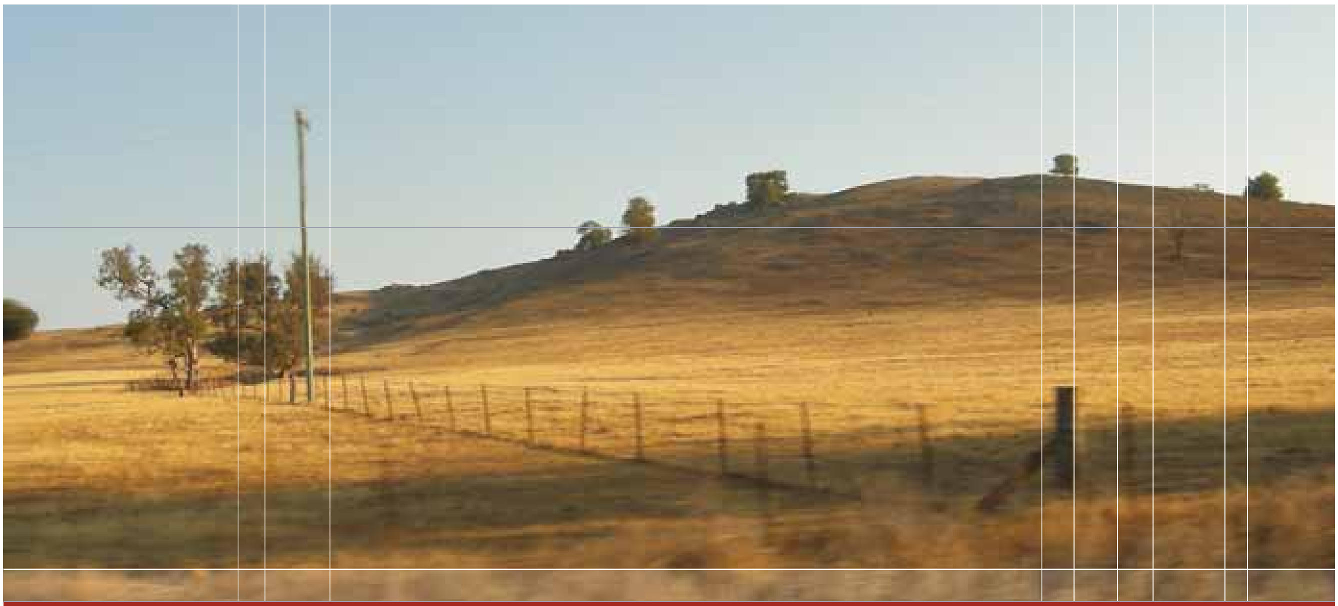

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groundwater management

issues affecting the efficient allocation of groundwater

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» *Groundwater has become increasingly scarce across much of Australia, with some reserves being substantially depleted. This has raised concerns over the efficiency and equity of current management arrangements.*

» *Groundwater systems tend to be complex and difficult to observe. As a result, sustainable groundwater yield estimates are often highly uncertain. Adding to the difficulty in managing these systems is the poor monitoring of extractions, with only 20–40 per cent of users metered.*

» *A cap and trade system may be suitable for some groundwater systems, with the cap providing the certainty needed to protect the integrity of the groundwater resource, and trade providing the mechanism for allocating consumptive water to its highest value uses.*

