Water Resour Manage (2009) 23:2605–2631
DOI 10.1007/s11269-009-9399-0

Managing Cumulative Impacts: Groundwater Reform in the Murray-Darling Basin, Australia

Charles Jonathan Nevill

Received: 22 May 2008 / Accepted: 9 January 2009 /
Published online: 30 January 2009

Abstract The cumulative impacts of incremental development present governments all over the world with major difficulties. Well-intended strategic approaches often fail, in whole or in part. In Australia, a joint Federal/State agreement in 1992 initiated reforms of State environmental legislation and policy, which led to the *Council of Australian Governments Water Reform Framework 1994*—an agreement to introduce comprehensive water reforms targeted at both financial and environmental issues. The Murray-Darling Basin, Australia's largest catchment, overlaps four States plus the small Australian Capital Territory. In 1995 pressing problems of land and water degradation, and the decline of widespread and important environmental values in the Basin, led only to a cap (an administrative limit or ceiling) on river water extraction, even though the importance of the surface water/groundwater connection was evident. Moreover, State Governments have been extremely slow to implement core groundwater reforms added to the *Framework* in 1996—with some important elements not yet implemented after 12 years. This delay, combined with the failure of States to implement commitments to the precautionary management of natural resources, has magnified the environmental and economic crisis facing the Basin. This crisis appears likely to worsen if current climate change predictions eventuate. Recent initiatives by the Australian Government acknowledge past procrastination, and provide a new administrative framework—an approach will only work if backed by political intelligence and will-power, and good-will and cooperation amongst State premiers. These factors have been absent in the past. The paper concludes with key recommendations aimed at comprehensive and integrated management of the cumulative impacts of incremental water-related development on a catchment-by-catchment basis.

C. J. Nevill (✉)
School of Government, University of Tasmania, Churchill Avenue,
Sandy Bay, Tasmania, 7005, Australia
e-mail: jonathan.nevill@gmail.com

Keywords Groundwater dependent ecosystems · Groundwater overdraft · Conjunctive management · Water policy · Governance · Freshwater · Precautionary principle

1 Introduction

The Australian (sometimes referred to as the Commonwealth or Federal) Government retains most government responsibility for raising revenue. However the State Governments retain most responsibility for natural resource management. Both tiers of government have an interest in promoting good management of the nation's natural resources. Given their different powers, they use different approaches (more below).

Most Australian rivers (particularly in the temperate south of the continent) feed on groundwater most of the time. Rivers and groundwaters are connected. When we extract water from a river's groundwater supply, we diminish that river's flow—even though the effect may not be noticed for some time. Generally speaking, freshwater biologists and river managers underplay the huge significance of groundwater in maintaining the health of rivers, streams, wetlands and associated vegetation communities, with the result that groundwater policy and management does not get the scrutiny it deserves—and needs. The needs of subterranean and hyporheic ecosystems are often entirely neglected.

Both surface waters and groundwaters within the Murray-Darling Basin have been grossly over-allocated for human use. Until very recently, little has been done to remedy this situation. Even now reform is happening far too slowly, and aquatic environments, and people, continue to suffer.

This paper focuses on the disjunct between the recognition of the need for integrated management of the cumulative impacts of incremental catchment development on the one hand, and extended delays in implementing management reforms on the other. Important principles for the management of cumulative impacts within the Basin have typically been recognised many years before programs based on these principles are implemented—if indeed they are ever implemented.

The integrated management of surface and ground waters is often referred to as 'conjunctive management'. This paper illustrates the problem of cumulative impact management by examining the integrated management of groundwater and surface water in the Murray-Darling Basin—or more correctly the lack of integrated management.

Important groundwater management policy reforms, agreed through the Council of Australian Governments (CoAG) water reform framework in 1996, have not been implemented in any comprehensive way—after more than a decade. The paper concludes with three key recommendations.

2 Groundwater Management

Groundwater is usually extracted through holes drilled into an aquifer (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. The rate of extraction will depend on the permeability of the aquifer and the number and depth of extraction points. If discharge exceeds recharge, groundwater levels will drop. The groundwater level in an unconfined surface aquifer is called the groundwater table. Extracting more groundwater than is recharged is referred to as groundwater mining. Extracting groundwater at a rate which prejudices important values (natural or agricultural) is referred to as groundwater overdraft. The Great Artesian Basin, a system of confined aquifers (aquifers confined by aquitards) underlying a large part of central and northeastern Australia, has been mined for over 130 years, with subsequent drops in aquifer level and pressure (GABCC 2000).

In some cases groundwater mining is a justifiable management approach, noting as an aside that some degree of mining must occur in disturbing the dynamic equilibrium of an aquifer (Sophocleous 2002) and is thus a feature of all groundwater extraction. In most cases aquifer management by State water agencies attempts to limit extraction to a ‘sustainable’ level. The approach of using the so-called ‘safe yield’, calculated as the aquifer recharge rate, was discredited in the 1980s, and is no longer widely used (Sophocleous 2000). Today Australian approaches use, generally speaking, the same philosophy governing limits imposed on surface waters. Extraction entitlements on river water seek to provide for beneficial uses of the extracted water (e.g. irrigation) while also protecting the river’s ecosystems as well as downstream extractive uses. In other words, they seek to impose ‘an

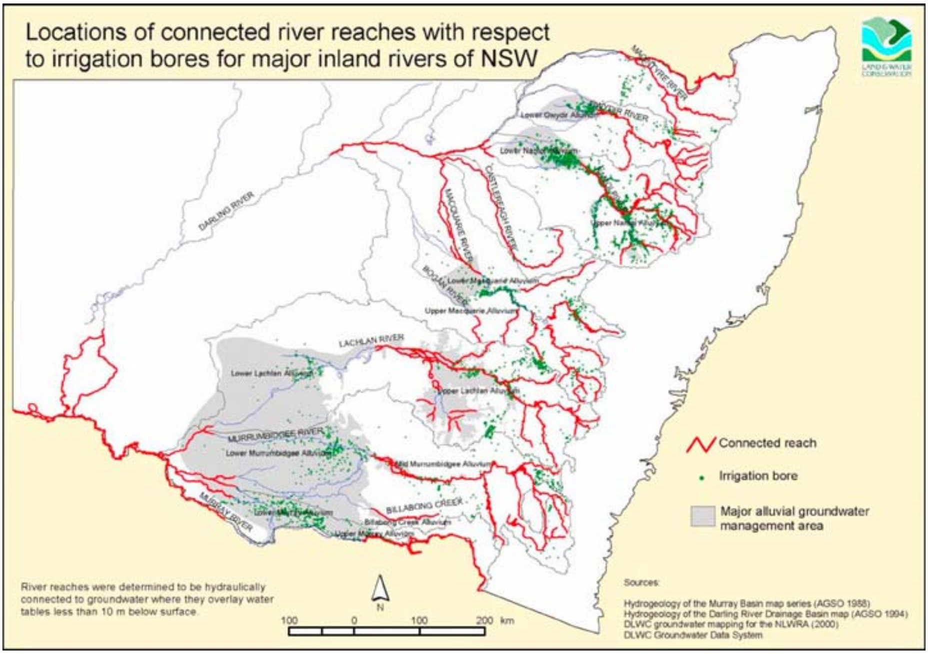

Fig. 1 NSW river reaches and groundwater management areas (Source: SKM 2006)

acceptable level of stress' on both the river ecosystem and downstream users of river water (human users). In just the same way, extraction entitlements on groundwater seek to impose an acceptable level of stress on groundwater-dependent ecosystems (including river ecosystems where these depend on groundwater flowing into rivers) and other human users of the aquifer. In Australia, the terms "acceptable yield" and "sustainable yield" are converging, although at this stage uniform definitions or calculation methods across Australia's eight States and Territories have not been adopted.

