Australian Government
National Water Commission

Integrating groundwater and surface water management in Australia

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Overview

Many parts of Australia are experiencing water resource pressures associated with growing population, expanding development and the effects of climate change. These pressures increase competition between social, environmental and economic uses of water and often force difficult trade-off decisions.

To ensure the needs of all water users including ecosystems are met in highly developed systems, available water resources – both groundwater and surface water – need to be used in an efficient, sustainable and coordinated way. Coordinated groundwater and surface water management is not a new concept yet implementation within Australia remains limited.

Trade-off decisions can be costly as well as socially divisive, and are already being required in systems that are at or approaching full allocation. It is in these systems in particular that integrating groundwater and surface water use and management in the next generation of water planning offers a means by which to use the overall water system more efficiently. In addition, development potential and future water security benefits (or avoidance of future re-adjustment impacts) may be possible in areas with suitable hydrological settings experiencing a low level of development at present.

In the past, water management arrangements typically treated surface water and groundwater as separate resources. In this paper, 'connection' between groundwater and surface water resources is not only limited to natural hydraulic connections (often known as 'connectivity') but also includes connections that are:

- artificially induced – e.g. managed aquifer recharge (MAR) schemes
- non-physical connections such as water use switching – e.g. areas in which groundwater and surface water can both be used
- management linkages between resources – e.g. integrated planning.

By understanding the nature of connection as well as the range of options to induce connection (natural, engineered or a 'management connection'), it is possible to design management regimes that take advantage of unique local situations. Such an approach can offer greater flexibility to achieve multiple water management objectives and in many cases satisfy multiple interests concurrently, thus avoiding or minimising the impact of trade-off decisions when allocating limited resources – something that may not be realised if only one part of the resource is considered and managed in isolation.

The objectives able to be achieved through integrating groundwater and surface water management are not unique to connected systems and apply across all facets of water management. For the purpose of this paper, they can be generalised into the following interrelated categories:

- improving security and reliability of supply
- managing third-party impacts
- maintaining water quality to acceptable levels
- improving water system efficiency and resource conservation
- storing and delivering water where and when it is needed.

Purpose of this paper

This discussion paper highlights the potential contribution that integrated groundwater and surface water use and management arrangements may make to optimise the economic, social and environmental outcomes of Australia's water resources.

Since the National Water Initiative (NWI) was signed in 2004 there has been substantial progress towards recognising and understanding connected systems and numerous examples of innovative and leading practice can be found. On an individual or farm scale, users are now able to optimise the groundwater and surface water resources within their control in areas where unbundling of land from water has allowed trade, and there is a growing awareness that optimisation on a whole-of-system scale offers broader benefits[1].

This paper identifies the water management objectives that integrating groundwater and surface water management may help achieve, and its findings provide practical first steps for governments to start realising the benefits of integrated management.

Overview of findings

It is important that potential opportunities for integrating groundwater and surface water management are not limited to physically connected systems in which cross-impacts are predicted or observed, or to systems where trade-off decisions need to be minimised. Systems with no hydraulic connection should also be included in the consideration of potential opportunities, as integrating groundwater and surface water use and management arrangements in these systems may also contribute to optimising the economic, social and environmental outcomes of managing Australia's water resources.

Finding 1 is the first practical step towards ensuring that current arrangements consistent with the NWI make the most of the potential benefits of a more integrated approach to water management:

> *The benefits of integrated groundwater and surface water management are more likely to be realised if systematic identification and consideration of the opportunities is undertaken by governments. This may be embedded in initial water planning or water plan review processes, reviews of entitlement arrangements, changes to water markets or when changing institutional arrangements.*
>
> *Where groundwater and surface water planning is currently separate, aligning review cycles and timeframes for surface water and groundwater planning may represent a no- or low-cost start, by allowing simultaneous consideration of opportunities and cross-impacts.*

[1] For example, the World Bank (Shah et al. 2006) described a similar situation in developing countries: 'Each day, hundreds of thousands of farmers in canal, tank, and other surface irrigation systems combine surface water with groundwater. They do so in an individual manner, uncontrolled by any scheme or basin-level entity. Conjunctive management, by contrast, refers to efforts planned at the scheme and basin levels to optimize productivity, equity, and environmental sustainability by simultaneously managing surface and groundwater resources. In many systems and basins, such planning is needed to raise crop water productivity.'

To take full advantage of potential opportunities, such consideration should not necessarily be limited by existing entitlement types, current water market arrangements or institutional arrangements.

Finding 2 aims to support the assessment of identified potential opportunities:

> *There are no agreed principles for quantifying the full costs and benefits of integrating groundwater and surface water management, including non-economic costs and benefits for a range of stakeholders, including the timeframes over which costs and benefits are considered, that are capable of capturing the wider impacts and benefits that may be beyond the scope of individual organisations.*
>
> *Such principles would benefit from joint consideration, agreement and adoption by all Australian governments.*

Introduction

In the past, water management arrangements typically treated surface water and groundwater as separate resources and assigned rights to take and use water accordingly (e.g. by a riparian rights system, or by defining a right to take water from a specific water source for a specific purpose). Such arrangements were a practical and administratively simple means by which to share water but could not deliver the potential broader benefits of an integrated approach. As systems approach full allocation and water becomes increasingly scarce, new demands will cause a reduction in availability to other users, including the environment. Integrated use and management of groundwater and surface water resources offers greater flexibility to manage the impacts of use, provide security of supply and in many cases satisfy multiple interests concurrently. Note that this combined use and management of groundwater and surface water cannot make 'new' water. Rather, integrated management can increase water availability by improving efficiency or providing ways to access otherwise under-utilised resources.

This discussion paper highlights the potential contribution that integrated groundwater and surface water use and management arrangements may make to optimise the economic, social and environmental outcomes of managing Australia's water resources. This paper applies to any situation where groundwater and surface water can be used or managed together, regardless of direct hydraulic connectivity[2]. To understand the range of possible ways in which all water resources may be used or managed together, it is necessary to understand the complementary properties of groundwater and surface water, and to design water management arrangements that take advantage of the whole water cycle.