» *Where there is a high degree of uncertainty about what can be sustainably extracted from groundwater systems, it may be prudent for policy makers to be conservative in allocating access to groundwater, and to formalise a set of management actions specifying restrictions on extractions in the event that stocks fall below predetermined thresholds.*

background

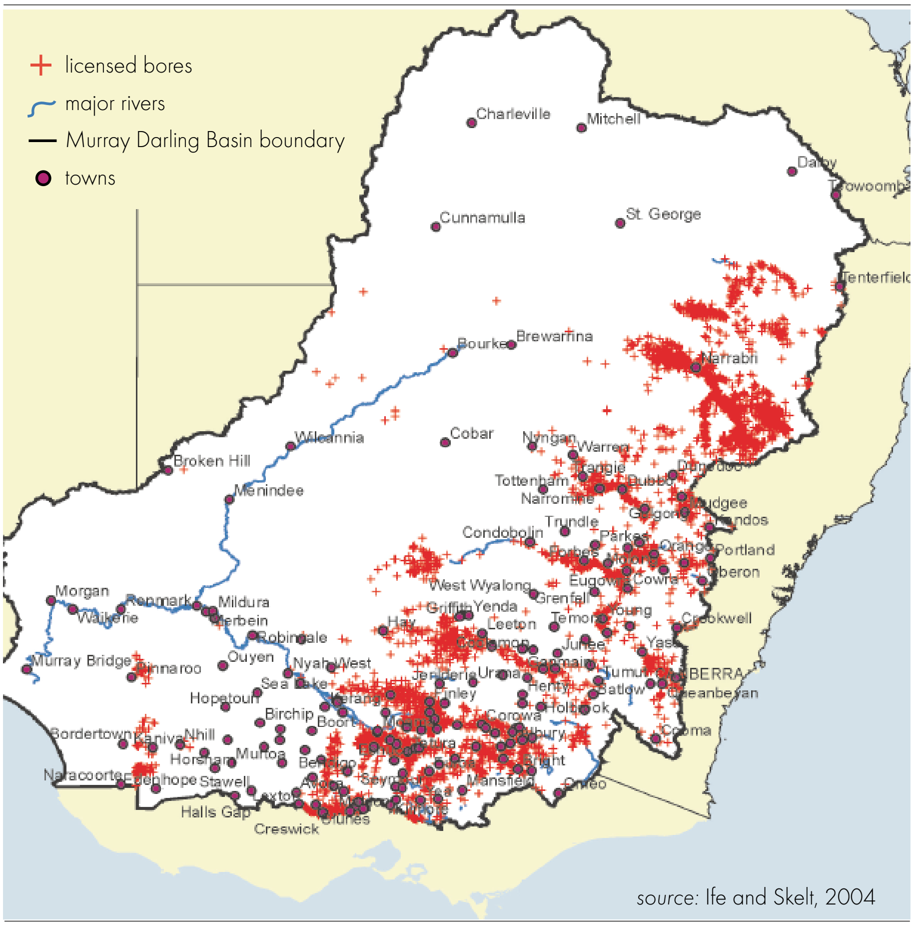
Most groundwater extracted in Australia is used by rural enterprises. While data on use, by activity, are dated, in 1996-97 it was estimated that 51 per cent of groundwater was used for irrigation, with a further 17 per cent being extracted for stock watering and other rural uses. The remaining 32 per cent was used to supply cities, towns and industry. Up to four million Australians used some groundwater for domestic water supplies (CSIRO 2001).

Access to groundwater for irrigation is rationed through a system of entitlements. Groundwater entitlements are issued by state and territory governments, and are typically separate from land and other property rights. In general, they specify the volume of groundwater that irrigators are entitled to extract in a given year, although other conditions may be attached (Natural Resource Management Standing Committee 2002). For example, some entitlements may specify maximum daily pumping rates, while others may specify additional volumes that can be extracted during droughts. There are currently around 145 000 groundwater entitlements in Australia, with a combined volume of 7000 gigalitres (ABS 2006).

Total groundwater use by the Australian agricultural sector was estimated to be 2800 gigalitres in 2004-05, equivalent to 40 per cent of total entitlements. Groundwater use in agriculture was highest in New South Wales (1030 gigalitres), Queensland (670 gigalitres) and South Australia (470 gigalitres). Groundwater accounted for 23 per cent of total water use in agriculture nationally and 82 per cent in the Northern Territory. Major groundwater irrigation districts include the Border Rivers (New South Wales), Namoi (New South Wales), Murrumbidgee (New South Wales), Lower Limestone Coast (South Australia), Goldfields (Western Australia), Balonne-Condamine (Queensland) and Shepparton (Victoria) districts (ABS 2006) – see map 1 for the locations of the major groundwater areas in New South Wales and Victoria.