Groundwater extraction is often clustered around aquifers underlying river valleys (Fig. 1) demonstrating, at a practical level, the interconnected nature of the resource.

3 Common Governance Problems

Certain problems have beset the use of groundwater around the world. Just as river waters have been over-used and polluted in many parts of the world, so too have aquifers. The big difference is that aquifers are out of sight. The other major problem is that water management agencies, when calculating the 'sustainable yield' of aquifer and river water, have often counted the same water twice, once in the aquifer, and once in its connected river. This problem, although understood for centuries, has persisted, partly through inertia within government agencies. Prior to the statutory reforms initiated by the CoAG water reform framework in the 1990s (see below), many Australian States managed groundwater and surface water through separate government agencies, an approach beset by rivalry and poor communication.

The (sometimes long) time lags inherent in the dynamic response of groundwater to development have generally been ignored by water management agencies, decades after scientific understanding of the issue was consolidated. In brief, the effects of groundwater overdraft (although undeniably real) may take decades or centuries to manifest themselves. In a classic study in 1982, Bredehoeft and colleagues (discussed in Sophocleous 2002) modelled a situation where groundwater extraction in a intermontane basin withdrew the entire annual recharge, leaving 'nothing' for natural groundwater-dependent vegetation communities. Even when the borefield was situated relatively close to the vegetation, 30% of the original vegetation demand could still be met by the lag inherent in the system after 100 years. By year 500 this had reduced to 0%, signalling death of the groundwater-dependent vegetation. The science has been available to make these calculations for decades; however water management agencies have generally ignored effects which will appear outside the rough timeframe of political elections (3 to 5 years). Sophocleous (2002) argued strongly that management agencies must define and use appropriate timeframes in groundwater planning. This will mean calculating groundwater withdrawal permits based on predicted effects decades, sometimes centuries in the future. So far, Australian water management agencies have shown a strong reluctance to meet this challenge.

As water moves through the landscape it collects soluble salts, mainly sodium chloride. Where such water enters the atmosphere through evapotranspiration, these salts are left behind. In irrigation districts, poor drainage of soils and surface aquifers can result in water tables coming to the surface in low-lying areas. Major land degradation problems of salinity and waterlogging result, combined with increasing levels of salt in surface waters. As a consequence, major damage has occurred to local economies and environments. Often, lessons of the past have not been learned (Ludwig et al. 1993).

Four important effects are worthy of brief mention. First, flood mitigation schemes, intended to protect infrastructure built on floodplains, have had the unintended consequence of reducing aquifer recharge associated with natural flooding. Second, prolonged depletion of groundwater in extensive aquifers can result in land subsidence, with associated infrastructure damage—as well as (thirdly) saline intrusion (Zektser et al. 2005). Fourth, draining acid sulphate soils, often found in low-lying coastal plains, can result in acidification and pollution of freshwater and estuarine streams (Sommer and Horwitz 2001).

Another cause for concern is that groundwater drawdown from over-allocated aquifers has the potential to cause severe damage to both terrestrial and aquatic ecosystems (Hatton and Evans 1998; Evans and Clifton 2001)—in some cases very conspicuously but in others quite imperceptibly due to the extended period over which the damage occurs (Sophocleous 2002).

Generally speaking, freshwater biologists and river managers underplay the huge significance of groundwater in maintaining the health of rivers and streams, with the result that groundwater policy and management does not get the scrutiny it deserves—and needs.

To illustrate the magnitude of potential effects, groundwater extractions in the lower Murrumbidgee Valley (central Murray Darling Basin) increased by around 50% over the 2 years to mid-2003 because drought reduced the availability of surface water. While this groundwater system provided irrigators with a significant buffer against reduced surface water availability, this increase in use led to a 10- to 20-m drop in hydraulic head in most parts of the deeper aquifer (Earth Tech Engineering 2003; quoted in Goesch et al. 2007:9). A study of the Dumaresq River Aquifer by the Queensland Government (Chen 2003; quoted in Hafi et al. 2006:11) indicated "the temporary sale of surface water at $100 a megalitre is estimated to result [through surface water/groundwater substitution] in additional aquifer drawdown … leading to the groundwater table falling a further 34 metres." Movement of the groundwater table on scales considerably smaller then these drops has the potential to cause the death of terrestrial vegetation over considerable areas, especially where climate change (through reduced rainfall) is placing vegetation communities under stress. Similarly, such changes can not only cut off natural groundwater flows to rivers, but reverse them, draining water away for river ecosystems already in stress.

At best, these changes place groundwater-dependent ecosystems under some physiological stress; at worst, they can result in irreversible loss of significant species and/or ecological communities (Danielopol et al. 2003; Pringle 2001; Zektser et al. 2005).

4 Basin Management History

Water management, under the Australian Constitution, is primarily the responsibility of the six States and two Territories. The Commonwealth Government seeks to influence water management in the States through agreements tied to funding programs.

The Murray-Darling Basin (the Basin) is the largest of Australia's two continental-scale river basins, and occupies about 14% of Australia's land area—including parts of five States and Territories (Fig. 2 below).

The cumulative impacts of incremental development in the Murray-Darling Basin have increased in importance over the last century as many of the Basin's aquatic ecosystems moved from general good health into crisis, and pressing problems of water quality and land degradation emerged. The environments and local economies of the Basin are now in crisis, and deeper crisis lies ahead. Their problems stem primarily from governance failures, exacerbated by declines in rainfall. Over the last 7 years (to December 2007) a combination of climate change and drought has reduced (modelled) annual outflow from the basin under natural (unexploited) conditions from a long-term median of ~11,000 to 4,300 GL (P. Cullen, personal communication, 2/2/08). Climate change predictions forecast further declines in

