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Speeding the transition towards integrated groundwater and surface water management in Australia

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A R T I C L E I N F O

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A B S T R A C T

Conjunctive water management involves the combined use of groundwater, surface water and/or additional sources of water to achieve public policy and management goals. Conjunctive water management enables greater water supply security and stability, helps adaptation to climate variation and uncertainty and reduces depletion and degradation of water resources. There are many opportunities to benefit from improved conjunctive water management if institutional and political barriers can be overcome. This article provides the first comprehensive assessments of progress towards conjunctive water management on a continental scale across the Australian States and Territories, and suggests an innovative approach towards overcoming barriers to integration. Conditions for the implementation of conjunctive water management have only been partially met by the Australian States. There has been progress towards integrated groundwater and surface water accounting and planning, but there is still little systematic attempt to plan and manage surface water and groundwater storage and use at a regional scale over time. Current policies effectively subsidise surface water storage and aquifer storage and recovery entitlements are not in place in some jurisdictions. A new paradigm of conjunctive water management is required involving systematic consideration of the beneficial integration of groundwater, surface water and other water sources in water plans and projects. Transition to conjunctive water management can be promoted by networks including change agents, bridging organisations and water management institutions supported by strong leadership from governments.

1. Introduction

In many parts of the world, water resources are under pressure from economic and population growth and climate change. Demand for water is projected to grow by more than 40% by 2050. By 2025, an estimated 1.8 billion people will live in countries or regions in which water is scarce, and two-thirds of the world's population could be living in conditions in which the supply of clean water does not meet the demand (UN, 2015). In recent decades, the use of groundwater has been increasing around the world, in response to the rising demands for drinking water supplies and food production for a growing global population. Today groundwater is estimated globally to provide 36% of potable water, 42% of water for irrigated agriculture and 24% of direct industrial water supply. Groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited leading to serious consequences such as water shortages, land subsidence and saltwater intrusion in coastal areas (Gleeson et al., 2012). In order to sustain groundwater use, careful management to conserve aquifers is required together with exploitation of opportunities for enhanced groundwater recharge (Taylor et al., 2013).

Coordinated management of groundwater and surface water in combination, otherwise referred to as conjunctive water management, can bring a number of benefits including enhanced water availability, security and water quality, better management of impacts of water use and greater capacity to adapt to climatic variation and uncertainty. Conjunctive water management aims to make the best use of multiple water sources including surface water, groundwater, recycled stormwater and wastewater at the scale of river basins and aquifers (GGGFA, 2015b; Alley, 2016). Conjunctive water management exploits the complementary properties of groundwater and surface water. Surface water flows are visible, but surface water supply is often highly variable. When groundwater is accessible and of suitable quality it is a stable and reliable source of supply, and aquifer storage avoids evaporative losses (National Water Commission, 2014b).

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Conjunctive water management can increase water supply security and stability by making the best spatial and temporal use of different water sources and storage. This includes using surplus surface water and recycled water to recharge aquifers and drawing water from aquifer storage when surface water is scarce. It can also lead to better timing of irrigation water delivery by compensating for shortfalls in water availability at critical times for crops and water dependent ecosystems (Evans and Evans, 2012). Conjunctive water management can improve water quality by mixing different water sources and combining water treatment with enhanced recharge to achieve specified water quality targets. Groundwater systems can be used to stabilise water quality, leach or dilute pollutants, control seawater intrusion, while surface water can be used to freshen saline aquifers.

Conjunctive water management can account for and address the cross impacts of groundwater and surface water use on connected resources and the environment. This can counteract waterlogging and salination, excessive river flow depletion, drying wetlands and aquifer exploitation (Winter et al., 1998; Sophocleous, 2002; Evans, 2007). If impacts cannot be avoided conjunctive water management can reduce the impact by transferring or sharing impacts across systems and deferring impact through time or distributing them over a wider area. Conjunctive water management can also help adaptation to climatic variation and uncertainty by means of supply diversification, underground storage and water transfers (Halstead and O'Shea, 1989; Agrawal, 2008). Aquifers can be used to store dam overflows and floods and smooth daily variation in urban water demand and seasonal variation in irrigation demand.

Despite its obvious advantages conjunctive groundwater and surface water management has not realised its potential. While the physical conditions for broadscale conjunctive water management exist in many parts of the world there are significant institutional and political barriers (GGGFA, 2015a; National Water Commission, 2011, 2014a). There is a continuing emphasis on supply driven surface water investments and lack of recognition of the structural importance of groundwater investment in conjunctive water resource management. Institutional barriers include gaps and inconsistencies in the structure of water entitlements and the slow development of integrated water resource plans and measures to address overallocation of water resources. There are gaps in information about groundwater - surface water interactions (Evans, 2007; Moench, 2004). Many impacts from these interactions are long-term and overlooked by policy-making in short-term political cycles. Resistance by some stakeholders to change and split responsibility for groundwater and surface water development and management present further challenges (Ross, 2012).

There are few comprehensive studies of institutional and political issues related to conjunctive water management. In 1996 the US Environment Protection Agency funded a comparative institutional analysis of conjunctive water management in Arizona, Colorado and California (Blomquist et al., 2004). This study showed the substantial influence of water entitlements, operational rules and management organisations on conjunctive water management. The Managing Connected Waters Project funded by the Australian Research Council and the Natural Heritage Trust aimed to provide a co-ordinated approach to groundwater and surface water management including institutional and communication issues (Fullagar, 2004; Brodie et al., 2007)[1]. Recently conjunctive water management has been affirmed as a key principle of international groundwater management by the Groundwater Governance: Global Framework for Action (GGGFA, 2015a,b) and other international and Australian policy papers have proposed key issues and principles for conjunctive water management (World Bank, 2006; Evans and Evans, 2012; SKM, 2011).

This article contributes to the literature on the implementation of conjunctive water management by means of the first assessment of progress towards conjunctive water management at a continental scale across the Australian States and Territories. The article also introduces an innovative approach to overcome barriers to conjunctive water management, drawing on insights from literature on water management transitions. The choice of Australia for this study is supported by the potential for conjunctive water management to address water supply variability and scarcity challenges, coupled with the observation that groundwater and surface water generally continue to be managed separately and there are few strategic conjunctive water management initiatives or projects.

The assessment is based on an analysis of Australian and State government legal and policy documents, reports and water plans, consultant reports, academic papers and media reports which the author carried out in 2013 on behalf of the National Water Commission (National Water Commission, 2014b). The author also draws on responses to semi-structured interviews with government water managers, consultants, academics and water users' representatives which he carried out in 2009 during his PhD research on conjunctive water management in the Murray-Darling Basin.

The remainder of this article is structured as follows. Firstly a framework for analysing the performance of conjunctive water management is presented, building on Australian and international policy studies (SKM, 2011; Evans and Evans, 2012; GGGFA, 2015b). Key prerequisites for conjunctive water management include clearly defined legislative and policy objectives, groundwater and surface water entitlements, integrated water planning, and coordinated management arrangements. Secondly the performance of conjunctive water management in the Australian states and territories is assessed, based on this framework. Comparison between Australia and examples from the western USA are included to place the Australian experience in an international context. Thirdly progress achieved on conjunctive water management and challenges are assessed and priorities and steps are suggested for speeding the transition to beneficial conjunctive management of water resources.