Groundwater is particularly attractive to surface water irrigators who can also access groundwater during periods of drought. Groundwater systems typically have a significant stock component, and are influenced less by short term climatic variability than surface water systems. As a result, groundwater systems tend to form a buffer against reduced surface water availability, with extractions increasing during droughts. Earth Tech Engi-

location of licensed bores in New South Wales and Victoria



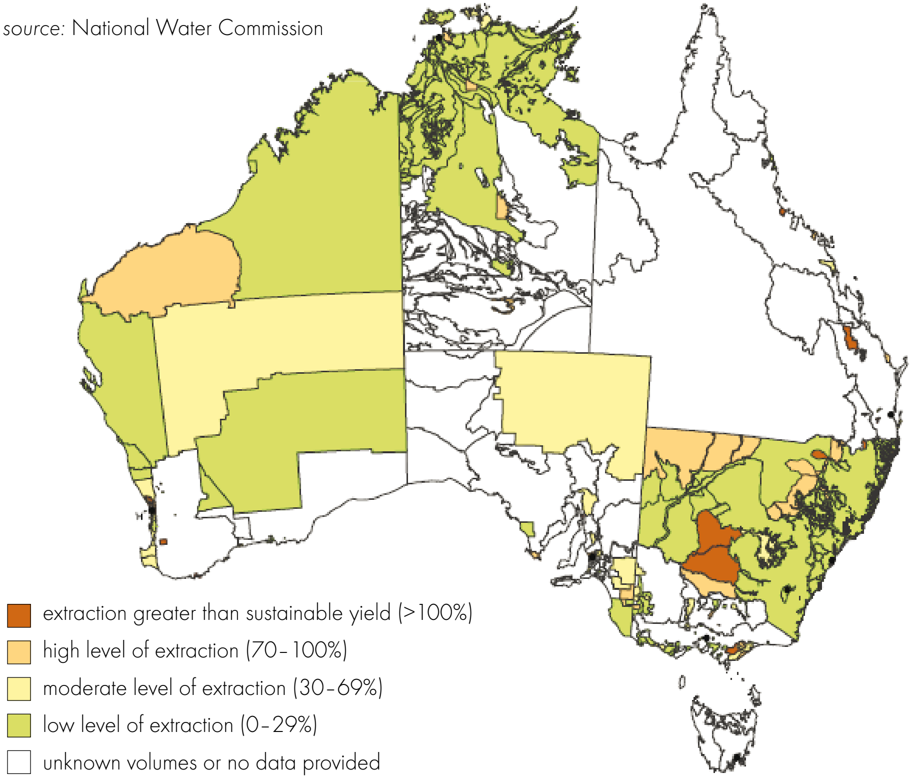
source: Ife and Skelt, 2004

neering (2003) estimated that groundwater extractions from the Lower Murrumbidgee Valley increased by around 50 per cent over the two years to 2002-03 because of the drought.

There is evidence that extractions in some groundwater systems are not sustainable. Map 2 illustrates the extent of groundwater extractions relative to sustainable yield across Australia. Overuse is indicated where extractions exceed the volume of groundwater that can be sustainably extracted (identified by the dark orange regions in map 2). Sustainability is assessed by comparing extractions with sustainable yield, which can be defined in a number of ways. Some states narrowly define sustainable yield as rainfall recharge. This definition does not factor in any discharge to groundwater dependent ecosystems. Other states use more sophisticated definitions. The National Groundwater Committee defines sustainable yield as an extraction regime (measured over a specified planning timeframe) that allows acceptable levels of stress and protects dependent economic, social and environmental values (National Water Commission 2006). This definition explicitly recognises the existence of tradeoffs between competing uses.