Properties of groundwater and surface water

Groundwater and surface water have distinct and complementary properties that strengthen the case for integrated water management, even when the resources are not physically connected. In this paper, 'connection' between groundwater and surface water resources is not only limited to natural hydraulic connections (often known as 'connectivity') but also includes connections that are:

- artificially induced – e.g. managed aquifer recharge (MAR) schemes
- non-physical connections such as water use switching – e.g. areas in which groundwater and surface water can both be used
- management linkages between resources – e.g. integrated planning.

Using the connections between groundwater and surface water resources (either natural, engineered or management-based), it is possible to manage water in ways that take advantage of the complementary properties.

[2] Thompson (2011) described a wider integrated management approach that is not limited by hydraulic connectivity: 'Making [hydraulic] connections … is only the first step. To maximize the societal benefits of … limited water resources, states must also provide for the integrated, dynamic, and adaptive management and use of each constituent element of the overall hydrologic system – or what I will call "multidimensional conjunctive management".'

Table 1: Properties of groundwater and surface water resources and use

Property	Surface water	Groundwater
Visibility	Highly visible	Invisible (subsurface)
Mobility	Moves quickly	Generally moves slowly
Variability	Often temporally variable	Often temporally stable
Storage	Expensive to store	Cheap to store (natural storage)
Quality	Generally good quality	Variable quality, often saline at depth
Location	Concentrated, linear, predictable flow	Diffuse, sometimes counter-intuitive 'flow'
Use impacts	Rapid, short term, downstream	Variable: often slow, long term, diffuse

The relatively slow and stable nature of many groundwater resources provides an opportunity to store short-lived surface water flows for later use (known as 'water banking' in some circumstances). The subsurface nature of groundwater storage could be used to avoid sacrificing otherwise productive land area for reservoirs at the surface, or to store public water supply below the urban areas it supports.

Physical connectivity between groundwater and surface water resources can take a variety of forms. There may be a natural connection such as gaining or losing river reaches, infiltration of rainfall (diffuse dryland recharge) or discharge through springs, seeps, diffuse upward leakage or phreatophytic plants. Connection can also be engineered by installing injection wells into partially saturated aquifer units or building infiltration basins – both examples of MAR. Connection can be more passively induced or enhanced by building levees to retain floodwaters in known groundwater recharge areas, or installing 'leaky' canal systems that divert river water to groundwater systems. Land-management practices that affect water at the land surface can also affect groundwater (e.g. changes to groundwater recharge associated with land clearing, forestry or urbanisation).

Where groundwater resources underlie surface water resources but are not hydraulically connected, the two resources may still be used and managed together on the basis of their complementary properties (e.g. using artesian groundwater during times of drought and allowing pressure recovery by ceasing groundwater take when surface water is available). Hence the use of conjunctive management principles should not be restricted to hydraulically connected systems.

By understanding the nature of connections, as well as the range of options to induce connection (natural, engineered or management-based), it may be possible to design management regimes that take advantage of unique local situations. Such an approach might also provide benefits that may not be realised if only one part of the resource is considered in isolation.

Various planning and management approaches: hydraulically connected systems as a single resource

Coastal macroplans, New South Wales

At present a range of approaches is being used to manage connected groundwater and surface water resources: the following looks at plans that manage connected systems as a single resource in NSW.

The Clyde, Deua and Tuross rivers each have draft water sharing plans (WSPs) on public display and implementation is expected in 2014. The overview of WSPs for unregulated and alluvial water sources in coastal NSW states that 'in many catchments, alluvial aquifers are "highly connected" with adjacent streams – that is, water readily flows from the aquifers to the streams and vice versa. Extraction of water from a highly connected alluvial aquifer will encourage water to move from the stream to the aquifer, and the hydrologic impact on the stream will be as if water had been extracted directly from the stream. To reflect this connectivity, highly connected alluvial aquifers have been included in unregulated water sharing plans'.

In the plans, no distinction is made between entitlements for alluvial groundwater and river water, which are subject to the same consumptive pool so that little risk of 'double allocation' of water resources occurs. However, deeper groundwater resources that are not 'highly connected' alluvial sources are subject to a separate groundwater-only water plan, with little cross-linking between them. As such, the NSW coastal macroplans are fully integrated with respect to alluvial groundwater.

Not all plans in NSW are integrated to this extent; by contrast, the WSP for the Macquarie and Cudgegong Regulated Rivers Water Source states that the plan 'does not include water contained within aquifer water sources underlying the water source, or to land adjacent to this water source'. This is an example of a separate surface water plan without direct operational cross-references to groundwater resources.

Sources: NSW Department of Primary Industries, Office of Water website: http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-on-exhibition/Draft-water-sharing-plans or, after commencement:

http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-commenced/plans_commenced/default.aspx

and http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-commenced/Water-source/Macquarie-and-Cudgegong-Regulated-Rivers/

(accessed 21 February 2014)

Various planning and management approaches: managing cross-impacts of use

Katherine / Tindall aquifer, Northern Territory

At present, a range of approaches is being used to manage connected groundwater and surface water resources: this case study looks at a plan that clearly recognises and takes account of the connection between groundwater and river baseflow in NT.

The guide to the Katherine / Tindall Water Allocation Plan (WAP) states:

'Water is often considered plentiful and reliable in the Top End, although in actual fact, 90 per cent of annual rainfall falls over the "wet season" while the remainder of the year is very dry. Perennial rivers in the Northern Territory are exclusively fed by groundwater in the dry season and recharge to these groundwater systems can change each year based on rainfall. The WAP recognises the volume of recharge to the Tindall limestone aquifer will vary from year to year and contains provisions to manage discharge to the Katherine River from this water source accordingly.