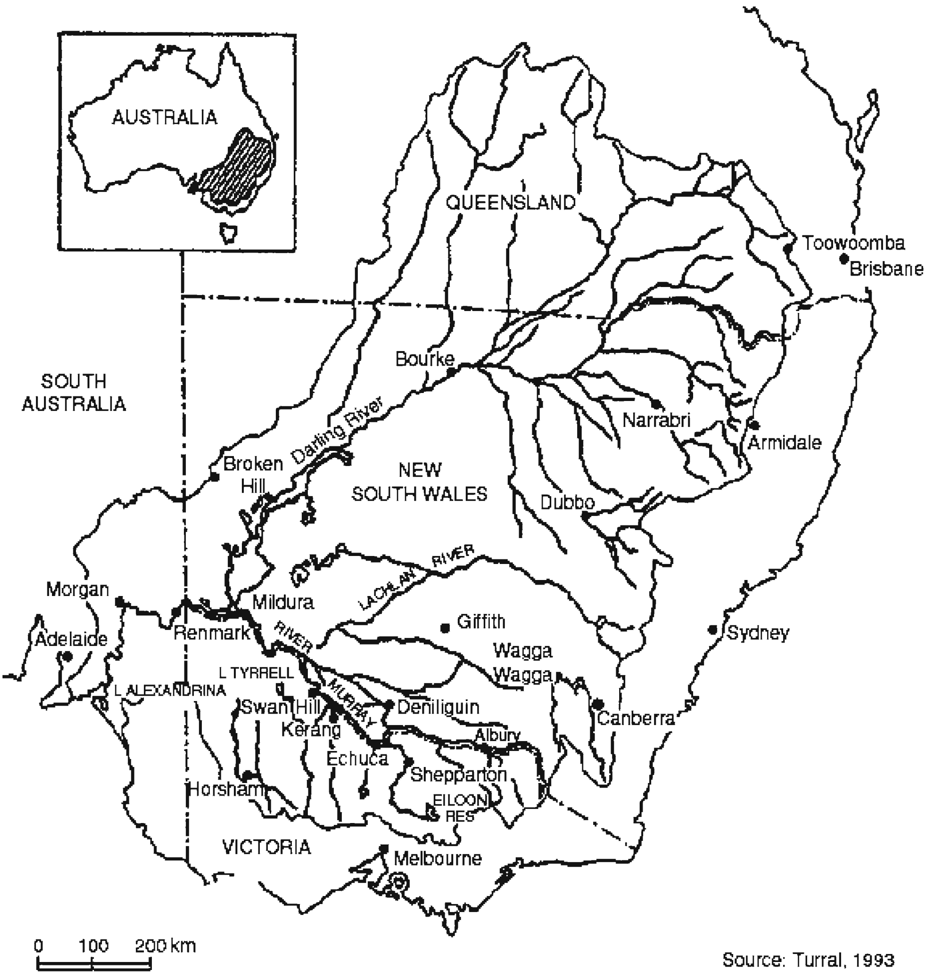

Fig. 2 The Murray-Darling Basin (Source: Turral and Fullagar 2007)

rainfall combined with increased water losses from evaporation. Clearly there are no easy solutions. The Murray-Darling Basin Commission (like its predecessor, the River Murray Commission) did not address serious failures in governance in an effective way.

By way of historical background, the *River Murray Waters Agreement 1915* created the River Murray Commission. While initially focussed on waterway storages and transport (building dams and locks) the Commission became increasingly occupied with environmental issues, particularly salinity. In this endeavour the Commission was hampered by its terms of reference and its membership. The 1915 Agreement was modified in 1987 to change the name and scope of the Commission; these changes came into effect in 1988. Five years later the *Murray-Darling Basin Agreement 1992* formalised the expanded scope of the new Murray-Darling Basin Commission (the Commission), and the creation of the Murray-Darling Ministerial Council (the Council), including water ministers from Queensland (Qld), New South Wales (NSW), Victoria (Vic), South Australia (SA) and the Australian Capital Territory (ACT), as well as the Commonwealth.

Soon after the Commission was created (1988) there was a general recognition that serious environmental problems related to water management required urgent attention, not just in the Basin but in many areas of southern and eastern Australia. Waters of many Australian rivers, streams and aquifers had been over-allocated—in some cases grossly over-allocated. In the Basin, total annual water entitlements (some in 'sleeper' or 'dozer' licences) issued by State water management agencies amounted to 14,680 GL in 1994/95, of which 12,131 GL were actually diverted, compared to the annual Basin river flow of 12,896 GL/year. In other words, licensed entitlements were 114% of the average available water, while usage ran at 94%—before accounting for groundwater withdrawals.

Flow patterns in the Murray had been drastically altered with the release of irrigation waters, moving the high flow period from Spring to Autumn—with consequent disruption of aquatic reproductive cycles (Ladson and Finlayson 2002). Over 50% of the Basin's average annual runoff (23,850 GL) had been diverted, compared to less than 3% in all but one of Australia's remaining drainage divisions. The long-term median annual river flow at its mouth prior to development is estimated at 11,318 GL, less than the average annual volume diverted for human use in 1995. It is not surprising that outflow to the sea has stopped on several occasions in recent years.

Australia's largest river system, the site of our most intense surface water and groundwater development, was (and remains) in serious trouble.

5 A Cap on River Water Diversion

The over-allocation of the Basin's waters, and the pressing environmental problems of land degradation, water quality and declining biodiversity values forced the Council and the Commission to confront the concept of limiting catchment development. Although integrated catchment management had, by this time, been the subject of long-standing discussion, the Council chose only to cap (i.e. to place a limit or ceiling on) water extraction from rivers. No controls were mooted on the development of irrigated land, harvesting of floodplain water, construction of levee banks and farm dams, draining wetlands, clearance of native vegetation, or extraction of groundwater—all issues of immediate concern to catchments in water crisis. It should be said, however, that all these issues were under discussion within State water agencies. The important point is that the Council was moving slowly, well behind current science and community concern—in spite of the urgency of the issues.

The Council introduced an interim cap in 1995 and a permanent cap on the diversion of water from the Basin's river system from 1 July 1997. The two primary objectives driving the decision to implement the Cap were:

- to maintain and, where appropriate, improve existing flow regimes in the waterways of the Murray-Darling Basin to protect and enhance the riverine environment; and
- to achieve sustainable consumptive use by developing and managing Basin water resources to meet ecological, commercial and social needs.

The cap was defined as: *The volume of water that would have been diverted under 1993/94 levels of development*. The cap, as a result, fluctuates from year to year, depending mostly on climate. To implement and monitor the cap, the Basin was divided into 24 'valleys' or allocation units. Each valley is to have an accredited model, applied annually, to determine a valley cap for the year in question. In practice, the total cap varies above and below roughly 11,000 GL/year (IAG 2007) compared to the river's 'natural' median flow of 11,318 GL/year (see above). Given that groundwater use was not capped, and that a significant percentage of groundwater was being extracted from aquifers feeding the river, only the most wildly optimistic of the nation's water managers seriously believed that the two primary objectives of the cap would be met.

6 Groundwater in the CoAG Water Reform Framework

In the year prior to the Ministerial Council's decision to establish a cap on river diversions in the Basin, these same ministers, together with water ministers from Western Australia and the Northern Territory, had met (with their Premiers) under the auspices of the Council of Australian Governments (CoAG). In February 1994 CoAG adopted "a strategic framework for the reform of the Australian water industry"—to become known as the water reform agenda or the water reform framework. The Framework had two central elements: *economic reform* to increase competition and efficiency within the industry, and *environmental reform* to increase emphasis on sustainable use of natural resources, and protection of environmental (especially biodiversity) values.

The Framework was to evolve over the following decade, through agreements reached both within and subsequent to CoAG meetings. Of immediate interest are the amendments summarized in a public letter from the Prime Minister to State Premiers and Chief Ministers of 10 February 1997. The governments agreed to specific additions then referred to as the 1996 CoAG water reform framework, including agreements focused on groundwater:

- to integrate groundwater and surface water resource management;
- to develop a nationally consistent definition and approach to calculating sustainable groundwater yield;

- to prepare groundwater management plans, policies and strategies;
- to base groundwater allocations on groundwater management plans;
- to ensure that such plans included environmental water provisions in accordance with agreed principles; and
- to address and retrieve over-allocation issues on a plan-by-plan basis.

These agreements made it look as though water management science, consolidated years and decades earlier, now had a good chance of underpinning comprehensive water management across the Basin. Commitments at this level should have prompted rapid implementation action in a Commission committed to “take a visionary approach, provide leadership, and be prepared to make difficult decisions”.