2. Framework for the assessment of the integration of groundwater and surface water management

2.1. Definition and scope of conjunctive water management

2.1.1. Definition

Conjunctive water management can be defined as the combined use of groundwater, surface water and/or additional sources of water to achieve public policy and management goals. There is a strong case for conjunctive management of groundwater and surface water under two conditions:

1. Groundwater and surface water resources are connected; surface water infiltrates to groundwater or groundwater flows into surface water. This means that the use of surface water will impact on groundwater and its users and vice versa.
2. The use of groundwater or surface water has impacts across other resources and their users. These cross-impacts may occur whether or not groundwater and surface water resources are connected, for example if groundwater or surface water is depleted the demand for other water resources is likely to increase.

[1] http://www.connectedwater.gov.au/framework/institutional_arrangements.html accessed 28 January 2012.

The connections between groundwater and surface water resources, and the extent of groundwater - surface water use impacts vary substantially. Within a given water management region groundwater and surface water resources are separated - geographically, or by impermeable "confining" layers of clay or rock. Therefore the strength and timeframes of connections vary substantially and are not well understood (Evans, 2007; Moench, 2004). Important distinctions can be made between regulated perennial and unregulated ephemeral rivers and alluvial and fractured rock aquifers (SKM, 2011). In addition, some aquifers contain non-renewable "fossil" groundwater which can be depleted like mineral resources.

The impacts of groundwater and surface water uses across other water resources and their users are also highly variable. These include impacts on the quantity and quality of water resources and on connected environmental assets and services. For example groundwater pumping can reduce streamflow and surface water availability while surface water use can reduce groundwater recharge. Groundwater can be polluted by agricultural chemicals, heavy metals, pharmaceuticals and other contaminants carried by surface water. Surface water can be polluted by saline or contaminated groundwater. Socio-economic impacts vary substantially between regions, according to the number of people and economic sectors dependent on groundwater and surface water, the intensity of resource use and the risks of pollution created by human activity. Conflicts over water use present political problems in some heavily exploited resources in the southern half of Australia, while there are opportunities for development in areas where resources are lightly exploited especially in the northern half of the continent (GGGFA, 2015a; National Water Commission, 2014a).

The case for conjunctive water management is strongest when connections are strong and rapid (SKM, 2011), but the general application of conjunctive water management on a precautionary basis is justified by gaps in information and uncertainties about cross impacts of groundwater and surface water use, and the fact that many of these impacts do not appear for many years.

2.1.2. Conjunctive water use and conjunctive water management

A distinction can be made between conjunctive water use and conjunctive water management

- Conjunctive water use refers to coordinated use by water users for specific purposes, for example irrigation, municipal use or mining. Private water users generally aim to maximise water use efficiency, and rarely take account of broader social objectives.
- Conjunctive water management refers to coordinated management of groundwater and surface water to optimise use of resources to meet broad social objectives, such as the supply of enough water of sufficient quality to meet municipal, agricultural, industrial and environmental requirements.

While some social benefits have been achieved by private conjunctive water use, such as that developed in many irrigation districts, private groundwater users are more likely to organise themselves to manage issues with an immediate impact on their production and the resource such as new wells, well depth and seasonal timing. They are unlikely to take action to manage impacts of pumping that emerge in distant locations or in the longer term such as remote impacts on streamflow, declining water tables and drying wetlands (Schlager, 2007). Irrigation managers aim to maximise irrigation water use efficiency and often neglect the associated reductions in groundwater recharge.

Coordinated conjunctive water management by private users and public authorities can ensure that "cross resource" impacts of groundwater and surface water use are fully accounted for and managed. This requires cross sectoral and cross agency coordination of water resources, land uses and the environment at multiple spatial and time scales and administrative levels. This goes beyond what has been achieved by private conjunctive water users (Foster and Van Steenbergen, 2011).

2.1.3. Additional sources of water for conjunctive water management

When the term conjunctive water management was introduced it referred to surface water and groundwater. More recently additional sources of water have been introduced including desalinated water, recycled stormwater and wastewater from sewage treatment plants and industrial processes (Dillon et al., 2012). These additional sources are available for human, agricultural or industrial use after appropriate treatment. The definition of conjunctive water management can be broadened to include conjunctive use of groundwater or surface water with one of these additional sources of water, when they are combined with either surface water or groundwater before further use. Conjunctive management of groundwater, surface water and additional sources includes combination of recycled or desalinated water with other surface water as well as underground storage, treatment and recovery of recycled water (managed aquifer recharge and aquifer storage and recovery). If one of these additional sources is supplied directly for human consumption or agricultural use after treatment without being combined with groundwater or surface water, this cannot be counted as conjunctive water management since there is only one source of water involved.

2.1.4. Bluewater and greenwater

The availability of water for plant growth and food production can be divided into the blue water in aquifers, rivers and lakes, and the green water in soil moisture (Falkenmark and Rockstrom, 2006).The scope of conjunctive water management can be further expanded to include land and water management practices that encourage infiltration, soil moisture retention and aquifer recharge such as slowing the passage of water in the landscape, increasing vegetative cover and modifying diversionary structures (National Water Commission, 2014b). The data collected for this article is insufficient to include soil moisture in the analysis of conjunctive water management. This is an important task for future research.

2.2. Framework for assessing conjunctive water management

In Australia the 2004 National Water Initiative established a national system of managing surface and groundwater resources for rural and urban use (COAG, 2004). The NWI (para 23x) further states that the connectivity between groundwater and surface water should be recognised and connected systems should be managed together. The Water Act 2007 (s. 20b) provides for the integrated management of basin water resources and the establishment and enforcement of environmentally sustainable limits of the quantities of groundwater and surface water that may be taken from a basin water resources. The physical preconditions for broadscale conjunctive water management and water banking exist in many parts of Australia, and there is significant community support (Rawluk et al., 2013) although there is varied public acceptance of different water sources such as recycled water and rainwater (Hurlimann and Dolnicar, 2016). While conjunctive water use including groundwater - surface water substitution and use of groundwater as a buffer has been widely practised by irrigators, progress towards conjunctive management of connected groundwater and surface water systems has been limited. There have been some small and medium sized aquifer recharge projects around urban centres but relatively few examples of catchment scale conjunctive water management and very few large scale recharge and recovery projects.

Interventions to promote conjunctive water management can be broadly divided into policies and regulations administered by water managers, field-based land and water practices and technology-based infrastructure. The first category includes permitting systems for water users and restrictions on water use, substitution of groundwater and surface water, foregoing use of a water resource in return for a benefit, carryover of water use entitlements, water banking and surface water - groundwater trading. The second category includes land and water management practices that encourage soil moisture retention and aquifer recharge by slowing the passage of water in the landscape, increasing vegetative cover, channelling water to areas with high recharge, protecting recharge areas and encouraging water infiltration through leaky ditches and channels. The third category includes dams, water transfer projects, aquifer storage and recovery, river bank storage, water treatment plants and seawater intrusion barriers (National Water Commission, 2014b; GGGFA, 2015a).

