Managed Aquifer Recharge in farming landscapes using large floods: an opportunity to improve outcomes for the Murray-Darling Basin?

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Abstract

Conjunctive use of surface and groundwater through Managed Aquifer Recharge (MAR) is underway in Australia, principally to reuse urban waste water. The opportunity for MAR in farming landscapes has received less attention and the extent this might occur using water from large flood events or dam releases has not been examined. This paper addresses that gap by drawing on the expertise of a multi-disciplinary team to provide an overview of the potential benefits and challenges to implementing MAR using water from large floods; examine the social acceptability of MAR amongst groundwater licence holders in a major Australian groundwater irrigation region (Namoi Valley); and identify future research needed to underpin a thorough assessment of MAR using large flood events. In summary, the appeal of MAR using water from large flood events is the opportunity it affords to replenish aquifers, return linkages between depleted groundwater and surface flows, and buffer the impacts of drought on irrigators and aquatic ecosystems. Most of the respondents to the Namoi survey agreed that MAR has merit. However, some respondents were concerned about the impact of recharge on groundwater quality and the possibility that MAR would be another intervention that would lead to over-exploitation of a scarce resource. A number of ways to implement MAR using large flood events are also canvassed, but most have not been thoroughly investigated and we identify key next steps to evaluate the feasibility of MAR.

Keywords

Managed Aquifer Recharge (MAR), social acceptability, Murray-Darling Basin, irrigation, farming, groundwater recharge

Introduction

The Murray-Darling Basin (MDB) covers one-seventh of the Australian continent, is the nation's food bowl, and has nationally and internationally significant natural and cultural assets (DoEWR 2004). There is growing evidence that natural assets of the basin have been in a state of decline as a result of clearing of native vegetation, the introduction of exotic species, allocation of surface flows to irrigation, barriers to connectivity, changes in water quality and the depletion of groundwater aquifers (MDBC 2001). Compounding water allocation and management issues is the predicted expansion of mining (ore, coal, and coal seam gas extraction) through parts of the Basin, which is likely to threaten MDB assets further. Despite the efforts of governments and rural landholders to address these issues, research suggests that the condition of the key MDB assets is deteriorating (Davies et al. 2008). Concurrently, climate change modelling predicts that there will be significantly less rainfall and even less runoff (from 10% to 40%) in the southern MDB over the next 60 years, which could drastically alter the landscape and economy of the region (Smith & Chandler 2010).

Over much of the MDB, groundwater extractions exceed recharge. The depletion of aquifers has reduced the connectivity between surface water and aquifers, to the extent that groundwater dependent ecosystems (GDE) and some in-stream and downstream ecological functions have been affected (Nevill 2009). There is also the potential for aquifer depletion to lead to saline ingress into freshwater aquifers due to the collapse and fracturing of aquitards (Jolly et al. 2001).

There are established strategies for addressing water security problems in the basin. These include purchasing water from irrigators to return to the environment (Bjornlund 2003); infrastructure upgrades to improve storage and delivery efficiency (Barnett et al. 2000); establishing water markets to assist the transfer of water from low to high value production or the environment (Bjornlund & Mckay 1996); new institutional arrangements that assume surface and groundwater are linked and ensure compliance with existing rules (Clifton & Evans 2001); and ensuring that large cities pursue water sources outside the Murray River and its tributaries (Dillon et al. 2009; Rutherford & Finlayson 2011). To further research in groundwater and to address important gaps in training of groundwater specialists, the

National Centre for Groundwater Research and Training (NCGRT) was established in 2009 with funding from the Australian Research Council and the National Water Commission.

Our view is that these are important steps but probably not sufficient to bridge the gap between projected available water supply and critical needs of the environment and people over the next 20 years and beyond. Water storage is the missing link in the Australian water reform agenda. Australia relies on surface water storages to ensure that water is available when needed and to act as a buffer against drought. Surface storage is inefficient because of evaporative loss. This suggests that Australia needs to evaluate more innovative options for conjunctive use of surface and groundwater, including Managed Aquifer Recharge (MAR). This paper attempts to do that by providing an overview of the potential benefits and challenges to implementing MAR using water from large floods; examining the social acceptability of MAR amongst groundwater licence holders and identifying future research needed to underpin a thorough assessment of MAR.

How does MAR work?

MAR and recovery enables cyclical water management with surplus surface water stored in aquifers in wet years and extracted for use in dry years. MAR is underway for the reuse of urban waste water in the United States (Thomas 2001) and many other countries, including Australia. The typical approach is for treated waste water from urban areas to be pumped into depleted aquifers for later reuse on sporting fields or for irrigated agriculture. By comparison, there are few examples of MAR in rural landscapes using non-urban sources of water, including river water. An important exception occurred in the Angas Bremer proclaimed region in South Australia in the early 1990s, where irrigators successfully used recharge to re-establish equilibrium in the aquifer and stop the intrusion of saline water (Bjornlund 1995). There is some small scale aquifer storage in South Australia (Dillon et al. 2009) and on a larger scale, river water from the Burdekin in Queensland is used to recharge a depleted aquifer to prevent seawater intrusion (Charlesworth et al. 2002).