Most of the flow in the Katherine River that occurs late in the dry season originates from Tindall aquifer discharge and as such is also referred to within the WAP.

Two water management zones have been established within the WAP area to manage the impacts of extraction near to the Katherine River. Extraction from the Tindall aquifer within Zone 1 can impact on the Katherine River within a short period of time. The potential for extraction in Zone 1 to noticeably reduce flows in the Katherine River is minimised through conditions on water trading, bore construction and licensing within that Zone.'

While the plan only covers one aquifer and does not control surface water resources, linking groundwater and surface water management via rules in the plan was essential to achieve several public benefit outcomes, given in the guide to the plan as:

'Water from the Tindall aquifer provides many social and economic benefits to the Katherine region because it provides for agricultural and industrial development and subsequently employment and growth. There are also significant ecological and cultural values associated with the Katherine and Daly rivers, which flow all year round because of the water discharged from the Tindall aquifer in the dry season. The public benefits described in this part of the plan are:

- environmental and cultural
- public water supply
- rural stock and domestic and other small volume groundwater uses
- agriculture, horticulture and industry
- economic growth.

Source: NT Department of Land Resource Management
website: http://www.lrm.nt.gov.au/water/water_allocation/plans/kwap (accessed 21 February 2014)

Various approaches: engineering a connection to optimise water access (small-scale managed aquifer recharge)

Angas Bremer, South Australia

The Angas Bremer region is an important wine district in SA. Extraction of groundwater in the years before 1980 – up to about 20 gigalitres (GL) per year – caused regional drawdown and an increase in salinity. Irrigators began experimenting with diverting flows from the Angas and Bremer rivers into irrigation bores. In 1987 a purpose-designed injection and recovery well was drilled. Peak managed aquifer recharge (MAR) activity occurred in 1992 when 2.4 GL was injected into about 30 wells. Water pressures rose to levels not seen since the 1950s. After 1990, water management policy gave incentives to exchange groundwater allocations for River Murray surface water, regional groundwater extraction fell by about 80 per cent and MAR played a less significant role. The millennium drought caused a rapid deterioration in lake water availability and quality (to salinity levels exceeding 3000 mg/L) and renewed interest in MAR.

MAR is permitted for about 30 wells in the region. In 2006–07 up to 0.5 GL was stored in a particular well, and the total regional injection was about 2.4 GL. MAR activity in the Angas Bremer region is managed through a water allocation plan and statutory approvals. Under the plan, 100 per cent of water recharged can be allocated, with annual extraction of recharged water capped at 7.5 GL. Licence conditions applying to MAR typically include:

- monitoring of groundwater and surface source water for salinity
- controls on the quality of source water
- draining and recovery metering
- allowance for carryover of unused recharge entitlements (for up to five years)
- limitations on the distance between extraction and injection locations (point of extraction may be no more than 500 m from point of injection).

One of the key factors in the success of water management in the region, including MAR, has been the partnership of local irrigators and state agencies in the development of policy.

Note that other systems exist in SA, also related to the wine industry. See Waterlines report no. 45, *Feasibility of managed aquifer recharge for agriculture* for further information on the Barossa.

Source: Ross, A 2013, Report to the National Water Commission.

Objectives and benefits of integrating groundwater and surface water

The objectives able to be achieved through integrating groundwater and surface water management are not unique to connected systems and apply across all facets of water management. For the purpose of this paper, they can be generalised into the following interrelated categories:

- improving security and reliability of supply
- maintaining water quality to acceptable levels
- managing third-party impacts
- improving water system efficiency and resource conservation
- storing and delivering water where and when it is needed.

These categories are non-prescriptive and can be reinterpreted as required. However the general principles can be applied widely and translated to the needs of individual jurisdictions, water systems or management areas in rural or urban settings. The objectives may be interrelated and overlapping.

Improving security and reliability of supply

Objectives related to security and reliability can include:

- maintaining water availability over a wide range of climate and other scenarios
- switching supply to manage availability, taking account of cross-impacts of surface water and groundwater use that can mutually affect the security or reliability of the other, or
- increasing overall availability (e.g. artificially increasing recharge – including water banking – to allow increased groundwater use in dry times).

Maintaining water quality to acceptable levels

Objectives related to maintaining water quality can include switching sources in response to water quality indicators, mixing water sources to achieve water quality targets, combining treatment and enhanced recharge to provide water at a specified quality, using groundwater systems to stabilise water quality and leach or dilute pollutants, or using MAR for seawater intrusion control or to freshen up saline-affected aquifers.

Managing third-party impacts

Third-party impacts of water use have the potential to undermine the security of supply, the reliability of the resource and water quality for other water users including the environment. Impacts of use can occur in both directions: groundwater use can affect surface water resources (especially streamflow), and surface water diversions can affect groundwater resources (especially recharge). Successful third-party impact management requires an integrated approach to account for the cross-impacts of water use. If impacts cannot be avoided, it can also contribute to achieving other objectives by:

- transferring (or sharing) impacts from one system to another

- deferring impacts through time or distributing them over a wider area (‘diluting’ impacts).

In general, the impacts of groundwater pumping on streamflow have been recognised significantly more widely than the impacts of surface water take on groundwater systems, so there remains a great opportunity for integrated management to make further progress against this objective.

Improving water system efficiency and resource conservation

Objectives related to improving water system efficiency and resource conservation can include reducing losses (e.g. storage and delivery losses, see below), improving transport and delivery energy efficiency by using underground flow paths, using plentiful resources in preference to (or to ‘top up’) scarce resources (e.g. harvesting and injecting or infiltrating a proportion of peak flood volumes for later use in dry times), or encouraging the use of unconventional resources such as water recycling (options that would otherwise not be available, or not receive community acceptance).

Storing and delivering water where and when it is available and needed

Objectives related to water storage and delivery include smoothing the cyclical differences between water availability and water demand. For example, the relatively slow nature of groundwater changes can be used to:

- opportunistically store dam overflows and floods
- smooth seasonal variation in irrigation water demand
- smooth daily or even diurnal variation in urban water demand.