Several authors have investigated the conditions for conjunctive water management in Australia (SKM, 2006, 2011) and internationally (Evans and Evans, 2012; Dillon et al., 2012; GGGFA, 2015b). Eight conditions for the implementation of conjunctive water management can be derived from this previous work. These conditions are summarised in Table 1 and explained in the following paragraphs.

A clear statement of the objective of conjunctive water management in legislation is a strong incentive for conjunctive water management. Policy statements provide direction but a legislated objective creates a legal obligation to implement conjunctive water management independent from policy changes. Legal provisions for conjunctive water management should take account of the objectives of related national policies and programs such as energy, food security and climate change. Effective conjunctive water management also requires policies and regulations that promote assessment of groundwater and surface water supply and storage options, match resources with requirements and enable interchange between groundwater and surface water supply and storage (Evans and Evans, 2012).

Surface water and groundwater connectivity can be classified and assessed in terms of the type and extent of the connection and the time lag between abstractions and impact. Most groundwater and surface water abstractions affect other resources and/or the environment. The National Water Initiative requires an assessment of the connectivity between surface (including overland flow) and groundwater systems (National Water Commission, 2011). Because of the wide range of connections between groundwater and surface water resources, context specific assessment of the impacts of the use of groundwater and surface water and related opportunities and risks is required in order to calculate sustainable groundwater and surface water use limits (SKM, 2011). This assessment requires a water balance that reflects the whole hydrological cycle and avoids double counting of water available for allocation from connected surface water and groundwater resources. For example, leakage from irrigation channels and groundwater discharges which become base flow should not be allocated to both groundwater and surface water users (Evans and Evans, 2012; Evans, 2007).

Key factors that affect sustainable groundwater and surface water use limits include rainfall, aquifer recharge and discharge rates and storage conditions, water quality, environmental requirements, legal constraints, socio-economic conditions and intergenerational equity. While sustainable use limits can be objectively assessed there are significant scientific uncertainties, and use limits are often disputed by stakeholders reflecting their different preferences. This has led to the development of concepts such as "consensus yield" (Pierce et al., 2013) and "acceptable yield" (Richardson et al., 2011) which include linked processes of scientific assessment coupled with stakeholder negotiation to set sustainable use limits.

Table 1
Conditions for conjunctive water management.

1	Objective of integrated management of GW and SW stated in legislation and policy
2	Sustainable GW and SW use limits, based on integrated assessments GW and SW resources
3	Entitlements to access, store and use GW and SW
4	Integrated GW and SW plans for connected resources
5	Exchange and trading of GW and SW enabled
6	Management of GW and SW centralised and coordinated
7	Stakeholder participation in decision-making
8	GW and SW metering and monitoring

Comprehensive, well defined and secure legal entitlements provide authority to use water and incentives to invest in collective water management (Ostrom, 2005; Bruns et al., 2005). Schlager and Ostrom distinguish five different entitlements related to common pool resources such as a water resource: access to a resource, use of a resource, management of a resource, exclusion of others from a resource, and transfer of an entitlement to use a resource to another owner (Schlager and Ostrom, 1992). Entitlements to store water in a surface water storage or an aquifer and then to extract it for use or transfer are also required to enable conjunctive water management. Decisions on the issue of entitlements to access, use, store and exchange GW and SW need to take account of possible economic, social and environmental impacts across the connection (SKM, 2011).

Groundwater and surface water plans including clearly specified, transparent and measurable objectives and rules for water access, use, storage and transfer provide direction for conjunctive water management and confidence for participants in a conjunctive use system. These plans need to enable extended banking of water in aquifers and extraction when it is required. When groundwater and surface water resources are connected, rules for surface water users need to take account of extent and timing of impacts on groundwater and the environment and vice versa (National Water Commission, 2011; SKM, 2011). Rules and their administration should be sufficiently flexible to respond to variations in water availability, socio-economic and political conditions and new knowledge (Pahl-Wostl, 2007).

Water markets and trading developed within an appropriate institutional framework and coupled with comprehensive water planning has increased farm production, assisted irrigators adaptation to climate risks and helped to deliver improved environmental outcomes (Grafton et al., 2016). Groundwater-surface water trading can also lead to increased efficiency. In principle groundwater to surface water trading can enable water to be transferred to the uses which give the best value for money. Groundwater-surface water trade is relatively uncomplicated when the resources are highly connected and connections are rapid such as shallow alluvial aquifers underneath rivers. In such cases groundwater and surface water can be managed as one resource (SKM, 2011). In other cases it is more complicated to set rules for groundwater-surface water trade because connections between groundwater and surface water are less strong, more delayed or not well understood, environmental impacts are uncertain or groundwater and surface water have different properties e.g. salinity and pollution. In addition plans often cover large areas within which groundwater-surface water connections vary substantially.

Fragmentation of roles and responsibilities for conjunctive water management is a major obstacle to good management (World Bank, 2006). Conjunctive water management requires effective coordination between groundwater and surface water policy, planning and management across multiple geographical and administrative scales. Coordination is also needed between water management and other related activities including land management, energy and spatial planning (Turral and Fullagar, 2007; Ross and Martinez-Santos, 2010). Management of surface water and groundwater can be integrated within one agency or coordinated between several agencies including government departments and a basin management organisation providing that groundwater and surface water managers work together and coordinate their activities.

Participation by groundwater and surface water users in decision making is necessary to ensure that users understand each other, have the opportunity to identify and make tradeoffs and craft mutually acceptable solutions taking account of relevant information and uncertainties (Emerson et al., 2012). Participation in water management planning encourages support for plan implementation from groundwater and surface water users (Sabatier et al., 2005). A participatory culture of education, demonstration and capacity building between governments, groundwater and surface water users enables integrated water use targeted at socially desired outcomes (Evans and Evans, 2012; Letcher et al., 2007).

Metering and monitoring of key variables such as water levels in reservoirs and aquifers, water abstractions, water uses and water quality are important to provide feedback about the performance of conjunctive water management, allow ongoing iteration and also to enable the enforcement of water plans and rules (Ostrom, 2005; GGGFA, 2015a). Groundwater and surface water monitoring should be coordinated in a single program (Evans and Evans, 2012).

While this framework and conditions give general guidance for the assessment of conjunctive water management, the wide variety of hydrogeological, socio-economic and political settings mean that there is no single template or formula that will provide for conjunctive water management in all places. The relative quantity, quality, accessibility and connectivity of groundwater and surface water resources varies substantially, and cross impacts of groundwater and surface water use range from large and immediate to small and long-term. In the following section the performance of conjunctive water management in Australia is assessed with reference to the conditions for conjunctive water management set out in Table 1.

3. Assessment of conjunctive water management in five Australian states and the Northern Territory

The main results of a comparative assessment of conjunctive water management in the five largest Australian states (New South Wales, Queensland, South Australia, Victoria, Western Australia) and the Northern Territory are summarised in Table 2.[2] An assessment of the availability of information for decision-makers, stakeholder participation and metering and monitoring is also provided. Further explanation is provided in the following paragraphs. Tasmania and the Australian Capital Territory are excluded because they are relatively small and marginal cases. Tasmania had no groundwater plans when the data collection for this analysis was completed in 2013 whereas in the ACT legislation requires groundwater and surface water to be considered and managed as one resource.

