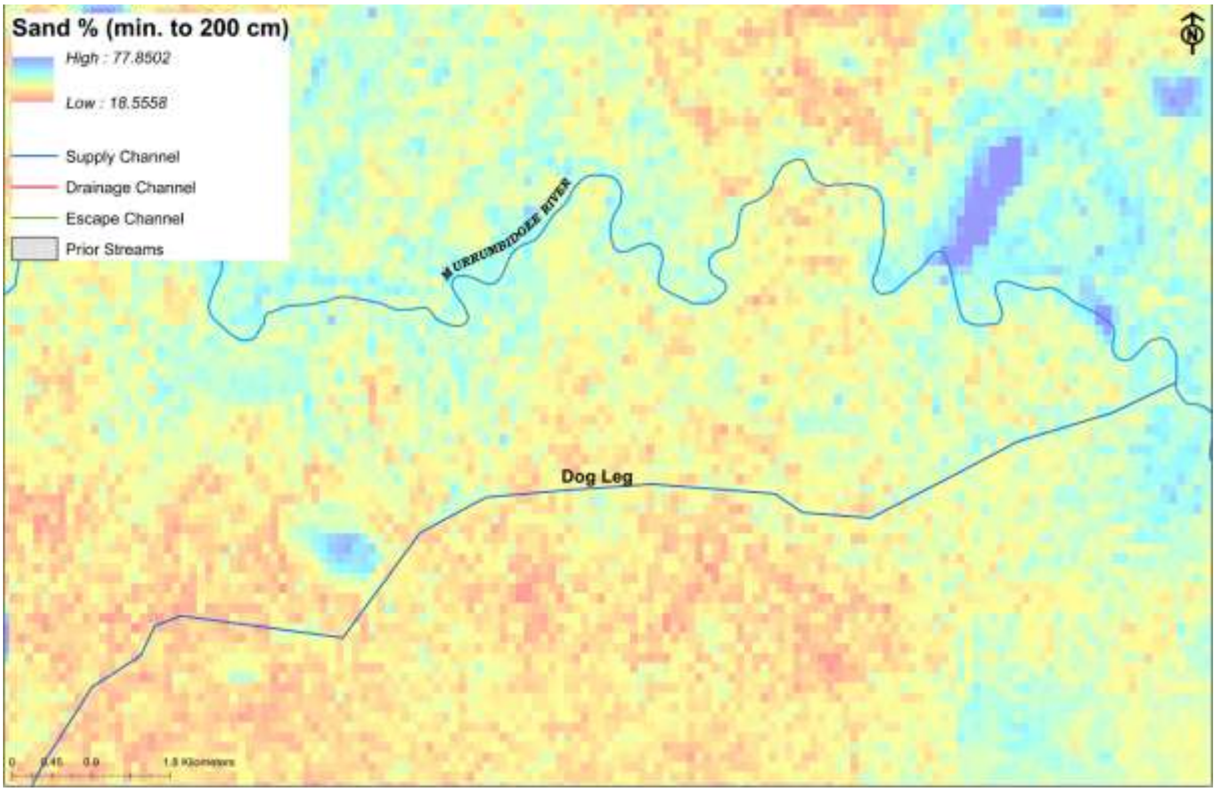


Figure 31 Dog Leg

More generally, areas where prior streams overlay channels could also hold potential (Figure 32), as it is likely that these areas are losing reaches, especially where water tables are low, and are easily accessed with existing infrastructure. These areas are concentrated south-east of Coleambally in Figure 32, requiring additional planning around rules and operational procedures for recovery and distribution of water, compared to locations at the top of the system.

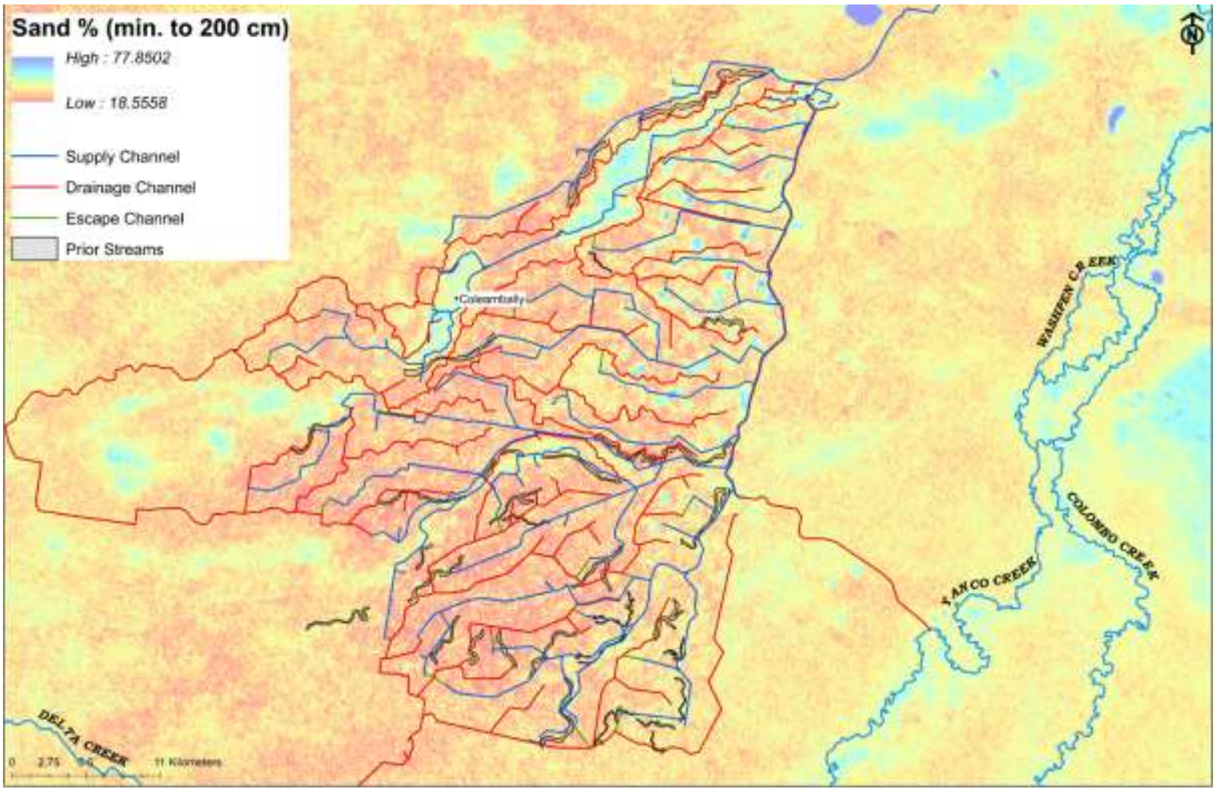
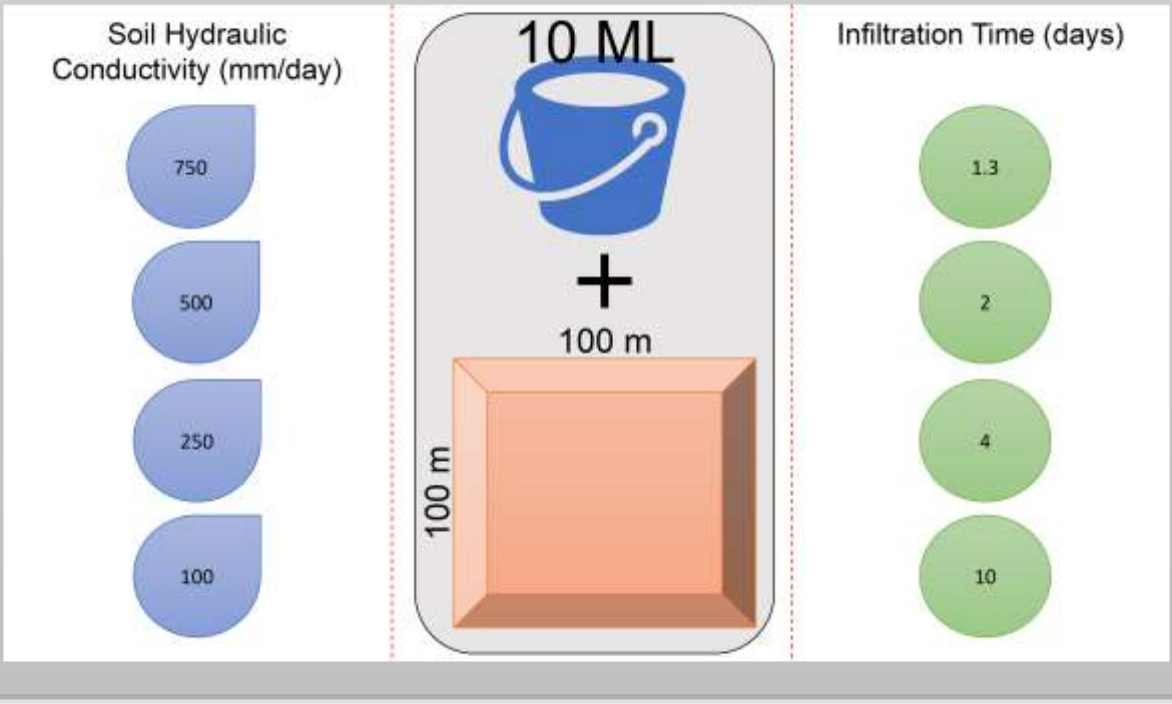


Figure 32 CICL channels overlaid with prior streams

BOX B Infiltration examples

Below is a basic example to show the impact of soil hydraulic conductivity on the infiltration time of a basin MAR system. The system consists of a 100 m x 100 m basin into which 10 ML is to be infiltrated.



A barrier to the long-term success of infiltration systems is the formation of an impermeable layer at the interface between the soil and the water and/or clogging of infiltration pathways in the soil by sediments present in the recharge water (Hutchison et al., 2013). These sediments decrease the soil conductivity, and therefore infiltration rates (Beganskas and Fisher, 2017; Hutchison et al., 2013; Ringleb et al., 2016). There are multiple techniques to limit clogging, including:

- Employing wetting and drying cycles, rather than continuous pooling, can disrupt the clogging layer resulting from large particle accumulation, restoring the area's native infiltration rates (Hutchison et al., 2013). This technique has proved successful at the infiltration sites in WA (Vanderzalm et al., 2015).
- Planting within the infiltration basin to sustain an open soil structure, so infiltration can bypass 'clogged' pores (Beganskas and Fisher, 2017; Hutchison et al., 2013). This technique would be most effective when used in conjunction with wetting and drying cycles to prevent plant death.
- Pre-treatment of water in sediment detention (settling) ponds to remove suspended soils under gravity (Arshad et al., 2014). Settling ponds are explored in depth below.

Settling Ponds

Settling ponds are introduced upstream of a MAR site to improve the water quality before infiltration or injection by removing suspended solids via gravity (Arshad et al., 2014; Beganskas and Fisher, 2017). This method is used to slow the clogging process when employing MAR (Arshad et al., 2014; Jakeman et al., 2016).

During a flooding event, sediment loads are increased (Olive and Olley, 1997), and the time taken to settle under gravity would be a limiting factor to the amount of water that can be taken into a settling pond (e.g. if settling is slow the flood event may be over by the time the settling tank(s) can be drained and more water can be taken in, so only one uptake is possible).

Below are methods to improve the speed and efficiency of sediment settling. Although not directly developed to complement MAR techniques, slow settling speeds are a universal problem, so innovation can come from further afield.

- The use of a gridded structure at the bottom of a tank increased the removal of particles by 10 – 30% in larger inflow volumes (He and Marsalek, 2014). The retention of the removed sediment was increased by a maximum of 41%. This is the result of the gridded structure 'trapping and storing' the sediment (i.e. reducing disturbance). At low inflow rates (< 4 L/s) the gridded structure did not improve sediment settling or retention, but at inflow rates between 4 L/s and 8 L/s, there was improvement. The gridded structure also makes sediment removal easier by limiting compaction by separating sediment within the grid. This could allow for suction to remove the collected sediment, rather than dredging. A simpler, but less effective method, would be to gravel the bottom of the tank/pond as the gravel alters the flow and creates shelters for the sediment deposition.
- Vegetation has been shown to enhance sedimentation as vegetation slows flows, traps sediment and increases stability/retention (Gu et al., 2017; Mudd et al., 2010; Nardin and Edmonds, 2014). If using a natural pond type settling tool, it may be useful to create a resilient constructed wetland to reduce total suspended solids (TSS) during flood events, with this water then being infiltrated as part of a MAR scheme. Constructed wetlands have proved useful in SA when treating stormwater runoff prior to recharge (Barnett et al., 2000). The longevity of such vegetation during periods devoid of recharge may be problematic.
- Wind also has an impact on preventing settling or resuspending sediment (Gu et al., 2017). Careful placement of inflow and outflow points considering the prevailing winds in the area could limit these effects (Gu et al., 2017). Generally, placing the inflow/outflow points in the opposite direction to the prevailing winds in beneficial (i.e. inflow/outflow N to S if the prevailing winds are W to E) (Gu et al., 2017). Vegetation can also shelter the pond from external wind effects (Gu et al., 2017).
- Distance between the inflow and outflow points should be maximized to allow for maximum energy dissipation, and therefore settling (Gu et al., 2017). This supports the elongation of ponds/tank structures (Gu et al., 2017). Teardrop and kidney-bean shaped ponds could provide benefit over square/rectangle ponds (Gu et al., 2017)
- To limit large inflow velocities, the inflow could be distributed/split into multiple smaller inflow points (Gu et al., 2017).
- Continued maintenance is required in many sediment tank/pond systems to remove settled sediment and eliminate its resuspension (Gu et al., 2017).
- Pond depths ranging from 1 m to 2.5 m (Gu et al., 2017).

Infiltration/injection as freshwater lens into shallow aquifer

This sub-section considers the potential for infiltration as a freshwater lens in the shallow aquifer in areas where salinity is higher. The existing freshwater lens research is largely focused on coastal aquifers/islands, although these are excluded from the following critique. The success of such a scheme is highly case specific and depends on building detailed understanding of local hydrogeology and its response to interventions (including pumping and injection). Knowledge of Coleambally hydrogeology is not currently sufficient to either reject or endorse the possibility of MAR in a freshwater lens.

Necessary conditions for MAR of a freshwater lens to be successful

The creation of a freshwater lens through infiltration may be a gamble; strict site selection is needed, and adding to a naturally occurring lens may be safer. Away from a waterbody (i.e. river, stream, ocean) the presence of a freshwater lens over a saline aquifer is most probable under topographically high regions (e.g. hill) in a flat area or when water is funnelled through otherwise impermeable sediment at an opening/weak point (Figure 33) (Houben et al., 2014; Laattoe et al., 2017; Pauw et al., 2015). If, based on the hydrogeology and surveying of the area, a freshwater lens can be found, it may be possible to add to the natural recharge (resulting from rainfall) of such a system to increase the height/length of the freshwater lens with the prospect of removal of this additional water when required (Asghar et al., 2002; Houben et al., 2014). Freshwater lenses have been (accidentally) created through infiltration so this is not impossible (Asghar et al., 2002).

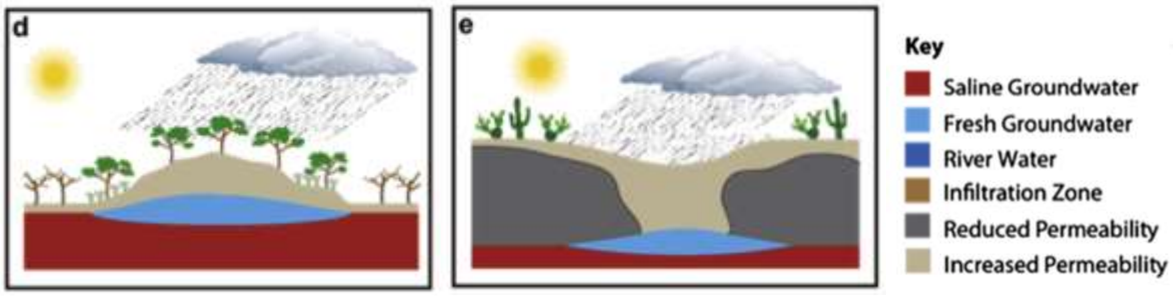


Figure 33 Inland natural freshwater lens forming away from other water bodies, particularly oceans (Source: Laattoe et al. 2017)

Injection of freshwater into a saline aquifer provides more control but is not infallible. The results of a physically based modelling experiment on the injection of freshwater into a saline aquifer as a remediation measure based in the Murray River area indicated that: lower injection rates (and therefore longer injection times) increased stability of lens formation, larger volumes of water created a larger lens, it is imperative to inject at the interface of the saturated/unsaturated zone, and a linear configuration of injection wells produced better results than a rectangular configuration (Alaghmand et al., 2015). Continued injection was needed to maintain the results (Alaghmand et al., 2015).

A possible problem associated with the injection of freshwater into a saline aquifer is that the lens can become conical in shape, resulting in saline water entering the extraction well before the injected freshwater has been completely extracted (i.e. some of the freshwater cannot be recovered) (Ward et al., 2007, 2008). There is also mixing at the boundary, which reduces the amount of extractable water that is of freshwater quality (Ward et al., 2008). Flow within the saline groundwater can interrupt the formed lens and increase mixing/promote diffusion, again reducing the amount of freshwater that can be extracted (Ward et al., 2009). Ensuring that water is extracted at suitable depths and rates could mitigate the risk of freshwater coning (Asghar et al., 2002).