Key requirements for MAR include the availability and suitability of aquifer storage and availability of surplus surface water and the means to convey it. Aquifer suitability depends on a number of factors including aquifer size, depth, permeability, stability, and connections with other aquifers and ecosystems. Highly permeable aquifers are relatively easy to recharge, but stored water is mobile and recovery fractions have to be applied to allow for losses. Hostetler (2007) made an initial assessment of the suitability of areas across Australia for "water banking". According to this assessment, the Namoi, the regional case study in this paper, is highly suitable for underground water storage.

The valley filling sediments in the Namoi Catchment consist of two aquifer types, and both have portions that are suitable for MAR. Immediately below the ground surface there is the unconfined aquifer (phreatic aquifer). This aquifer is up to 30 m thick. In the unconfined aquifer, MAR would need to target the sand and gravel paleochannels that meander through ancient floodplain silts and clays (Wray, 2009). The paleochannels range from tens to hundreds of metres wide. The meandering axis length can range from hundreds to thousands of metres. The unconfined aquifer overlies the semi-confined aquifer system, which extends to bedrock. In the semi-confined aquifer system, there are sand and gravel rich paleochannel belts that can be targeted for MAR (Giambastiani et al. 2009; Kelly et al. 2012). The paleochannel belts have widths ranging from hundreds to thousands of metres, and extend east-west for many kilometres.

The underlying fractured sedimentary rocks, which are part of the Great Artesian Basin (GAB), are not suitable for recharge because water within these rocks is already under significant upwards pressure (there is recharge from the GAB into the base of the Lower Namoi alluvium), and the hydraulic conductivity of the sedimentary rocks is relatively low compared to the unconsolidated valley filling sediments.

There are several potential ways to use large floods for MAR in farming landscapes. Two broad approaches to accomplish recharge are basin infiltration and well injection methods. An example of basin infiltration is stormwater collected off-stream into ponds designed to allow percolation into the shallow aquifer. Basin infiltration methods are suitable for recharging shallow, unconfined aquifers even with raw or poor quality water (Rai et al. 2001; Pedretti et al. 2012). These methods require permeable soils and potentially large surface areas to be effective. However, such methods are less effective for recharging deeper semi-confined aquifers. Well injection methods such as Aquifer Storage and Recovery (ASR) can be used for recharging unconfined, confined and semi-confined aquifers (Pyne 1995).

The benefits

MAR using river water during large floods could be employed in farming landscapes, with a range of potential environmental, economic and social benefits, providing it is carefully managed. These benefits include:

- replenishing depleted aquifers so that surface and groundwater are reconnected to support important in-stream ecological functions and GDE, particularly during drought and under climate change scenarios;
- storing irrigation allocations in aquifers adjacent to irrigation districts rather than in distant upland dams, thereby returning river reaches to more natural flow regimes and reducing evaporation losses from storages;
- providing a storage for environmental water that can be strategically used to sustain high value environmental assets during drought or by topping-up small to medium floods;
- preventing salt water ingress into freshwater aquifers (economic and environmental benefits);
- enabling irrigators to “bank” water (eg. supplementary water) for later use as part of an effective response to drought; and to the extent that environmental values are not compromised, provide additional water for irrigation and the flow-on benefits in terms of food, employment and landholder capacity to implement best practice natural resource management (NRM);
- reducing evaporation losses from on-farm dams through the conjunctive use of surface and groundwater to provide a buffer for irrigators during drought;
- restoring the groundwater head in the semi-confined aquifers, and eventually reducing groundwater pumping costs for irrigators;
- replenishing and maintaining groundwater levels in the unconfined aquifers primarily used for stock and domestic bores.

The challenges

The common technical issues surrounding MAR projects include difficulties related to identifying suitable aquifers and recharge sites, sub-optimal quality of storm/flood water and surface and borehole clogging with fine sediments or microbiological activity. Few mechanisms exist to directly inject storm/flood water into aquifers due to these technical issues. To overcome such issues, temporary surface storages are normally built to capture and stabilize storm water, however using flood water adds significantly to the scale of storage.

An additional technical challenge with MAR on larger scales is to quantify the net recharge and net recoverable volumes considering subsurface heterogeneity across a region. Current approaches typically produce qualitative maps of the potential recharge sites in a GIS environment (Hostetler 2007; Helm et al. 2009; Smith & Pollock 2010; Pedriro et al. 2011). These qualitative approaches are not able to specify how subsurface hydrogeological conditions will respond to the additional storage and changes in the water table. As part of the work of the NCGRT, researchers are scoping the potential of MAR at four different levels:

1. Assessment of source water availability and water quality during flood events;
2. Evaluation of different aquifer recharge methods to gauge their effectiveness and efficiency (relative costs) under a range of hydrogeological conditions;
3. Assessment of the net storage and transmissivity potential of selected aquifers; and
4. Assessment of MAR recovery efficiencies of selected aquifers.