3.1. Integration of groundwater and surface water planning and management in legislation and policy

Under Australia's federal system of government the States and Territories have the primary right to own or control and use water (Lucy, 2008). The objectives of New South Wales and Victorian legislation and the Western Australian state water plan specifically refer to the integration of groundwater and surface water management. These references encourage conjunctive water management. In the other jurisdictions policy and legislation does not specifically refer to the integration of groundwater and surface water management. In most jurisdictions the declaration of water management areas and determination of their boundaries is left to the discretion of the responsible Minister or administrator. The Water Act 2007 and the 2008 Murray-Darling Basin Intergovernmental Agreement provide specific direction towards conjunctive water management. This provides impetus for further integration in the next generation of State and Territory water plans.

Water legislation and policy in all of the jurisdictions gives substantial discretion to Ministers and agencies in the determination of sustainable use limits, priorities for water allocation, and priorities and timetables for water planning. Ministerial and agency discretion concerning high-level intervention coupled with pragmatic planning processes can have advantages in dealing with uncertainty and the unexpected but can lead to concerns about a lack of procedural fairness (Gardner et al., 2009).

3.2. Assessment of groundwater and surface water resources and establishment of sustainable use limits

All jurisdictions have developed technical approaches to assess connected groundwater and surface water resources and to establish sustainable use limits, based on the classification and analysis of water resources, the degree of connectivity, cross impacts of use and timing of impacts. The main surface water resources and their movements are comparatively well understood but there are still major shortfalls in information about groundwater quantity, quality and dynamics, and the connections between groundwater and surface water (National Water Commission, 2011). Catchment-scale models of water resources are a relatively recent phenomenon, groundwater and surface water models are usually separate, there are few integrated models and in any case it is difficult to model groundwater surface water connections (Rassam et al., 2008). Some phenomena are not usually accounted for in models or water balances, such as the effects of surface water - groundwater interactions and the impacts of farm dams, afforestation and irrigation recharge.

Despite technical advances in the assessment of connected groundwater and surface water resources, groundwater and surface water use limits are set separately.[3] In most jurisdictions sustainable use limits for surface water are determined using an estimate of the total water resource or total divertible resource less environmental water requirements. In the Murray-Darling Basin current surface water sustainable use limits are based on the 1995 Murray Darling Basin Cap. From 2019 new sustainable use limits will be implemented to be consistent with the limits set in the 2012 Murray Darling Basin plan. This plan also sets limits on groundwater use, which take account of estimated rainfall recharge to groundwater. Base flow, through flow, discharge and groundwater dependent ecosystems were considered in setting these limits.

[2] This assessment was carried out by the author for the National Water Commission in 2013, and updated using the Commissions fourth biennial assessment of the NWR in 2014. This assessment is based on review of a large number of state policy documents and plans, which are not referenced individually in this article.

[3] Methods used by the jurisdictions are summarised in the National Water Commission's Second Biennial Assessment of progress in implementation of the NWI http://archive.nwc.gov.au/library/topic/assessments/ba-2009 p. 67–68 accessed 27 June 2013.

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Table 2
Summary of assessment of conjunctive water management.

	QLD	NSW	VIC	SA	WA	NT
Objective of CWM stated in law	No	Yes	Yes	No	No	No
Integrated assessment of GW and SW resources and use limits	Integrated assessment hindered by gaps in information about GW resources and GW-SW connections. GW and SW limits set separately					
Comprehensive system of secure tradable entitlements	Incomplete	Yes except storage	Yes except storage	Yes	No	No
Integrated GW and SW plans that account for cross impacts	Staged integration	Macro plans	Regional water strategies	Yes	Small number	Small number
GW and SW trading	No	No	No	No	No	No
Centralised management in one organisation	Yes	Yes	No	No	Yes	Yes

3.3. Entitlements to access, store and use groundwater and surface water

Entitlements and rules for conjunctive water management can be divided into four categories; access, use, storage and exchange. Each source of water requires clearly defined, secure entitlements and rules to enable sustainable and efficient operation. At the same time flexible implementation of water entitlements and rules is needed to allow for changes in knowledge, and unforeseen climatic extremes, droughts and floods. In the Murray-Darling Basin flexible surface water allocations are achieved by providing entitlement holders with seasonally or annually adjustable shares of their water entitlements. Groundwater entitlement holders and surface water licence holders in other regions are generally allocated a volumetric amount of water that may be reduced at the discretion of the Minister or other relevant authority in response to emergencies.

Australian jurisdictions have established tradable groundwater and surface water use entitlements for most water resources. Apart from Western Australia and the Northern Territory these have legislated security. By contrast individual groundwater and surface water storage entitlements have not been established. Surface water storage and distribution services are supplied at very low cost to users, with no accounting for evaporative losses. These losses are substantial, for example it is estimated they amount to 3000 GL/year in the Murray-Darling basin, almost 30% of the average sustainable diversion limit (SDL) in the Murray-Darling Basin Plan and more than the amount of water that had to be recovered from users to achieve the SDL. In dry parts of the basin losses can be expected to be greater. Long-term mean evaporation from reservoirs in Texas is estimated at 7500 GL/year, equivalent to 61% of total agricultural water use or 126% of total municipal water use in the state during 2010 (Wurbs and Ayala, 2014).There is little incentive for water users to consider underground storage, and there are very few large-scale underground storage projects in Australia.

In addition to the lack of storage entitlements there are significant gaps and exemptions in the water entitlement and allocation frameworks in the Australian jurisdictions. Stock and domestic use is not included in the water allocation framework, and capture of overland flows is not fully regulated. Mining, forestry and other industrial water use is regulated separately, with an emphasis on water quality rather than water quantity impacts. There has been some progress in regulating water use by forestry in South will Australia, Victoria and Tasmania, and more limited progress towards establishing water access entitlements for the mining sector.

3.4. Integrated groundwater and surface water plans

Australian jurisdictions have made considerable progress in developing water plans that take account of significant connectivity between groundwater and surface water but there are noticeable differences between groundwater and surface water plans. Most surface water plans across the Australian jurisdictions find that connectivity does not exist or is not a significant issue. By contrast most groundwater plans recognise that connectivity exists and many include measures to address it. Most surface water plans do not include any assessment of impacts of surface water diversions on groundwater recharge or measures to deal with these impacts.

Detailed assessments, and in some cases partial assessments are accompanied by rules to manage cross impacts. There are a large variety of rules and rule settings established to deal with specific conditions and objectives in different water planning areas. These rules include various types of pumping limits, cease to pump and well spacing rules, joint management arrangements, low flow bypass, roll over, triggers and targets. Examples are set out in Table 3.

In the first generation of water plans groundwater and surface water plans were generally separate. Since the NWI in 2004 some jurisdictions have rationalised and/or combined new groundwater and surface water plans in regional water resource planning "envelopes" which cover multiple groundwater and surface water resources. Examples include macro plans in New South Wales and amalgamated water plans in South Australia. In Victoria regional sustainable water strategies have been prepared including the integrated consideration of groundwater and surface water resources. Some catchment plans have been amalgamated although Victoria has completed only one conjunctive water plan at the catchment scale. Queensland water resources plans did not initially include groundwater, but base flow management and groundwater rules are being integrated into Resource Operational Plans, and will be progressively incorporated into Water Resource Plans. A small number of plans in Western Australia and the Northern Territory include both groundwater and surface water.