7 Implementation of the Cap

While the cap on river water diversions has been, overall, a limited success, full compliance with the cap has not yet been achieved. After more than a decade, procedures allowing a full audit of cap compliance are still to be finalised. Queensland in particular delayed compliance measures while rapidly expanding water allocations. In an examination of the lower Balonne catchment (Queensland), Tan (2000) presents evidence indicating that in the years immediately following the interim cap, the Queensland State Government maintained a casual attitude to increasing development of floodplain water harvesting, allowed catchment farm dams to increase by 90%, and licensed a 50% increase in diversions. The total capacity of off-stream dams in the Lower Balonne increased from 247 GL in 1994 to 827 GL in 1999. The most recent cap audit report draws attention to the lack of agreed measures for assessing Queensland compliance with the cap (IAG 2008), more than a decade after the cap was first imposed. It seems difficult to explain the long delay the MDBC has had in reaching agreement with Queensland without invoking arguments related to incompetence or deliberate intransigence.

Tan also draws attention to other important issues which have pervaded water management in all Australian States: a cavalier attitude on the part of State Government water agencies to both procedure and accountability, political influence on bestowing water allocations, and issues of pervasive non-compliance (on the part of irrigators) with extraction licence conditions. All these have undermined effective management of catchment cumulative impacts across the nation (see for example Nevill (2001b) discussing Victorian arrangements).

As mentioned above, the Commission’s estimates of annual average river flow (at the Murray’s mouth) and annual median river flow, under natural conditions, are 12,896 and 11,318 GL respectively. In 1994/1995, diversion entitlements for surface water ran to 14,680 GL, and usage at 12,131 GL. The latest MDBC monitoring report (MDBC 2008:48, 60) put total surface water entitlements for 2006/2007 at 13,408 GL, and total surface water usage at 5,234 GL (the lowest on record). Groundwater usage rose from 1,100 GL in 1999/2000 to 1,703 GL in 2006/2007. Total Basin water use was estimated at 6,937 GL.

Broad estimates of sustainable groundwater yields currently available are based on rules of thumb, and are likely to be substantially inaccurate (see the discussion of provision for environmental flows to groundwater dependent ecosystems in Nevill 2008). Recent reports (CSIRO 2008; Goesch et al. 2007; WRON Alliance 2007) have highlighted the lack of data (and lack of a coherent national approach) on environmentally sustainable groundwater yields. This important constraint should be noted when considering the latest Basin water usage audit report (MDBC 2008:59):

> The estimated sustainable yields in Groundwater Management Units (GMU) of the Basin are reported to be 1696 GL (note Victorian SY values are not available). Out of this, 2632 GL was already allocated in 2006/07, which constituted 155% of SY. But this allocation percentage does not take into account Victorian SY values as Victoria does not mange its groundwater on the basis of SY. The total usage of groundwater in the Basin was 1703 GL, which was 65% of allocation and 100% of SY (excluding Victoria's SY). The groundwater usage was 33% of surface water diversion in the Basin. This reinforces the fact that groundwater is an important resource in which there is a considerable scope for future development within the current allocation. A report by Sinclair Knight Merz (2003) estimated that there is strong linkage between groundwater use and surface water flows, with an average reduction in surface water flow of 600 ML for every 1000 ML of groundwater use.

Over-allocations in some areas have been reduced during the last decade, however the reductions have been slow, and have not been adequate to provide the environmental flows the river needs (Jones et al. 2002). Table 1 provides a brief summary, showing changes in entitlements and usage since the cap was introduced. Table 1 shows that entitlements for both surface and groundwater far exceeded the capacity of the catchment when the cap was introduced, if any allowance is to be made for environmental flows. Rather than a cap, urgent reductions in extractive use were needed, particularly with respect to surface water. Imposing the cap was a politically acceptable but scientifically indefensible solution.

Table 1 also shows that both surface and groundwater entitlements have been reduced since the cap was implemented, as has surface water usage. Total usage is now (2006/2007) well below the long-term median natural river flow. Has the cap's objective of "sustainable consumptive use" been achieved? The answer is "no". While usage is now below the long-term median river flow, the modelled 'natural' average river flow over the decade 5/98 to 5/08 was only 6921 GL (pers. comm J. Davis 19/1/09). If this recent flow estimate is an indicator of future flows (which it may be, taking climate change into account) then the Basin is still in deep trouble. Coupling this simple analysis with other concerns—such as the absence of defensible calculations for groundwater sustainable yield, long delays in addressing water metering (and water theft), and continued poor controls over farm dam construction and the harvesting of floodplain flows—produces a dismal prognosis. It must also be born in mind that the availability of surface water has been over-estimated, and the impacts of groundwater extraction on surface waters under-estimated by a possible 840 GL/year (CSIRO 2008:47).

The waters of the Basin remain grossly over-allocated for human use, and the Basin's environments, and human communities, will continue to suffer.

Table 1 Annual basin natural flows, water entitlements and extractive use (median and average natural flows are long-term, estimated by modelling studies)

Year	Long-term median flow	Long-term average flow	Surface water entitlements	Surface water usage	Groundwater entitlements	Groundwater usage	Total entitlements	Total usage
1994/1995	10,657	11,673	14,680	12,131	3,250	1,200	17,930	13,331
2006/2007	10,657	11,673	13,408	5,234	2,632	1,703	16,040	6,937

Source: MDBC (2008), Goesch et al. (2007), Joe Davis (MDBC) pers. comm 7/1/09. Measurements in GL

8 Groundwater Reforms Stagnate

Two years after CoAG's groundwater reform policies had been accepted by all Australian Governments, the Council published their *Floodplain wetlands management strategy*. While 'Objective 3' of this document (water allocations) mentions river flows, mention of groundwater management plans, or groundwater environmental flows is entirely absent (MDBMC 1998:11).

Cullen et al. (2000) in a review of CoAG reforms, noted "Generally there appears to be poor integration of the management of groundwater systems and surface water systems despite their acknowledged interconnectedness." Others echoed these views: Nevill (2001a:84) in a major review of State and Commonwealth water policy, recommended the urgent implementation of integrated groundwater and surface water management.

In November 2000, CoAG agreed to support a joint State/Commonwealth initiative, the *National Action Plan for Salinity and Water Quality*. The Action Plan made a 7-year, $1.4 billon commitment to improving land and water management in 21 stressed catchments across the nation, working largely through 35 regional resource management (NRM) agencies set up under Commonwealth guidelines. The Action Plan provided a mechanism to reinforce earlier commitments to integrated groundwater and surface water management, and to tackle issues of over-allocation. While the action plan *did* reinforce the need for integrated management, in fact little action was taken. Moreover, the opportunity to reduce over-allocation was largely missed, in spite of the availability of funds to buy back licences—the explanation appears to lie in bureaucratic and political inertia.

Importantly, the opportunity to extend the concept of comprehensive water management caps was also missed. The Action Plan restricted its recommendations in this regard: "caps [should] be set for all surface and groundwater systems identified as over-allocated or approaching full allocation." Firstly, this recommendation should have been extended to all moderately and heavily used catchments, not just those approaching full allocation. Inevitably, by the time a catchment is approaching full allocation, some important management options have already been closed. Logically, establishing catchment caps should depend on the availability of knowledge about a catchment's capacity, not on the extent of commitment of that capacity. Adaptive catchment management will be facilitated by early establishment of the catchment's limitations. Secondly, the way the recommendation was subsequently interpreted by NRM agencies was restricted to flow caps rather than comprehensive caps covering matters such as farm dams, levee banks, wetland draining, native vegetation clearance, and the development of intensive irrigation areas. Better guidance should have been provided, not just by the Commonwealth.

In 2001 the Council published their *Integrated catchment management in the Murray-Darling Basin 2001–2010*. This was a vehicle which could have emphasised the CoAG groundwater reforms, yet mention of these important policies was (inexplicably) entirely absent. Coherent discussion of the pressing issue of environmental flows was also entirely absent. Notably absent too was any discussion of the difficult but important issues of addressing over-allocation in both surface and groundwater, as well as caps on water related infrastructure and land developments (MDBMC 2001:12). Rather than take a visionary stand, this document carefully avoided the most contentious (and pressing) issues.