Map 2 indicates that overuse occurred in some groundwater units located within the Murray Darling Basin. While extractions (1250 gigalitres) were estimated to be lower than sustainable yield (2450 gigalitres) for the Murray Darling Basin as a whole in 2000-

map 2 **level of groundwater extractions relative to sustainable yield**
July 2004–June 2005 groundwater management units



source: National Water Commission

01 (Earth Tech Engineering 2003), around 15 per cent of groundwater management units located in the Basin were overused. For example, groundwater extractions at Katunga in northern Victoria were almost three times sustainable yield for that region (Ife and Skelt 2004).

While the volume of groundwater estimated to have been extracted from the basin was lower than sustainable yield in 2000-01, the volume of water specified in entitlements for consumptive use was significantly higher than sustainable yield (3250 gigalitres compared with 2450 gigalitres). Increasing demand for irrigation water, combined with restrictions on access to surface water, may lead to the activation of entitlements that are currently unused or partially used in groundwater systems located in the Murray Darling Basin. This activation may be accelerated by irrigators substituting groundwater for surface water in the event that less surface water is available in the future. In a recent study by Sinclair Knight Merz (2003) it was assumed that future groundwater extractions would increase by 1–5 per cent a year. If future groundwater extractions increase by 3 per cent a year, sustainable groundwater yield for the Murray Darling Basin (2450 gigalitres) is likely to be reached by around 2025.

Concerns over ineffective management of groundwater have increased in recent years. Most recently, a group of groundwater professionals prepared a position paper on national groundwater reform (Evans et al. 2006). Their paper highlighted the need to identify sustainable yield in groundwater systems, and to return use in overallocated systems to sustainable levels. In January this year the Australian Government announced its intention to address overallocation in the Murray Darling Basin. As part of this process, the CSIRO has been commissioned to derive sustainable yield estimates for surface and groundwater systems for catchments in the Murray Darling Basin by the end of the year (Commonwealth of Australia 2007).

box 1 **what is groundwater?**

Groundwater is contained in geological strata called aquifers. Specifically, it is contained in the pore spaces separating material comprising the aquifer. Aquifers can be composed of a wide range of materials, including sand, gravel, limestone and fractured granite. The more permeable the aquifer (the greater its hydraulic conductivity), the more easily groundwater will flow through it. Groundwater generally moves relatively slowly through an aquifer, except in the case of fractures. How long water is retained in an aquifer will depend on the distance between the locations of recharge and discharge, and the speed with which it moves.

Groundwater is usually extracted through wells. How much can be extracted will depend on how much water is in the aquifer initially, how much new water enters (recharges) the system and how much water is discharged through avenues other than extraction. If discharge exceeds recharge, groundwater levels will drop. Extracting groundwater through wells will cause groundwater levels to drop. Extracting more groundwater than is recharged is referred to as groundwater mining (Peralta 1995).

key differences between groundwater and surface water

Managing groundwater is, in many respects, more challenging than managing surface water (see box 1 for a description of groundwater). This is largely because aquifers are difficult to observe, making it difficult to identify key biophysical relationships. For example, it is likely to be much more difficult to accurately identify groundwater recharge than inflows into surface water systems, or to identify the impact of different extraction regimes on groundwater dependent ecosystems than the impact of surface water extractions on surface water dependent ecosystems. Where sustainable groundwater yield estimates are available, they are often assumed to be only within 25 per cent of their true value (Evans et al. 2003).

Groundwater use is also poorly monitored relative to surface water use. This reduces the information available to policy makers to determine and enforce more sustainable groundwater extraction regimes. According to the National Water Commission (2006), large scale metering of bores has only commenced in the past five to ten years. Moreover, not all bores are metered in metered areas. Overall, the commission estimates that only 20–40 per cent of major users are currently metered.