3.5. Exchange and trading of groundwater and surface water

Groundwater and surface water trading can offer opportunities to improve spatial and temporal allocation of water. Two-way surface water-groundwater trading is feasible in connected systems, especially where resources are highly connected and connections rapid. These conditions only apply in a limited number of settings. More generally gaps in knowledge about surface water groundwater connections and risks of adverse long-term impacts have led Australian water managers to take a cautious approach to groundwater - surface water trading. For example, moving water rights from an aquifer to a river could decrease river flows in the short term, but this could be offset by increased baseflow in the long-term. Moving river entitlements to an aquifer would benefit some groundwater users but increased groundwater use might adversely affect existing groundwater users and third parties. In addition it is complicated to determine rules of exchange between groundwater and surface water entitlements with different characteristics (AGT, Hamstead and Baldwin, 2011). There are very few recorded cases of groundwater and surface water trading in Australia. Water allo-

Table 3
Examples of rules to manage connectivity.

Name	Rule type	Details
Pioneer Water Resource area (QLD)	Pumping limit in "affected" areas	In these areas GW pumping can be restricted to prevent seawater intrusion
Peel (NSW)	Cease to pump	Cease to pump rules for bores near streams based on stream level.
Hunter (NSW)	Joint management	Treat GW and SW as one resource (if bores <40 m from stream)
Ovens (Vic)	Extraction limit	Staged extraction limits depending on measured stream flow
Marne Saunders (SA)	Low flow by-pass	SW structure by pass when flow rate less than specified%
	Well spacing	400 m between wells
W Mt Lofty (SA)	Well spacing	100–400 m between wells depending on resource
	Extraction speed limits	Linked to a maximum threshold flow rate
Lower Gascoyne (WA)	GW use limits with exceptions	Maximum monthly drawdown, with unrestricted pumping periods
	GW use triggers	Based on groundwater levels and quality.
Tyndall (NT)	Target water level	Target water level in Katherine River to protect GDEs

cation could also be improved by groundwater and surface water storage markets. Surface water use entitlements based on shares of reservoir storage capacity and inflows of reservoir are being trialled in Australia (Hughes, 2013).

3.6. Management of groundwater and surface water centralised in one organisation

Australian jurisdictions have relatively centralised water planning and management systems. At the highest level groundwater and surface water is managed together. At lower levels groundwater and surface water management is separated. While the primary authority for water management is usually a single minister supported by a single lead government agency, conjunctive water management typically involves multilevel governance interactions between a large number of individuals, groups, organisations and institutions including governments. Decisions are the product of complex cycles of interaction in which the participants have varying degrees of influence, but no single one is dominant" (Connell et al., 2007). Surface water issues generally dominate the water policy agenda which has led to a surface water centric management, rather than strategic management of groundwater and surface water (Ross, 2012). Groundwater issues receive less priority and groundwater is often under-represented and understaffed.

New South Wales, Queensland, Western Australia and the Northern Territory centralise management and planning authority, and State Departments develop both policy and detailed local plans. In Victoria and South Australia the State Governments set overall objectives, and State Departments provide a policy and planning framework within which regional and local water management bodies develop detailed local plans and rules.

3.7. Stakeholder participation in decision-making

Each jurisdiction has statutory consultation mechanisms in water planning, but consultation often appears more symbolic than real. Although participative modelling, assessment and planning methods are rated highly by stakeholders, less collaborative methods of participation such as information giving and allowing written submissions, are often preferred by authorities because they are 'safer' and more easily managed (Tan et al., 2012). In some instances consultation takes place after policy changes have been made, in other instances high level interventions overtake collaborative processes without taking account of stakeholder views (Bowmer, 2003). The initial top down consultation on the Murray-Darling Basin plan resulted in widespread protests (Gross, 2011) and community support for the plan was only obtained after a much more prolonged consultative process. The Western Australian system of examining alternative management options, and the Northern Territory system of consultation to define priority uses offer innovative collaborative management processes.

3.8. Groundwater and surface water metering and monitoring

The use of surface water is generally measured and monitored by water supply agencies and in some cases by industrial users (ABS, 2015). Monitoring groundwater use presents more problems because unlike surface water irrigation water is supplied to users through a regulated system, there are a large number of wells mostly on private farms. Groundwater use is not monitored as systematically as surface water. Gaps in monitoring and measurement lead to gaps in data required to develop and run models (Kelly et al., 2007).

Metering of water use has been introduced in regulated river systems and all of the jurisdictions, but metering of unregulated surface water systems and groundwater is not standardised. The quality of metering and the frequency with which meters are read vary widely. The Council of Australian governments has developed a National Framework for Non-Urban Water Metering to establish a national standard (Council of Australian Governments, 2010). In New South Wales most of the regulated river systems and about 50% of groundwater extraction is metered. Victoria has over 50,000 metered extraction sites and extensive modernisation is underway. Queensland is progressively introducing metering while South Australia is taking a risk based approach to the implementation of the new standards (National Water Commission, 2011).

In summary there is much scope for further development and use of conjunctive water management in Australia. Queensland, New South Wales, Victoria have established key elements of National Water Initiative (NWI) compliant systems, but face challenges in integrating previously separate groundwater and surface water entitlement and allocation systems. Western Australia and Northern Territory are still in the process of establishing a NWI compliant water entitlement system. Accounting for impacts of groundwater pumping on streamflow has improved, but there has been less progress on accounting for the impacts of surface water diversions on recharge. There is still little or no systematic attempt to plan and manage groundwater and surface water use and storage at a regional scale over time and aquifer storage and recovery entitlements have not been established. Water for petroleum and gas, mining and forestry is generally managed separately from, and not well integrated with the national water management system.

4. Progress towards conjunctive water management in the Western USA

The potential of conjunctive water management and managed aquifer recharge is illustrated by the development of these techniques in California and Arizona, which also illustrates the potential of conjunctive water management and managed aquifer recharge under various institutional settings. Conjunctive water management in California is the result of multiple initiatives over many years mainly involving water users and municipal governments. In Arizona conjunctive water management has been driven primarily by an innovative state government aquifer recharge program. Conjunctive water management activities consist mainly of aquifer recharge and storage of "excess" or unused portions of Arizona's allotment of Colorado River water, which is conveyed by the Central Arizona Project (CAP) canal (Sugg et al., 2016).

Conjunctive water management in California is supported by water imported through the Central Valley Project and the State Water Project canals and aqueducts which have shifted water sources from mostly groundwater use to integrated use of surface water (70% during wet periods) and groundwater (70% during droughts (Scanlan et al., 2016). Since 2002 $1.5 billion has been spent on integrated regional water management activities initiated by 48 regional water management groups (CDWR, 2016). Recently, the California Department of Water Resources (CDWR) and the Association of California Water Agencies conducted a survey that recorded 89 integrated management programs across the State (CDWR, 2015). Conjunctive water management methods vary. In coastal areas such as Los Angeles County and Orange County, surface water and treated wastewater are injected into aquifers for aquifer replenishment and water banking, and to provide a barrier to seawater intrusion (Drewes, 2009). In other districts, conjunctive management is used for flood control, drought relief, and local and statewide water supply reliability improvement (CDWR, 2014). These investments have been given a further boost by the US$7.12 billion authorised by the California legislature in 2014 for State water supply infrastructure including surface and groundwater storage and water recycling (Ballotpedia, 2016).