Both techniques share some similar needs with a confined or semi-confined aquifer potentially more suitable (Houben et al., 2014; Pauw et al., 2015), however, a small confined aquifer may impede the growth of a freshwater lens (Pauw et al., 2015). Based on lab experiments, it appears that flowing saline groundwater could alter the shape and position of a freshwater lens (Rotz and Milewski, 2019), possibly limiting extraction from a stationary well site. The careful positioning of multiple wells (injection and recovery) could be used, but the placement would depend on the time between intended injection and extraction (Miotliński et al., 2014).

How would you know whether the creation of your lens is working out?

The use of a well into which instruments can be inserted allows electroconductivity to be measured at different depths to establish the thickness of a freshwater lens (Pauw et al., 2015). Having multiple wells in a formation would also allow for the shape of a freshwater lens to be monitored over time (Pauw et al., 2015). There are many piezometer monitoring sites in the Coleambally area that could be used for this purpose (see Section 5.3.6), though their suitability for any specific injection site would need to be evaluated.

Geoelectrical and electromagnetic investigations have been used to understand both the spatial extent and thickness of a freshwater lens (Houben et al., 2014). Such a technique requires an educated approximation or prior knowledge of the bounds of the lens to assist in the selection of where the profiling begins (i.e. if the starting point was the middle of the lens it would take significant time and resources to reach the extremities). This approach was supplemented by electroconductivity of water samples collected from wells, to assist in identifying the location of the fresh/saline interface (Houben et al., 2014). Above ground, the presence of saline tolerant flora (or the lack of saline intolerant flora) can be used as a proxy (Houben et al., 2014) (also see Figure 33).

Similarly, direct current (DC) resistivity and time-domain EM (TEM) were shown to be useful in the delineation of a freshwater lens in the Murray Basin (Barrett et al., 2002). TEM proved less time consuming then DC resistivity, however, both techniques were suggested to be more successful and cheaper than drilling and collecting data from wells (Barrett et al., 2002).

Injection into deep aquifer

The success and ease of an injection based MAR project into a deep aquifer depends on aquifer characteristics (Yuan et al., 2016). Confined or semi-confined deep aquifers are generally more suitable for direct injection (Yuan et al., 2016). Suitable sites to support injection wells into the deep aquifers in the Coleambally area were identified by Khan et al. (2008a).

Below are details of several injection-based MAR schemes in Australia (Table 11). The range of injection rates observed at these sites was used to calculate injection times for a quantity of water (Box C).

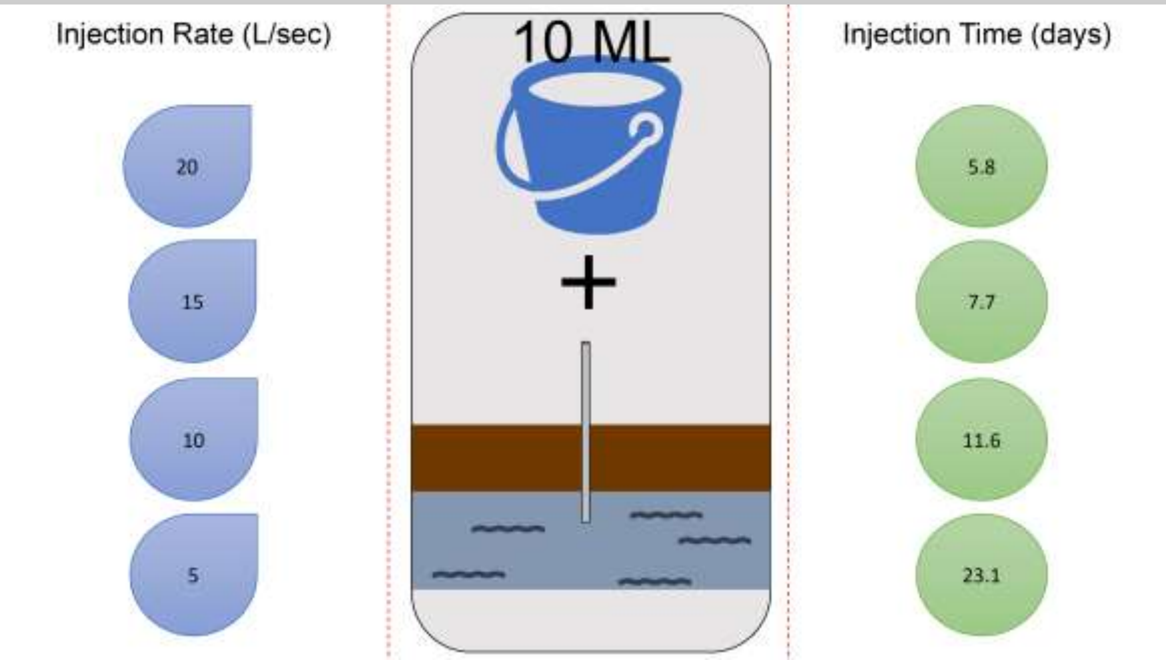
Table 11 Characteristics of direct injection MAR projects that target deep aquifers.

Name and Location	Aquifer Type	Injection Rate (L/sec) [method]	Depth (m) of injection well	Notes	Source
Andrews Farm, South Australia	Confined limestone aquifer	20 [under gravity]	180	-	Barnett et al. (2000)
The Paddocks, South Australia	Low permeability confined limestone aquifer	7 [under pressure]	164	Low permeability of the aquifer resulted in water having to be injected under pressure	Barnett et al. (2000)
Regent Gardens, South Australia	Fractured rock	10	80	-	Barnett et al. (2000)

Settling ponds would also be useful as a pre-treatment when injecting into a deep aquifer, to minimise clogging of the injection well (Arshad et al., 2014). Regularly pumping water in reverse (i.e. out of the injection well) is another method to clear suspended soil (Barnett et al., 2000).

BOX C Injection examples

Below is a basic example to show the impact of injection rate on the recharge time of a well-based MAR system. The system consists of a well into which 10 ML is to be infiltrated. The injection rates are based on the range observed over three MAR systems in SA (Barnett et al., 2000).



5.3.5 Recovery efficiency

Local hydrogeology is the major factor that dictates recovery rates from a MAR scheme (Arshad et al., 2014; Dillon, 2016). Therefore, the recovery efficiency varies between MAR schemes, with 80 – 100 % recovery efficiencies possible (Arshad et al., 2014; Khan et al., 2008a). It is common for projects that target saline aquifers to experience reduced recovery efficiencies due to mixing of the recharge water with native saline water in the aquifer (Arshad et al., 2014). The recovery efficiency into saline aquifers has been shown to decrease with the time between injection and recovery (Farid et al., 2018). The recovery efficiency of saline aquifers can be increased with increasing injection volumes and successive cycles (Farid et al., 2018; Khan et al., 2008a). Using multiple injection and recovery wells has also been shown to improve recovery efficiencies (Miotliński et al., 2014). The recovery rate can also be dictated by limits imposed by policy (Vanderzalm et al., 2015).

A breakdown of several MAR projects in Australia, with details of the recovery and an explanation of why these efficiencies were observed is given in Table 12.

5.3.6 Monitoring design to manage effects

Monitoring equipment of MAR projects can range from permanent wells and piezometers to geophysical methods such as direct current (DC) resistivity and time-domain EM (TEM) surveys (Barrett et al., 2002; Maliva, 2015; Pauw et al., 2015). There are currently 737 piezometers located across the Coleambally region (Figure 34) [49]. These piezometers primarily monitor groundwater levels in the Shepparton Formation aquifer [42]. To monitor the deeper aquifers, data from WaterNSW groundwater sites could used [50]. Piezometric data has previously been used in the area to calculate recharge (Christen et al., 2000; Khan et al., 2008a), and could be employed to assist in monitoring the effect of managed recharge in the area. At piezometer sites, additional equipment could be used to monitor water quality in the aquifer, for example salinity (Dillon, 2016).

The past occurrence of salinity problems (Khan et al., 2008a), as a result of a raised water table in the area, would need to be monitored. In addition to existing piezometers, new soil water monitoring equipment and piezometers could be strategically placed in at risk areas to ensure it does not occur again due to MAR.

The Australian Guidelines for Water Recycling: MAR do not specify recommended monitoring (NRMMC, EPHC & NHMRC, 2009 [51]). Other Australian MAR schemes have monitored groundwater levels on a monthly basis initially, but moved to measurements every three months once the scheme is well established (Zulfic & Barnett, 2007). The guidelines in South Australia recommend the installation at least one continuous monitoring device, that is correlated to the concerns of that project (e.g. salinity, pressure), for projects which recharge more than 20 ML/year (SA EPA, 2004). Given that MAR in Coleambally would occur in an area with substantial groundwater pumping and water application, more frequent monitoring and additional tracer-based techniques may be needed to gain confidence in dynamic groundwater flow patterns and the ability to recover recharged water.

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[49] https://www.colyirr.com.au/annual-compliance-report, accessed 21 April 2020

[50] https://realtimedata.waternsw.com.au, accessed 19 May 2020

[51] A joint publication of the Natural Resource Management Ministerial Council (NRMMC), Environment Protection Heritage Council (EPHC) & National Health Medical Research Council (NHMRC)

Table 12 Recovery characteristics of several MAR schemes in Australia, with reasoning to support the recovery efficiencies.

Scheme Name	Location	Type	Infiltration/Injection Amount (ML) [number of cycles]	Recovery Rate (L/sec)	Recovered Amount (ML)	Recovery efficiency (%)	Explanation	Source
The Paddocks	Adelaide, South Australia	Injection of storm water for irrigation	75 [1]	15	75	100	Injection into aquifer with native salinity suitable for irrigation	Barnett et al. (2000)
Regent Gardens	Adelaide, South Australia	Injection of storm water for irrigation	50 [1]	-	20	40	Injection into highly saline aquifer	Barnett et al. (2000)
Aquifer Storage and Recovery Field Trial	Bolivar, South Australia	Injection of nutrient rich water for irrigation	704 [4]	-	501	71	Injection into highly saline aquifer	Vanderzalm et al. (2015)
Aquifer Storage Transfer and Recovery Trial	Anglesea, Victoria	Injection of recycled water for consumption	1) 3.5 2) 5.4 3) 18.6 [3]	1) 25 2) 19 3) 9	1) 4.8 2) 5.1 3) 11	1) 137 (as this was a trial, in the first cycle more water was extracted then recharged) 2) 94 3) 59	Groundwater extraction limits in place for area	Vanderzalm et al. (2015)

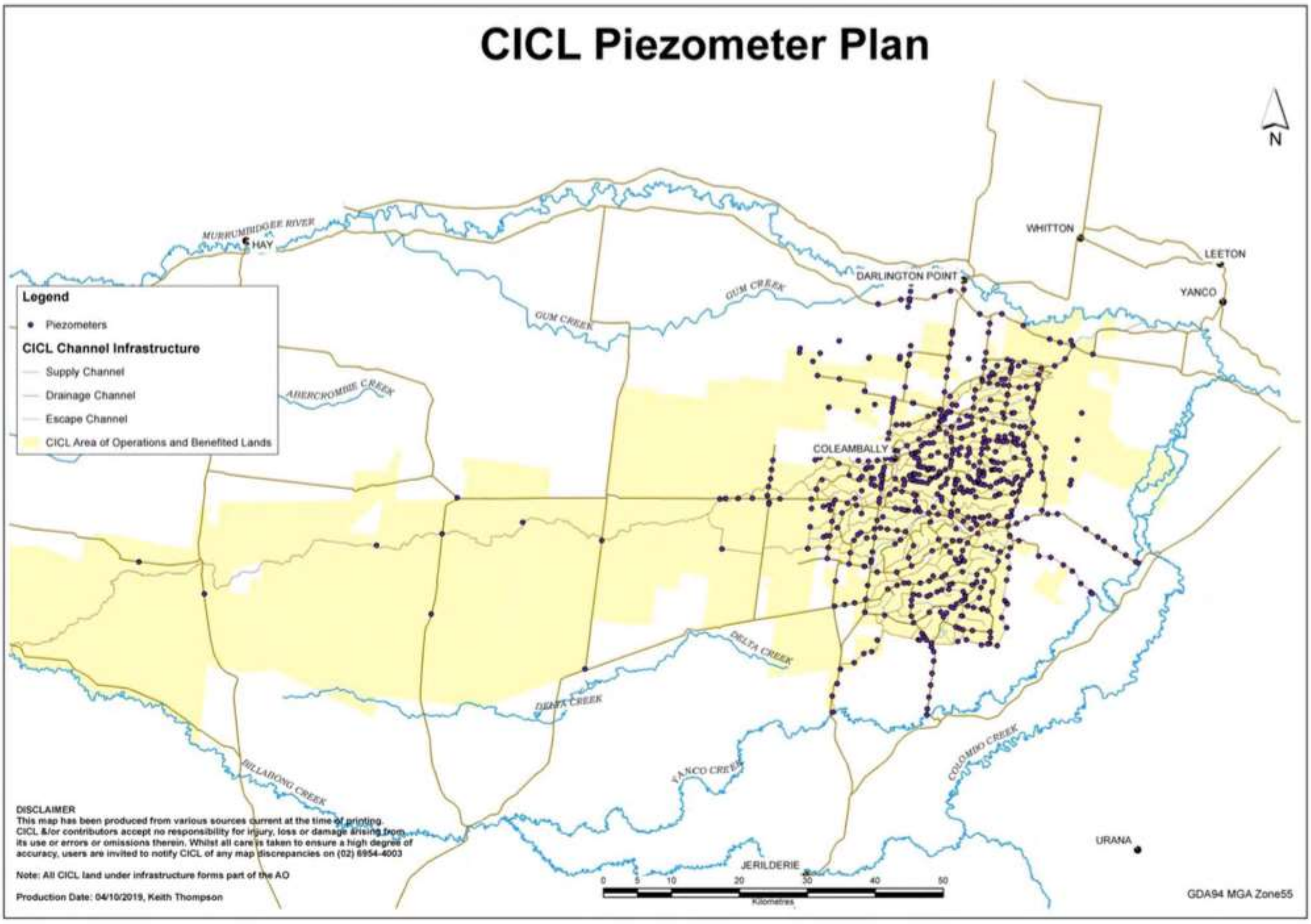


Figure 34 Location of piezometers in the Coleambally region. (Source: https://www.colyirr.com.au/annual-compliance-report, accessed 21 April 2020)

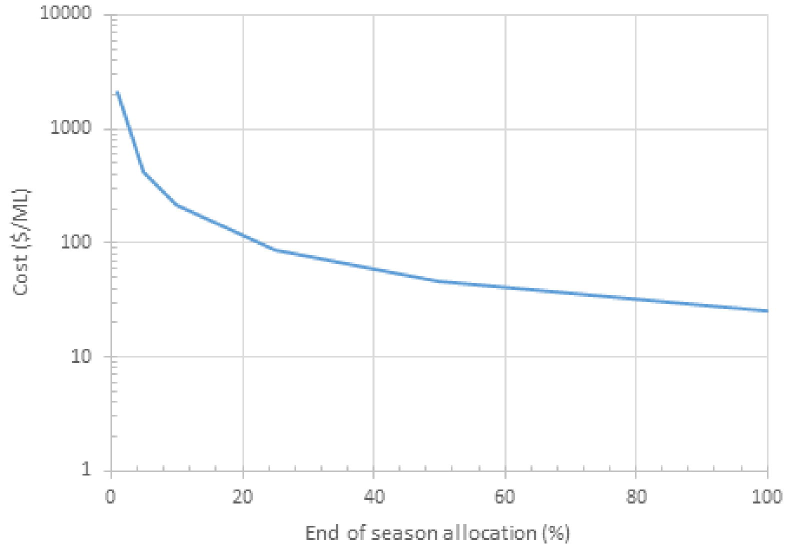
5.4 Financial viability

5.4.1 Surface water delivery costs

Given that many charges in delivering water are fixed costs, the cost per ML to deliver surface water varies with the total volume delivered. Kieran O'Keefe from CottonInfo provided costs associated with the delivery of water. In the example provided in Figure 35, if general security allocation is 100% then it costs $25/ML to deliver, but if the allocation is 1% then this increases to $2076/ML. Therefore, water available through MAR is most competitive in dry years, especially if it can help reduce the marginal cost of water, or avoid fixed costs.

5.4.2 Construction costs of dams

Turkey nest dams are dams that can be pump fed and gravity extracted; they require a reasonably flat site with good dam building clay ≤ 1 m below the ground in order to be cost-effective (Stanton, 2005). As turkey nests are, like ring tanks, off-stream storages with a continuous embankment, they should have a similar cost per unit size to construct and maintain (CSIRO, 2013). Benjamin (2018) estimated the cost to establish a 4 GL ring tank, assuming there was no need to buy clay in, at $1.7 million. Estimates of ongoing costs varied considerably depending on the energy costs needed to fill the storage but may be on the order of $10,000 to $100,000 per year. Further assumptions regarding site-specific maintenance and infrastructure lifetime would be needed to allow a direct comparison with a specific MAR scheme, but these numbers are already indicative that MAR schemes with substantial costs may still be competitive with large surface storages.