The Wentworth Group of independent scientists (2003:8) in their major report *Blueprint for a national water plan*, called for the development of *comprehensive water accounts* on a valley catchment basis; a "publicly available set of water accounts for each river valley and groundwater system across Australia, so that all water users, the community and river managers can make informed decisions". Limits must be established: "If one use consumes more water, another must consume less". The Group were adamant that "there can be no double counting". They stressed that linkages between groundwater and surface water must be recognised and accounted for. Here was a statement of plain good sense—'visionary' by comparison with the Council's inept policy development.

9 Vision and Caution

In regard to natural resource management, the Commonwealth Government and all State and Territory Governments espoused a strong commitment to the precautionary approach in the early 1990s (through, for example, the *National strategy for ecologically sustainable development*; Government of Australia 1992). According to the precautionary approach, where there is the possibility of significant harm, lack of scientific certainty should not prevent prudent action to avoid or mitigate such harm.

The possibility of serious damage to land, water and biodiversity values in the Basin had been clear for years or decades. Uncertainty is a pervasive feature of all water management, especially groundwater management. Application of precaution should increase as either uncertainty increases, or the severity of possible hard increases (Preston 2006). Yet precaution appears conspicuously absent from the Commission's action program and from its corporate statement. At the State level, Coffey (2001) found an absence of precaution in regard to the Queensland Government's water planning program, and it seems likely similar investigations would draw the same conclusion in other States (see a Victorian example discussed in Nevill 2001b).

Where surface waters and groundwaters are connected, a common-sense precautionary strategy is to apply extraction caps simultaneously to both resources. To my knowledge this has not been done anywhere in Australia. In Victoria for example, the Sustainable Diversion Limits (SDLs) which have been established as caps for surface water basins should have been accompanied (immediately) by caps to limit further groundwater extraction in all but deep confined aquifers. It is hard to understand why this has not been done—given the commitments of all Australian government to precautionary resource management.

According to Cullen (2006:5):

> To avoid making further costly mistakes with groundwater I believe we need to reverse the burden of proof. We should assume aquifers are connected to surface water unless proven otherwise, and we should assume any further extraction of groundwater is not sustainable unless demonstrated otherwise.

The immediate and widespread adoption of precautionary target and limit reference points is urgent (see the discussion in Section 13 below).

Another obvious and important precautionary policy regarding integrated management should be to assume, in the absence of a validated local model, a 1:1 ratio between groundwater extraction and surface baseflow reduction—see Box below. In other words, a precautionary assumption is made that the volume extracted from the adjacent aquifer is equal to the resulting flow reduction in the river. This should apply in all cases other than those where zero connection between a groundwater resource and surface waters (no matter how distant) can be clearly demonstrated. There appears to be no evidence that the Commission, or any State water agency, have even considered applying such a policy.

Box 1 A precautionary default

An obvious precautionary policy regarding integrated management would be to assume, in the absence of a validated local model, a 1:1 ratio between groundwater extraction and surface baseflow reduction.

Many groundwater planners would argue that this precautionary 'default' is unduly conservative. However, within a risk assessment framework (the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality,* ANZECC 2000, provide a good example of a risk-based approach to setting management targets) the function of a stage-one precautionary default is just that: to consistently err on the conservative side. Where there is good evidence which can justify a less conservative default through a connectivity risk assessment, or better still a validated model which can be used to determine a realistic catchment/aquifer water balance, then much less conservative parameters can be determined, and used with confidence by management. Those who believe that such a precautionary default is inappropriate should justify their position with scientifically sound evidence, taking into account the need to apply the precautionary principle in situations of risk and uncertainty.

In applying the precautionary principle, "the greater the possible harm, and the greater the uncertainty, then greater should be the caution" (Nevill 2006). Put another way: "The type and level of precautionary measures that will be appropriate will depend on the combined effect of the degree of seriousness and irreversibility of the threat and the degree of uncertainty" (Justice CJ Preston in *Telstra Corporation v Hornsby Council*, New South Wales Land and Environment Court 133, 24 March 2006, para 161).

In the issue under discussion, very high levels of threat are often combined with very great uncertainty. The threat under discussion (some would argue unlikely) is extremely serious: widespread unsustainable groundwater drawdown can produce, after decades or centuries, parched and denuded landscapes, an absence of ecological and agricultural resilience, and collapsed regional economies. Such damage can be, for all intents and purposes, irreversible once widespread vegetation death occurs and local townships collapse. Bearing in mind this high level of possible harm, the application of a solidly conservative first-stage default is fully justified.

According to Evans (2007:66) "A draft national policy to address the impacts of surface water/groundwater interaction in Australia (SKM 2006) proposes ten policy principles to be adopted at the national level. Perhaps the most significant principle is that the jurisdictions need to assess the impacts of groundwater abstraction on streams, and if no assessment is undertaken then a 1:1 hydraulic relationship is to be adopted. The adoption of the 1:1 impact is based on the precautionary principle and although, as discussed earlier, this is unlikely to be the norm, there are many situations in Australia where this is the case."

A key aspect of the precautionary principle is that it reverses the 'onus of proof'. Rather than adopting an assumption that a proposed activity will have no environmental impact unless there is already evidence to suggest otherwise, the precautionary principle obliges decision-makers to seek evidence from an activity proponent demonstrating that the activity will in fact have no significant effect.

A first-stage precautionary default of a 1:1 assumption is a logical and prudent approach.

At a national level, Australia formally endorsed use of the precautionary principle in natural resource management through the *World Charter for Nature 1982*, and later through the *Rio Declaration 1992*. All States endorsed the precautionary principle in 1992, as mentioned above. In spite of these commitments, and in full knowledge that many Basin groundwaters and surface waters were linked, the NSW State water agency has had a long track-record of issuing groundwater licences far in excess of demand (Goesch et al. 2007). *This approach is the reverse of precautionary*.

Over the Basin as a whole, 2004/2005 groundwater entitlements amounted to 3,250 GL/year, compared with an estimated sustainable yield of only 2,450 GL/year (Goesch et al. 2007:5). To make matters worse, almost all minor groundwater users are unmetered. Goesch et al. (2007:1) estimated that 60% to 80% of major users (across Australia) have not been required to meter their usage. Unmetered flows make accurate catchment water planning impossible, and foster a culture where compliance with licence conditions is seen as unimportant. It should also be noted that present assessments of groundwater sustainable yield are substantially inaccurate: Evans et al. (2003) have suggested regular inaccuracies of around 25%, and this estimate may itself err on the conservative side, given the complications in making such estimations (IAHA 2004).

Vision (although some would argue the elements were obvious) can be discerned in CoAG policy documents—in our case-study, related to integrated groundwater and surface water management. CoAG's policy on this issue was clearly stated in 1996 and re-stated in 2000. Vision too can be found in independent reports, such as the Wentworth Groups (2003) call for comprehensive water accounts. Authors such as Nevill (2003) amongst others, called for a comprehensive approach to the management of catchment cumulative effects—in effect a similar argument to that of the Wentworth Group. The Commission's own *Groundwater Technical Reference Group* (GTRG) had "a long held view that there should be a cap on total (surface water and groundwater) diversions within the basin and that the water resource should be managed in an integrated manner" (GTRG 2004:ES4).