Conjunctive water management and managed aquifer recharge in the Central Valley has reversed previously declining groundwater level trends of up to 2.5 m per year (Scanlan et al., 2016) and enabled some recovery of aquifer levels. The scale of integrated water use and aquifer storage facilities in California are much bigger than their Australian counterparts. In Orange County California one water bank holds around 300 GL a year – enough for the annual household use of 2.3 million people (Dillon et al., 2009). The Semitropic Water Storage District in central California holds up to 2000 GL for its members.

Integrated water use in Arizona accounts for about 25% of Central Arizona Project canal deliveries from the Colorado River and has helped stabilize and reverse long-term groundwater storage losses. In terms of volume, Arizona's recharge efforts are extensive, with about 5000 GL of Colorado River water, in-state surface water and effluent having been stored in the States' aquifers (Megdal et al., 2014). Impacts of integrated water use and managed aquifer recharge in Arizona can be seen from comparisons of recent rising groundwater level trends in the Active Management Areas (0.1–0.5 m per year), in comparison with declining trends (0.5–1.3 m per year) in irrigated areas that lack access to surface water to support integrated use or managed aquifer recharge (MAR). Flexibility translates to resilience. By expanding the portfolio of water sources in the southwestern US and increasing the options provided by water transportation infrastructure allowing water trading among users, conjunctive water management and MAR enhances system resilience to drought (Scanlan et al., 2016).

5. Speeding the transition to conjunctive water management

Conjunctive water management involves integrated use, storage and exchange of different sources of water. Australia faces a number of challenges in making the transition to conjunctive water management. These challenges are very similar to those faced in transitions in other sectors: institutional fragmentation, lack of common vision, undefined organisational responsibilities, regulatory disincentives and lack of offsetting incentives, poor organisational commitment, technological path dependency, perceived high risks of new technologies, poor community capacity to meaningfully participate, and lack of experience with facilitating integrated management processes (Farrelly and Brown, 2011; Loorbach and Rotmans, 2010).

Transition management offers one framework to help understand what is required to shift from separate management of groundwater and surface water to integrated management. Transition management has been proposed as a tool for achieving transformative change in governance (Loorbach, 2007; Van de Brugge and Van Raak, 2007). Case studies illustrate how transitional management involves an adaptive co-evolutionary process involving frontrunners or agents who develop new approaches and technologies, a transition arena in which a network of frontrunners can develop a common vision and process and a space or niche inside existing governance arrangements through which innovative changes are promoted. Transitions often meet resistance from the existing regime and a favourable context for change is a key to transition management (Loorbach and Rotmans, 2010).

Transition management in the water sector can be illustrated by a detailed study of the evolution of stormwater management in Melbourne, Australia between the 1960 and 2010 (Brown et al., 2013). In this case study a small group of frontrunners from across government, private, community and scientific sectors facilitated a broader and more diverse actor-network that steered this transition over decades. The establishment of networked bridging organisations that facilitated collaboration across government agencies, water managers, scientists and knowledge brokers was also crucial in forming alliances that supported transition in practices across the city. There was no single cause–effect relationship nor one dominant intervention or action that shifted the urban stormwater management regime. Rather new narratives emerged from interaction between frontrunners and their networks which influenced scientific thinking and on-the-ground experiments. These led to new institutional structures and enabling administrative tools. Each these dimensions is equally important in explaining the evolution of sustainable stormwater management.

High-level leadership is a further important enabling factor for transition. The integration of environmental considerations into broader policy considerations requires high level leadership and cultural change as well as new institutional structures and networks (Ross and Dovers, 2008). High-level policy entrepreneurs play a key role in initiating and driving water transitions (Huitema and Meijerink, 2010), and high level leadership is also important in creating a supportive environment for change (Huntjens et al., 2010).

The above discussion suggests that a change of paradigm to conjunctive water management can be promoted by six key elements:

– network of frontrunners or change agents;
– bridging organisations that will facilitate collaboration between change agents and other water policy organisations, operational managers, water users, scientists and knowledge brokers;
– arenas where change agents and other stakeholders can collaborate;
– experiments and pilot projects in conjunctive water use, storage and exchange;
– high level leadership both to initiate change and to create a supportive environment for change;
– mechanisms for evaluation, learning and feedback - at two levels; among the front runners and among the general policy community.

There are already a significant number of projects for conjunctive water management, especially in the driest states South Australia and Western Australia, and in the cities of Perth and

Adelaide. The Western Australian Water Corporation has set a target for Perth of 30% of recycling of all metropolitan wastewater by 2030 and 60% recycling by 2060 (Western Australia Water Corporation, 2009). South Australia has a target of 60 GL of recycled stormwater and 75 GL of treated wastewater for non-human consumption by 2050 (Government of South Australia, 2009). Victoria has established a policy framework for aquifer recharge, some trials are being carried out around Melbourne, and conjunctive water management has been practised in a few catchments in Queensland such as the Burdekin and Lockyer Valley.

These developments have been assisted by bridging organisations and networks in Australia at various scales. At the national scale the Australian water recycling centre has promoted national awareness of opportunities for water recycling and promoted a national program of Managed Aquifer Recharge and Storm Water Use Options (MARSUO) pilot studies. At the municipal scale the cities of Adelaide and Perth have taken a leading role in aquifer recharge. While these organisations and networks have been successful across urban areas such as Adelaide and Perth, there is an opportunity for national or state based organisations to act as an arena for the discussion and development of broadscale conjunctive water use and storage. Options include the Murray Darling Basin Authority and State Water Corporations.

There are two significant barriers to the further development of conjunctive water use and storage; the limited amount of surplus water for underground storage experiments and the so-called hydro-illogical cycle. In many parts of Australia and throughout the Murray -Darling basin groundwater and surface water is fully allocated. In order to obtain water for underground storage water users usually have to purchase water at market rates. When stored in aquifers the water becomes the subject to carryover provisions, which generally allow three years of storage or less. Moreover, water can be obtained most easily and cheaply for underground storage during wet years, but in these years farmers are focused on maximising production and the enthusiasm for investment in new sources of water supply and storage is at its lowest point. Yet this is the best time to replenish groundwater banks so that they will be available during the next dry period.

New visions of conjunctive water management through time championed by front-running organisations and high-level political and bureaucratic leaders, coupled with broadscale conjunctive water management pilot projects will be needed to overcome these barriers.

6. Conclusions

This review of progress towards conjunctive water management in Australia reveals some progress in conjunctive use of water resources, but little progress on integrated dam and aquifer storage or trading between groundwater and surface water. There are major opportunities for conjunctive water management using underground water banking and managed aquifer recharge. Developments in the Western USA indicate the potential of conjunctive water management, and opportunities for groundwater and surface water trading could be further explored.