Source: Kieran O'Keefe CottonInfo

$16.02/Delivery entitlement
$916.87/Large outlet

Yearly Peak flow charge $57.30/ML for 20ML
$1,146

$3.22/ML	Access
4.75/ML	Usage

Yearly cost is fixed at $28,999

Figure 35 Variation in delivery cost of water with allocation based on fixed costs

5.4.3 Levelised cost of MAR water

This is a summary of the estimated range in costs to construct and operate a Managed Aquifer Recharge (MAR) scheme in rural areas of Australia. It is intended to be a general guide as to how much MAR may cost given some of the major cost variables that contribute to its implementation, but it does not explicitly include all known variables that influence costs. Therefore, this is a simplistic and general view of realistic input values based upon available research and data in Australia.

Method and assumptions

The costs given in this summary represent the cost incurred to 'recharge' water into the aquifer and then to extract, or 'recover' that water. The recharge and recovery costs vary greatly depending on the site characteristics. If aquifers are permeable and shallow, then infiltration basins can be used to recharge the aquifer (Arshad et al., 2014). However, in systems where the infiltration rates are low, the aquifer is confined and/or at depth, or there is a shallow saline aquifer near the surface, injection wells might be required to recharge the aquifer. This analysis explores the *Recharge cost*, expressed as $/ML recharged, from the different MAR systems (i.e. infiltration basin versus injection well), including the levelised capital costs, and indexed maintenance and operation costs, plus the foregone production cost (i.e. opportunity cost) from the area required to implement the MAR scheme. The lifespan of the infrastructure is assumed to be 30 to 40 years for an infiltration basin according to Arshad (2015) and Dillon et al. (2009b), respectively, and 20 years for injection wells (Khan et al., 2008a; Arshad, 2015), with a 7% discount rate. The *recharge cost* also accounts for the cost of the water recharged, being either supplementary water, unused surface water, surface water traded onto the farm, or foregone surface water from the existing entitlement.

The volume of water that can be extracted from a MAR scheme can vary depending on the aquifer material, water quality and applicable policies. This *Recovery Rate*, expressed as a percentage of the volume of water recharged, typically varies from 80-85% to 100% (GHD Pty Ltd and AGT Ptd Ltd, 2011; Khan et al., 2008a). The *Recovery costs* in this analysis account for the potential difference in the *Recovery Rate*, and also the difference in groundwater pumping costs. Therefore, *Total recharge and recovery cost* is the *Recharge cost* (converted to $/ML recovered) + the *Recovery cost*, given as the $/ML recovered. Costs presented in the various literature have been adjusted to 2018 values.

The following costs have not explicitly been accounted for in this analysis.

- Pipes and transmission costs. These vary with the distance between the water source and the recharge area, which are very site specific. Piping costs have been estimated as $13/m for 100 mm main piping in an urban system (Dillon et al., 2009b). These values can be estimated and included once case study areas have been selected.

- Water treatment costs prior to recharge; therefore, this analysis assumes that the recharge water does not require any treatment. e.g. ASR water treatment of flood water = \$250/ML capital cost and \$150/ML ongoing cost (Arshad, 2015). Injected water may likely need to be de-oxygenated to avoid the aquifer material will becoming oxidised.
- Monitoring costs for water quality and aquifer level during the MAR operation.

Other assumptions that warrant explicit mention, beyond that given in Table 13 are:

- Entitlement diversion charges are the costs per ML to use water, and cover a range reported for both NSW and QLD. These values do not include any fixed costs for irrigation as it is assumed that there would not be any additional fixed costs above what is already paid as part of the on-farm irrigation practice.
- Lost revenue from foregoing surface water entitlement was assumed to be in the range of gross margin values reported in the NSW DPI farm budgets for irrigated cotton. However, it is then assumed that this water is then extracted, minus recovery losses due to extraction (i.e. between 80% and 100% depending on the scenario).
- The price of surface water traded is for temporary (allocation) trade. The range in values given are believed to cover a realistic range in surface water trade prices from the 1990's to today, for both NSW and QLD, but it has been noted that trade prices have been recorded from \$1/ML to \$800/ML. It is assumed that the water diversion (usage) charges for traded water are the same as for accessing owned entitlements. Fixed costs for the trade application (i.e. \$49.50 in NSW) have not been included.

Journal papers, reports, thesis and other available data were collated to determine the low and high cost values for the various water sources and MAR systems (Table 13). The mean of the low and high values was used as the moderate cost between them. To explore the range in *Recharge costs*, scenarios were run using each combination of water source (i.e. Supplementary/ unused surface water, surface water entitlement and surface water trade) set to a low, moderate and high cost, combined with each option of MAR system (i.e. Basin and Wells) also set to a low, moderate and high cost. Consequently, 54 Scenarios were run. For each scenario, a low, moderate and high recovery cost (Table 14) was added to explore the range in total cost (i.e. recharge cost plus recovery cost).

Table 13 Ranges in input values used for the MAR costing (SW – surface water).

	Name	Description	Assumed cost and references		Assumptions
Alternate MAR water sources	Supplementary water	Excess water available for pumping from the river once excess flow has been declared	Diversion charges (NSW DPI, nd; Queensland Competition Authority, 2011; Water NSW, 2018)	\$3 -\$20/ML	Cost accounts for usage charges, but doesn't include pumping from the river.
	Unused SW	Unused SW already being stored on-farm, but is not used for irrigation before the end of season	Diversion charges (NSW DPI, nd; Queensland Competition Authority, 2011; Water NSW, 2018)	\$3 -\$20/ML	Pumping cost was not included as it is assumed that the water can be moved by gravity to the MAR recharge location.
	SW trade	Surface water traded temporarily (allocation trade) onto the farm for the purpose of MAR	Trade price (Aither Pty Ltd, 2017; Kaczan et al., 2009)	\$50 - \$300/ML	Fixed costs for trade applications have not been included. In NSW this is \$49.50 per application (GHD Pty Ltd and AGT Ptd Ltd, 2011). Diversion charges do not include any fixed costs. Assume that these are already paid as part of the original irrigation activity.
			Diversion charges (NSW DPI, nd; Queensland Competition Authority, 2011; Water NSW, 2018)	\$3 -\$20/ML	
			Total SW trade cost	\$53 - \$320/ML	
	SW entitlement	Irrigator SW entitlement that is purposefully released for MAR, instead of being carried over in the regional SW storage, or used for irrigation on-farm	Diversion charges (NSW DPI, nd; Queensland Competition Authority, 2011; Water NSW, 2018)	\$3 -\$20/ML	Pumping cost was not included as it is assumed that the water can be moved by gravity to the MAR recharge location. Diversion charges do not include any fixed costs as these are already paid as part of the original irrigation activity. Lost revenue, based upon unused water is the gross margin value of the water that is used for MAR recharge instead of being used for crop irrigation and production. Note that 80-100% of this water would be expected to be used at a later date for crop irrigation.
			Lost revenue (based on unused water) (NSW DPI, 2017)	\$342 - \$517/ML	
			Total SW entitlement cost	\$345 - \$517/ML	
MAR infrastructure	Infiltration basin	Water is infiltrated under gravity into the aquifer in a purpose built basin	Levelised capital, maintenance and operation costs (Arshad, 2015; Dillon et al., 2009b; Khan et al., 2008a)	\$57 - \$181/ML	Capital, maintenance and operation costs are levelised to 2018 values, based on a 40 year lifespan of the basin, as part of the cheapest calculations, to a 30 year lifespan of the basin for the most expensive basin option. Assumed 20 - 60m^2 is required for each ML recharged.
			Cost of lost production from MAR area (Dillon et al., 2009b; NSW DPI, 2017)	\$2 – \$16/ML	
			Total Infiltration basin costs	\$59 - \$197/ML	
	Injection wells	Water is injected through an existing or new bore	Levelised capital, maintenance and operation costs (Arshad, 2015; Khan et al., 2008a)	\$210 - \$260/ML	Capital, maintenance and operation costs are levelised to 2018 values, based on a 20 year lifespan of the wells. Assumed 1m^2 is required for each ML recharged using wells.
			Cost of lost production from MAR area (Dillon et al., 2009b; NSW DPI, 2017)	8c – 27c/ML	
			Total Injection well cost	\$211 - \$260/ML	

Table 14 Details of the Recovery cost scenarios used in the analysis (GW – groundwater)

Recovery cost scenario	Recovery rate (% of recharge volume)	GW pumping cost ($/ML)
Low	100%	$33
Moderate	90%	$77
High	80%	$120

Results

A full copy of the scenario results, sorted by increasing total cost, is given in Appendix A, but Table 15 provides a summary. The cheapest MAR system to implement and run (i.e. the first line in Table 15) is a 'low cost' basin infiltration system with the water sourced from 'supplementary flow or unused surface water' with 'low diversion charges' (i.e. $3/ML). In this case, it would cost $62/ML to recharge water into a MAR scheme, and assuming a 100% recovery rate of the water and a pumping cost of $33/ML, the total cost for recharge and recovery is $95/ML of water recovered. If the recovery rate was less (i.e. 80%), and the pumping costs greater (i.e. $120/ML), then the cost for both the recharge and recovery is $198/ML of water recovered. Note that if the recovery rate was 100%, then banking surface water entitlement, rather than supplementary water, would achieve the same costs for MAR (i.e. $95/ML).

Table 15 Summary of estimated recharge and recovery costs for rural MAR schemes in Australia (SW – surface water)

MAR system		Water source		Total recharge cost ($/ML recharged)	Total recharge and recovery cost ($/ML recovered)		
Type	Cost	Type	Cost ($/ML)[a]		Low cost[b]	Moderate cost[c]	High cost[d]
Basin	Low	Supplementary/ Unused SW	3	62	95	145	198
Basin	Low	SW trade	53	112	145	201	260
Basin	Moderate	Supplementary/ Unused SW	11.5	140	173	232	294
Wells	Low	Supplementary/ Unused SW	3	214	247	314	387
Basin	High	Supplementary/ Unused SW	20	217	250	318	391
Basin	Low	SW entitlement	345	242	95	218	351
Wells	Moderate	Supplementary/ Unused SW	11.5	247	280	351	429
Wells	Low	SW trade	53	264	297	369	449
Wells	High	Supplementary/ Unused SW	20	280	313	388	470
Basin	Moderate	SW trade	186.5	315	348	426	513
Basin	Moderate	SW entitlement	431	385	173	320	483
Wells	Low	SW entitlement	345	394	247	386	541
Wells	Moderate	SW trade	186.5	422	455	545	647
Wells	Moderate	SW entitlement	431	492	280	439	618
Basin	High	SW trade	320	517	550	651	766
Basin	High	SW entitlement	517	527	250	423	615
Wells	High	SW trade	320	580	613	721	845
Wells	High	SW entitlement	517	590	313	493	694

[a] The value shown represents either a (L)ow, (M)oderate or (H)igh cost given the potential range for that particular source
[b] Low cost is 100% recovery rate with groundwater pumping cost $33/ML
[c] Moderate cost is 90% recovery rate with groundwater pumping cost $77/ML
[d] High cost is 80% recovery rate with groundwater pumping cost $120/ML

The most expensive MAR system uses a 'high cost' well system with expensive water ($320/ML) from high value surface water trade. Then, depending on the recovery rate and groundwater pumping costs, the *Total recharge and recovery cost* ranges from $613 - $845/ML. This cost is very high, and almost certainly beyond the financial feasibility of cotton growers on a seasonal basis. However, even this most expensive option is comparable to surface water trade prices in the Southern MDB in 2008, which reached about $800/ML.

Basins are generally cheaper than injection wells, due to the high capital, maintenance and operation costs required to implement a well. The cheapest well system has a recharge cost of $214/ML, and a total recharge and recovery cost of $247/ML (assuming 100% recovery rate and $33/ML for groundwater pumping).

The cost of recharge water is highly variable, and a key control on the financial feasibility of MAR. Recharging 'unused surface water' into an aquifer for MAR essentially comes at no cost, ignoring any transmission costs. The benefit of this is that between 25 and 50% of this water could be saved from evaporative loss if it were stored underground. However, for storage from one season to the next, only a highly efficiently MAR system located in an area with high surface water evaporation is likely to be financially beneficial. For example, Figure 36 plots a line which shows the conditions when production from surface water storage of 100 ML for one season equals that of storing it underground for one season, allowing for evaporative loss, groundwater recovery rates and pumping costs. It was assumed that there were no surface water pumping costs, groundwater pumping costs were $33/ML, and a moderate gross margin for cotton was used ($420/ML). The orange area above the line shows when MAR storage is more profitable than surface water storage, and the blue area below the line shows when surface water storage is more profitable. In the figure, if a surface water storage has an evaporation rate of 50%, then the recovery rate of the MAR system must be 87%, or greater for the MAR system to be more profitable after one season of storage. Or, if a surface water storage has an evaporation rate of 35%, then the recovery rate of the MAR system must be 95%, or greater for the MAR system to be more profitable after one season of storage. The more efficient the surface water storage, the greater the recovery rate required from a MAR system to be able to match the profit after one season.

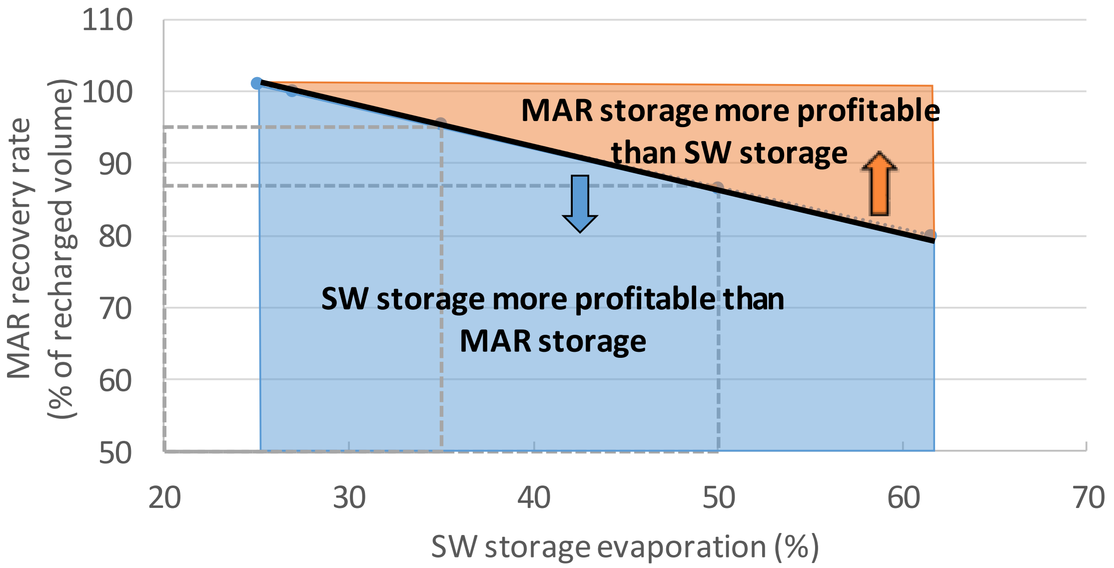
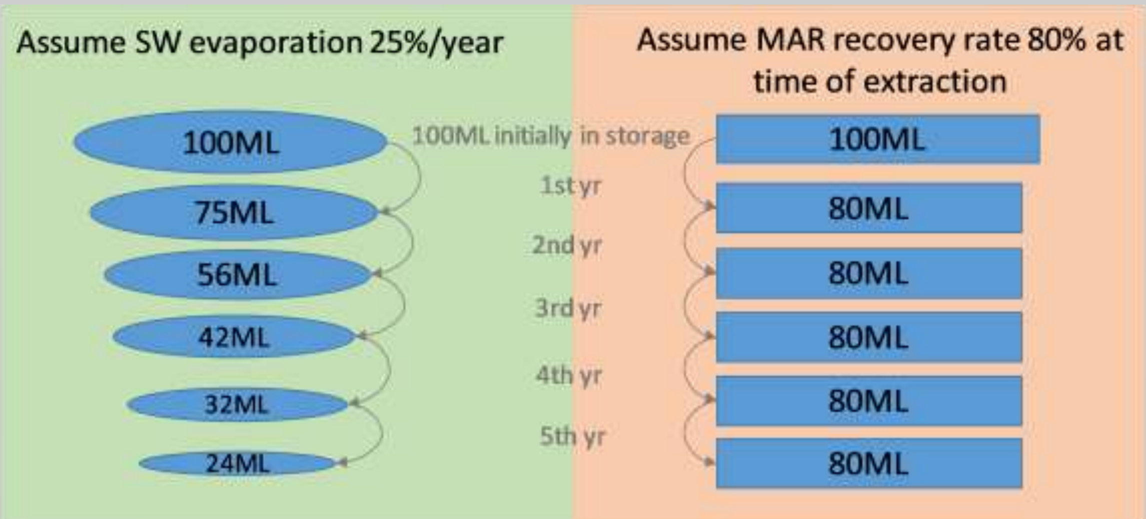


Figure 36 Comparison of profit from surface water (SW) storage of 100 ML for one season, compared to groundwater storage in a MAR system.

However, if 100 ML of unused surface water was stored underground for five years, instead of being stored above ground for the same period, even with a low evaporative loss from surface water storage, and low recovery rate from MAR, and allowing for pumping costs, the MAR scheme would generate about three times more profit than the surface water storage (Box D).

Box D. Worked example comparing the profit from storing 100 ML in a surface water (SW) storage compared to in a MAR scheme for five years. Note this doesn't allow for the evaporation rate to increase as the water in storage decreases, nor does it discount the groundwater (GW) recovery rate through time.