10 Policy Without Action

No doubt the 'long held view' quoted above had been communicated to the Commission on a number of occasions—but where was the response? Where indeed was the response on the part of State water management agencies to their long-standing CoAG commitments?

In 2004, the Commission published a report by the GTRG: *Estimated impact of groundwater use on streamflow in the Murray-Darling Basin*.

According to the GTRG (2004:ES4):

- "Each jurisdiction has legislative and policy that allows for the integrated management of surface water and groundwater, but implementation of the integrated approach has not occurred to-date.
- The intended outcomes of the Cap on surface water diversions have been compromised as a result of the increased groundwater use since 1993/1994.
- The jurisdictions have identified technical and planning investigations that will be undertaken and investigations that are needed to reduce uncertainty, although the implementation plan for these investigations has not been made clear."

A later report by Land and Water Australia (LWA) stated:

- Australia has no agreed method for assessing the sustainable yield of groundwater (LWA 2007:13).

Comparing these outcomes with the CoAG 1996 policy commitments (see the Prime Minister's letter referenced above) it is clear that, *after nearly a decade, no effective action had been taken, either by the Commission or by State agencies, to implement core CoAG groundwater policy*.

A survey of all State water agencies, undertaken in late 2007, confirmed this finding (Nevill 2008). This survey focused on conjunctive water balance planning, and delivery of agreed environmental water allocations to groundwater-dependent ecosystems. The survey found no implementation of conjunctive water balance planning, and only one water allocation plan (across the whole nation) in full compliance with agreed environmental flow principles. These two policy elements are essential for the management of cumulative effects across the Basin, and fundamental to any management program aimed at sustainable use of groundwater. This inaction is, apparently, not restricted to the Basin, but appears as a major failure across the whole of Australia. Western Australia, Queensland and South Australia appear the most progressive States in a disappointing field (Nevill 2008).

11 Recent Developments

11.1 2004

CoAG's commitment to integrated groundwater and surface water management was re-stated again in the development of the National Water Initiative 2004. The *InterGovernmental Agreement on a National Water Initiative*, signed by the Commonwealth and participating States on 25 June 2004, listed "recognition of the connectivity between surface and groundwater resources, and connected systems managed as a single resource" as one of ten core NWI objectives (paragraph 23).

Paragraph 82 required the development of: "water resource accounts that can be reconciled annually and aggregated to produce a national water balance, including … systems to integrate the accounting of groundwater and surface water use where close interaction between groundwater aquifers and streamflow exist…". Paragraph 83 requires that: "States and Territories agree to identify by end 2005 situations where close interaction between groundwater aquifers and streamflow exist and implement by 2008 systems to integrate the accounting of groundwater and surface water." As discussed above, limiting these actions to situations where "close interaction between groundwater … and streamflow exists" is not a precautionary approach, given generally high levels of uncertainty regarding groundwater/surface-water interaction.

The *National Water Commission* (NWC) was created as a Commonwealth agency to oversee implementation of the NWI on behalf of the Commonwealth and CoAG. Its activities include oversighting water reform in the States (formerly the role of the National Competition Council—NCC) but it no longer has the ability to penalise the States for non-compliance by withdrawing Commonwealth support payments. Its water reform audit activities also appear less formalised and probably less effective than those of its predecessor (the NCC). The NCC had in fact used its penalty provisions: it had withdrawn the so-called 'trache' payments on a small number of occasions, and had been outspoken in identifying some non-compliance issues—a source of irritation to the States.

In late 2004 the Commonwealth Government (through the Natural Heritage Trust) funded Sinclair Knight Merz (SKM) to survey groundwater and surface water management in all Australian jurisdictions, with a view to recommending a national approach to integrated management. Their report, published in February 2006, proposed 10 core principles on which a national framework for integrated management could rest (SKM 2006). The report recommended actions by the Commonwealth Government to develop the framework in consultation with the States, including actions to establish technical education and public awareness programs. The landmark report contained model water balances, and outlined key elements of integrated water plans. Although the report was considered by the National Water Initiative Committee (reporting to the Natural Resource Management Ministerial Council) the report's recommendations were not formally endorsed, and remain, largely, without implementation.

11.2 2006

The Natural Resource Management Ministerial Council (NRMMC) met in Christchurch on 24 November 2006. Here "Ministers agreed a report for CoAG outlining progress in 2005–2006 on implementing the NWI. … States and Territories will report back to Ministers on progress of arrangements for the management of shared groundwater resources. Ministers noted that where water is being extracted from connected ground and surface water systems, water plans should reflect this connectivity".

The same month a group of senior Australian hydrogeologists released a short statement titled *National Groundwater Reform* (Evans et al. 2006). Their call for better groundwater management reiterated (with a sense of urgency and frustration) many of the policy initiatives dormant over the previous decade. Moving past policy, the group's statement of concern drew attention to serious funding shortfalls related to water infrastructure and data collection, technical and public education, and compliance programs. In brief, the group's main points were:

- Planning must identify sustainable levels of groundwater extraction and Governments must return over-allocated systems to sustainable levels.
- All groundwater use, except low-yielding domestic or stock bores, must be licensed and large users metered.
- We must develop a compliance program to stop unauthorized use of groundwater.
- All groundwater must be properly priced to pay for the ongoing resource assessment, monitoring and management, and compliance program.
- There are opportunities for surface water to be stored in aquifers rather than surface storages which have such high evaporation losses.
- Effective management of groundwater cannot be achieved with the current organisational arrangements within Government.
- Environmental water allocations must be managed by agencies that are not the same agencies who allocate water.

These are basic approaches which should have been incorporated into State government water management programs many years ago. While in several cases token commitments have been made, they still remain without enthusiastic implementation across the nation.

In December 2006, an Australian Government Senate Committee report drew attention to the failure of the States and the Commission to address over-allocation of groundwater in the Basin. In particular, the report quoted from the Commission's *Water Audit Monitoring Report 2004/05*: 65:

> The estimated sustainable yield … [of groundwater in] the Basin is reported to be 1534 GL/yr (Victorian SY figures are not available). Out of this, 2950 GL was already allocated in 2004/05, which constituted 192% of the sustainable yield. The total usage of groundwater in the Basin was 1490 GL, which was 51% of the allocation, and 97% of the sustainable yield (SCRRAT 2006:41).

Groundwater resources, which could have been reserved specifically as a drought buffer in a highly variable climate, have been spent—to the detriment of both human and non-human inhabitants of the Basin.

In a short but important paper, Professor Peter Cullen, a Commissioner in the National Water Commission, made the following comments and recommendations (Cullen 2006:6):

> Last century Governments encouraged the development of groundwater with little understanding, and took the view that they could redress any problems through a process of "adaptive management". However, landholders and communities developed expectations, and when the groundwater ran out believed Governments should compensate them for encouraging them to invest in a resource which was illusionary. Substantial taxpayer funds are now being invested in Northern NSW to redress these mistakes.

> There are still many parts of Australia where groundwaters are neither licensed nor metered. As a first step, there should be a moratorium on any new bores taking groundwater unless it can be shown that the groundwater system is not over-allocated. This is a simple application of the precautionary principle—don't spend without understanding your limits. Any new bore should be licensed and metered, and any theft of water should be treated by withdrawing the entitlements. All existing bores should be registered and metered within 5 years, or should be shut down.
>
> Management agencies need to withdraw groundwater licences that have not been used. The failure to withdraw sleeper licences when surface water trading commenced saw them activated and traded with serious consequences.