There are also several uncertainties around each of these topics, including the frequency of large floods; the extent that aquifers recover naturally during flood events; and the extent that regional aquifer pressures change and the implications of such changes. Ecological uncertainties also need to be addressed, including those that relate to the level of benefit MAR is likely to provide to ecosystems.

The development of MAR in the northern MDB, including the Namoi, has been constrained by the encouragement of on-farm surface water storage and the lack of development of entitlements and rules for MAR. The development of large dams has also reduced the imperative of exploring MAR as an option. Most water users in the MDB are supplied from large reservoirs owned by public or private organisations. Irrigators also receive supplementary water that they can store when heavy rainfall events lead to dam spills and high channel flows (Dillon et al. 2009). Supplementary water can be stored, but the capacity to do so is limited by the extent of above ground storage and current rules limiting water banking in aquifers. In NSW, dryland farmers are also allowed to divert and store up to 10% of the total water inflows on their property. This surface water centric approach is less than ideal for two reasons. Firstly, diversions could reduce the amount of natural flooding and lead to degradation of floodplains and the environment. Secondly, there is a great deal of evaporative loss from surface water storages. It is estimated that average annual evaporation from on-farm storages in the MDB exceeds 1000 GL – enough to supply Melbourne, Sydney and Adelaide (SKM et al. 2010, WSAA 2010).

MAR using surface water is not feasible without an entitlement to store water in an aquifer and to recover it. In NSW there is no legal and administrative arrangement to enable purposeful underground storage of water and subsequent use. Groundwater enters the “common pool” once it is underground, and can be accessed by anyone with a groundwater-use licence. Current NSW policy does not recognise ownership of artificially recharged groundwater. Clear ownership and accurate measurement and accounting of stored volumes would be required – taking account of experience with managed aquifer recharge in South Australia, and the guidelines now being trialled in Victoria.

Effective long-term water management by MDB irrigators requires multi-year carryover or banking of water allocations. Aquifer recovery rules need to allow for losses owing to lateral movement, evapotranspiration, interaquifer leakage and inefficiencies in recovery due to water quality constraints. In NSW groundwater users have a water account, and they can carryover water for up to three years. However, this limited carryover does not allow MAR over the full extent of wet-dry (El Niño - La Nina) climate cycles. In addition, water releases from large upstream dams are not planned to optimise water supply phasing and delivery using intermediate storages, including aquifer storage. Therefore, the full benefits of cyclical surface water-groundwater management cannot be obtained under the current institutional arrangements and infrastructure.

Social acceptability of MAR using large floods

Environmental advocates, including conservation groups, and many scientists are likely to be sceptical of proposals for MAR using river water in farming landscapes. They may be concerned that this unproven technology represents an attempt to ignore the “limits to growth” in the driest continent. Floods perform critical ecological functions and there will be concerns about the ecological impacts of capturing and storing water from large flood events.

While these concerns are far from resolved, there is at least strong support amongst groundwater license holders.

While we have reservations about suggesting technological solutions to environmental problems, our view is that the magnitude of the challenges being faced is such that all options need to be considered. Indeed, there may be options that enable us to adapt in ways that are consistent with a desire to respond effectively to our highly variable climate. Combining MAR with water from large flood events can be achieved within existing water entitlements for the environment and consumptive use or to provide additional water storage capacity. Our focus on large flood events and aquifer storage also acknowledges the negative ecological impacts of existing dams in reducing the frequency of small and medium floods on the Murray (Gippel & Blackham 2002).

Social acceptability of MAR amongst groundwater licence holders in the Namoi

Australia's farmers manage around 65% of the continent and have entitlements to access large volumes of surface and groundwater. Clearly, they are key stakeholders in any decisions about MAR. Any assessment of MAR should also explore the social acceptability of the technology with rural landholders.

A study of all groundwater licence holders in the Namoi by the authors offered a unique opportunity to examine the social acceptability of MAR among this key stakeholder group. In the following sections we briefly describe the study location, the survey methodology and key findings and discuss some of the implications of those findings.

The Namoi is a catchment area in the northern NSW region of the MDB [Figure 1]. Covering nearly 40,000 km^2, the Namoi catchment includes the urban areas of Tamworth and Gunnedah. The Cockburn, Namoi, Mooki, Macdonald, Manilla, and Peel rivers intersect the catchment and the region is bordered by the Liverpool, Warrumbungle, and Nandewar Ranges. The Namoi is an intensive agricultural area focussed on cotton production and is the area extracting the largest groundwater volume for irrigation in the MDB. Indeed, Namoi cotton irrigators use 15.2% of the total groundwater pumped annually in the MDB. The scale of groundwater use over time has dramatically lowered groundwater levels (in excess of 20 metres) in the Namoi (Giambastiani et al. 2009), leading to cuts in irrigator groundwater entitlements of up to 80% in the past ten years (CSIRO 2007).