Assume a moderate cotton gross margin $245/ML

Assume no SW pumping costs
SW profit after 5 yrs = 24 x 420
=$10,080

Assume GW pumping cost $33/ML
GW profit after 5 yrs = 80ML x $420/ML –
(80ML x $33/ML)
= $30,960

In this analysis, access to supplementary water provides the cheapest source of water for MAR, and its seasonal variation in availability makes it well suited to long-term underground storage in MAR systems for a drought reserve. For example, in the Murrumbidgee in 2004-2009 there were very few days where supplementary flow was available. However, in years such as 2012-14, or 2016, supplementary flow was available for over 200 days each year. Assuming that the aquifer had the storage capacity, water could be harvested and recharged during these wetter periods, for a very low cost, and banked underground for the drier periods.

Irrigators without a supplementary water entitlement can trade in surface water for a MAR water source, particularly if the water is bought strategically. The minimum purchase price of surface water for this analysis was assumed to be $50/ML (Table 14), which resulted in *Total recharge and recovery costs* of $145 to $260/ML recovered using a 'low cost' Basin infiltration system. However, surface water trade prices are regularly as low as $20/ML, with reports of as little as $1/ML being paid for surface water entitlement in very wet years. Strategically trading water for these prices during wet periods, would make the cost of surface water trade water comparable to supplementary or 'unused surface water', and therefore increase the financial feasibility of a MAR scheme using that source.

Key findings

The three key findings from the preceding analysis are:

- Water can be provided via a MAR scheme for $95/ML. In this case, a low cost infiltration basin is used to recharge the water, with a high recovery rate (100%) and low groundwater pumping cost ($33/ML). These conditions are most likely in shallower unconfined aquifers where high natural infiltration rates are possible and the water source is of good quality and not saline.
- The most expensive MAR scheme is based on 'high cost' wells recharged from high value surface water trading. These schemes cost in the order of $800/ML recovered, which is comparable to peaks in the surface water trade prices.

- Generally, MAR seems financially feasible for cotton growers, if it is strategically managed for drought reserves. This way, water can be sourced and recharged when it is readily available, and therefore cheap to purchase. However, given that surface water can be provided for about $20 to $40/ML (NSW DPI, nd), MAR does not seem as desirable for a regular seasonal storage option.

5.4.4 Costs of purchasing high security water entitlements

There is significant cost associated with purchasing high security water entitlements. During 2018/19 Coleambally high security water entitlements totalled 8,388 ML (Table 3), which to buy back at a price of $8,500/ML, would cost $71 million. High security water entitlements only make up a smaller portion of available water (Figure 14). Direct market purchase of high security water entitlements is therefore unlikely to be a realistic means of providing for community sustainability given that Section 5.1.3 estimated that on the order of 60 GL would be required within the catchment of a cotton gin to meet their target number of bales.

5.5 Environmental considerations

5.5.1 Environmental assets and watering

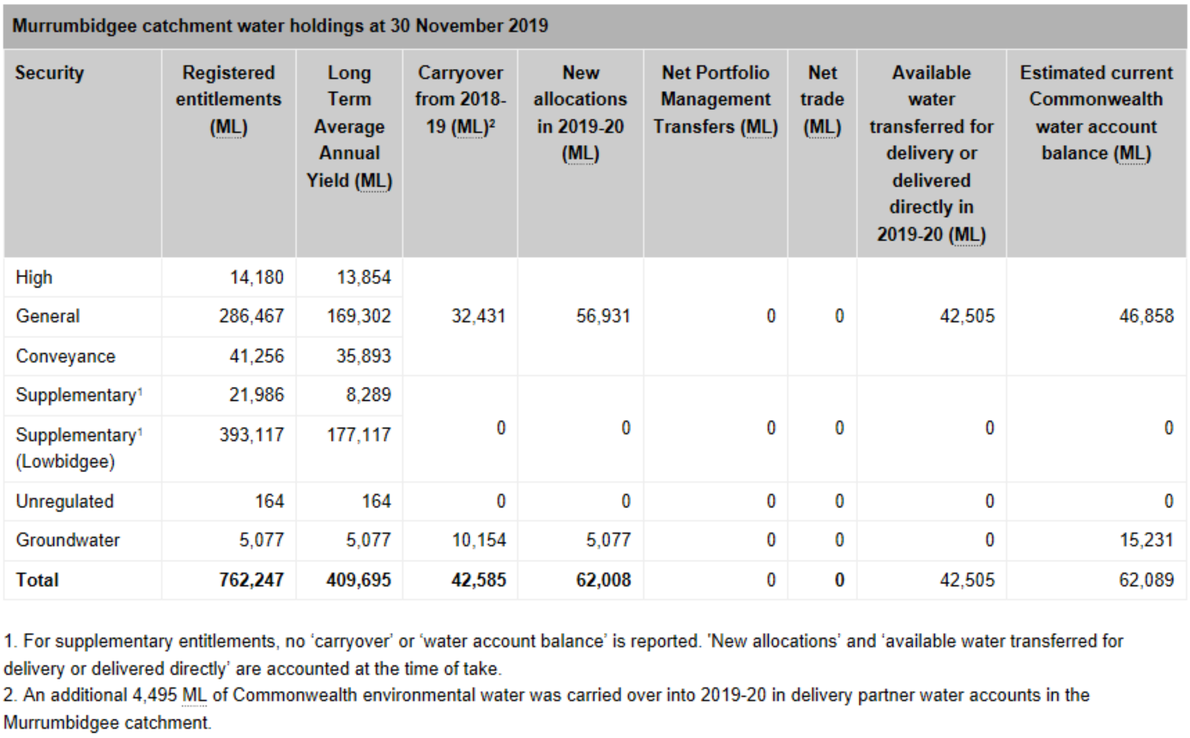
The Commonwealth Environmental Water Office (CEWO) objectives for environmental watering of Murrumbidgee assets focus on in-channel assets (Murrumbidgee River channel) and off-channel assets (Yanco Creek system, mid-Murrumbidgee wetlands, Lowbidgee floodplain wetlands, and Junction Wetlands). The Commonwealth is a substantial actor in the catchment in terms of water holdings (see Table 3) including a large volume of supplementary water for the Lowbidgee (Table 16). They work with NSW DPIE in the planning and delivery of all environmental water, including CEWO holdings.

5.5.2 Effect of supplementary water capture on environmental flow delivery

WaterNSW (2019) states that *"Supplementary access is made available when flows are more than those needed for; environmental water rules, domestic stock and native title rights, and water orders for other licence categories. Supplementary access announcements also consider the water required to fill Lake Victoria when Murrumbidgee general security Available Water Determinations (AWD) are above 70% and the NSW Murray valley's AWD plus carryover is less than 60%."*

Some concerns have been raised about supplementary licenses favouring those who can quickly take water when notice of a supplementary event is given, to the detriment of others (especially Lowbidgee users). For example, in their submission to the ACCC inquiry into water markets in the Murray Darling Basin, one individual wrote that *"The Supplementary Licenses issued in around 2007 now only have an extraction component (extraction limit) and no time component to diversions. The diversions can be taken at any rate and at any time once a supplementary event is declared for the relevant reach of the river. This has allowed some supplementary license holders to significantly compress their diversion times to a fraction of what were taken during the history of use period (via substantially larger diversion infrastructure)"*. This person argues that this has consequences for the river, its dependent ecosystems and other Murrumbidgee and Lowbidgee supplementary license users (submission at https://www.accc.gov.au/focus-areas/inquiries-ongoing/murray-darling-basin-water-markets-inquiry/submissions).

Table 16 CEWO water holdings in the Murrumbidgee catchment (Source: http://www.environment.gov.au/water/cewo/about/water-holdings, accessed 12/02/2020)



Murrumbidgee catchment water holdings at 30 November 2019

Security	Registered entitlements (ML)	Long Term Average Annual Yield (ML)	Carryover from 2018-19 (ML)[2]	New allocations in 2019-20 (ML)	Net Portfolio Management Transfers (ML)	Net trade (ML)	Available water transferred for delivery or delivered directly in 2019-20 (ML)	Estimated current Commonwealth water account balance (ML)
High	14,180	13,854	32,431	56,931	0	0	42,505	46,858
General	286,467	169,302						
Conveyance	41,256	35,893						
Supplementary[1]	21,986	8,289	0	0	0	0	0	0
Supplementary[1] (Lowbidgee)	393,117	177,117						
Unregulated	164	164	0	0	0	0	0	0
Groundwater	5,077	5,077	10,154	5,077	0	0	0	15,231
Total	**762,247**	**409,695**	**42,585**	**62,008**	0	**0**	42,505	62,089

1. For supplementary entitlements, no 'carryover' or 'water account balance' is reported. 'New allocations' and 'available water transferred for delivery or delivered directly' are accounted at the time of take.
2. An additional 4,495 ML of Commonwealth environmental water was carried over into 2019-20 in delivery partner water accounts in the Murrumbidgee catchment.

Attachment B of the *Commonwealth Environment Water Portfolio Management Plan (Murrumbidgee River Valley) 2019-20* outlines the standard operating procedures of the potential watering actions (CEWO, 2018). Supplementary allocations, pending announcements and priorities for watering, are specifically mentioned that they may be used for:

- the mid-Yanco Creek anabranches and wetlands
- the Lowbidgee Wetlands,
- contributing to baseflows, freshes and recessions of natural bankfull and overbank flows for native fish passage, reproduction or survival, and
- restoring natural flow variability

Under the 'Don't miss a drop' scenario CICL and environmental water holders may need to work together to meet their respective needs should the delivery of environmental water via supplementary flows down the Yanco Creek system be planned.

5.5.3 Water quality risks

As highlighted in Section 5.6.2, there are some concerns regarding the risk that MAR poses to groundwater. That said, all groundwater sources are subject to the NSW Aquifer Interference Policy (NSW AIP; see Section 5.7.2 for more detail). Potential MAR schemes in the Murrumbidgee catchment that involved injection would certainly require an aquifer access license and a groundwater use license for a share of the consumptive pool (or be able to demonstrate such licenses could be obtained), and demonstrate that minimal impact considerations can be met [52]. If the latter cannot be demonstrated, then the proponent would need to propose remedial actions. Since it is proposed that 'river' water is used, injection into deep aquifers or low salinity shallow aquifers might not pose a serious risk to groundwater quality, although it is important to note that the potential for geochemical reactions has

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[52] The situation regarding infiltration based systems is less clear (see Section 5.7.2) although it could be argued that in the context of a shallow aquifer where infiltration might increase the risk of waterlogging, and salinization, this would constitute interference and there is a need to address the risk of deleterious environmental and other impacts (see Section **Error! Reference source not found.**).

not been examined in this report. For more saline areas, Section 5.3.4 suggests that there is the potential for infiltration or injection into aquifers to form freshwater lens. If successful, this might reduce the risk of salinisation of the root zone in these areas, however this is highly uncertain.

5.5.4 Possible environmental benefit of MAR schemes

The draft Murrumbidgee Long Term Water Plan Part A: Murrumbidgee catchment report recognizes the extent to which the Mid and Lower Murrumbidgee Alluviums support terrestrial and aquatic ecosystems in the catchment. To illustrate this, the potential terrestrial and aquatic groundwater dependent ecosystems (GDE) for the mid-lower Murrumbidgee catchment are shown in Figure 37 and Figure 38, respectively. Limited GDEs are mapped around the CIA.

Although the plan focuses on the management of surface water, it does define some groundwater related ecological objectives:

- *EF6 Support groundwater conditions to sustain groundwater dependent biota* through flows in the category of large freshes, large freshes with wetland connection or small overbank flows.
- *NV3 Maintain the extent & maintain or improve the condition of river red gum communities closely fringing river channels* through inundation or groundwater recharge anytime of the year, with an ideal frequency of inundation of four to ten years in ten to maintain good general condition of riparian vegetation.
- *EF6 Support groundwater conditions to sustain groundwater-dependent biota* through large freshes and wetland/overbank flows to contribute to recharging of shallow groundwater aquifers. The plan notes the *"This recharge can reduce the salinity of shallow aquifers & raise water tables, providing critical soil moisture for deep-rooted vegetation in the riparian zone & on low-lying floodplains".*

Although these objectives focus on surface water flows that lead to natural recharge, there may be potential ecological benefits of MAR schemes. The Milestone 2.1 report of Ross (2020) highlighted the use of MAR schemes in the USA and Spain to achieve environmental outcomes including improved water quality, flood storage, bird habitat and natural corridors.

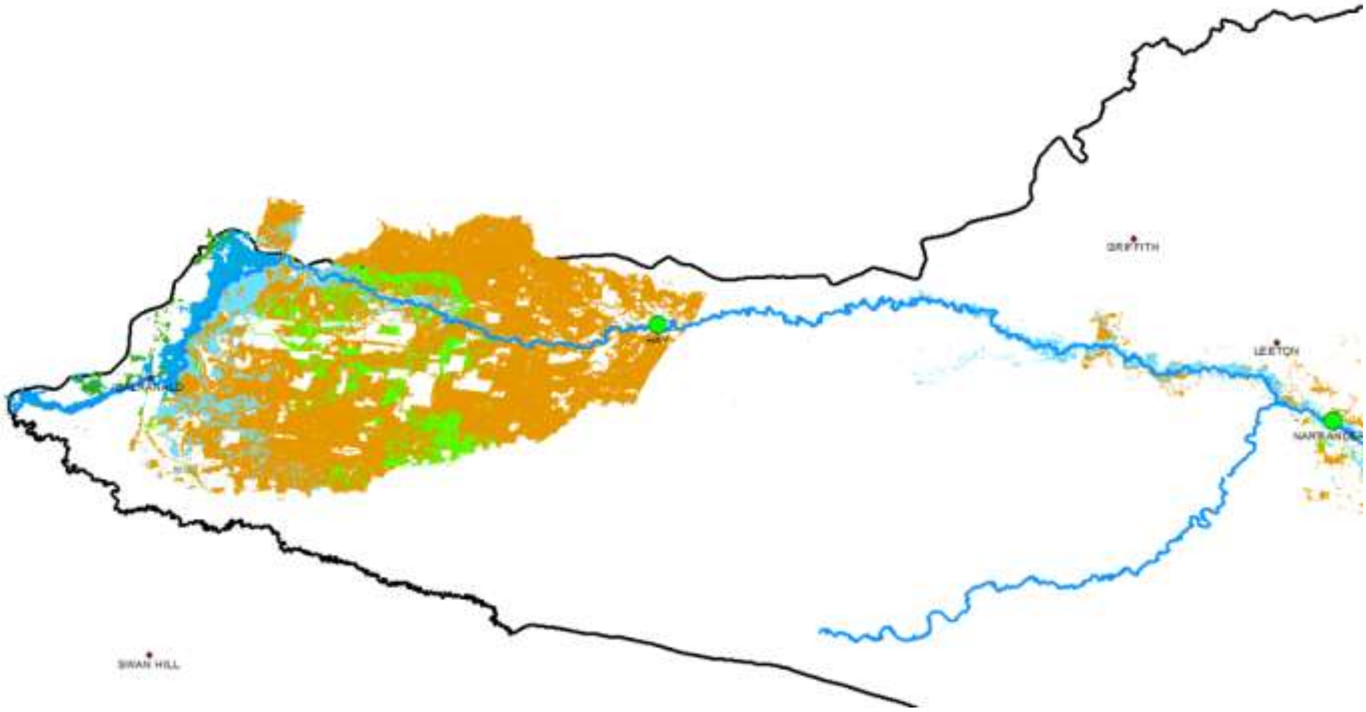

Figure 37 Potential terrestrial groundwater dependent ecosystems (GDEs) http://www.bom.gov.au/water/groundwater/gde/map.shtml

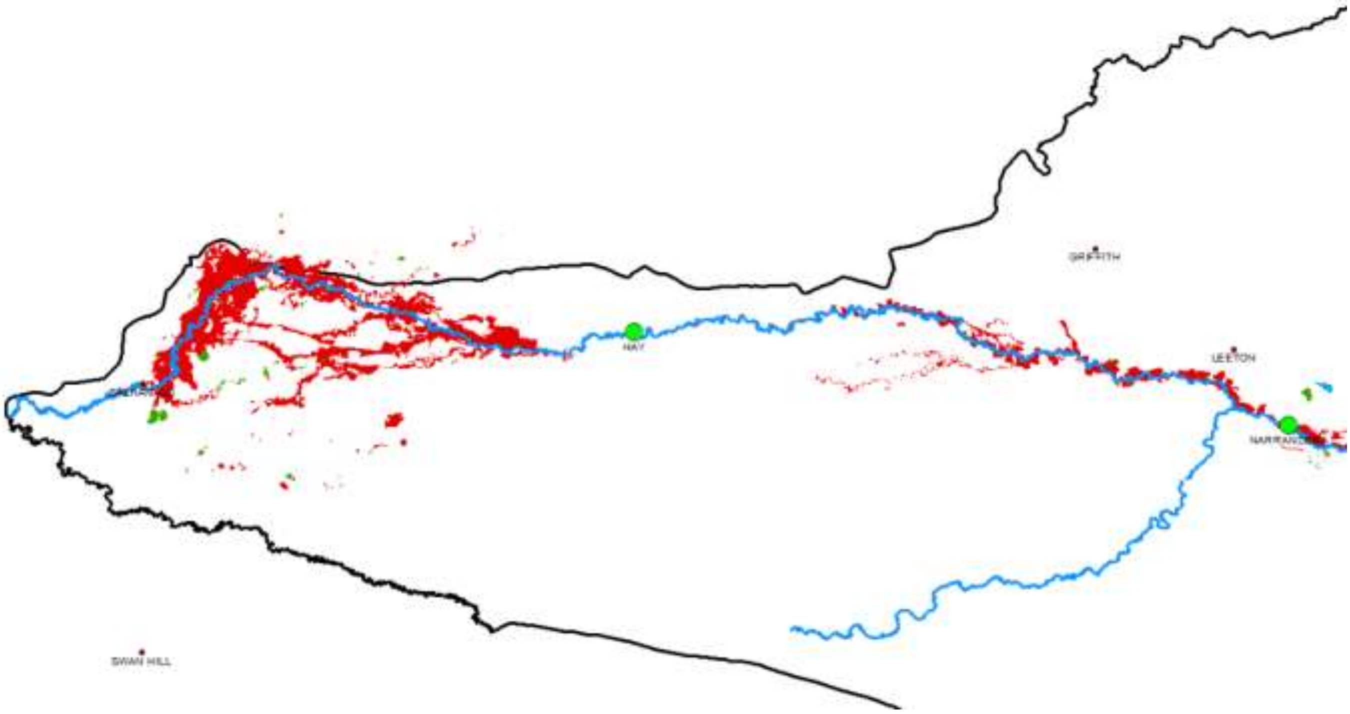

Figure 38 Potential Aquatic groundwater dependent ecosystems (GDEs) http://www.bom.gov.au/water/groundwater/gde/map.shtml

5.6 Social acceptability

5.6.1 Enablers for MAR adoption in the Coleambally Irrigation Area of Operations

The 2018-2023 Strategic Plan lists the CICL vision as "Excellence in sustainable water and irrigation management" to be achieved through its mission "By being at the forefront of water delivery services and promotion of member interests." Forward thinking innovation and leadership in the community, industry and in partnerships are listed as key values. The CICL are well placed to be early adopters of MAR, across all three MAR scenarios, should the CICL Board and members be so inclined. The district has prior experience with early adoption of Total Channel Control (TCC) technology. The layout of the district and co-operative structure provides an institutional mechanism to coordinate the capture of water in wet years. The CICL has well established rules [53] around the governance of the cooperative and the water supply and drainage services provided to members, and processes to review and update these rules with approval of members. The CICL has experience with water use and groundwater level monitoring, both of which are central to enabling stronger involvement in conjunctive water use.