11.3 2007

In January 2007 the Commonwealth Department of Prime Minister and Cabinet published *A National Plan for Water Security*. The Plan proposed a $10 billion, 10-point plan "to improve water efficiency and address over-allocation of water in rural Australia." Of immediate interest, the Plan included several points relevant to our discussion:

4. addressing once and for all water over-allocation in the Murray-Darling Basin;
5. a new set of governance arrangements for the Murray-Darling Basin;
6. a sustainable cap on surface and groundwater use in the Murray-Darling Basin; and
10. completion of the restoration of the Great Artesian Basin.

Point 4 repeated historic commitments made in a variety of forums, but never effectively addressed. Point 5 sought to "reconstitute the MDBC as a Commonwealth Government agency reporting to a single minister." The report pointed out: "the MDBC has known for several years that the cap on diversions needs to be reduced and include groundwater to be effective, but his has not been achieved." Importantly, the report stressed the need for mandatory metering of licensed water usage (p. 8), and the need to seal free-flowing artesian bores (DPMC 2007).

While these are all commendable goals, so too are the earlier CoAG groundwater reforms, which remain today as empty promises. Australia is not short of good policy, but the nation is short on politicians and bureaucrats willing to implement it.

11.4 Commonwealth Groundwater Action Plan

In the lead-up to a Federal election, the Commonwealth Government announced a $52 million *Groundwater Action Plan* (Turnbull 2007a). Fifty million dollars of the Plan's budget will be spent largely on technical and scientific investigations. Only $2 million will go towards a capacity building program for groundwater managers—an issue highlighted in the recommendations of the 2006 draft framework document (SKM 2006) discussed above.

To put this in the perspective of the Government's funding priorities, $850 million was earmarked (also in the lead-up to the Federal election) just to assist local municipalities repair and upgrade local roads, while $64 million was allocated to assist the South Australian Government in the upgrade of the Port Augusta to Port Wakefield road, a minor national highway.

The Government's 2007 "action plan" showed no awareness of the extent of the nation's groundwater problems. The proposed level of expenditure is paltry compared to the sums necessary to tackle even the most pressing of the groundwater industry's problems. Two million dollars would fund only a few annual salaries in addressing capacity building—an urgent need. Well over $100 million is needed to address the most urgent of the issues of metering and compliance highlighted by Evans et al. (2006)—and these matters do not even feature in the information published on the action plan. The proposed plan does not progress key elements of the draft management framework (SKM 2006), or address the major concerns of Evans et al. (2006). In particular, the pressing issue of addressing over-allocation through buy-back or compensation appears to be entirely missing from the action plan.

The opposition (Labor) party, perhaps with an eye on rural votes sensitive to water restrictions, offered no better proposals. The difficult issues, and the need for adequate funding, were once again avoided by both major political parties.

11.5 The Commonwealth's Water Act 2007

Following the Prime Minister's initiative in January 2007, the Commonwealth Government attempted to persuade Basin States to refer their water management powers to the Commonwealth, on the basis of a comprehensive *Water Bill 2007*. The *Water Act 2007* passed through parliament in August 2007, and was subsequently amended by the incoming Labor Commonwealth Government.

The *Water Act 2007* replaced the Commission with a Commonwealth agency, the *Murray-Darling Basin Authority*, with the primary responsibility to develop a *Basin Plan*. "The central element of the Basin Plan will be the introduction of a sustainable and integrated cap on groundwater and surface water diversions" (Turnbull 2007b). The Commission will be obliged to act in accordance with the Basin Plan. "The Authority will also be responsible for advising the Minister on the accreditation of state water resource plans for consistency and compliance with the Basin Plan" (Turnbull 2007a). The Plan must develop components addressing environmental watering, water quality and salinity management. It will commence operation in 2011.

The new Authority occupies the same building, and carried over most of the staff from the Commission—but with a new chief executive officer (Rob Freeman, a Commissioner of the former Murray Darling Basin Commission). The new administrative arrangements are not a guarantee of that the long-standing failures of the Commission will be addressed. As argued above, water extraction caps are not in themselves a solution. Even if they were, State governments have demonstrated reluctance to implement caps designed to help the Basin as a whole. After over a decade, full compliance with the surface water Basin cap has yet to be demonstrated (IAG 2008). Two years after the Commonwealth Government announced its intention to require a cap on MDB groundwater extraction, CSIRO (2008:47) reported: "future groundwater extraction [in the Basin] could (according to current groundwater management plans) reach 3,528 GL/year by 2030" [above the 2004/2005 extraction level of 1,795 GL].

The waters of the Basin remain over-allocated to human use, and a wind-back, rather than a cap, is urgently needed—a retreat from development which needs careful thought and much community consultation (if social and financial pain is to be minimized). Without courage and real political will, the new Authority is likely to (again) adopt a narrow interpretation of 'comprehensive and integrated planning', and we may well see a perpetuation of the lack of vision, and the lack of caution, which have dogged management of the Basin for the last 100 years.

12 Conclusions

There are many Acts of Parliament, as well as important strategic policies, that are based on good intentions and sound logic but which fail at the level of implementation. This is particularly the case with respect to attempts to control the cumulative impacts of incremental development occurring over a substantial period of time. Even though a strategy may be put in place to control or prohibit new developments which would (for example) extract additional water from a catchment, it appears to be almost a general rule that the strategy will be subverted by numerous small approval decisions running directly counter to the intent, if not the letter of the strategy (Odum 1982). This tendency is compounded where the costs of resource degradation fall on the community (and future generations) rather than on the individual who benefits from resource exploitation (Hardin 1968).

In spite of the very obvious damage caused by the cumulative impacts of incremental water-related development, catchment management within the Basin remains characterised by both a lack of vision and a lack of caution. Surface waters and groundwaters have been grossly over-allocated for human use. Until very recently, little has been done to remedy this situation, and even now reform is happening far too slowly. Major government initiatives, such as the *National Action Plan 2000* and (to a lesser extent) the *National Water Initiative 2004* have failed to recognise or emphasise the pervasive and intractable damage caused by the cumulative impacts of incremental catchment development. Many major groundwater bores, not only in the Basin but across the continent, remain unlicensed and un-metered, and where compliance programs exist they are often (usually) poorly resourced.

Existing problems relate primarily to failures in governance rather than problems caused by, for example, scientific uncertainty or changing climate (Connell 2007). The full implementation of CoAG groundwater commitments, long ignored, is now essential—if further environmental and economic damage is to be avoided. It would appear that this will not happen under existing management arrangements and cultures, so these must change. Political will and intelligence must be brought into play immediately.

In many cases good groundwater management results in more efficient storage than damming surface water. Unchecked development of small farm dams across Australia is altering the hydrology of the rural landscape, to the great detriment of stream flows (Finlayson et al. 2008) What is needed is the integrated and comprehensive management of connected ground/surface water resources, including sound provision of adequate environmental flows. In some cases this may mean increased use of groundwater combined with reductions in surface water use. Over-allocation must be addressed, and, where possible, avoided by prudent foresight.