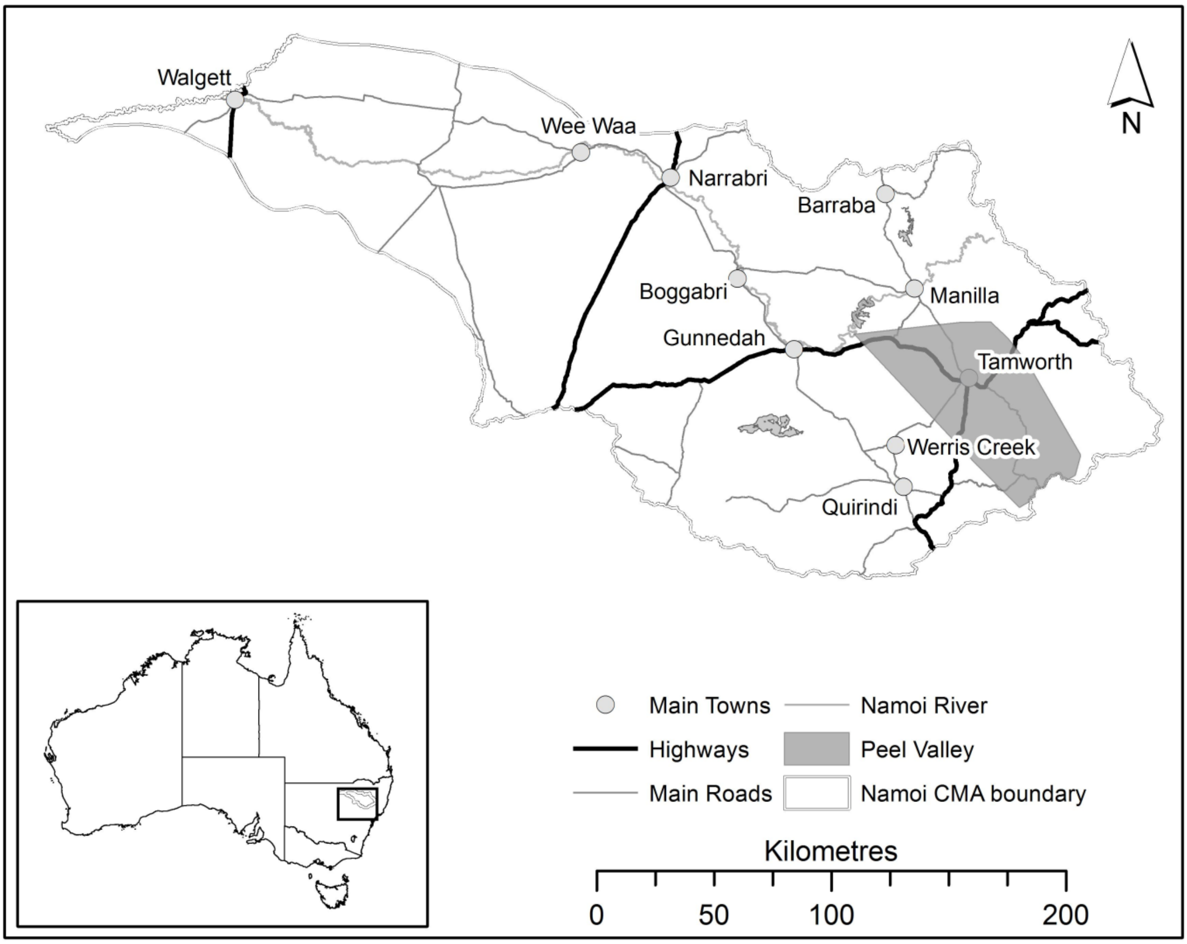

Figure 1 **Location of the Namoi Catchment and area surveyed in 2011**

This region appealed as a useful case study to explore opportunities for MAR using large flood events: agriculture is highly profitable and dependent on irrigation using groundwater; aquifers are depleted; and the lower Namoi regularly experiences large floods. Figures 2 and 3 show hydrographs of maximum monthly flows for the Namoi River at Narribri and Mollee, indicating the occurrence of high flood events since 1892. During a 2009 field trip examining groundwater use in the Namoi the authors formed the view that few other opportunities offered the potential triple bottom line benefits of MAR.