Groundwater systems also comprise a much larger stock component than surface water systems, which have to rely on dams or weirs to store water. This means that groundwater systems tend to be influenced less by short term climatic variability than surface water systems. Consequently, groundwater use tends to increase in drought years, when surface water availability declines. As stated in the previous section, groundwater extractions in the lower Murrumbidgee Valley increased by around 50 per cent over the two years to 2002-03 because of the drought. While this groundwater system provided irrigators with a significant buffer against reduced surface water availability, this increase in use led to a 10–20 metre drop in hydraulic head in most parts of the deeper aquifer (Earth Tech Engineering 2003).

goal of groundwater management

efficiency

The goal of natural resource management is to maximise the net social benefits from resource use over time. For groundwater, these benefits include any private and external benefits derived from groundwater use less any private and external costs. Externalities include any costs or benefits imposed on or accruing to third parties through the activities of another party.

In the absence of externalities, the net benefits from groundwater use will be maximised at the point where the net marginal private benefits derived from groundwater use are equalised across all potential users. For instance, if the benefit from using one more megalitre of water in enterprise A (say $150) exceeds the cost from using one less megalitre in enterprise B (say $100), there would be a net private gain equivalent to $50 less transaction costs in transferring water from enterprise B to A.

externalities

As is the case for many natural resources, there are external costs associated with groundwater use. Excessive groundwater use can impose significant costs on third parties, including other water users and the environment. For example, excessive use of water could lead to land subsidence, loss of habitat or ecological diversity, and reduced dilution and assimilation of contaminants (National Academy of Sciences 1997). Excessive use in coastal aquifers has also led to sea water intrusion in Queensland, while salinity recycling is a problem in parts of South Australia (Natural Resource Standing Committee 2002).

For other water users, in the absence of some form of regulation or informal agreement, individual groundwater users will have little incentive to consider the increased pumping costs imposed on other users as a result of their pumping activities, or the costs associated with reduced stock available for future use (Hafi and Cao 2002; Provencher and Burt 1993). They will also have little incentive to consider the impact of their pumping activities on other users where aquifers or surface water systems are linked. For example, in the Murray Darling Basin the Condamine, Lower Gwydir, Upper Namoi, Lower Macquarie, Upper Lachlan, Murrumbidgee and upland Victoria groundwater management units exhibit medium to high stream aquifer connectivity.

Earth Tech Engineering (2003) estimate that around 45 per cent of the additional groundwater that could be 'sustainably' extracted from the Murray Darling Basin each year is located within connected water systems. If groundwater extractions increased by 550 gigalitres a year in connected water systems within the Murray Darling Basin, these additional extractions could ultimately lead to a 330 gigalitre a year reduction in surface water availability across the basin (based on an estimated leakage coefficient of 0.6), adversely affecting downstream surface water users and the environment.

managing groundwater use

In the absence of price signals that reflect the external costs of groundwater use, irrigators will have few incentives to constrain consumption to socially optimal levels. As a result, governments may need to intervene to ensure that at least some of these costs are accounted for by groundwater users. This raises the question of what form of intervention is appropriate. For example, it may be possible to achieve a regulatory solution by restricting access to water, or a market based solution by either taxing water use to reduce consumption or imposing a cap on extractions and allowing trade in consumptive allocations. The instrument that policy makers ultimately select should depend on its relative efficiency and effectiveness in achieving the desired goal.

It is unlikely that price or quantity based instruments will be efficient and effective in achieving the desired allocation of groundwater if used in isolation. While quantitative restrictions may be highly effective in reducing use, they are likely to be inefficient in allocating groundwater for consumptive use. In contrast, price instruments such as taxes may be relatively ineffective in reducing consumptive use. The reason for this is that the demand for water for consumptive use tends to be relatively unresponsive to price movements. Hence, there will be no guarantee on the level of water to be extracted using price instruments. It is also likely to be impractical to set an efficient tax where there are significant movements in demand for and supply of groundwater caused by climatic variability.