Timing requirements may be accommodated by allowing dam releases to mimic natural flow regimes by re-timing releases, coupled to local aquifer storage near irrigation areas; that is, using aquifers as local reservoirs to on-supply water from large dams.

Storing water efficiently could also be achieved by underground storage, either in natural aquifers or engineered systems, to reduce the evaporative losses involved in surface water storage, In addition, land requirements would be reduced because the storage could spatially overlap with the productive or urban land it supported.

Achieving multiple objectives: cross-sectoral recycling

Werribee Irrigation District, Victoria

The Werribee Irrigation District is an important vegetable-growing area on the western fringe of metropolitan Melbourne. Using water from the Werribee River, the aquifer below and the recycled water scheme, more than 400 growers produce lettuces, broccoli, cabbages and many other vegetables for local consumption and export.

The Werribee Irrigation District benefits from one of the largest recycled water schemes in Australia. The scheme was designed to help overcome drought-related water shortages and to secure water for greater production in the future. Growers received the first deliveries of recycled water under the scheme in January 2005. Southern Rural Water delivers the recycled water (supplied by Melbourne Water) to participating growers through its existing irrigation channels and pipelines. The recycled water is treated through the standard wastewater treatment system and two additional disinfection systems – chlorination and ultraviolet light. The Department of Health has classified the Class A recycled water as safe for irrigation of food crops, including those eaten raw.

Melbourne Water is working to reduce the salinity of the recycled water, which at present needs to be mixed with water from the Werribee River. Water is also available from coastal aquifers, which supply only about 10 per cent of demand towards the end of summer when surface water availability is lower. This situation creates a risk of vulnerability to seawater intrusion (SWI) in the dry times at the end of the season, so more reliable, alternative surface water supply (i.e. recycled water) allows better management of the groundwater system to manage the risk of SWI.

The scheme also delivers an efficiency benefit: the recycled water used in this scheme would otherwise be discharged into Port Phillip Bay.

The scheme at least partially contributes to each of the major water management objectives identified in this paper. It increases security of supply by providing an additional constant-volume source, maintains water quality by mixing water from different sources, manages groundwater drawdown and SWI (which manifest as third-party impacts), conserves resources and improves efficiency by minimising waste outfall, and allows groundwater of a suitable quality to be available when it is needed most.

Source: Southern Rural Water website: http://www.srw.com.au/page/page.asp?page_id=323 (accessed 21 February 2014)

Unrealised opportunity: improving security while minimising losses

Potential for MAR near Broken Hill, New South Wales

At present Broken Hill's water supply relies on a 110 km pipeline from the Darling River at Menindee. Substantial volumes (about 300 GL) of water also need to be retained in the adjacent Menindee Lakes Storages (MLS) to secure the town's water requirements.

Changing the management of Menindee Lakes to provide enhanced water security for Broken Hill and reduce these evaporative losses is possible, but the city’s water supply would first need to become less reliant on the MLS. A feasibility assessment was undertaken in 2011 that compared a ‘groundwater extraction-only’ scheme with a conjunctive use scheme including MAR as a key component, which found an excellent aquifer (the Calivil Formation) with high storage capacity, very high transmissivities and significant volumes of fresh groundwater. The aquifer is sandwiched between variably thick clay aquitards, and over much of the target area can be characterised as varying from a confined to a ‘leaky confined’ system. These excellent hydraulic properties make the Calivil Formation aquifer potentially suitable for groundwater extraction and/or MAR injection, with good recovery efficiencies.

The feasibility study found that significant volumes of groundwater use (during drought conditions when recharge is negligible) would be unsustainable even over a 12-month period. A conjunctive use option would be feasible, however, and involve a significant MAR component. Under this option, Broken Hill and Menindee water would be supplied from existing surface water arrangements during non-drought times, with a MAR component providing water security during drought events. The Jimargil sub-area represents a premium MAR site that would provide more than 90 per cent recovery efficiencies, and could be developed into a strategic water storage to secure Broken Hill's potable water supply for three years during drought conditions. This option would provide a buffer against future climate variability and change, deliver significant water savings by reducing evaporative losses, improve source water quality over time, have minimal environmental impact, preserve some local water amenities for community use, and enable key elements of the engineered MLS to be returned to a more natural condition.

This scheme would see continuing but reduced storage of water at MLS, augmented by a more secure underground storage using suitable aquifers.

Sources: Lawrie et al. 2011, *Securing Broken Hill's water supply: assessment of groundwater extraction and conjunctive water supply options at Menindee Lakes*, Geoscience Australia Professional Opinion 2011/02.

Additional information: Commonwealth Department of the Environment website: http://www.environment.gov.au/topics/water/rural-water/sustainable-rural-water-use-and-infrastructure/menindee-lakes (accessed 21 February 2014)

Achieving multiple objectives: improving water system efficiency, reliability and sustainability

Ophthalmia Dam, Newman, Western Australia

Newman's connection with the mining industry has meant that its water supply system has developed as part of the mining activities. The town water supply is drawn from several bores drilled into in-filled paleovalleys north-east and west of the town. BHP Billiton operates the bores and treats the water, while the Water Corporation operates the reticulated supply scheme and is the licensed water service provider.

Groundwater levels had been falling as a result of unsustainable draw from the aquifer. Ophthalmia Dam was constructed in 1981 to increase recharge, mostly by leakage from stream beds during runoff and to a lesser extent by direct infiltration of rain over the surface. The potable water supply bores are drawing from a superficial aquifer system – so water quality and quantity is heavily influenced by the quality and quantity of surface water. Groundwater flow direction generally mimics the direction of surface water flows.

An aquifer recharge system was also constructed below Ophthalmia Dam and comprises four excavated recharge ponds, two river basins and an open-earth canal, which can be flooded as required from Ophthalmia Dam. If monitoring data indicate that groundwater abstraction from the Ophthalmia borefield is approaching or is projected to exceed the aquifer's sustainable yield, then the aquifer recharge scheme can be brought into action.