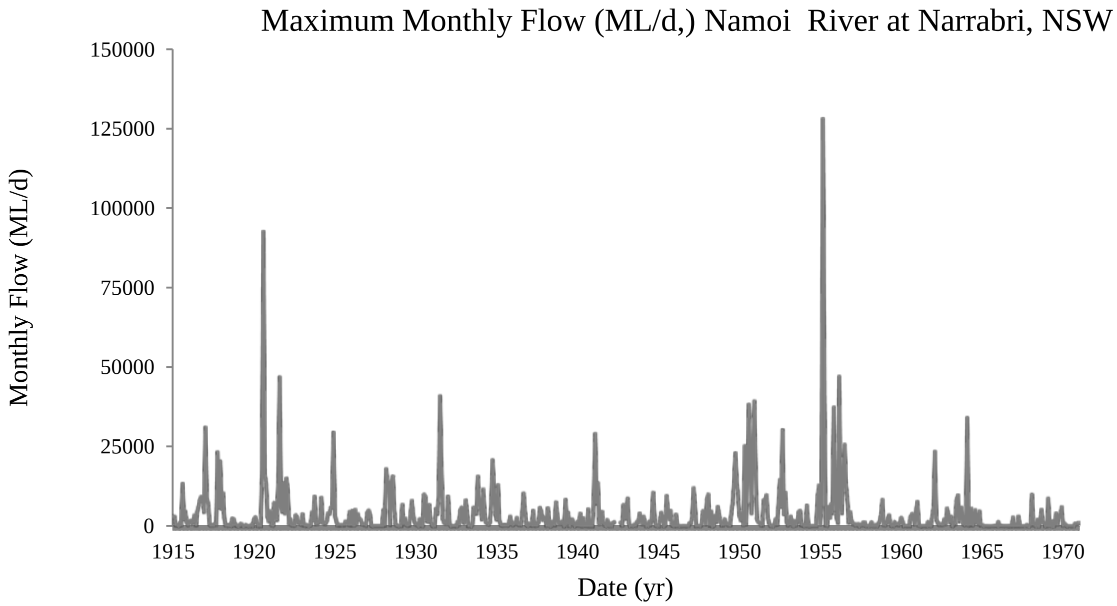

Figure 2 **Maximum Monthly Flows at Narrabri (Source: NSW Office of Water, 2012)**

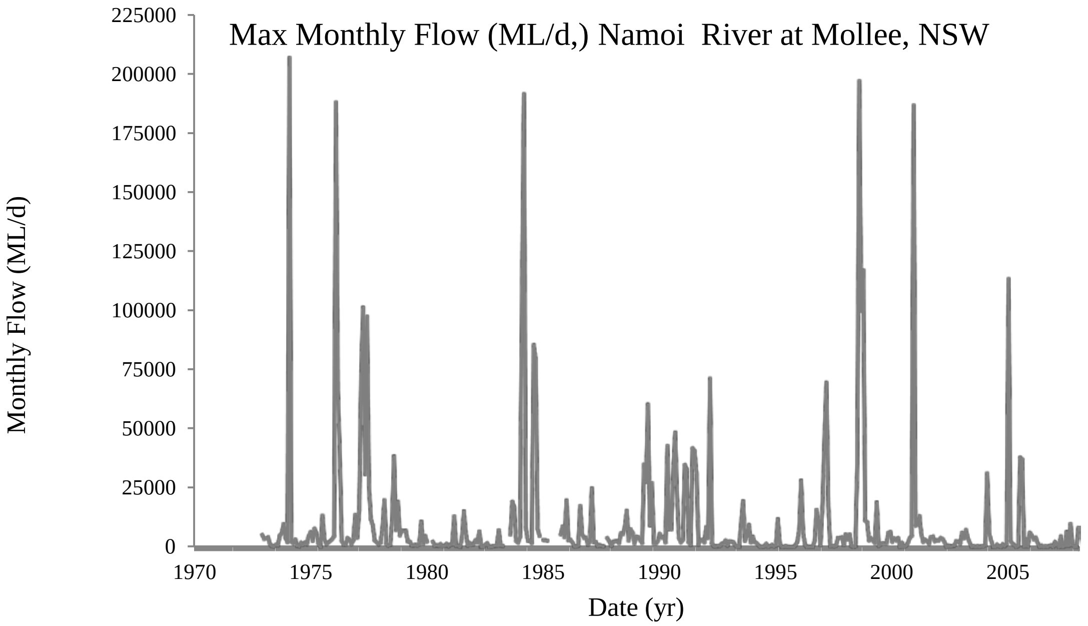

Figure 3 **Maximum Monthly Flows at Mollee (Source: NSW Office of Water, 2012)**

Survey methodology

Using a NSW Office of Water database, a survey was posted to all farming properties associated with a groundwater licence in the Namoi in 2011, with the exception of those in the Peel Valley. From the initial mailout to 447 property owners, 210 useable surveys were returned. After taking into account surveys ‘returned-to-sender’ and other legitimate reasons for non-returns (e.g. property sold; owner overseas), a final response rate of 54% was achieved.