A more practical option for allocating groundwater relies on using price and quantity instruments in tandem. It involves restricting access to water for consumptive use, allocating property rights to the consumptive pool, and allowing trade between consumptive users. The aim of capping extractions is to balance the environmental needs of water dependent ecosystems and the consumptive needs of current and future users. The cap provides a high degree of certainty about availability for environmental use, whereas trade provides a mechanism for allocating consumptive water to its highest value uses. This cap and trade model is consistent with that being used in surface water systems in Australia.

Making the cap and trade model operational will involve identifying a cap on extractions, and allocating water identified under this cap to consumptive users. Despite the information requirements for a cap and trade option being significantly lower than for a regulatory solution (where data would need to be available on the costs and benefits of water use by individual users), these requirements may still be substantial.

Ideally, the overall cap on extractions would be set to equalise the marginal benefits between consumptive and environmental use, and between current and future use. The cap on extractions would also vary to reflect changes in biophysical and economic variables, such as reduced recharge or increased returns to irrigated activities. As alluded to earlier, it may be difficult and expensive to identify the net marginal values for consumptive and environmental uses needed to identify an efficient cap for groundwater. Adding to this difficulty and expense is the fact that many groundwater systems are difficult to observe, and are often unalike. This lack of similarity increases information costs since data acquired for a particular aquifer may not be applicable elsewhere.

dealing with uncertainty

While knowledge of groundwater systems has increased in recent years, the reality is that many of these systems remain poorly understood. Where uncertainty is high about what can be sustainably extracted from these systems, it would be prudent for policy makers to be conservative in allocating access to groundwater.

It may also be prudent for groundwater managers to formalise a set of management actions that would be activated in the event of groundwater stocks falling below some predetermined thresholds. This would be particularly the case where there was a risk that extractions could lead to severe and irreversible damage to groundwater dependent ecosystems or compromise future availability for high value activities such as irrigated tree and vine crops. Such an approach would involve clearly stating the management actions necessary to achieve defined environmental and economic objectives. It would also contain a process for monitoring and assessing the environmental status of a groundwater system and the economic gains from extracting groundwater for productive use. It would also be necessary to define a set of rules to control the level of extractions based on these environmental and economic assessments of the groundwater system.

This type of approach could provide the community with a reasonable level of confidence that groundwater resources were being managed for long term environmental and economic sustainability, and the irrigation industry with a more certain operating environment. One of the main benefits of this type of approach is that a predetermined set of operating rules would be in place to cope with unexpected changes in the state of an aquifer.

To implement this type of strategy, it would be necessary to specify the relevant 'reference' points needed to guide management decisions. For example, 'target' reference points would be needed that specified the desired status of stocks and desired extractions. 'Limit' reference points that identify points beyond which the risk to the aquifer and related ecosystems is regarded as unacceptably high would also be required. A set of operational rules would then be required to regulate extractions, so that stocks remained at target levels. These rules would also specify the action to be taken if the limit reference point was breached.

It is important to recognise that there are varying amounts of information available on groundwater systems, and that full quantitative assessments for all aquifers would not be possible. Rather, a risk management approach would be required, whereby extraction levels would be reduced as uncertainty around sustainable yield estimates increased. For aquifers where sufficient information were available, identifying the relevant reference points would involve the construction of groundwater simulation models capable of testing the impact of various extraction and recharge scenarios. These models could also be used to evaluate various management controls, and provide the basis for modifying these management controls.

The uncertainty and variability surrounding sustainable yield estimates need to be understood and incorporated into any decisions on granting access to groundwater systems. Over time more data may become available that could reduce the level of uncertainty about sustainable yield estimates.