For investment in MAR to be worthwhile (particularly as an early adopter), there is a need for critical mass – large enough water volumes to be stored, large enough operations to bear the cost, and the ability to realise benefits at scale. The CICL structure provides each of these advantages. The CICL itself has a certain level of water allocations that could be used at a pilot stage. If the pilot showed promise CICL and co-operative members could scope potential opportunities for scaling up in future, and implications for changes to CICL rules that would need to be backed by voting members. As discussed in Section 5.2.2, banking the CICL and members' supplementary water allocations, or banking even part of their general security entitlements would provide substantial volumes of water. The CICL's use of fixed delivery entitlements provides a certain level of weather-independent security to enable long term investment, and the CICL is currently in a relatively strong financial position. Channel infrastructure provides a mechanism to potentially widely share recovered water throughout the district, with the ideal location involving storing MAR water at the top of the system, where infiltration does appear to be suitable (Section 5.3.4).

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[53] https://www.colyirr.com.au/s/CICL-Rules-effective-27-April-2020.pdf, accessed 18 November 2020

As part of the adoption of TCC, CICL were able to retain some of the water savings achieved . In the most recent season, CICL gave their members 12% additional allocation in two 6% tranches (totalling 58,000 ML), at no cost and based on held DE, followed by an offer in August 2019 for purchase of an additional 4% (CICL, 2020b). Efficiency savings together with CICL's carryover enabled CICL to provide this member benefit and make additional water allocations and water offer.

This additional water has allowed some individuals to sell their general security allocations on the open market, which provides private benefits but arguably has limited benefit for the community . If the CICL were to move towards explicit support of community sustainability, the processes for allocating this water could be revisited with members; formal support for any changes to rules would be required. Recovered water from MAR could then be distributed according to similar rules, depending on how it was sourced. Such changes constitute a substantial shift from the *status quo*, but cannot be discounted as a possibility.

The CICL is also institutionally well placed to take a more active role in conjunctive water use, within which MAR could eventually play a role. As a result of rising water tables in the 1990s and increasing soil salinity, the CICL undertook a Land and Water Management Plan (LWMP) that included extensive monitoring of water tables throughout the district, which continues to this day as part of compliance monitoring. As a member-owned co-operative, CICL also has a long history and user trust in metering of water use and compliance with the reporting requirements against operating licences (e.g CICL, 2020b). These precedents can enable an expanded role for CICL in this area. At the moment, groundwater levels are not actively used as part of the planning of water delivery, and groundwater use is metered by WaterNSW, from whom the CICL then need to request data for their reporting. It could be in both CICL and WaterNSW's interest to give CICL a greater role in groundwater use metering, in giving greater awareness and control to CICL over how water is used within their district, and providing greater on the ground presence for WaterNSW. Understanding of the relationship between groundwater levels, and surface and groundwater use could then lay the ground for taking into account groundwater availability in surface water delivery, expansion of conjunctive water use, and use of MAR to strategically replenish groundwater levels as part of this broader strategy.

While adoption of MAR is still expected to be a substantial long term investment, it is clear that the CIAO holds some considerable advantages. Consistent with the CICL's values, this is best approached through leadership of broader partnerships rather than lone investment. There are substantial uncertainties remaining and the changes required require close involvement of technological experts, members, WaterNSW and regulators, amongst other partners.

5.6.2 Key informant attitudes to Managed Aquifer Recharge as a concept

The social acceptability, or how 'appealing' the idea of MAR is, was explored through the interviews and stakeholder workshops. It is noteworthy that these discussions were with people associated with the Coleambally district, and did not take into account the wider community impact, such as for those who use the various surface water storages (i.e. Burrinjuck Dam and Blowering Dam) and streams for recreational purposes such as water sports and fishing. For example, anecdotal evidence suggests that the low water levels experienced in local 'water resorts' such as Good Hope and Wee Jasper, in the upper Murrumbidgee catchment, could be further exacerbated if surface water is stored in aquifers in the Coleambally District rather than in Burrinjuck Dam. This impact, and their social and economic consequence, should be investigated in the implementation of any MAR pilot programs in the CIA.

During the key informant interviews, and after an explanation of MAR, participants were asked for their opinion on the social acceptability of MAR in their region. Opinions were mixed between respondents. Some were keen saying *"The 'times right' [for MAR] because of what's happening with water availability and the technology"* or that *"Lots of bores have been put in recently. To put extra water down there would be good"*. One other irrigator saw MAR as another means for increasing the carryover of surface water and he is '*not in favour of more carryover*'.

The two main problems identified with MAR were that there is no new water for MAR ('who owns it') and the water quality risks. Regarding the first concern, the issue relates to the questions: who would own the water, where does the water come from, and how is recovery managed to avoid third party impacts? Examples of the differing sentiment for these two issues and overall acceptability are given in Table 17. Other issues were related to evaporation losses and energy costs to pump. For example, one respondent noted that Lake Coola (near Narrandera, outside the Coleambally District) is about 6m deep and is subject to high levels of evaporation. There are also the energy costs to pump it in there in the first place, not to mention the water is owned by someone. These constraints are the same for the Nimmie Caira.

Table 17 Examples of pro-MAR and anti-MAR sentiments expressed during the key informant interviews.

Theme	Support for MAR	Concerns with MAR
Who owns it?	"Not big on the idea of putting water in big storages, because it is not good to be used 1 in 8 years … I would like to think that we can use it to decrease the economic impact of general security licenses. General security license holders will suffer most from climate change.	"the water is owned by someone" "If it's a large capacity bore, how do you take it without impacting the neighbour?"
Water quality	"You can measure water in and out and where the aquifer is up to, so you would think there would be no third party impacts.	"Contamination scares me!" You have to have guarantee that the water was free of contaminants. "The Deep aquifer is pristine and nothing is wrong with it". What filters would be used?
Social acceptability	"MAR would be an excellent idea. Surface water is only a short-term solution. MAR would offer surety. Every 9-10 years is would be worthwhile".	"MAR risks are too high. Happy to ride out the peaks and troughs in water supply" "You need 100% agreeance before you can get it!"

5.6.3 Responses to scenarios

The scenarios described in Section 4 reflect updates based on discussion with the Murrumbidgee local stakeholder group at the CICL office in Coleambally on 17th February 2020. A summary of the discussions is provided below, along with potential solutions and changes made to the scenarios.

Don't miss a drop

Several issues were raised that mean that this scenario was not considered to be feasible as originally written. Gaps have now been addressed and more detail has been added. These issues relate to the feasibility of capturing large supplementary events, equity issues around MAR recovery, and how a pilot would work.

Feasibility of capturing large supplementary events

The capture of large volumes of water from supplementary events was considered not to be feasible at the time they occur, likely in spring time, just before planting. The supplementary events occur over a couple of weeks, with the volume to be captured having to be brought into the system within time windows that span days. The main channel offtake is capable of drawing 10 GL/day although the estimated maximum capacity of the main canal is about 6 GL/day (Shahidi et al. 2012). In times of high delivery demand from members, ~ 3.5 GL/day could be considered to be the average maximum operating capacity. Additionally, supplementary water is likely to be available in wet years where large crop areas are to be planted, and the channel system also needs to handle crop orders. Supplementary flows may also be used for filling of rice paddies and for initial irrigation of cotton. The volume of available supplementary water is also now lower than it has been in the past, with large volumes sold out of the CIAO, with substantial purchases by private companies with larger storage capacity, and increased prices (a rise from $600/ML to $900/ML was quoted in the workshop).

For the scenario to be considered feasible, there is a need to be more explicit about the volume of supplementary water that can be realistically captured. CICL members retain ~20 GL of supplementary entitlements (see Section 5.2.2). Taking into account the limitations of the main channel intake, 20 GL would take less than four days to capture if it was all delivered in a single event and the CICL system was set up to take it on. It is likely that a supplementary event would last at least that long. If needed, further options for capturing supplementary water flows could be considered in future, e.g. in flooding of wetlands.

Whether or not members can currently take advantage of supplementary water announcements depends on antecedent conditions. During the December 2017 supplementary event, members who had waterlogged farms and full dams could not take advantage of the supplementary water allocation and so only 25% (5,041 ML) of CICL member supplementary water of CICL entitlements were taken, compared with) between September to November 2016 when 100% take of supplementary water was achieved (see Figure 16 in Section 5.2.2). This event was much longer in duration, with little rainfall in the local area, so members were able to use supplementary water to start their summer crops.

The question then becomes: how could the CICL system be set up to potentially approach a recharge water inflow rate of 6 GL/day while meeting other water delivery needs? The need for water treatment (e.g. settling ponds, Section 5.3.4) means that the water is unlikely to be directly injected. Recharge capacity is determined by the combination of the volume of storage sites and number and injection/infiltration rates of MAR sites. Current temporary storage is provided by CICL's Main Canal Off-stream Storage (800 ML). Other existing infrastructure includes Tombullen storage (~11 GL), which is owned and operated by WaterNSW but connected to the main intake. Negotiating alternative operational arrangements would dramatically increase capacity, with the advantage that both storages can be gravity fed. Currently, extracting water by gravity from CICL's Main Canal Off-stream Storage, however, requires dropping the level of the main canal, which may present operational difficulties. The potential for further temporary storages has also been discussed within CICL.

Terminal water storages would also be provided by settling ponds and infiltration basins directly. Infiltration of large events is likely to take on the order of months even with a large number of infiltration basins (e.g. 10 basins, Section 5.3.4), with each basin providing substantial storage capacity in the meantime. Similarly, a large number of wells would likely be used (Section 5.3.4), which increases the total recharge rate and would also require settling ponds that provide additional temporary storage capacity. Infiltration through drainage canals also substantially increases the available capacity. Needless to say, there are substantial uncertainties here about how many sites could be set up and how they would be operated, but it would be possible to gradually scale up the MAR scheme over time rather than plan a single large investment.

Given that the issue is in getting water out of the channel system as quickly as possible to make room for further inflows, meeting irrigator needs is unlikely to be an issue. Even if wet conditions do not reduce water delivery demand, institutional arrangements would ideally allow irrigator deliveries to be provided from CICL supplementary entitlements, in exchange for the use of (part of) the irrigator's entitlement for MAR at a later date. If a supplementary event is expected, it may also be possible to begin MAR with conveyance water prior to the event, increasing recharge time, and potentially making space in temporary storages and the channel.

The current version of the scenario (Section 4.1) reflects these considerations, by emphasizing that the ability to capture a full 20 GL of supplementary water is unlikely to be an investment in a single turn-key MAR scheme. Rather, infrastructure and operational capabilities would be built up over time to gradually improve capture and storage capacity, starting from the *status quo*, complemented with multi-stakeholder efforts to build social licence and the policy environment in which MAR would operate.

Equity issues around MAR water recovery

The second major issue raised relates to equity in access to recovered water. Given CICL is a co-operative, it is important that all members benefit from the scheme in accordance with the CICL rules. These rules are already reviewed and updated as needed and would need to be with any uptake of MAR in the future. If infiltration occurs in the north of the scheme, where water quality is superior, then an irrigator in the south still needs to be able to benefit. Irrigators without bores or with low pumping capacities should not be required to invest in a new one, and the cost of pumping should also be considered. Groundwater tends to be higher salinity, and salinity levels vary considerably in space, but water quality would need to be maintained in the delivered water, groundwater, and channels. It was remarked that altered salinity can affect soil infiltration properties.

The layout of the CIAO and the structure of CICL also provides opportunities to remedy this issue (Section 5.6.1). Any MAR scheme would initially be designed to be completely transparent to members but ensure they would not be directly exposed to its operation. Small initial MAR volumes could simply free up conveyance water use. The CICL already operates two bores that provide groundwater that is mixed with surface inflows. Larger MAR volumes would be delivered by similar mechanisms, likely with an expansion in the number of production bores used. The use of CICL bulk water entitlements for MAR means that the co-operative can maintain strong oversight over the distribution of water, managing risks as part of their existing operations. In future, if MAR were expanded to provide members with the opportunity to recharge their entitlements, then this could perhaps be organized as a financial arrangement, where the allocation is traded to CICL for this explicit purpose, or new water distributions arrangements could be designed. Determining these future arrangements is not necessary for an initial MAR scheme to be set up.

The current version of the scenario (Section 4.1) includes more discussion of these initial delivery arrangements, given their importance for the feasibility of the scenario.

How a pilot would work

Further detail was requested regarding the nature of the pilot, particularly regarding location and size, and the scenario has been expanded accordingly. The pilot would likely take a multi-stage approach, avoiding any form of long term commitment while providing a clear pathway to taking MAR to scale (e.g. maxing out recharge of a 20 GL supplementary event). An initial desktop analysis would identify a list of priority test sites for infiltration and injection, considering soil and aquifer properties and operational concerns for delivering the recharge water from the channel, and considering both the shallow and deep aquifers. A monitoring plan would be developed to evaluate performance and understand recharge behaviour. Initial pilots would proceed with relatively small volumes of conveyance water (e.g. max 10 ML) and recovery of minimal volumes of water (up to 3 ML without a Water Access License), as this requires minimal regulatory approval. The number of sites tested would depend on resources available for the project, but ideally would aim to identify a small but non-trivial recharge capacity to proceed to the next multi-year stage, in case of a flood event (e.g. min 1 GL/year). It would be undesirable for a supplementary event to occur without gaining any measurable benefits from MAR.

The pilot would be structured within a research project that provides external support and close collaboration with research and development corporations, regulators and supporting consultants for long term operation of the scheme. Costs to the CICL would include in-kind labour, new piezometers, and the water used, though further contributions may allow an expanded work program. Once the properties of the priority sites have been explored, project approval would be obtained for recovery of water, along with agreement on clear mechanisms for expanding the number of MAR sites and the MAR volumes to be recharged and recovered over the long term. Careful consideration would specifically be given to avoiding externalities for environmental water and other users, and to develop rules regarding recovery of the water at times when the groundwater source is otherwise subject to reduced allocations. Such approvals would likely happen in conjunction with development of similar approvals for pilots in other regions in NSW, namely for recovery of infiltration in the Murrumbidgee Irrigation district. License conditions, monitoring and compliance requirements are likely to be similar, and joining forces can help provide the critical mass to support development of capacity within the irrigation company, consulting, and government sectors.

A key idea here is that agricultural MAR in NSW is at a stage where technical risk is fairly low (all the technologies are fairly well understood), but that there are substantial uncertainties regarding site-specific performance and operation, including regulation, which can only be completely resolved through experimentation. If there is a need to know everything before beginning, then nothing will happen, and so an adaptive mentality is essential.

Multi-year surface storage

This scenario was previously named “More turkey nest dams”. It is intended as an alternative method for capturing supplementary water without MAR. As previously written, the scenario also discussed ways in which turkey nest dams could be used to support MAR, which was a source of confusion. It now focuses exclusively on the idea of multi-year surface storage, which was not considered feasible for the CIA by workshop participants, but provides a point of comparison against MAR.