The success of a new technology or policy can often be predicted by assessing its perceived acceptability by stakeholders (Madsen & Ulhøi 2001). To examine its social acceptability, typically a test is used that involves a process of judgement by individuals (Brunson 1996). Attitudinal surveys can be a valuable way to test social acceptability. The survey included items expected to provide insights into groundwater licence holder’s values, beliefs, attitudes, and trust in the Office of Water, land use and land management practices. Survey data were intended to contribute to an (NCGRT and Cotton Catchment Communities CRC) integrated project examining the environmental, economic and social impacts of climate change and water reform in the Namoi. A page in the survey was allocated to items exploring the social acceptability of MAR. Survey recipients were provided with an introduction to the concept of MAR, including the use of large floods [readers are referred to Sharp and Curtis (2012) for the introductory text]; asked to indicate the extent they agreed with four statements related to MAR; and invited to provide written comments about MAR. The focus in this paper is on results from Item 1 of the questionnaire [Figure 4] which is used as a measure of the social acceptability of MAR; and the written comments that about one quarter (n= 56) of respondents provided. Together, these data provide useful insights into the social acceptability of MAR amongst this key stakeholder group.

To explore the nature of support/opposition to MAR, we examined relationships in the survey data where support for MAR was the dependent variable. Spearman’s Rho test was used to compare responses to the MAR item with all other continuous or Likert scale items in the survey. Next, to compare how responses differed between those who favoured versus those who opposed MAR, we collapsed the six response options for Item 1 [Figure 4] by

Your views about MAR	Your view
Aquifer storage and recovery (MAR) appears to be a good idea.	
If public funds were used to develop the infrastructure for MAR, I would be prepared to invest in technology to improve the water-use efficiency on my farm.	
I would be prepared to invest, along with others, to develop MAR in my water sharing plan (WSP) area **without** public funding.	
I am interested in learning more about the interception of large floods to implement MAR in my WSP area.	

RESPONSE OPTIONS:

Strongly disagree	Disagree	Unsure	Agree	Strongly agree	Not applicable
1	2	3	4	5	6

Figure 4 **Survey items exploring social acceptability of MAR**

combining the 'Strongly Agree' and 'Agree' to represent those supporting MAR and combining the 'Disagree' and 'Strongly Disagree' options. This resulted in four categories: YES (n=135), NO (n=18), UNSURE (n=51) and Not Applicable (N/A) [Table 2]. As there was only one N/A response, this was excluded from further analysis. Mean scores for all survey items were then calculated. Because of the large difference in the sample sizes of these categories we used Levene's test for homogeneity of variance to test the hypothesis that the variances in the groups are equal. Levene's test showed that the YES/NO/UNSURE variances were significantly different on most other survey items (eg. the items: "Caring for the weak and correcting social injustice"; "Fostering equal opportunities for all community members"), indicating that statistical tests using these groupings would be unreliable. Similar variances between groups ensures that any relationships found to be significant were likely to be a genuine effect and not due to the differences in sample size. We therefore elected to combine the NO and UNSURE groups and have labelled them "NO". Applying Levene's test using these revised groupings showed that the new YES/NO groups had similar variances for

Social and farming characteristics	Mean scores*		Test for significant differences between groups	Test for significant relations with survey item 1
	Yes (Support MAR)	No/Unsure (Not support MAR)	Yes/No Stats	Yes/No Stats
Property size (n=174)	1000 ha (n=113)	840 ha (n=61)		
Groundwater entitlement (ML) (n=204)	248 ML (n=135)	200 ML (n=69)		p=.006 r=.193
Area laid out to irrigation water year 2010-2011 (n=185)	155 ha (n=124)	80 ha (n=61)		
Property principal place of residence (% Yes) (n=197)	87%	81%		
Time property has been in their family (n=193)	26.5 years (n=128)	33 years (n=65)		p=0.032 r=-.154
Percentage of male respondents (n=200)	92%	88%		
Age (n=199)	57 years (n=131)	53 years (n=68)		
Hours per week worked on-property past 12 months (hrs/wk) (n=197)	56.5 hours (n=132)	50 hours (n=65)		
Occupation as farmer (% Yes) (n=197)	82%	87%		
Completed a short course relevant to property mgt past 5 years (n=197)	70%	65%		
Bought water temporary market past 5 years	27.3%	4.3%	U =1456 p=.000 r=-.31	p=.000 r=.340 n=136
Bought water permanent market past 5 years	18%	12.5%	U =1707.5 p=.024 r=-.19	p=.004 r=.245 n=137
Plan to buy water temporary market next 5 years	21.8%	4.3%	U = 2062 p=.008 r=-.21	p=.000 r=.298 n=154
Plan to buy water permanent market next 5 years	19%	11.5%		p=.026 r=.181 n=152
Plan to change tillage technique next 5 years	55.8%	48.2%		p=.000 r=.245 n=167
Plan to routinely test water quality next 5 years	49 5%	39.7%		p=.009 r=.207 n=157
Plan soil moisture mapping next 5 years	39.7%	22.9%	U = 1802.5 p=.016 r=-.20	p=.004 r=.238 n=146