While collecting more information on sustainable yield would tend to improve decisions on granting access to groundwater systems, the benefits of acquiring additional information would need to be compared with the costs. The research agenda on sustainable yield should be driven by the information needs of groundwater managers. Research on sustainable yield should be targeted in the first instance at groundwater systems where extractions are leading to significant environmental damage or seriously compromising future availability for high value consumptive activities. IAH Australia (2004) suggests a system for prioritising the level of effort applied to the assessment process based on the level of risk of the resource being overallocated. Under this approach, priority would be given to research into aquifers that have a high level of allocation relative to yield and for which sustainable yield estimates are highly uncertain.

trade

Making the trade component of a cap and trade system operational would involve allocating rights (referred to as entitlements) to the consumptive pool of water identified under the cap. While the manner in which these rights would be allocated have wealth implications for individual users, the method of allocation should not reduce the capacity of this option to efficiently distribute groundwater to those who value it most.

Groundwater entitlements would need to be clearly specified and transferable if the benefits from consumptive use are to be maximised. For instance, the level of security should be sufficient to provide irrigators with the information they need to make efficient investments. Well specified rights would be of little value, however, if they were not enforced. For this to occur, groundwater use would need to be monitored. According to the National Water Commission (2006) only 20–40 per cent of major groundwater users are currently metered. To ensure compliance, a system of penalties would need to be introduced, with these penalties exceeding the benefits of noncompliance.

The extent to which trade increased the benefits from groundwater use for any given level of restriction on resource access would depend on the variability in marginal returns between users. The benefits may be substantial where there is significant variability in marginal returns between users. Conversely, the gains may be minimal where there is little variability in marginal returns from groundwater use. The gains from trade in groundwater may be relatively small compared with those from trade in surface water because of the discrete nature of many groundwater systems. The discontinuous nature of many groundwater systems (in contrast to many surface water systems) means that irrigators within these systems are often engaged in similar activities. This is an important consideration when considering the introduction of trade, since the transaction costs in some instances may outweigh any additional benefits from being able to transfer groundwater to other users.

Other factors that need to be taken into consideration when trading groundwater include the localised effects of drawdown on neighbouring irrigators. These impacts could include both quantity and quality effects. For example, excessive drawdown by one irrigator could reduce availability to other irrigators within the vicinity in the short term, or increase salinity levels. The impact of extractions on groundwater dependent ecosystems could also vary with the proximity of irrigators to these ecosystems.

Finally, if trade were to be introduced, it would be important to resolve any overallocation prior to its introduction. If trade was introduced before overallocation issues were resolved, unused and partially used entitlements could be activated, increasing the complexity and cost of reducing overallocation.

benefits of more flexible management

The aim of restricting access to groundwater is to increase the sustainability and efficiency of resource use. It may be possible to minimise the costs of restricting access to groundwater (and hence increase the net benefits from groundwater use) by adopting more flexible management rules. For example, it may be possible to introduce more flexible annual extraction rules.

Given the hydrogeological characteristics of some groundwater systems, there may be scope to increase returns to irrigators by providing them with the flexibility to extract more water in dry years and less in wet years, while limiting aggregate use to long term sustainable yield. ABARE (Goesch, Qureshi and Hafi 2003) recently estimated the benefits of allowing irrigators located in the McLaren Vale Prescribed Wells Area in South Australia the flexibility to access a total of 5.5 megalitres per hectare over a five year period compared with a situation where extractions were restricted to a maximum of 1.1 megalitres per hectare a year. To protect the aquifer from any major deviations at the extraction point, an additional constraint, restricting extractions to a maximum of 1.5 megalitres per hectare in any given year, was also imposed.