A new paradigm of conjunctive water management and storage is required. This involves the systematic consideration of the opportunities for beneficial integration of groundwater and surface water use and storage in all new water plans and development projects involving significant use of water resources. Two key policy and institutional conditions are missing in Australia and need to be put in place: guaranteed recovery of water stored underground and extended carryover arrangements to allow long term underground storage.

There are already some front-running organisations and networks driving the adoption of new sources of water supply and aquifer storage in Australian cities. Generally there is no parallel transition towards conjunctive water management in rural areas. The deadline for preparation of the next generation of water plans in the Murray-Darling basin is not until 2019, and investments in water resource development and storage in northern Australia are under consideration. These scheduled developments in the MDB and Northern Australia provide significant opportunities to (re)design water plans to take full account of the opportunities for conjunctive use of groundwater, surface water and recycled water over wet and dry climatic cycles.

Leadership from the Council of Australian Governments is required to lead national efforts towards integrated water resource use and management, because responsibilities for managing water allocation and water quality are divided between many agencies in the Australian government and state jurisdictions. Support from water managers, irrigation associations and water corporations is also crucial. The last national meeting on conjunctive water management in Australia was held in 2004. A renewed national discussion would consolidate the advances with water recycling and aquifer storage and recovery that have been made in urban areas, and encourage investors and governments to initiate pilot studies and further experiments in broadscale conjunctive water use.

References

Agrawal, A., 2008. The role of local institutions in adaptation to climate change. In: Paper prepared for the Social Dimensions of Climate Change, Social Development Department. World Bank, Washington.

AGT, Hamstead, M., Baldwin, C., 2011. Feasibility of Managed Aquifer Recharge for Agriculture. Canberra: Waterlines Report No. 45.

Alley, W.M., 2016. Drought-proofing groundwater. Groundwater 54 (3), 309.

Australian Bureau of Statistics, 2015. Water Account, Australia, 2013–14: Explanatory Notes. Canberra. <http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/4610.0Explanatory%20Notes12013-14?OpenDocument> (accessed 30 October 2016).

Ballotpedia, 2016. California Proposition 1, Water Bond. <https://ballotpedia.org/California_Proposition_1,_Water_Bond_(2014)>.

Blomquist, W. et al., 2004. Common Waters Diverging Streams. Resources for the Future, Washington.

Bowmer, K.H., 2003. Learning from existing practice. Reflections on developing a water sharing plan. In: Wilson, B.P., Curtis, A. (Eds.), Agriculture for the Australian Environment. Proceedings of the 2002 Fenner Conference. Johnstone Centre, Charles Sturt University, Albury, pp. 201–222.

Brodie, R. et al., 2007. An Adaptive Management Framework for Connected Groundwater-Surface Water Resources in Australia. Bureau of Rural Sciences, Canberra.

Brown, R. et al., 2013. Actors working the institutions in sustainability transitions: the case of Melbourne's stormwater management. Global Environ. Change 23 (4), 701–718.

Bruns, B., Ringler, C., Meinzem-Dick, R. (Eds.), 2005. Water Rights Reform: Lessons for Institutional Design. International Food Policy Research Institute, Washington, DC.

California Department of Water Resources (CDWR), 2014. California Water Plan: Update 2013, Volume 3 <http://www.waterplan.water.ca.gov/cwpu2013/final/> (accessed 20 May 2016).

California Department of Water Resources (CDWR), 2015. Groundwater Update 2013 <http://www.waterplan.water.ca.gov/docs/groundwater/update2013/content/statewide/GWU2013_Ch_2_Statewide_Final.Pdf> (accessed 20 May 2016).

California Department of Water Resources (CDWR), 2016. Integrated Regional Water Management Plans <http://www.water.ca.gov/irwm/> (accessed 20 May 2016).

Connell, D. et al., 2007. Delivering the national water initiative: institutional roles, responsibilities and capacities. In: Hussey, K., Dovers, S. (Eds.), Managing Water for Australia: The Social and Institutional Challenges. CSIRO, Canberra.

Council of Australian Governments, 2004. Intergovernmental Agreement on the National Water Initiative. Canberra.

Council of Australian Governments, 2010. The National Framework for Nonurban Water Metering. <http://www.idc-online.com/technical_references/pdfs/civil_engineering/The_National_Framework_for_Non_urban_water_metering.pdf> (accessed 31 January 2017).

Dillon, P., et al., 2012. Management of Aquifer Recharge and Discharge Processes and Aquifer Storage Equilibrium. Thematic Paper Number 4: Global Groundwater Governance Project. <http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/Thematic_papers/GWG_Thematic_Paper_4.pdf>.