The workshop participants thought that the scale and costs for turkey nest dams were probably comparable to those of MAR. Therefore, the research team sourced additional cost estimates for dam construction (Section 5.4.2). A 4 GL ring dam was estimated at \$1.7 M with ongoing costs on the order of \$10-100 k. Multiple storages with a total capacity of 20 GL would therefore be on the order of \$8 M.

In contrast to MAR, new dams would likely be difficult to expand gradually over time. They would involve large individual projects. While MAR would likely also require large surface areas because storages would need to be gravity fed, MAR could be operated with a larger number of small settlement ponds and basins. By design, total evaporation losses would also be higher with surface storage as the water is kept for long periods of time, including over the summer, though this could be mitigated by evaporation reduction technologies at additional cost. Large dams also introduce new risks of dam failure, which may particularly be an issue with dams that are usually empty but occasionally rapidly filled.

Despite the challenges, private companies along the river have implemented this scenario. It has led to some equity concerns, namely about who gets access to the supplementary flows. As it is now, large privateers have the financial capacity to invest in the dams and the supporting infrastructure to capture large volumes of water quickly, while other farmers do not. MAR (through the *'Don't miss a drop'* scenario) provides a solution for providing this capability to a broader group of farmers.[54]

Storing water for community sustainability

Three issues were raised about this scenario: misunderstanding of CICL water entitlements, restrictions on potentially anti-competitive behaviour, and difficulty in pinning down "community benefits". The comment was made that this scenario involves a degree of "social engineering."

The previous version of the scenario implied that existing CICL "member benefits" could be used as a mechanism for distributing water. The revised scenario clarifies that this is not a mechanism upon which to build. New rules would need to be established.

The workshop participants highlighted that the CICL is bound by quite stringent rules around competition, monitored notably by the ACCC. An example was given of another irrigation district that had established price mechanisms to keep water in the region, which was disallowed as a restriction on trade. Review of water competition law is outside the scope of this study, but it does appear that some mechanism could be established. At least initially, the MAR scheme being envisaged is wholly operated by CICL with existing CICL water entitlements (e.g. conveyance water). As a thought experiment for future work, the researchers suggested a hypothetical philanthropic donation of water entitlements incorporated in a "Coleambally Water Trust" and managed by CICL, with the condition that the water is used to support the long term sustainability of the town and district. It seems reasonable that a supporting legal framework could be established, but legal expertise would be required.

The flow-on consequences of a reliable dry year MAR water supply were hotly contested, and the desirability of different outcomes remains unclear. It was agreed that MAR water being traded out of the district would benefit mostly individual irrigators rather than the local community. The viability of the CICL itself is not at high risk of drought years, as delivery entitlements are structured as fixed rather than variable charges. As long as irrigators remain viable in the long term, the CICL will too. This may be different in other irrigation districts. The volume of water required was also called into question, as in the mid-2000s, general security allocations of ~38% were considered insufficient for long-term sustainability. The research team subsequently obtained estimates from a local cotton gin on ideal minimum production (Section 5.1.3), but further research is needed. Some participants considered it likely that the outcome of reliable water would be skyrocketing of the value of water and a transformation of cropping from opportunistic annuals to perennials (especially nuts), though this transformation

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[54] One irrigator interview for this research stated the *"Murrumbidgee River floods once or twice in 14 years. The costs to invest in that water isn't worth it"*. Establishing a scheme such as proposed in 'Don't miss a drop' scenario has the potential to make it worthwhile.

would face issues related to workforce and scale. While this is clearly not advantageous to the cotton industry, it was not clear whether this would be beneficial for the CIAO as a whole, though the benefits of diversification in the district were emphasized by the workshop participants. Therefore, implementation of MAR in this scenario needs to be preceded by a clear understanding of community objectives, a proposed water distribution policy with expected outcomes, and clarity over who bears the cost of MAR scheme development in light of the anticipated benefits. The revised scenario emphasizes this point.

Alternatives for providing water for community sustainability

A scenario was previously included with the title “Redistributing high security surface water entitlements”. It was intended as an alternative means of achieving community sustainability objectives without MAR. The term “redistribution” was, however, considered problematic by the workshop participants, and it was also suggested that other water allocation policy changes should also be put on the table. The replacement scenarios are titled “Community sustainability through high security entitlements” and “Survival water for drought through policy change”.

It was pointed out that tying high security entitlements to the sustainability of particular communities effectively ties water back to land – albeit at a regional scale – like the old bulk licenses. It would support infrastructure development within the Coleambally and allow water to flow to high-value crops within the region. As discussed with respect to the previous scenario, it would therefore play into the hands of horticulture given the value-adding of labour, processing, manufacturing. Horticulture would move in and community might benefit, with a cautionary note being that diversification is key to Coleambally sustainability and that is one reason lower value opportunistic crops are grown now. A concern raised in the workshop was that many members would not have the capacity to invest in horticulture (low capital, lack of necessary skills, etc.). Therefore, compared to the situation in current water markets, this scenario could be considered to induce significant market distortion whether it occurs through CICL control over an increased volume of water allocations, or through government interventions to make changes to water management. There was a sense that savvy farmers make money out of water market and would not like CICL acting on ‘their’ behalf; this is reflected in the chairman and CEO report in the 2020 Annual Report (CICL, 2020a).

The revised scenarios now start with the premise that these are considered long term, radical changes and that societal and regulatory change would likely be required to go ahead, including involvement of the wider irrigation community across the Murray Darling Basin. Most mechanisms for achieving these changes are currently too radical to be considered feasible in the short term, so the scenarios avoid making explicit suggestions and instead describe the intermediate outcomes that may ease such a transition. In particular, it was highlighted that there would be substantial concern over economic impacts of policy changes, and a need to demonstrate the economic benefits for the community before a change occurs, alongside other impact assessments.

The idea of providing survival water in drought times particularly relates to changes in the use of environmental water. There is still substantial uncertainty regarding the volume and delivery of environmental water over time, and it may be possible for changes to be made. This scenario mainly echoes arguments made by Senator Perin Davey in December 2019 [55]. These arguments are presented as an example of currently discussed alternatives rather than as endorsement.

Integrated groundwater-surface water delivery

While it was previously portrayed as a radical change, this scenario was in fact of most interest to the Murrumbidgee stakeholder group. To some extent, both CICL and MI are already using both surface and groundwater, and monitoring both surface and groundwater resources to some degree (albeit without using MAR). For example, CICL have two wells that feed into the main channel. All members who have both groundwater and surface water licenses

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[55] https://www.damiandrum.com.au/19-12-05/, accessed 2 April 2020. To date, it seems as though the Private Members bill has not yet been introduced.

practice integrated groundwater-surface water use at an individual level. While this scenario was built with a dry climate in mind, there is already a precedent in a wet climate, with the efforts to keep water out of the areas where an increase shallow water table is to be avoided.

Therefore, the key to this scenario lies in emphasizing the need to build capacity to monitor and control groundwater levels and groundwater use, in both the shallow and deep aquifers, which is a precursor to effective use of MAR as a groundwater level management strategy. Tracking both surface and groundwater in (near) real-time is, however, a social challenge especially given there has been a shift away from the gains that had been made on telemetering. The CICL currently rely on annual email requests to WaterNSW for groundwater use data. In terms of monitoring infrastructure for groundwater levels, there are a number of publicly accessible bores that can look at quantity as well as quality, in addition to CICL's existing network of piezometers, which are currently read manually. Accounting for river water that is being pumped as groundwater also remains an issue.

The critical value of this scenario is the potential to support business continuity and ensure sustainability of infrastructure. There would need to be effort to quantify the costs borne to all involved. In the CIA, groundwater license irrigators are looking at a cut in allocation by 50% next year due to very high extraction rates over the last few years [56]. It is important to note that we are not in a stable market, and at some stage, there may be further reform. There is no cap on buyback for environmental water and there may be requests for additional purchases. From an MI perspective, the potential efficiency in water delivery is attractive as is MAR for the potential to increase production of high value crops. Across irrigation districts comparisons could be made to get a sense of how much of a mix between surface and groundwater is worthwhile (Murrumbidgee Irrigation, Goulburn-Murray Water, CICL, Murray Irrigation, Mildura).

Overall conclusion

Overall MAR was seen as an opportunity to increase the in-house water storage capability of irrigation companies and regions etc, albeit one that remains highly uncertain and in need of further work to prove its feasibility. After discussion and revision, all scenarios suggest that proceeding with a MAR pilot would be worthwhile, especially if it could be supported within the context of a research project. Given the need for MAR policy development, irrigation companies have an important role to play in helping to provide input into development of water management in this space, in collaboration with NSW DPIE and WaterNSW.

5.7 Governance arrangements

5.7.1 The MDBA and MAR

The Murray-Darling Basin Authority (MDBA, 2019) recognises MAR as a method to increase water security in the basin, by storing water when it is readily available to be used during periods of water scarcity (MDBA, 2019). To ensure that MAR is equitable to other surface water allocations, double-counting is avoided (MDBA, 2019). This is to say that the water to be used through MAR is only counted as part of annual allocations when it is extracted from the surface source, and not counted again when it is eventually extracted after storage in the aquifer (MDBA, 2019). For management purposes, the recharged MAR water is still accounted for and reported (MDBA, 2019).

Responsibility for implementation of these principles lies with the Water Resource Plans developed by state governments. There are currently no provisions for managed aquifer recharge in Water Resource Plans (or state Water Sharing Plans) in New South Wales, but the Water Sharing Plan for the Murrumbidgee Alluvial Groundwater Sources (2019) 69(1)(a) indicates that the plan may be amended to include rules for MAR.

There are currently two areas in the Murray-Darling Basin that practice relatively small scale MAR, in the Australian Capital Territory (ACT) and Angas Bremer in South Australia (SA). A summary of the water stored and extracted in these systems recently is present below (Table 18; MDBA, 2019).

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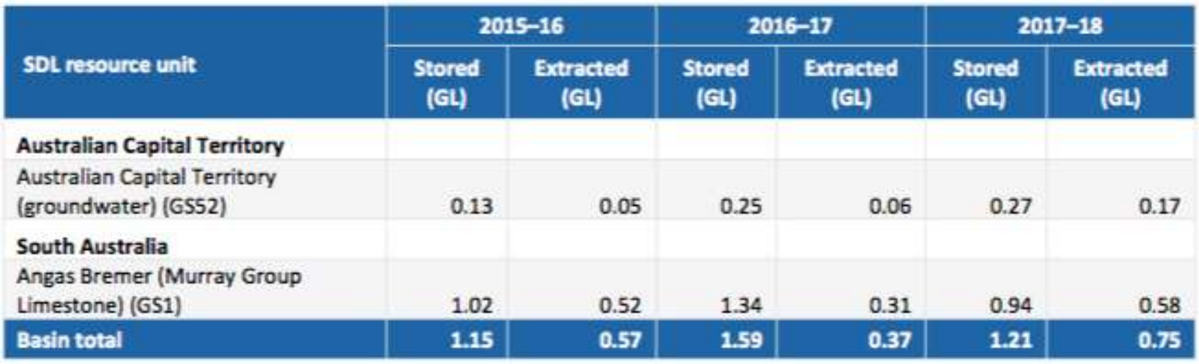
[56] Bidgee+Groundwater+Stats+(2006-19) Excel Spreadsheets from http://www.mgi.org.au/updates, accessed 12 May 2020

Table 18 Managed aquifer recharge volumes 2015-16, 2016-17 and 2017-18 (MDBA, 2019)



SDL resource unit	2015–16		2016–17		2017–18	
	Stored (GL)	Extracted (GL)	Stored (GL)	Extracted (GL)	Stored (GL)	Extracted (GL)
Australian Capital Territory						
Australian Capital Territory (groundwater) (GS52)	0.13	0.05	0.25	0.06	0.27	0.17
South Australia						
Angas Bremer (Murray Group Limestone) (GS1)	1.02	0.52	1.34	0.31	0.94	0.58
Basin total	**1.15**	**0.57**	**1.59**	**0.37**	**1.21**	**0.75**

The MAR pilot program in the ACT is part of a larger project to harvest stormwater as a non-potable water source for urban irrigation purposes, and therefore preserve potable water (ACT Government, 2014). The harvested and filtered stormwater is injected into a single bore, where it is stored and retrieved by local organisations, both public and private, when required (ACT Government, 2014; MDBA, 2019). This program operates on a neighbourhood scale (ACT Government, 2014), and in recent years stored more water than what was extracted.

To assess the feasibility of MAR in the ACT, a report based on available data and technical assumptions was developed (ACT Government, 2014). The most cost-effective infrastructure options that did not compromise performance were also explored (ACT Government, 2014). Community focus groups were also held throughout the process to assess public attitudes and preferences concerning the project (ACT Government, 2014). Several pond systems were constructed to increase stormwater capture, ensure that irrigation demand was met and that the project was cost-effective (ACT Government, 2014). In the ACT, the Water Act 2007 [57] requires an application for a "recharge license" from the EPA [58] for any works intended to increase the quantity of groundwater. It is necessary to hold a water access entitlement, and the application process considers the applicant's environmental record and risks from rising groundwater levels, including for ecosystems and surface water. Conditions may be imposed on the license and it may be cancelled if damage is being caused.

In SA, surface water from the River Murray and its tributaries in the Eastern Mount Lofty Ranges are recharged into the Angas Bremer groundwater system (MDBA, 2019). In the 1970s, in response to increased demand, groundwater salinity rose sharply, limiting extraction (Dillon et al., 2009; Thomson, 2008; Newland, 2015). To combat this, viticulture farmers began extracting water from the ephemeral Bremer River into personal irrigation wells and allowing it to recharge under gravity (Thomson, 2008), which substantially decreased the salinity of the recovered water (Dillon et al., 2009). By the 1990s, a total of 30 wells were recharging, at its peak, 2.4 GL/year into the groundwater system, with this project being run by local farmers with the support of the SA Government (Dillon et al., 2009). The amount of water recharged depended heavily on availability and therefore fluctuated substantially (Zulfic & Barnett, 2007). This system is an example of the conjunctive use of surface and groundwater resources to supply a region (Dillon et al., 2009; Newland, 2015; Thomson, 2008).

To support the growth of aquifer storage and recovery (ASR) in the region, policies were developed by the Angas Bremer Water Management Committee (Thomson, 2008). Two central policies were the right to extract 50% of the volume stored, as well as credits for up to three years to allow the use of stored water that had not been used in the same year (Thomson, 2008).

Improved management and monitoring strategies were also put in place to strengthen the local water resource and control salinity (Thomson, 2008). Several of these were added as new conditions to existing water licenses held by irrigators including: (1) mandatory reporting of water volumes and hectares irrigated, (2) an on-farm monitoring well

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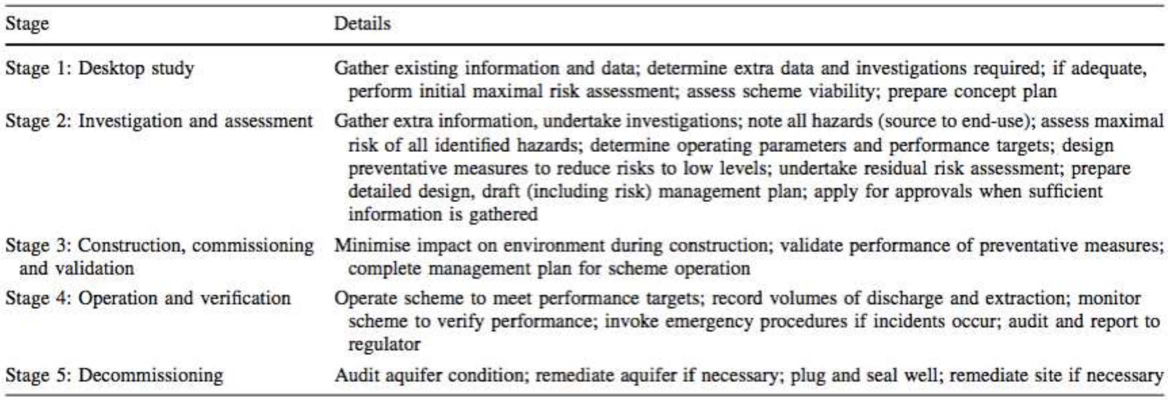
[57] https://www.legislation.act.gov.au/a/2007-19/, accessed 24 March 2020

[58] https://ablis.business.gov.au/service/act/recharge-licence/3935, accessed 24 March 2020

which is used to measure and report the height of the water table four times a year, (3) the use of on-farm devices to measure the amount of salt in the root zone and (4) the planting and maintenance of two hectares of deep-rooted winter active vegetation for every 100 ML water allocation (Thomson, 2008). On a district level, data-loggers were installed at 24 wells (12 into the confined aquifer, 12 into the unconfined aquifer), to record the water level in the wells every 15 minutes. There are also additional wells where data is collected on a three-monthly basis (Zulfic and Barnett, 2007). This data can be used to understand the aquifers' response to rainfall, flooding events, irrigation and ASR activity (Thomson, 2008).

MAR schemes in SA require a permit from Department for Environment, Water and Natural Resources (DEWNR) and are regulated by the state's Environment Protection Authority (EPA) (SA EPA, 2004), which oversees water quality (Newland, 2015). Other state agencies may become involved depending on the construction necessary for the project and the end-user of the water (Newland, 2015). A stepwise methodology has been developed as a guide to establishing a MAR scheme in SA (Table 19; Newland, 2015). A code of practice for Aquifer Storage and Recovery is provided as a practical guide for project proponents (SA EPA, 2004).