While ABARE's research indicated that the benefits from more flexible annual extraction rules were relatively modest for irrigators located in McLaren Vale, it is likely that the benefits from being able to access additional water in drier years would be greater the more restrictive the allocation regime, the more variable the rainfall pattern and the more valuable the irrigated farming activity. The benefits of more flexible annual extraction rules would therefore be likely to increase if rainfall were to become lower and more variable in the future.

complexity of shared water

Shared water comprises that component of water that either feeds into a stream or river from an aquifer (the 'gaining' stream), or conversely, discharges from a river or stream into an aquifer (the 'losing' stream). Connectivity can be complex, with a single river in some instances both gaining and losing water, depending on location. It may also be the case that any amount of groundwater pumping in a connected system will deplete stream flow, and that the rate of depletion will vary with the rate of pumping and distance from the river.

Policy makers have a number of options for addressing the 'double allocation' of shared water in connected systems, and reallocating this water. Where they have a good understanding of the groundwater system, and groundwater–surface water connectivity, the preferred option may be to allocate property rights to shared water and allow trade in these rights once the overallocation issue has been resolved (Goesch and Hafi 2006).

The success of this management regime would, however, be highly dependent on being able to monitor groundwater irrigators' use of shared water, and enforcing any restrictions on access to this water. These monitoring and enforcement costs could be considerable, and would need to be factored into any benefit–cost analysis of altering existing arrangements. Similar to the case where groundwater-only systems are poorly understood, policy makers should be conservative in allocating access to shared water in systems where connectivity is poorly understood. It may also be preferable to delay the introduction of trade until the interactions between surface water and groundwater are better understood, to avoid any unwanted third party impacts.

conclusion

Groundwater is an important input to irrigated agriculture in Australia, accounting for nearly a quarter of agricultural water use. While it is not possible to accurately determine the extent of groundwater use in Australia, there are a number of groundwater units that are overused or approaching overuse. There is also the issue of overallocation of groundwater entitlements, with the volume of water attached to entitlements in the Murray Darling Basin exceeding sustainable yield. Increasing demand for irrigation water combined with restrictions on access to surface water may lead to the activation of groundwater licences that are currently unused or partially used. If groundwater extractions were to increase by 3 per cent a year, sustainable groundwater yield for the Murray Darling Basin is likely to be reached by around 2025.

Excessive groundwater use can impose significant costs on third parties, including other consumptive users and the environment. It is unlikely that price or quantity based instruments would be both efficient and effective in achieving any desired reduction in groundwater use if used in isolation. It may, however, be possible to combine the use of price and quantity instruments to achieve a reduction in groundwater use. For example, it may be possible to introduce a cap and trade system whereby the cap provided the certainty needed to protect the integrity of the groundwater resource, with trade providing the mechanism for allocating consumptive water to its highest value uses. This cap and trade model is consistent with that being used in surface water systems in Australia. If trade were to be introduced, however, it would be important to resolve any overallocation before its introduction. If trade were introduced prior to resolving overallocation, unused and partially used entitlements may be activated, increasing the complexity and cost of reducing overallocation.

Ideally, any cap on extractions would need to be set to equalise the marginal benefits between consumptive and environmental use, and between current and future use. It would also vary to reflect changes in biophysical and economic variables such as reduced recharge or increased returns to irrigated activities. While more information on sustainable yield would tend to improve decision making on the level at which to set the cap, the benefits of acquiring additional information would need to be compared with the costs. Research on sustainable yield should be targeted in the first instance at groundwater systems where extractions are leading to significant environmental damage or seriously compromising future availability for high value consumptive activities.

While knowledge of groundwater systems has increased in recent years, the reality is that many of these systems remain poorly understood. Where there is a high level of uncertainty about what can be sustainably extracted from these systems, it would be prudent for policy makers to be conservative in allocating access to groundwater. It may also be prudent for groundwater managers to formalise a set of management actions that would be activated in the event that groundwater stocks fell below some predetermined thresholds. These management controls would specify restrictions on extractions in the event that target or limit thresholds were exceeded. This type of transparency on management controls should not only help protect the resource, but also help users such as irrigators to make more informed investment decisions.

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