Table 2 **Comparing those in favour/not supporting MAR, Namoi, 2011: Social and farming characteristics** (%) is the percentage of respondents who said they either *Did this* (for past 5 years) or % *Plan to do this/ do more,* plus *Definitely intend to do this/do more* (for next 5 years). The grey shaded cells identify no significant difference/relationship.

all survey items reported in this paper. Comparisons of these groups were undertaken using Pearson's Chi-Square (i.e. to look for significant relationships between the YES/NO groups and categorical social data) and Mann Whitney *U* tests (i.e. to test for significant differences between YES/NO respondents on other continuous or Likert scale items). Responses to the item requesting written comments on MAR were open coded into themes (Glaser & Strauss 1967) with quotes identified that were either representative of those themes or provided particular insights into social acceptability of MAR.

Key findings

<u>MAR passes the test of social acceptability</u>

Just over two-thirds of the survey respondents supported the concept of MAR in the Namoi. With a further one quarter unsure, only a small proportion of respondents opposed the concept [Table 1]. The written comments provided insight into the reasons respondents supported, opposed or were unsure about MAR. Of the 210 respondents, 56 provided written comments. Among the respondents who were in support of MAR, sixteen provided written responses. One of these respondents explained they had been working for years to promote MAR in the region.

> *[It is] about time someone promoted artificial recharge, farmers in our area have been trying to convince the government departments to develop the process for years.*

Survey item exploring social acceptability of MAR in Namoi	**In favour of MAR (Agreed/Strongly agreed)**	**Not in favour of MAR (Disagreed/Strongly disagreed)**	**Unsure**
Aquifer storage and recovery (MAR) appears to be a good idea.	n=135	n=18	n=51
	66.2%	8.8%	25%

Table 1 **Proportion of respondents supporting MAR in the Namoi, 2011**

Some respondents were concerned with the idea of MAR, although not opposing it outright (n=17). One respondent wrote that groundwater licence-holders would need much more information because they were sceptical that MAR could work without impacts to the environment or groundwater entitlements.

> *We require much more explanation before this can be considered. It is rare that these processes occur without loss of entitlement and asset and an increase in taxes on the water user.*

Another set of respondents were opposed to MAR (n=4) because of the risk of negative environmental impact.

> *Aquifers are ancient pristine water sources and should NOT be contaminated with flood flows or Coal Seam Gas.*

Key differences between those supporting MAR and those opposed/unsure

To further explore the social acceptability of MAR we tested for significant differences in the farming and social characteristics of those supporting and those opposed/unsure. While there appeared to be differences between the two groups for a number of the items in Table 2, many of these differences were not statistically significant. We also tested for significant relationships between support for MAR using responses to Item 1 as the dependent variable in pairwise analyses with the farming and social variables included in the survey. From these data, we have constructed four narratives (i-iv below) that we suggest are plausible and provide useful insights about the social acceptability of MAR amongst our respondents.

i) MAR supporters are more business-like and innovative

In this study, licence-holders who considered MAR to be socially acceptable tended to be more business-like in that they were operating on a larger scale, more likely to be engaged in the water market and planning to adopt innovative management practices linked to improved water-use efficiency [Table 2]. For example, there was a trend (but not significant differences) for MAR supporters to be operating larger properties, have larger areas laid out for irrigation, own larger groundwater entitlements and spend more time in on-property work. Supporters of MAR were significantly more likely to have entered the water market to purchase permanent or temporary water in the past five years and intend to purchase temporary water in the future. MAR supporters were also significantly more likely to plan to implement soil moisture mapping, and there was a significant positive relationship between support for MAR and the intention to routinely test water quality and change tillage practices in the next five years [Table 2].

ii) MAR supporters appear to be more egalitarian and more interested in collective action

MAR supporters were significantly more likely to express support for the guiding principle of *Fostering equal opportunities for all community members,* and there was a significant relationship between MAR support and support for the guiding principle of *Caring for the weak and correcting social injustice* [Table 3]. MAR supporters were significantly more likely to agree that collective management of groundwater at the local scale would ensure operating rules are appropriate to local conditions and environmental circumstances [Table 3]. At the same time, survey data suggests MAR supporters hold strong views about their property rights and are less concerned about others when it comes to the use of groundwater underlying their properties [Table 3]. To an extent, this finding supports the previous narrative about the strong business focus of this cohort of Namoi landholders.

iii) Those not supporting MAR are more concerned about environmental impacts

Survey respondents who opposed or were unsure about MAR tended to place greater importance on environmental conservation. The No/Unsure cohort were significantly more likely to say that *A healthy Namoi River enhances the enjoyment I get from the local landscape* and there was a significant negative relationship between support for MAR and agreement with the statement that *Returning water to the environment is the best way to improve habitat for in-stream life in the Namoi River* and [Table 3]. It seems that those who do not support MAR are less interested in production and profit if these outcomes are likely to have negative impacts on the health of the environment that underpins their lifestyle and livelihood.