Dillon, P., et al., 2009. Managed Aquifer Recharge: an Introduction. In: Waterlines Report Series No. 13. National Water Commission, Canberra.
Drewes, J.E., 2009. Ground water replenishment with recycled water: water quality improvements during managed aquifer recharge. Groundwater 47 (4), 502–505.
Emerson, K. et al., 2012. An integrative framework for collaborative governance. Publ. Admin. Res. Theory 22 (1), 1–29.
Evans, R., 2007. The Impact of Groundwater Use on Australia's Rivers. Land and Water Australia, Canberra.
Evans, W.R., and Evans, R., 2012. Conjunctive Use and Management of Groundwater and Surface Water. Thematic Paper 2: Global Groundwater Governance Project. <http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/Thematic_papers/GWG_Thematic_Paper_2_01.pdf>.
Falkenmark, M., Rockstrom, J., 2006. The new blue and green water paradigm: breaking new ground for water resources planning and management. J. Water Resour. Plan. Manage. 132 (3), 129–132.
Farrelly, M., Brown, R., 2011. Rethinking urban water management: experimentation as a way forward? Global Environ. Change 21 (2), 721–732.
Foster, S., Van Steenbergen, F., 2011. Conjunctive groundwater use: a lost opportunity for water management in the developing world? Hydrogeol. J. 19 (5), 959–962.
Fullagar, I., 2004. Rivers and Aquifers: Towards Conjunctive Water Management. Workshop Proceedings, Adelaide 6–7 May.
Gardner, A., Bartlett, R., Gray, J., 2009. Water Resources Law. Chatswood NSW, Lexis Nexus.
Gleeson, T. et al., 2012. Water balance of global aquifers revealed by groundwater footprint. Nature 488 (7410), 197–200.
Groundwater Governance Global Framework for Action (GGGFA), 2015a. Global Diagnostic on Groundwater Governance. <http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/GWG_DIAGNOSTIC.pdf>.
Groundwater Governance Global Framework for Action (GGGFA), 2015b. Global Framework for Action. <http://www.groundwatergovernance.org/fileadmin/user_upload/groundwatergovernance/docs/GWG_FRAMEWORK_FR.pdf>.
Government of South Australia, 2009. Water for Good <http://www.environment.sa.gov.au/about-us/our-plans> (accessed 28 May 2016).
Grafton, R. et al., 2016. On the marketisation of water: evidence from the Murray-Darling Basin, Australia. Water Resour. Manage. 30.3 (2016), 913–926.
Gross, C., 2011. Why justice is important. In: Basin Futures. ANU Press, Canberra, pp. 149–162.
Halstead, P., O'Shea, J., 1989. Bad Year Economics: Cultural Responses to Risk and Uncertainty. Cambridge University Press, Cambridge.
Hughes, N., 2013. The Water Storage Problem. Global Water Forum. <http://www.globalwaterforum.org/2013/12/09/the-water-storage-problem/>.
Huitema, D., Meijerink, S., 2010. Policy entrepreneurs and change strategies: lessons from 16 case studies of water transitions around the globe. Ecol. Soc. 15 (2).
Huntjens, P. et al., 2010. Climate change and European river basins. Regional Environ. Change 10 (4), 263–284.
Hurlimann, A., Dolnicar, S., 2016. Public acceptance and perceptions of alternative water sources: a comparative study in nine locations. Int. J. Water Resour. Develop. February:1–24.
Kelly, B. et al., 2007. Groundwater Knowledge and Gaps in the Namoi Catchment Management Area. National Centre for Groundwater Management, University of Technology, Sydney.
Letcher, R.A., Croke, B.F., Jakeman, A.J., 2007. Integrated assessment modelling for water resource allocation and management: a generalised conceptual framework. Environ. Modell. Software 22 (5), 733–742.
Loorbach, D., 2007. Transition Management: a New Mode of Governance for Sustainable Development.
Loorbach, D., Rotmans, J., 2010. The practice of transition management: examples and lessons from ford distinct cases. Futures 3, 237–246.
Lucy, J., 2008. Water Regulation: The Laws of Australia. Thomson Reuters Australia Ltd., Sydney.
Megdal, S. et al., 2014. Water banks: using managed aquifer recharge to meet water policy objectives. Water 6, 1500–1514.
Moench, M., 2004. Groundwater: the challenge of monitoring and management. In: Gleick, P. (Ed.), The World's Water; the Biennial Report on the World's Water Resources 2004–05. Island Press, Washington.
National Water Commission, 2011. The National Water Initiative – Securing Australia's water future: 2011 assessment. Canberra. <http://webarchive.nla.gov.au/gov/20160615060553/http://www.nwc.gov.au/publications/topic/assessments/ba-2011>.
National Water Commission, 2014a. Fourth Assessment of the 2004 National Water Initiative. Canberra. <http://webarchive.nla.gov.au/gov/20160615062247/http://www.nwc.gov.au/publications/topic/assessments/australias-water-blueprint-national-reform-assessment-2014>.
National Water Commission, 2014b. Integrating Groundwater and Surface Water Management in Australia. Canberra. <http://webarchive.nla.gov.au/gov/20160615062939/http://www.nwc.gov.au/publications/topic/sustainability-and-groundwater/integrating-groundwater-and-surface-water-management-in-australia>.
Ostrom, E., 2005. Understanding Institutional Diversity. Princeton University Press, Princeton.
Pahl-Wostl, C., 2007. Requirements for adaptive water management. In: Pahl-Wostl, C., Kabat, P., Moltgen, J. (Eds.), Adaptive and Integrated Water Management: Coping with Complexity and Uncertainty. Springer, Berlin.
Pierce, S.A. et al., 2013. Aquifer-yields continue as a guide and typology for science-based groundwater management. Hydrogeol. J. 21, 331–340.
Rassam, D. et al., 2008. Recommendations for Modelling Surface-Groundwater Interactions Based on Lessons Learnt from the Murray-Darling Basin Sustainable Yield Project. CSIRO, Canberra.
Rawluk, A. et al., 2013. Managed aquifer recharge in farming landscapes using large floods: an opportunity to improve outcomes for the Murray-Darling Basin? Australas. J. Environ. Manage. 20 (1), 34–48.
Richardson, S. et al., 2011. Connecting science and engagement: setting groundwater extraction limits using a stakeholder-led decision-making process. In: Basin Futures. ANU Press, Canberra. 2014.
Ross, A., 2012. Easy to say, hard to do: integrated surface water and groundwater management in the Murray-Darling Basin. Water Policy 14 (4), 709–724.
Ross, A., Dovers, S., 2008. Making the harder yards: environmental policy integration in Australia. Aust. J. Publ. Admin. 67 (3), 245–260.
Ross, A., Martinez-Santos, P., 2010. The challenge of groundwater governance: case studies from Australia and Spain. Regional Environ. Change 10 (3), 299–310.
Sabatier, P. et al., 2005. Swimming Upstream: Collaborative Approaches to Watershed Management. MIT Press, Cambridge, Massachusetts.
Scanlan, B. et al., 2016. Enhancing drought resilience with conjunctive use and aquifer recharge in California and Arizona. Environ. Res. Lett. 11, 1–11.
Schlager, E., Ostrom, E., 1992. Property rights regimes and natural resources: a conceptual analysis. Land Econ. 62 (3), 249–262.
Schlager, E., 2007. Community management of groundwater. In: Giordano, M., Villholth, K. (Eds.), The Agricultural Groundwater Revolution: Opportunities and Threats to Development. CABI Publishing, Wallingford.
Sinclair Knight Merz (SKM), 2011. National Framework for Integrated Management of Connected Groundwater and Surface Water Systems. In: Waterlines Report No. 57. Canberra.
SKM, 2006. Towards A National Framework for Managing the Impact of Groundwater and Surface Water Interaction in Australia. Report to the Department of Agriculture, Fisheries and Forestry.
Sophocleous, M., 2002. Interactions between Surface Water and Groundwater: the State of the Science. Hydrogeol. J. 10, 52–67.
Sugg, Z. et al., 2016. Conjunctive groundwater management as a response to sir sue-ecological disturbances: a comparison of 4 Western US States. Texas Water J. 7 (1), 1–24.
Tan, P.L., Bowmer, K.H., Mackenzie, J., 2012. Deliberative tools for meeting the challenges of water planning in Australia. J. Hydrol 474, 2–10.
Taylor, R.G. et al., 2013. Groundwater and climate change. Nat. Clim. Change 3 (4), 322–329.
Turral, H., Fullagar, I. (Eds.), 2007. Institutional Dimensions in Groundwater Development in Australia. CABI Publishing, Wallingford.
United Nations, 2015. The Millennium Development Goals Report 2015. <http://www.undp.org/content/dam/undp/library/MDG/english/UNDP_MDG_Report_2015.pdf>.
Van de Brugge, R., Van Raak, R., 2007. Facing the adaptive management challenge: insights from transition management. Ecol. Soc. 12 (2), p33.
Western Australia Water Corporation, 2009. Water Forever: Towards Climate Resilience: Summary. Perth. <https://www.watercorporation.com.au/-/media/files/about-us/planning-for-the-future/water-forever-50-year-plan-summary.pdf>.
Winter, T.C., et al., 1998. Groundwater and Surface Water – A Single Resource. US Geological Survey Circular 1139.
World Bank, 2006. Conjunctive Use of Groundwater and Surface Water. World Bank, Washington. <http://siteresources.worldbank.org/INTARD/Resources/Notes_Issue6_web.pdf>.
Wurbs, R., Ayala, R., 2014. Reservoir evaporation in Texas, USA. J. Hydrol. 510, 1–9.