Table 19 Stages of a MAR scheme (Newland, 2015)



Stage	Details
Stage 1: Desktop study	Gather existing information and data; determine extra data and investigations required; if adequate, perform initial maximal risk assessment; assess scheme viability; prepare concept plan
Stage 2: Investigation and assessment	Gather extra information, undertake investigations; note all hazards (source to end-use); assess maximal risk of all identified hazards; determine operating parameters and performance targets; design preventative measures to reduce risks to low levels; undertake residual risk assessment; prepare detailed design, draft (including risk) management plan; apply for approvals when sufficient information is gathered
Stage 3: Construction, commissioning and validation	Minimise impact on environment during construction; validate performance of preventative measures; complete management plan for scheme operation
Stage 4: Operation and verification	Operate scheme to meet performance targets; record volumes of discharge and extraction; monitor scheme to verify performance; invoke emergency procedures if incidents occur; audit and report to regulator
Stage 5: Decommissioning	Audit aquifer condition; remediate aquifer if necessary; plug and seal well; remediate site if necessary

Neither Victoria nor Queensland have any active MAR schemes in the Murray Darling Basin. Victoria does provide guidelines that describe the overall application and approval process and the roles and responsibilities of different organisations [59]. The focus is on project-based approval by a nominated MAR scheme manager. There is no single MAR policy, but various aspects of MAR implementation fall under different regulations. Goulburn-Murray Water also has a current project developing a decision support tool for assessing MAR suitability. Queensland does not have a specific MAR policy either. The Burdekin delta has Australia's longest running MAR project, with local water boards responsible for maintaining groundwater levels in the area and preventing the intrusion of seawater (Dillon, 2009).

5.7.2 The NSW Water Policy context

Ross (2019) reviewed existing policies, legislation and regulations that impact on the implementation of MAR operations, with special reference to cotton growing areas in New South Wales and Queensland.

In NSW, access to surface water for recharge operations is determined by applicable water allocation regulations, notably under the Water Management Act (2000) and the Water Management Amendment Act (2018). Water recharge to aquifers becomes part of the consumptive pool and subject to aquifer extraction limits set in water plans. No specific rights are granted to recharged water. The MDBA's provision for avoiding double counting has not yet been implemented in state policy.

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[59] Guidelines for MAR – health and environmental risk management, https://www.epa.vic.gov.au/about-epa/publications/1290, accessed 24 March 2020

NSW does have a specific Aquifer Interference Policy (AIP). While the focus of the policy is primarily on mining activities, the policy specifically mentions injection works used to transmit water into an aquifer. It appears that MAR through infiltration is not explicitly discussed in the policy (Box E). Approved aquifer interference activities including MAR require an aquifer access licence and a groundwater use licence for a share of the consumptive pool. In water sources where water sharing plans do not yet apply, an aquifer interference activity is required to hold a water licence under Part 5 of the Water Act 1912.

Under the NSW AIP proponents of aquifer interference activities including MAR are required to demonstrate that they can obtain the necessary licences, and ensure that minimal impact considerations can be met or propose remedial actions. Minimal impact considerations include impacts on water table levels, water pressure and water quality in different types of groundwater systems, and impacts on connected alluvial aquifers and surface water systems and other water dependent assets. These include impacts on water supply bores, GDEs and culturally significant sites that are groundwater dependent and take account of uncertainty. Thresholds are set so that the impacts of both an individual activity and the cumulative impacts of activities within each water source can be considered.

The NSW AIP requires proponents to take a risk management approach to assess the potential impacts of aquifer interference activities, with the level of detail proportion to a combination of the likelihood of impacts occurring on water resources uses and dependent ecosystems, and potential consequences of these impacts. The minimal impact assessment provides a rigorous and independent assessment of potential impacts of the projects on agricultural land and water resources before a development application can be lodged. Part 4 of the Environmental Planning and Assessment Act 1979 provides a streamlined approval process for the assessment.

5.7.3 Australian Guidelines for Water Recycling: Managed Aquifer Recharge

The Australian Guidelines for Water Recycling: Managed Aquifer Recharge (NRMMC, EPHC & NHMRC, 2009) provide recommendations to minimise the effect on *water quality, human and environmental health* as a result of a new MAR project. The guidelines detail entry-level assessments that should be undertaken to prior to a MAR project being undertaken and which comprise both a viability assessment (Figure 39) and an assessment of the degree of difficulty associated with the project.

How this report addresses the components of the viability assessment is outlined in Table 20. The CIA presents a range of different levels of difficulty for MAR (Table 21), allowing a pilot to begin with easier MAR sites, and proceeding to increase recharge capacity with more difficult sites and methods as experience is gained.

Box E. How does the AIP relate to MAR?

Under the *Water Management Act 2000* an aquifer is a geological structure or formation, or an artificial landfill, that is permeated with water or is capable of being permeated with water. The Act defines an aquifer interference activity as any of the following:

- the penetration of an aquifer,
- the interference with water in an aquifer,
- the obstruction of the flow of water in an aquifer,
- the taking of water from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations, and
- the disposal of water taken from an aquifer in the course of carrying out mining or any other activity prescribed by the regulations.

Examples of aquifer interference activities include mining, coal seam gas extraction, injection of water, and commercial, industrial, agricultural and residential activities that intercept the water table or interfere with aquifers.

Unlike injection systems, infiltration schemes are not explicitly mentioned in the policy. Infiltration could, however, be classed as an activity that interferes with aquifers. In the context of a shallow aquifer where infiltration might increase the risk of waterlogging, then this could be considered interference. However, infiltration into an aquifer that has substantial drawdown and where the recharge volumes have limited effect may not be considered interference.

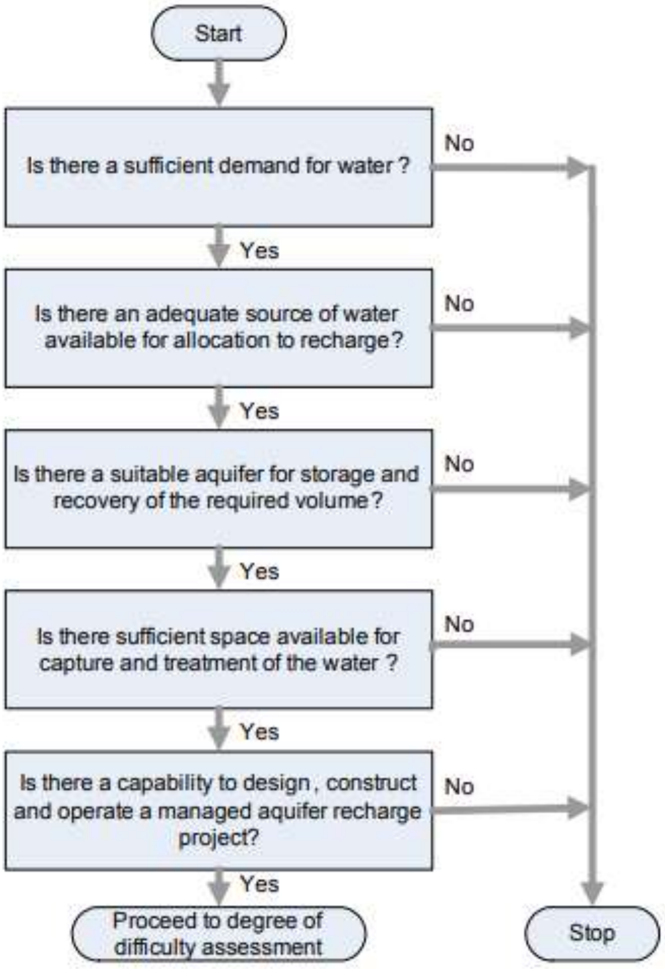

Figure 39 A flowchart of the entry-level viability assessment (Source: NRMMC, EPHC & NHMRC, 2009).

Table 20 Mapping the content of this report against the viability assessment components recommended by the Australian Guidelines for Water Recycling: Managed Aquifer Recharge entry-level viability assessment and this report (NRMMC, EPHC & NHMRC, 2009).

Attribute from the Guidelines	Notes from Guidelines	Assessed in this report	Comments
Is there a sufficient demand for water?	The ongoing volumetric demand for recovered water should be sufficient to warrant investment in the proposed project; if this is not the case, there needs to be a clearly defined environmental benefit. Either one of these criteria is essential for managed aquifer recharge. Projects involving recharge of partially treated water where recovery is incidental do not qualify as managed aquifer recharge	Yes in 5.1.2 and 5.1.3	
Is there an adequate source of water available for allocation to recharge?	Entitlement to water to be used for recharge needs to be secured. Mean annual volume of recharge should exceed mean annual demand, with sufficient excess to build up a buffer storage to meet reliability and quality requirements. In an already over allocated catchment, an entitlement to surface water is unlikely to be available	Yes in 5.2.1 to 5.2.5	
Is there a suitable aquifer for storage and recovery of the required volume?	Presence of a suitable aquifer is critical for managed aquifer recharge. Such an aquifer needs to have an adequate rate of recharge and sufficient storage capacity; it also needs to be capable of retaining the water where it can be recovered. Low salinity and marginally brackish aquifers are preferred, to maximise the volume of recovered water that is fit for use after fresh recharge water mixes with ambient groundwater. Regional maps showing the potential of aquifers as storages for managed aquifer recharge have been developed for some urban and rural areas, and are available from water resources managers in the local jurisdiction. In over allocated aquifers, water managers may have additional constraints on the proportion of recharge that may be recovered.	Yes in 5.3.1 and 5.3.3	
Is there sufficient space available for capture and treatment of the water?	For stormwater recharge systems (either open space or dams), wetlands, ponds or basins are needed to detain sufficient water to achieve the target volume of recharge. Similarly, space needs to be available for whatever treatment process, if any, is subsequently determined to be required. For recycled water from a sewage treatment plant, generally no additional detention storage will be required at the recharge facility.	Yes in 5.3.1, 5.3.4 and 5.6.3	There is sufficient space now to support a pilot project, and over time the potential to build infrastructure to support larger schemes. While land within the irrigated area is at a premium, space within the broader area of operations is unlikely to be a constraint.
Is there a capability to design, construct and operate a MAR project?	Knowledge of hydrogeology and water-quality management is vital for the successful design, construction and operation of managed aquifer recharge projects. Also necessary for some projects are geotechnical know-how, and expertise in water storage and treatment design, water sensitive urban design, hydrology, monitoring and reporting. ***Proponents who do not have these skills are encouraged to gain access to them before proceeding with Stage 2 investigations.*** The number of consultants experienced in investigations and design of managed aquifer recharge projects is growing.		Development of capacity and skills is a key component of the proposed pilot. Expertise from across Australia would be accessed, and leveraged with the aim of building local expertise.

Table 21 The Australian Guidelines for Water Recycling: Managed Aquifer Recharge entry-level degree of difficulty assessment: attributes to consider.

Attribute from the guidelines
Does source water meet the water-quality requirements for the environmental value of ambient groundwater?
Does source water meet the water-quality requirements for the environmental values of the intended end uses of the water on recovery?
Does source water have low quality; for example: total suspended solids >10 mg/L, total organic carbon >10 mg/L, total nitrogen >10 mg/L? Also, is the soil or aquifer free of macropores?
Does ambient groundwater meet the water- quality requirements for the environmental values of intended end uses of water on recovery?
Is either drinking water supply, or protection of aquatic ecosystems with high conservation or ecological values, an environmental value of the target aquifer?
Does the salinity of native groundwater exceed either of the following: (a) 10 000 mg/L, (b) the salinity criterion for uses of recovered water?
Is redox status, pH, temperature, nutrient status and ionic strength of groundwater similar to that of source water?
Are there other groundwater users, groundwater-connected ecosystems or a property boundary within 100–1000 m of the MAR site?
Is the aquifer: (a) confined and not artesian?, (b) unconfined, with a water table deeper than 4 m in rural areas or 8 m in urban areas?
Is the aquifer unconfined, with an intended use of recovered water that includes drinking water supplies?
Is the aquifer composed of fractured rock or karstic media, or known to contain reactive minerals?
Has another project in the same aquifer with similar source water been operating successfully for at least 12 months?
Does the proponent have experience with operating managed aquifer recharge sites with the same or higher degree of difficult, or with water treatment or water supply operations involving a structured approach to water-quality risk management?
Does the proposed project require development approval? Is it in a built-up area; built on public, flood-prone or steep land; or close to a property boundary? Does it contain open water storages or engineering structures; or is it likely to cause public health or safety issues (e.g. falling or drowning), nuisance from noise, dust, odour or insects (during construction or operation), or adverse environmental impacts (e.g. from waste products of treatment processes)?

5.7.4 Potential for MAR water recovery rules

As discussed in the preceding sections, there are currently no specific rights to recover MAR water, although there are some rules in place surrounding the recharge process itself, and both the MDBA and NSW Water Sharing Plans identify the need to develop suitable policy. Development of MAR policy is also on the radar of the NSW Department of Planning, Industry and Environment (DPIE).

There are precedents of jurisdictions internationally that have established general rules for MAR water recovery, and other jurisdictions in Australia where location-specific rules have been established. From the point of view of establishing clear regulations for sustainable use of MAR in the context of conjunctive water use, it would be ideal to aim for state-wide regulations for NSW that minimize burdens on MAR scheme operators while minimizing risk of adverse impacts. This will help ensure equity of access to MAR, making it available to small as well as large operators.

As one possible path forward, state-wide regulations for MAR could be added to groundwater water sharing plans, as already highlighted by the plans themselves. Consistent rules could be used across the state while allowing for variations across different water sources. The rules would need to address water quality requirements for recharged water, with provisions for standard monitoring and treatment requirements avoiding case-specific assessments where possible. Accounting rules would need to be developed to define how the recharged and recoverable volume of water is to be monitored, especially for infiltration basins where measuring inflows is unlikely to be a reliable indicator of water reaching the aquifer. Analysis would be needed to understand the impact of MAR on the groundwater source generally, including risks related to high groundwater levels, residence times, aquifer leakage and losses, and return flows to surface water. Additional rules may then be needed, for example, capping MAR volumes, restricting the location of MAR, or developing triggers that limit the use of MAR. Similar processes have already been undertaken for determination of extraction limits for groundwater, and existing groundwater models would likely provide a suitable starting point for such analysis.

There are, however, larger scale ripple effects of MAR use that would also need to be considered. MAR provides a means to privatise water storage (with a similar effect to existing large farm dams), reducing dependence on socialized costs and benefits of WaterNSW-operated reservoirs. Depending on the scale of MAR schemes, they may have substantial impacts on surface water flow regimes, with potentially unanticipated impacts for other water users, aquatic ecosystems and delivery of environmental flows. While access to surface water for MAR is in principle already regulated (see Section 5.2), the widespread use of MAR may also bring to light limitations that previously did not need to be addressed.

Moreover, if the purpose were to make MAR widely available as a conjunctive water use technique, the MAR rules themselves would need to be designed accordingly. Ross (2019) suggested that design of MAR policy ensure that recharged water has a higher level of security than naturally recharged groundwater – that access to recharged water will be restricted only after other entitlements to groundwater. Certainty and security in policies and rules on the amount of stored water that can be recovered will be necessary to promote investment in MAR, but this may be made more difficult due to an increasingly variable climate. It is not yet clear how recovery entitlements should be specified such that they provide an incentive for adoption of MAR, but also take into account uncertainties about the water system and future conditions.

It is clear that substantial upfront work is needed to establish generally applicable state-wide or even water-source specific MAR water recovery rules. That no policy currently exists in NSW is fortuitous because it means that there is an opportunity to help write it. However, realistically, this also means that (barring sudden political intervention) development of general rules should be considered a long term endeavour involving shared learning between project proponents, regulators, researchers, consultants and other interest groups. This would allow potential rules to be iteratively tested in restricted settings rather than immediately rolled out at scale.

5.7.5 Potential MAR project assessment process

The current governance arrangements and need for testing of water recovery rules suggest that initial investments in MAR in Coleambally should proceed in a pilot project setting. Initial tests of recharge and monitoring can be performed within existing regulations. Recovery of water will involve collaboration with NSW DPIE and MDBA to undertake a site-specific impact assessment. The WSP for the Murrumbidgee Alluvial Groundwater Sources could be amended to allow extraction of recharged water subject to approval by DPIE. As noted above, both ACT and Victoria regulate MAR using project approval processes, and any MAR through injection wells in NSW would already need to obtain project approval according to the aquifer interference policy.

In addition to concentrating research resources and efforts in specific locations, the use of pilot projects is also likely to reduce risks by avoiding large scale impacts. In most cases, MAR schemes are unlikely to cause impacts on water tables or water pressure above the minimal impact thresholds. Also, MAR using natural water is unlikely to have a significant impact on water quality. MAR schemes are unlikely to be large enough to cause significant impacts on adjacent groundwater and surface water sources. Possible impacts will still need further investigation, both before approval is given and as part of monitoring conditions on the approval, but such investigations can be factored into the design of the pilot project.