Water levels in the Ophthalmia borefield have shown long-term stability in groundwater storage in the aquifer since the dam's construction, and the artificial recharge system has not yet been needed. The current integrated supply scheme is predicted to be able to meet the anticipated future increase in Newman's potable and non-potable water requirements. The scheme has successfully addressed unsustainable groundwater take, secured supply for both the town and the mine, and provides an attractive surface water amenity to an isolated arid-zone community.

Source: WA Department of Water 2009, *Newman Water Reserve drinking water source protection plan*, Water resource protection series, report no. 97. http://www.water.wa.gov.au/PublicationStore/first/86586.pdf (accessed 21 February 2014)

Further information: *Australia's water resources: from use to management*, 2006, Ed. JJ Pigram, CSIRO Publishing, Australia (Chapter 6)

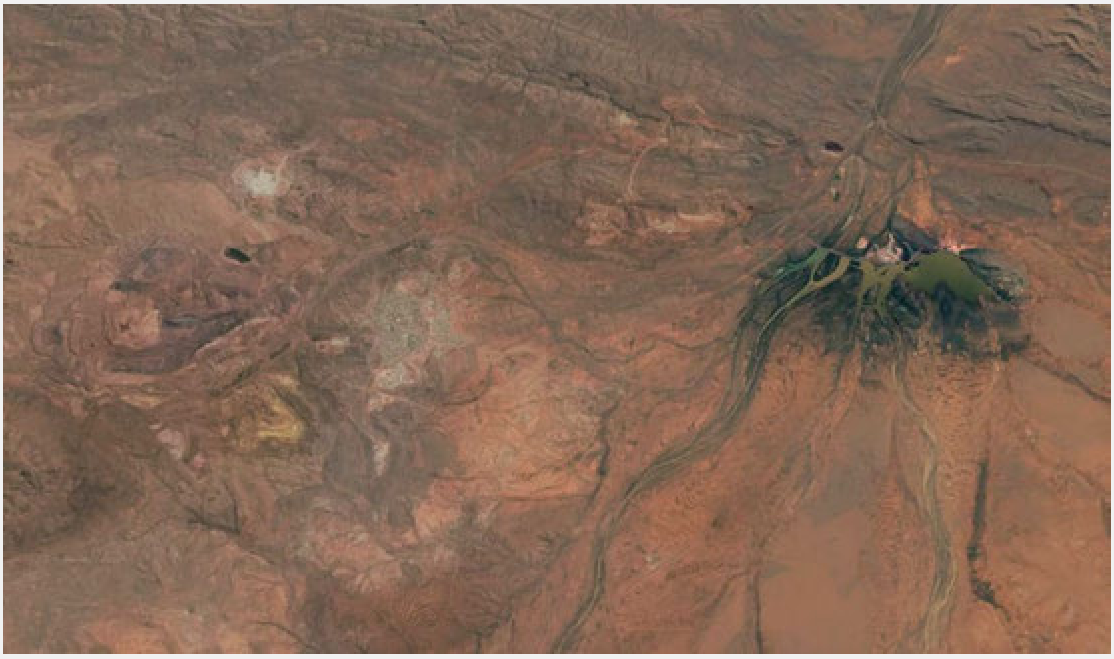

Figure 1: Arial view showing the close proximity of Ophthalmia Dam (right), Newman town site (centre) and Mt Whaleback mine (left of town). Image source: Google Earth Pro 7.1. 2013. TerraMetrics, map data layer. http://www.google.com/earth/index.html (accessed 26 February 2014).

Achieving multiple objectives: improving water quality (SWI control) and reliability

Lower Burdekin region, Queensland

The Lower Burdekin region occupies a low-lying coastal delta plain with a tropical climate. Its geology comprises extensive alluvial deposits extending to depths of 80 to 100 m. These deposits form an unconfined aquifer that is hydraulically connected to the ocean.

MAR operations in the Lower Burdekin region aim to prevent saltwater intrusion into the alluvial aquifer and to provide reliable groundwater for irrigated agriculture. Major features of the MAR operations include temporary riverbed sand dams constructed in the Burdekin River during the wet season and permanent pumping stations along the river banks for the diversion of river water to distribution channels, natural waterways and large recharge pits. As the temporary sand dams are prone to erosion during the high flows of the wet season, they are rebuilt annually and maintained as needed.

The Lower Burdekin MAR schemes have been successful at preventing saltwater intrusion into the unconfined alluvial aquifer at the mouth of the Burdekin River, while also providing greater security of supply for agricultural and municipal water users. Local geological conditions permit the schemes to use proven, cost-effective methods to recharge the permeable, unconfined aquifer, while the reliability of river flows used by the schemes is bolstered by the presence of the Burdekin Falls Dam.

Water demand exceeds water available for recharge for about two months during summer. Recharging lagoons, channels and pits during non-peak periods has ensured that users’ needs are mostly met during this peak demand period. This approach also prevents the fresh/saline interface intruding inland during peak irrigation periods.

Under the current operations, irrigators may source their water from groundwater and surface water, which is distributed throughout the region in open channels. Local water boards administer the MAR scheme and surface water diversions, but management of groundwater extractions is a state government responsibility, even in areas that are directly recharged by the MAR scheme.

Source: GHD & AGT 2011, *Feasibility of managed aquifer recharge for agriculture*, National Water Commission, Canberra, Waterlines report no. 45.

Integrated management and the National Water Initiative

The NWI established a comprehensive system of water resource planning and allocation in which the over-arching objective centres on 'a nationally-compatible, market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes' (Paragraph 23).

Paragraph 23 (x) further states that the connectivity between groundwater and surface water should be recognised and that connected systems should be managed together. Since the NWI was signed in 2004, all Australian jurisdictions have made substantial progress towards recognising physically connected systems that display groundwater and surface water connectivity, but physical connectivity is just one type of connection. This discussion paper applies to any situation in which groundwater and surface water can be considered as connected through natural connectivity, engineered connections or use and management connections.