Values-related survey items	% Agreed/Strongly agreed* Mean scores (M)**		Test for significant difference between groups	Test for significant relations with survey item 1
	Yes (Support MAR)	No/Unsure (Not support MAR)	Yes/No Stats	Yes/No Stats
Caring for the weak and correcting social injustice	62.6% M=3.66	53.6% M=3.61	no significant difference	p=.036 r=.21 n=197
If governments and water users agreed to the collective management of groundwater at the local scale, that would ensure operating rules are appropriate to local conditions and environmental circumstances.	75% M=3.86	58.8% M=3.63	U = 3772 p=.045 r=-.14	p=.040 r=.145 n=200
Fostering equal opportunities for all community members	59.45% M=3.66	43.95% M=3.35	U = 3528 p=.018 r=-.17	p=.000 r=0.295 n=199
Further reductions of water entitlements will threaten economic viability of people like me	85.3% M=4.41	76.8% M=4.04	U =3726.5 p=.028 r=-.16	p=.017 r=.167 n=198
Landholders should have the right to use groundwater underlying their properties, even if that action impacts on others.	12.8% M=2.23	8.8% M=1.99	U= 3847 p=.047 r=-.14	no significant relationship
Returning water to the environment is the best way to improve habitat for in-stream life in the Namoi River	21.2% M=2.76	27.9% M=2.94	no significant difference	p=.021 r=-.163 n=200
A healthy Namoi River enhances the enjoyment I get from the local landscape	69.9% M=3.71	86.2% M=4.03	U = 3382.5 p=.027 r=-.16	no significant relationship

Table 3 **Comparing those in favour/not supporting MAR, Namoi, 2011: Values-related items. *** (%) is the percentage of respondents who said *Agreed/Strongly agreed* or *Important/Very important*. ****M = means score, measured on a scale from 1 ‘Not Important’ to 5 ‘Very Important’.

iv) Those not supporting MAR have longer-term connections to the land and see themselves as opinion leaders

Those who did not support MAR were more likely to have had the property in the family for longer [Table 2]. Subsequent analysis established that respondents whose family had held the property for longer were significantly more likely to agree that *Having power and being able to lead others* (r=.160, p=.027, n=198) was a guiding principle in their lives.

These findings suggest that support for MAR is likely to be strongest amongst those groundwater licence holders with a strong business focus and the support of this group will largely depend on the strength of the MAR business case. Interestingly, while this group is concerned about protecting their property rights, they are also likely to support collective approaches to groundwater governance. Opposition to MAR is likely to be strongest amongst licence holders with strong conservation values who will need to be convinced that MAR will not lead to negative environmental impacts. Survey data suggests this cohort is likely to include people with considerable influence in their communities.

Conclusions

In this paper we have argued that Australia needs to explore innovative strategies for addressing water security in the MDB. We have suggested that Managed Aquifer Recharge (MAR) in farming landscapes using surplus water from large flood events has the potential for significant environmental, social and economic benefits. MAR is a proven technology in urban contexts in Australia, but the opportunity for MAR in farming landscapes has received little attention. In our limited scoping of the options for MAR, we have identified some challenges that need to be addressed as part of a thorough feasibility assessment. For example, we need to identify the extent that large floods can be used to replenish depleted aquifers; the extent this can occur without affecting the ecological benefits of large floods; and effective ways to infiltrate flood water and effectively store it for long periods of time in aquifers. In addition, there will need to be assessments comparing MAR with other sources of water supply or savings, including irrigation infrastructure upgrades and water market initiatives. We also need to establish institutional arrangements that enable those with surface water entitlements to store water in aquifers and recover that water for later use, including for the environment.

Our research in the Namoi suggested that a majority of groundwater licence holders who responded, supported MAR using water from large flood events. Some respondents were either unsure or opposed to the concept because they were uncertain about what was involved or concerned about the risks of negative environmental impacts. Despite the apparent high level of social acceptability of MAR amongst the Namoi survey respondents, many issues need to be explored in terms of the potential roles of rural landholders in MAR. These include questions about how MAR fits with existing water sharing plans and allocations; who pays for MAR infrastructure where there are private benefits; how to secure rights to access water stored in an aquifer through MAR; and opportunities for collective governance arrangements to manage MAR on private land. Of course, non-farming stakeholders would also need to be convinced that this technology is feasible, does not represent a threat to water quality, will not involve a breach of the Murray-Darling Basin Plan limits to diversions of surface and groundwater for consumptive use (MDB Cap), and that the benefits of MAR will not be captured by a small cohort of landholders.

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