Based on the project team’s current understanding, a pilot would involve the following regulatory requirements:

- Ensure relevant water allocation licenses are held for the water to be recharged
- Ensure no prohibitions exist on the use of land used for infiltration
- Ensure all permissions are obtained for new piezometers
- Infiltration can occur without further approvals unless the infiltration basin intercepts the water table
- For injection, licenses for bore construction are required
- Prior to injection, ensure the NSW Aquifer Interference Policy is followed

  - As long as volumes are small, it appears unlikely that the pilot would be considered a State significant development under the Environmental Planning and Assessment Act 1979, but the project should likely seek approval given the lack of precedents
  - Aquifer impact assessment will involve demonstrating there is no more than minimal harm, as defined in the NSW AIP
  - Establishment of baseline groundwater conditions
  - Details of potential impacts on nearby water users and ecosystems
  - Details of potential for increased saline or contaminated water flows and changes in hydraulic connectivity
  - Details of a monitoring program, reporting procedures, and contingency plans
- Water recovery will require collaborative development of an additional project approval describing conditions on recovery and the related impacts of withdrawing water outside of the WSP extraction limits.
  - Extraction of volumes under 3 ML are subject to an exemption
  - If the MAR volumes recovered are small, project approvals may not be substantial

Where MAR volumes are large, public comment may be required, and a full approval process would need to be developed with NSW DPIE.

6. Synthesis

The CIA was selected for an intensive investigation into the potential feasibility of MAR given the interest of the CICL in the project. Also, as an irrigation co-operative, the CICL should be better placed to be an early adopter of MAR than individual member irrigators. Analyses to assess the potential feasibility of MAR in the CIA included interviews with local stakeholders interviews, desktop review of scientific, government and other literature, analysis of existing spatial data, financial analyses, discussions with the Steering Committee and the Murrumbidgee stakeholder group, and discussions with MDBA and NSW Government representatives.

The feasibility assessment facilitated the identification and evaluation of three MAR scenarios highlighted promising opportunities for MAR in the irrigation district:

- *Don't miss a drop:* Capture and banking of water during wet years
- *Storing water for community sustainability:* using stored water in a way that benefits everyone
- *Integrated groundwater and surface water delivery:* using MAR to complement conjunctive use

The scenarios, developed iteratively with feedback provided by the stakeholder group, enabled us to refine the feasibility assessments and to provide recommendations for MAR pilot(s) in the Coleambally areas or the Mid-Murrumbidgee valley. Each scenario was backed up by evidence from analyses against each of the seven criteria for the feasibility of MAR. This synthesis section firstly summarises key learnings on the methodological framework applied in this research and some of the feasibility criteria, then concludes with recommendations for both the CICL and CRDC.

6.1 Key learnings

The feasibility + scenario framework: Framing the Coleambally research using the seven feasibility criteria enables us to take a whole-of-system view of MAR and assess the potential barriers and facilitators in operationalising the MAR, and to suggest how future pilot projects could be implemented. Scenarios allow us to focus on the information needed to decide whether to take the next step towards MAR implementation or not.

Water availability: Despite little un-utilised consumptive water, there are opportunities to capture what volume of entitlements are not used or to rethink how the current volumes are used and managed within a scheme to provide outcomes to irrigators and community.

Financial viability: Our analysis of the estimated range in costs to construct and operate a Managed Aquifer Recharge (MAR) scheme in rural areas of Australia suggest a general range from $95/ML recovered – for schemes with low cost infiltration basin, 100% recovery rate, and groundwater pumping cost of $33/ML to $800/ML. The upper range is comparable to peaks in the surface water trade prices. Generally, MAR seems financially feasible for cotton growers, if it is strategically managed for drought reserves but less so as a regular seasonal storage option when surface water costs are cheaper than the lowest estimate of MAR costs.

Technical feasibility: Our analysis, based on soil and aquifer characteristics of the area, identified three possible MAR schemes: infiltration into low salinity areas, infiltration/injection into a saline aquifer to form a freshwater lens and injection into a deep aquifer. Monitoring plans were also explored, with particular focus on using the over 700 piezometers already present in the area.

Governance arrangements: MAR policies are not yet in place in NSW or Queensland, which is an opportunity to ensure rules play to the strengths of MAR while minimising associated risks. Pilots for recharge and monitoring can already go ahead with current regulatory frameworks, and are needed to build confidence and expertise.

6.2 Recommendations

Based on the scenarios presented in Section 4, we conclude that MAR shows promise in the CIAO for a broad range of circumstances and associated costs. Investment in MAR has the potential to benefit cotton production in the region by increasing or securing water supply and therefore justifying capital investments and providing greater certainty for the cotton supply chain.

However, it should be noted that providing water security was considered to be a transformative change. Benefits are more obvious for perennial crops than annuals like cotton, and therefore special attention is needed to how costs and benefits of stored water are shared. It remains possible for MAR to be transformative for cotton and not just for the broader agricultural sector, but the CRDC and broader cotton industry will need to ensure their voice is heard in MAR developments, such that they enhance rather than reduce the resilience of the cotton industry 60.

There is strong local support for a pilot MAR scheme be undertaken in the CIA. A low-cost pilot project consisting of retrofitted bores or small scale infiltration basins would provide invaluable practical experience in the planning, construction and operation of a MAR scheme within the Murray Darling Basin, whilst improving the understanding of local hydrogeology as it relates to MAR, and providing a vehicle to collaboratively design legal frameworks for the recovery and use of consumptive water. Such a pilot would enable irrigation corporations within the mid-Murrumbidgee valley to evaluate the true feasibility and value of MAR at a regional scale.

To conclude, three recommendations each for both the CICL and the CRDC are provided in Figure 40, drawing on the developed MAR scenarios. The recommendations are linked but framed differently for CICL as a prospective local driver of, or investor in MAR, and CRDC as a potential facilitator or supporter who can influence or leverage other activities in this space. The recommendations emphasise that a partnership-based approach is necessary to achieve the potential industry wide benefits, with Coleambally acting as a pilot that could be applied to irrigated agriculture elsewhere in Australia. We argue that the recommendations are 'no loss', i.e. applying the recommendations would result in advances in knowledge, capability and relationships regardless of whether MAR is implemented in the long-term and provide sufficient flexibility that there are many ways that the recommendations can be pursued. For example, low-cost pilot projects gain understanding about the entire system and improved groundwater monitoring could assist in developing conjunctive use, with or without MAR. The recommendations are also meant to be pursued in a staged manner, so the need for large initial investment and access to resources is minimized, and barriers to further development can be identified and addressed.

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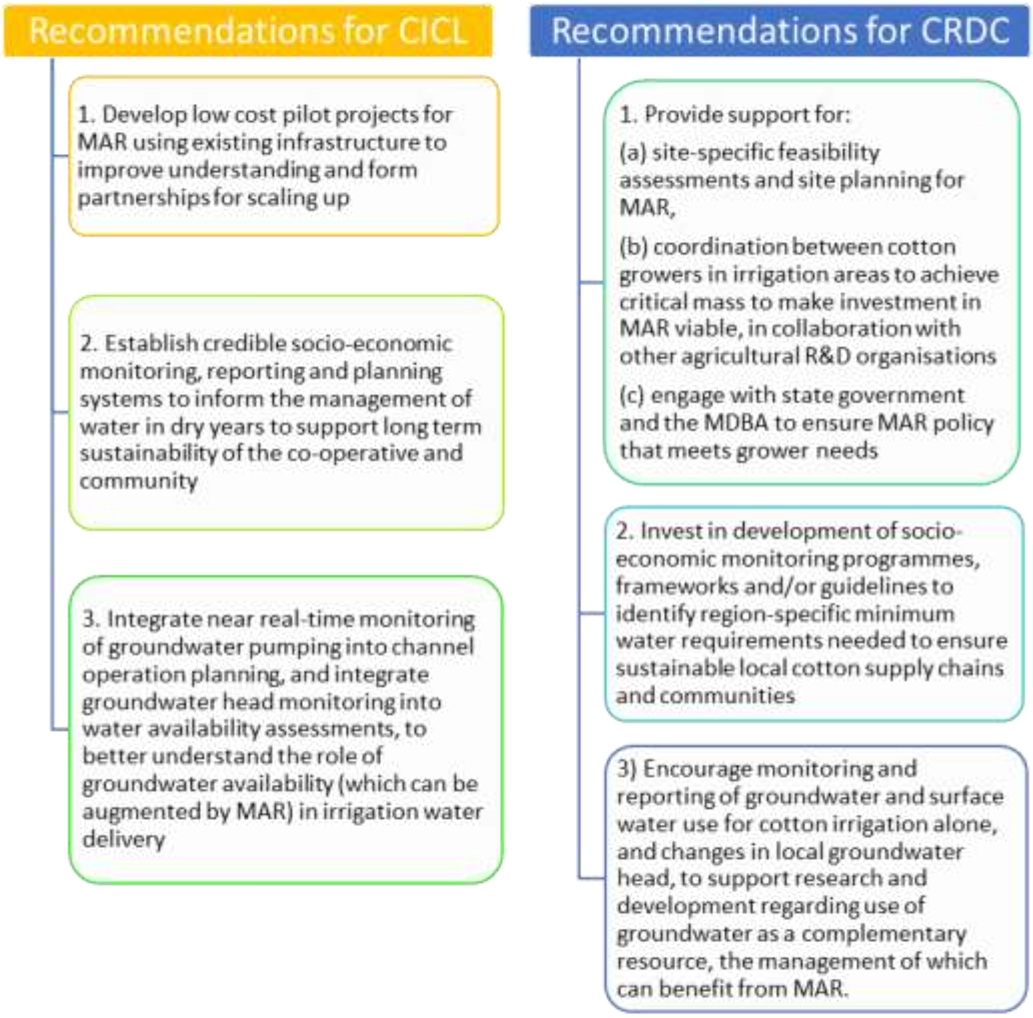
[60] https://www.crdc.com.au/publications/resilience-assessment-australian-cotton-industry, accessed 24 April 2020



Recommendations for CICL

1. Develop low cost pilot projects for MAR using existing infrastructure to improve understanding and form partnerships for scaling up

2. Establish credible socio-economic monitoring, reporting and planning systems to inform the management of water in dry years to support long term sustainability of the co-operative and community

3. Integrate near real-time monitoring of groundwater pumping into channel operation planning, and integrate groundwater head monitoring into water availability assessments, to better understand the role of groundwater availability (which can be augmented by MAR) in irrigation water delivery

Recommendations for CRDC

1. Provide support for:

(a) site-specific feasibility assessments and site planning for MAR,

(b) coordination between cotton growers in irrigation areas to achieve critical mass to make investment in MAR viable, in collaboration with other agricultural R&D organisations

(c) engage with state government and the MDBA to ensure MAR policy that meets grower needs

2. Invest in development of socio-economic monitoring programmes, frameworks and/or guidelines to identify region-specific minimum water requirements needed to ensure sustainable local cotton supply chains and communities

3) Encourage monitoring and reporting of groundwater and surface water use for cotton irrigation alone, and changes in local groundwater head, to support research and development regarding use of groundwater as a complementary resource, the management of which can benefit from MAR.

Figure 40 Recommendations for the CICL and CRDC stemming from this research.

Acknowledgments

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Appendix A General structure of key informant interview questions

The questions for the interview are:

1. Do you have access/entitlement to both surface water and/or groundwater?
2. Do you have access to opportunistic water sources during wet periods? These could include those made available to irrigators during high river flows, such as supplementary entitlements in NSW.
3. What influences how you use your irrigation entitlement each season? For example, if you have access to both surface water and groundwater, do you have a preference for one water source over the other? Do you vary the irrigated area, irrigation rates, or crop types in notably drier/wetter seasons?
4. If you use groundwater for irrigation, what is the maximum pumping rate you can achieve?
5. Do you ever have unused surface water or groundwater at the end of a season? This could be water that is on-farm, or in the case of surface water, still held in regional storages. If so, how often does this happen, is it a large proportion of your allocation, and what happens with the unused water?
6. Have you ever bought allocation water (seasonal water/temporary traded) for irrigation? If yes
    a. What was the main intended purpose for the water? e.g. finishing off a crop already planted, planting more crop at the beginning of the season, buy water when its cheap to sell when its sale price is greater.
    b. How often do you buy water? e.g. seasonally, every few years, only during really dry periods
    c. Have you ever bought water to irrigate a crop during a dry period? If yes, was it expensive?
7. Do you know how much water evaporates from your surface water storages?
8. Have you implemented any measures to try and decrease the evaporation from your surface water storages? e.g. minimise time water is in storages, deepening dams, Evaporation Mitigation Techniques such as monolayers, floating covers and shade cloths.
    a. If yes, which one(s) and are you happy with its performance?
    b. If no, why not?
9. How much would you be prepared to pay for additional water in an average season?
10. How much would you be prepared to pay for additional groundwater in a drought?

After an explanation of MAR is provided, and any questions from the participant addressed, the participant will be asked for their opinion on the following:

11. If it hasn’t already been clarified in the above discussion, the potential demand for more water for irrigation (either in total, or increased water security between seasons)
12. Potential sources of water they'd consider using for MAR
13. The financial and economic viability of a MAR scheme for them given a range of cost estimates
14. The social acceptability of MAR in their region.

In addition, and depending on their expertise, they'll be invited to comment on the following, as it relates to MAR in their region:

15. Technical feasibility of a MAR scheme,
16. Any potential risks or gains for the environment, and
17. Governance arrangements restricting or enabling a MAR scheme.

Appendix B Financial costs for all scenarios

MAR system		Water source		Total recharge cost ($/ML recharged)	Total recharge and groundwater pumping recovery cost ($/ML recovered)		
Type	Cost	Type	Cost ($/ML)		100% recovery, Costs $33/ML	90% recovery, Costs $77/ML	80% recovery, Costs $120/ML
Basin	Min	Supplementary	3	62	*95*	*145*	*198*
Basin	Min	Entitlement	345	404	*95*	*218*	*351*
Basin	Min	Entitlement	431	490	*104*	*243*	*397*
Basin	Min	Supplementary	11.5	71	*104*	*155*	*208*
Basin	Min	Supplementary	20	79	*112*	*164*	*219*
Basin	Min	Entitlement	517	576	*112*	*269*	*442*
Basin	Min	Trade	53	112	*145*	*201*	*260*
Basin	Mean	Supplementary	3	131	*164*	*222*	*284*
Basin	Mean	Entitlement	345	473	*164*	*294*	*438*
Basin	Mean	Supplementary	11.5	140	*173*	*232*	*294*
Basin	Mean	Entitlement	431	559	*173*	*320*	*483*
Basin	Mean	Supplementary	20	148	*181*	*241*	*305*
Basin	Mean	Entitlement	517	645	*181*	*346*	*529*
Basin	Mean	Trade	53	181	*214*	*278*	*346*
Basin	Max	Supplementary	3	200	*233*	*299*	*370*
Basin	Max	Entitlement	345	542	*233*	*371*	*524*
Basin	Max	Supplementary	11.5	209	*242*	*308*	*381*
Basin	Max	Entitlement	431	628	*242*	*397*	*569*
Wells	Min	Supplementary	3	214	*247*	*314*	*387*
Wells	Min	Entitlement	345	556	*247*	*386*	*541*
Basin	Max	Supplementary	20	217	*250*	*318*	*391*
Basin	Max	Entitlement	517	714	*250*	*423*	*615*
Wells	Min	Supplementary	11.5	222	*255*	*323*	*398*
Wells	Min	Entitlement	431	642	*255*	*412*	*586*
Wells	Min	Supplementary	20	231	*264*	*333*	*408*
Wells	Min	Entitlement	517	728	*264*	*438*	*632*
Wells	Mean	Supplementary	3	238	*271*	*341*	*418*
Wells	Mean	Entitlement	345	580	*271*	*414*	*572*
Basin	Min	Trade	186.5	246	*279*	*349*	*427*
Wells	Mean	Supplementary	11.5	247	*280*	*351*	*429*
Wells	Mean	Entitlement	431	666	*280*	*439*	*618*
Basin	Max	Trade	53	250	*283*	*354*	*433*
Wells	Mean	Supplementary	20	255	*288*	*360*	*439*
Wells	Mean	Entitlement	517	752	*288*	*465*	*663*
Wells	Max	Entitlement	345	605	*296*	*441*	*603*
Wells	Max	Supplementary	3	263	*296*	*369*	*449*
Wells	Min	Trade	53	264	*297*	*369*	*449*
Wells	Max	Entitlement	431	691	*305*	*467*	*649*
Wells	Max	Supplementary	11.5	272	*305*	*379*	*460*
Wells	Max	Entitlement	517	777	*313*	*493*	*694*
Wells	Max	Supplementary	20	280	*313*	*388*	*470*
Wells	Mean	Trade	53	288	*321*	*397*	*481*
Wells	Max	Trade	53	313	*346*	*425*	*512*
Basin	Mean	Trade	186.5	315	*348*	*426*	*513*
Basin	Min	Trade	320	379	*412*	*498*	*594*
Basin	Max	Trade	186.5	384	*417*	*503*	*599*
Wells	Min	Trade	186.5	397	*430*	*518*	*616*
Wells	Mean	Trade	186.5	422	*455*	*545*	*647*
Wells	Max	Trade	186.5	447	*480*	*573*	*679*
Basin	Mean	Trade	320	448	*481*	*574*	*680*
Basin	Max	Trade	320	517	*550*	*651*	*766*
Wells	Min	Trade	320	531	*564*	*666*	*783*
Wells	Mean	Trade	320	555	*588*	*694*	*814*
Wells	Max	Trade	320	580	*613*	*721*	*845*