Groundwater and surface water resources are often physically connected, but the extent and timing of connectivity can vary from system to system. Some systems can be classed as 'highly connected' resources (e.g. river water and adjacent alluvial groundwater) in which groundwater and surface water display a 1:1 'exchange rate' within the same season, whereas other systems may display slower or more limited mutual impacts (e.g. groundwater pumping could reduce streamflow by a proportion of the pumped volume over a multi-year timeframe[3]), or very little observable connectivity in the case of 'fossil' groundwater resources. Groundwater and surface water connectivity can be considered as a continuum from 'highly connected' to 'non-connected', with a great range of possible scenarios in between, depending on the specific hydrogeological setting as well as the spatial scale and timeframe being considered.

Designated categories such as 'highly connected' or 'moderately connected' found in previous resources on this topic should not be used exclusively to determine how a resource is managed. Regardless of the level of connectivity (i.e. where a system is on the continuum), there may be opportunities for integrating groundwater and surface water management that will be specific to that area. Different treatment of different systems should come from considering the situation and the opportunities, benefits and costs of integration, as well as from the level of connectivity – but not from the level of connectivity alone.

Paragraph 23 (x) reflected the most immediate impacts that were being observed when the NWI was signed in 2004: 'recognition of the connectivity between surface and groundwater resources and connected systems managed as a single resource'. Systems that display high physical connectivity tend to display the impacts of 'double accounting' and resultant over use more quickly than many other groundwater systems, so integrated groundwater and surface water management in Australia has typically focused on systems that display rapid connections and high use impacts, especially impacts of groundwater pumping on streamflows.

[3] See SKM 2011, *National Framework for Integrated Management of Connected Groundwater and Surface Water Systems*, National Water Commission, Canberra, Waterlines report no. 57 for a more complete categorisation of connection types.

More recently, further understanding of the possible cross-impacts of water resource use and of the time lags between use and the resulting impacts has expanded the range of situations in which integrated management may be considered to be desirable, and Paragraph 23 (x) is seen as a minimum commitment of signatories to the NWI. Managing surface water and groundwater together will often be necessary to optimise the hydrological cycle as a whole, and thereby optimise the economic, social and environmental outcomes of water resource use and achieve the intent of the NWI.

Capturing opportunities and tackling limitations

Systematic consideration of integration options

The first step towards more widely realising the potential benefits of integration is to achieve systematic consideration of integrated management arrangements that may be possible, and their associated costs and benefits. Each system will need to be considered individually, but ideally using a consistent set of considerations across all areas.

Despite the success of some current arrangements in which integrated groundwater and surface water management is achieving multiple benefits, examples remain relatively isolated and *ad hoc* in nature. The inherent complexity of managing connected systems has led to a lack of identification of opportunities in jurisdictions, and an even greater lack of rigorous assessment of costs and benefits of those opportunities. As understanding continues to develop, there is scope for more systematic consideration of opportunities within existing water planning and management processes in both the rural and urban sectors.

In the absence of barriers (e.g. a policy stance, institutional arrangements that cannot enable certain proposed schemes, or unintended disincentives such as losing ownership rights), where opportunities have been identified that can demonstrate benefit in simple terms, they have generally been implemented. However, the identification of opportunities and mechanisms to implement them is neither consistent nor straightforward.

The Commission encourages all governments with water planning and management responsibilities to focus on systematic consideration of the opportunities, benefits and options for further integration of surface water and groundwater resource management. This could be achieved through several means, including but not limited to:

- including all potential water systems and users within a designated area, irrespective of water quantity and quality (potentially also including partially saturated geological systems that could be developed into productive aquifers)
- considering alternative options for storage and delivery of water
- formally considering potential groundwater and surface water integration in water planning processes, including in review processes to account for changing circumstances, technologies and economics
- improving flexibility in water entitlement and allocation frameworks to allow for groundwater and surface water exchange or offset
- considering any opportunities or limitations that connected groundwater and surface water systems may present to the operation of water markets
- aligning objectives across the various institutions that are involved in groundwater and surface water use and management (see next section).

Regardless of the specific approach adopted and any possible increase in management flexibility that would be required, systematic consideration of integration options should still align with other NWI principles, such as conducting resource assessments as part of water planning and providing publicly accessible, transparent and consultative processes.

Finding 1

The benefits of integrated groundwater and surface water management are more likely to be realised if systematic identification and consideration of the opportunities is undertaken by governments. This may be embedded in initial water planning or water plan review processes, reviews of entitlement arrangements, changes to water markets or when changes to institutional arrangements are made.

Where groundwater and surface water planning is currently separate, aligning review cycles and timeframes for surface water and groundwater planning may represent a no- or low-cost start, by allowing simultaneous consideration of opportunities and cross-impacts.

Demonstrating the value proposition

While systematic consideration of opportunities should be embedded in high-level policy at a whole-of-jurisdiction level, the implementation of integrated groundwater and surface water use and management arrangements will always need to be tailored to specific hydrogeological contexts at the catchment, subcatchment or even local level, and each proposal will require consideration on its merits.

While it is not the role of government to direct water to specific uses at specific times to achieve a theoretically optimised output, it is important to develop frameworks and governance arrangements that can recognise the opportunities that a specific area may present and provide incentives to take advantage of them, as well as implementation flexibility to enable new initiatives. Water resource plans can be the primary instruments to achieve this, noting that they require supporting policy and legislative environments to enable them to do so.

Supportive high-level policy is an essential start, but each situation will present its own combination of opportunities and constraints. In each case, the new opportunities may promise benefits, and changing the *status quo* may involve costs. However, as with most aspects of water management, the costs and benefits are often not straightforward and involve complex and interrelated economic, social and ecological considerations and trade-offs.

Where there is a cost involved in change, there is a need to establish when the benefits outweigh the costs, and to act when they do. Here ‘cost’ and ‘benefit’ are not necessarily economic costs and benefits because the benefits are often multiple and non-economic in nature, hence being difficult to attribute directly. Costs can more often be directly attributed in economic terms, so there is a pressing need to develop a robust way of considering both costs and benefits when some of the costs and benefits are non-economic and can be distributed over a range of stakeholders and various timeframes. A lack of agreed approaches to determine the economic, non-economic and wider costs and benefits of integrating groundwater and surface water use and management, including the timeframes over which costs and benefits are considered, appears to be inhibiting reform in several areas.

Additionally, it may be helpful – despite the difficulty – to quantify and communicate any lost opportunities associated with non-optimised management arrangements, and to also consider the true cost of a ‘do nothing scenario’ as an ongoing loss rather than as a ‘zero baseline’, as is often assumed.

Achieving multiple objectives: satisfying multiple users and multiple values

Arizona Water Bank, United States

The Arizona Water Banking Authority (AWBA; Water Bank) was established in 1996 to increase use of the state's Colorado River entitlement and develop long-term storage credits for the state. AWBA stores or 'banks' unused Colorado River water by injecting it into partially saturated regional aquifers, to be used in times of shortage to secure water supplies for Arizona. Key benefits of the Water Bank are listed as drought protection, enhanced water management and water rights settlements with indigenous communities. It has also achieved several statewide and interstate benefits, including:

Credits for Colorado River communities: As an example, cities in Mohave County may acquire credits through the AWBA for water stored in central Arizona and redeem those credits by diverting water directly from the Colorado River.

Water banking storage agreements: Some Arizona entities have expressed an interest in using the AWBA's services to store water they have a legal right to store. While nothing prevents these entities from banking water on their own, it may be more efficient for the AWBA to administer and oversee water banking for individual Arizona entities.

Long-term storage credit lending: Since the AWBA's inception, Arizona entities have expressed an interest in borrowing long-term storage credits. Under the 1999 statutory amendments, the AWBA may lend long-term storage credits to any Arizona entity and should be able to receive reasonable compensation for lending credits.

Effluent recharge: AWBA can store recycled effluent for the same purposes allowed for Central Arizona Project (CAP) water when all available excess CAP water has been stored or when excess CAP water is not available to the AWBA.

Interstate benefits: The AWBA can allow some users in California and Nevada to annually store unused Colorado River water. The contracting state would pay to store water in Arizona, helping to replenish Arizona's aquifers in the short term, and in the future would be able to draw a similar quantity directly from the Colorado River. The program does not involve the sale of any future rights to water, only a specific quantity of unused water. The AWBA began storing water for the Southern Nevada Water Authority in 2005. Water stored on behalf of Nevada provides a temporary water supply for Nevada and allows time for development of other non-Colorado River resources. It also provides Arizona additional flexibility to achieve its long-term water management goals.

Source: AWBA website: http://www.azwaterbank.gov (accessed 21 February 2014)

In many cases, multiple agencies (both public and private) have an interest in groundwater and surface water management and responsibilities are divided between them. In the absence of aligned objectives, current arrangements may not provide incentives to consider wider impacts and benefits that may be beyond the scope of each individual agency[4]. Better

[4] The same may be said for why water markets alone will not optimise the total resource, even if applied to both surface water and groundwater – each individual market participant may optimise the resources at their disposal, but has no incentive to consider wider impacts or potential benefits to other participants. It would be presumptuous to expect market rules to have considered all externalities including cooperation of participants to optimise whole-of-system performance.

understanding – and agreement – on how to assess multiple costs and benefits over a range of stakeholders may provide deep insights for designing governance arrangements that align management objectives across agencies. In some cases non-aligned objectives can present barriers to further integration, such as perverse price signals or disincentives to invest in optimised supply options. A common understanding of costs and benefits will first be required before such barriers can be challenged.

Finding 2

There are no agreed principles for quantifying the full costs and benefits of integrating groundwater and surface water management, including non-economic costs and benefits for a range of stakeholders[5], including the timeframes over which costs and benefits are considered, that are capable of capturing the wider impacts and benefits that may be beyond the scope of individual organisations.

Such principles would benefit from joint consideration, agreement and adoption by all Australian governments.

Wider implications

Greater awareness and an increasing number of proposals to integrate groundwater and surface water use and management will raise practical questions, not only about how to achieve a robust, systematic consideration of opportunities, but also how to assess the benefits and implement any viable options that are identified. Some of the questions cut across all aspects of water planning and management.

Well-directed efforts to integrate groundwater and surface water management will require policy setters to address:

- how to incorporate integrated management principles into existing arrangements
- how to assess the materiality of the need for integration: this applies both to the materiality of cross-impacts and also of the trade-off decisions that could be minimised or averted
- the role of water planning, regulation and markets in implementing new arrangements.

One of the highest-level choices is how to manage changes to existing arrangements. Jurisdiction-wide changes can be implemented quickly, effectively and ensure consistency between all areas, yet tend to be resource intensive. They may be appropriate when an existing system is seriously underperforming. By contrast, existing arrangements throughout Australia tend to be well-established and largely functioning as intended – the NWI remains a sound basis for water planning and management in Australia. As foreshadowed in Finding 1, it may be more efficient to include consideration of integrated groundwater and surface water

[5] For example, this has been partially achieved elsewhere in the water sector (e.g. MARSUO) – urban water utilities have made some progress towards tools to consider multiple benefits (especially around the ‘soft’ measures of liveability) from single investments. See Ganji, A, Kandulu, J, Hatton MacDonald, D, Dandy, G & Maier, H 2012, *Managed aquifer recharge and stormwater use options: preliminary net benefits report*, MARSUO Milestone Report 5f, Goyder Institute for Water Research.

use and management opportunities within initial water planning or water plan review processes in a staged manner, and to use any future changes to entitlement arrangements, water markets and institutional arrangements to facilitate further integration. In this way, resources can be more efficiently targeted towards areas in which there are the greatest opportunities or the greatest risks.

In establishing the areas of greatest opportunity or greatest risk, it will be necessary to assess the materiality of both the cross-impacts to be managed, and the trade-off decisions to be minimised or averted.

Where there are discernable cross-impacts between groundwater and surface water use, it is essential to at least manage the impacts. This has been the focus of almost all previous activity in Australia, and there are a suite of established tools in most (but not all) jurisdictions to do this. Water plans and management arrangements can be interfaced (linking separate plans) or integrated (planning groundwater and surface water together) and both approaches have been shown to work in certain settings. It is important for water planners and managers to use all available tools (and combinations of tools)[6] to avoid predicted impacts as well as to address observed impacts, and to progressively reduce exemptions such as domestic and stock water use and water for extractive industry developments. It may be necessary to reverse assumptions about the burden of proof involved in implementing some tools to reduce the information burden on governments and improve the range of uses and users included in the water planning framework. Longer-term planning that increases the range of cross-impacts that are considered[7] may avoid remedial action in future, which almost always comes at a high social as well as considerable economic cost to governments.

Where there are trade-off decisions that could be minimised or averted, it will be necessary to establish the costs and benefits of integrating groundwater and surface water management. Finding 2 is aimed at overcoming the present difficulty of demonstrating the full costs and benefits, and could include considerations such as the significance of each trade-off, the significance of potential gains compared with the current *status quo*, and the ability of any proposed new arrangements to make gains or reduce trade-offs.

It is important that potential opportunities for integrating groundwater and surface water management are not limited to physically connected systems in which cross-impacts are predicted or observed, or to systems where trade-off decisions need to be minimised. Systems that are not hydraulically connected should also be included in the consideration of potential opportunities, as integrating groundwater and surface water use and management arrangements in these systems may also make a contribution to optimising the economic, social and environmental outcomes of managing Australia's water resources.

The role of water planning, regulation and markets in implementing new arrangements will also require careful consideration. Some aspects of water planning and regulation establish jurisdiction-wide frameworks, while others allow for arrangements that recognise and take advantage of local circumstances. Examples may include:

- Entitlement structures are typically defined at a whole-of-jurisdiction level, yet licence conditions and allocations against each entitlement can vary locally. Security

[6] Tools may include caps, sustainable diversion limits, set-back distances or minimum spacing for bores, trigger levels, thresholds, zoning, trading rules and restrictions, offsets, fees and price signals, compulsory reductions, buy-backs, and other means tailored to each area.

[7] At present the only cross-impact that is widely considered is the impact of groundwater pumping on streamflow, which may give the impression that impacts are 'one-directional'. Other cross-impacts include the effect of flow regime on recharge and land management in diffuse recharge areas.

of existing entitlements may not correlate with improved overall security of supply, so it may be necessary to revisit current entitlement arrangements.

- Water planning frameworks apply at a whole-of-jurisdiction level, yet the definition of the water sources covered in each plan (e.g. all water within a spatial area as an integrated plan, or just one slice of the total resource as a separate groundwater or surface water plan) is necessarily tailored to the resources in each area.

It is the consideration of opportunities (see Finding 1) that should be consistent and cover all areas, not the management response, which may allow for local variation. Variation that is based on consideration of local issues is both acceptable and appropriate provided that the principles of the NWI are maintained and the process used to develop those arrangements is transparent, documented and agreed.

This paper recognises that most jurisdictions have already made progress towards integrating groundwater and surface water management and presents two findings aimed at consolidating those gains. The findings represent the first practical steps towards more widely reaping the benefits of integrated groundwater and surface water management.

Past and current success

This section presents a directory of the case studies presented in this paper that achieve one or more of the objectives/benefits outlined previously, which are:

- improving security and reliability of supply
- maintaining water quality to acceptable levels
- managing third-party impacts
- improving water system efficiency and resource conservation
- storing and delivering water where and when it is needed.

These examples represent a small sample of the great number of areas where integrating groundwater and surface water use and management has solved (or at least partially addressed) wider management problems, or where major opportunities exist. In all cases, proposed management actions were rightly considered on their merits and practical benefits – often opportunistically – rather than as part of a vague ‘integration’ agenda.

The current lack of an agreed method to consider the full costs and benefits of integrating groundwater and surface water management creates a challenge to present these case studies in a consistent manner. These examples do not attempt to document the full range of costs and benefits in each case but are intended to provide an overview of what is possible when both groundwater and surface water resources are used and managed together to take advantage of local or regional conditions, as well as human needs.

Table 2: Examples of integrating management highlighted in this discussion paper

Theme	Description	Region	Page
Variety of management approaches	Connected systems as a single resource	Coastal macroplanning, NSW	3
	Managing cross-impacts of use	Katherine / Tindall aquifer, NT	4
	Engineering a connection (small-scale MAR) to optimise water access	Angas Bremer, SA	5
Achieving multiple objectives	Improving water system efficiency, reliability and sustainability	Ophthalmia Dam, WA	11
	Improving water quality (SWI) and reliability	Lower Burdekin region, Qld	13
	Cross-sectoral recycling	Werribee Irrigation District, Vic.	8
	Satisfying multiple users and multiple values	Arizona water bank, US	17
Unrealised opportunity	Improving security while minimising losses	Potential for MAR near Broken Hill, NSW	9

Further reading

The following list is not exhaustive but provides a selection of further information on the benefits and challenges of integrating groundwater and surface water use and management.

Dillon, P, Pavelic, P, Page, D, Beringen, H & Ward, J 2009, *Managed Aquifer Recharge, an introduction*. National Water Commission, Canberra, Waterlines report no. 13.

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SKM 2011, *National Framework for Integrated Management of Connected Groundwater and Surface Water Systems*, National Water Commission, Canberra, Waterlines report no. 57.

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