As a matter of urgency, cumulative effects within the water resource industry must be taken much more seriously. *Catchment management programs must have five critical elements*:

- the need to manage cumulative effects through the establishment of strategic development caps on a catchment basis must be *formally recognised in water resource legislation and in NRM planning processes*, and appropriate procedures must be established to set and implement the caps in consultation with stakeholders;
- *caps must be comprehensive and inclusive*; stakeholder consultation programs must establish caps covering: water extraction from both surface and groundwaters, the construction of farm dams (number and volume), agricultural drains, impediments to fish passage, and levee banks, the development of intensive irrigation and agroforestry, the clearance of deep-rooted vegetation, and activities (e.g. stock access) capable of degrading riparian vegetation essential to the health of river ecosystems;
- *passive adaptive management* principles (plan, implement, monitor, report, review—as used in the ISO 9000/14000 standards) must be rigorously incorporated within catchment planning processes (noting these principles already form part of Commonwealth NRM guidelines);
- the caps on development *must be set well ahead of the point where the catchment enters a stressed or crisis situation*; and
- last but not least, the caps must be set in a *precautionary* way, and a precautionary approach must be taken to conjunctive connectivity (as described above, including a default 1:1 assumption, and the use of target and limit reference points—see below).

Plans to protect catchment ecosystems cannot be effective without adequate knowledge of the relative value and the current condition of these ecosystems. There is an urgent need to develop comprehensive State inventories of inland aquatic ecosystems, incorporating both value and condition data (Kingsford and Nevill 2006) as well as critical dependencies on ground and surface water flows. Such inventories are slowly developing across Australia, but could benefit greatly by the development of a national framework supported by Commonwealth funding. Collaborative programs within the NWI towards this end are again moving far too slowly.

There have been long-standing calls by Australian groundwater experts for the States to develop a common method for determining necessary environmental flows for groundwater-dependent ecosystems, and a common method for determining aquifer sustainable yields. These are, of course, aspects of the same problem, and need to be addressed within the agreed framework of catchment/aquifer water balance planning.

13 Recommendations

Recommendations 1 The importance and intractable nature of the cumulative impacts of incremental water-related development must be recognised through changes to government legislation, policy, and management arrangements. Catchment management programs must be initiated including *all* five key principles outlined above, and such programs must be implemented urgently and enthusiastically.

Recommendations 2 Two of the most pressing practical issues, in implementing CoAG groundwater policy commitments, are to:

(a) develop catchment/aquifer management plans (or water allocation plans) which clearly demonstrate effective integration between ground and surface water management. Such plans must use an accurate catchment/aquifer water balance to produce a water balance account, and use this account in determining allocations in a precautionary way. Plans must use principles of sustainability which acknowledge the long timeframes involved in aquifer response. If groundwater is to be used as a buffer against drought, it is vital that a reserve be left for this purpose, for example by aiming to allocate no more than 50% of the annual sustainable yield in 'average' years.

and

(b) develop integrated surface/groundwater plans which include a specific allocation for environmental flows (to protect identified values in related groundwater dependent ecosystems) calculated and delivered in a way which meet agreed Commonwealth/State environment flow principles (ARMCANZ 1996a). Note that these principles remain official CoAG policy, although they have been under review. In line with recommendations in Evans et al. (2006) environmental allocations should be determined by an agency separate from the agency immediately responsible for determining water allocations.

Recommendations 3 A recommendation made by Goesch et al. (2007:14) is particularly important: it relates to the *prior* determination of management responses: ie the use of decision rules formulated in advance. The authors, bearing in mind the difficulty of making decisions on water allocation which place farmer's livelihoods at risk recommend that:

> "… groundwater managers [should] formalize a set of management actions that would be activated in the event of groundwater stocks falling below some predetermined thresholds.
>
> 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 [or above] target levels. These rules would also specify the action to be taken if the limit reference point was breached."

Example rules would reduce groundwater allocations as a target point (which might be groundwater table level near a connected stream) was approached. For example, additional restrictions might apply on pumping volumes or times. Once a target point had been exceeded, heavier restrictions would apply; for example irrigation extractions might be prohibited while still allowing extractions for limited town water and rural stock and domestic uses. Once a limit point was reached, all groundwater extraction in that aquifer should cease. It is important to stress again that such actions *must be discussed and agreed in advance*. This approach also reduces the likelihood of political 'interference' in agreed decision-making processes—see comments by Tan (2000) quoted above.

13.1 Factors Affecting All Recommendations

It is also important that integrated management should be applied to *all* surface/aquifer systems, not just highly connected systems. As IAHA (2004:14) pointed out: "It has been shown that even in disconnected systems, the use of one resource can affect the other". Precaution should increase as uncertainty increases.

Following the discussion above, State Governments need to agree on a common approach to determining (and applying) aquifer sustainable yields.

Another challenge for management planning is to determine the relative priority of water users (including GDEs) in receiving allocations in a scenario of 'permanent' reductions in rainfall—which climate change appears to be bringing to southern and eastern Australia. How does one compare the water needs of a high value agricultural enterprise with a stygofaunal community which may support fauna found nowhere else (Humphreys 2006)? Among the principles currently supported by COAG is Principle 4, which states:

> In systems where there are existing users, provision of water for ecosystems should go as far as *possible* to meet the water regime necessary to sustain the ecological values of aquatic ecosystems, whilst recognising the existing rights of other water users (ARMCANZ 1996b) [emphasis added].

A critical aspect affecting implementation of all three of these recommendations, is the routine use of independent peer review prior to finalising plans and associated allocations. It is essential that the plans, their supporting information, as well as the peer reviews be readily available to all stakeholders and interested parties.

Acknowledgements My thanks to Ray Evans and Simon Hone for their help in alerting me to errors and omissions in the draft manuscript, and to Brian Finlayson, Tony Ladson, Jane Coram, John Harris and Imogen Fullagar for their helpful insights and additions, and assistance with references. Two anonymous referees provided encouragement and critical comment. I thank Marios Sophocleous for the inspiration.

References

ANZECC Australian and New Zealand Environment and Conservation Council (2000) Australian and New Zealand guidelines for fresh and marine water quality. Department of the Environment and Heritage, Canberra

ARMCANZ Agriculture and Resource Management Council of Australia and New Zealand (1996a) National principles for the provision of water for ecosystems. Standing Committee on Agriculture and Resource Management, Canberra

ARMCANZ Agriculture and Resource Management Council of Australia and New Zealand (1996b) Allocation and use of groundwater: a national framework for improved groundwater management in Australia. Task Force on CoAG Water Reform, Canberra

Chen D (2003) Report on Dumaresq River groundwater model: model development. Department of Natural Resources and Mines Queensland, Brisbane

Coffey F (2001) Assessment of water resource plans under the Water Act 2000 (Queensland) with consideration of ecological outcomes and environmental flow objectives in the context of the precautionary principle and sustainable management. Environ Plann Law J 18:244–256

Connell D (2007) Water politics in the Murray-Darling Basin. Federation Press, Sydney

CSIRO (2008) Water availability in the Murray-Darling Basin. CSIRO Division of Land and Water, Canberra

Cullen P (2006) Flying blind—the disconnect between groundwater and policy. Paper presented to the Murray-Darling Basin Groundwater Workshop, Canberra, 19 September

Cullen P, Whittington J, Fraser G (2000) Likely ecological outcomes of the COAG water reforms. Cooperative Research Centre for Freshwater Ecology, Canberra

Danielopol DL, Griebler C, Gunatilaka A, Notenboom J (2003) Present state and future prospects for groundwater ecosystems. Environ Conserv 30:104–130. doi:10.1017/S0376892903000109

DPMC Department of Prime Minister and Cabinet Australia (2007) A national plan for water security. Department of Prime Minister and Cabinet, Canberra

Earth Tech Engineering (2003) Review of selected factors that may change future flow patterns in the River Murray system. Murray Darling Basin Commission MDBC, Canberra

Evans R (2007) The impact of groundwater use on Australia's rivers: technical report. Land and Water Australia, Canberra

Evans R, Clifton C (2001) Environmental water requirements to maintain groundwater dependent ecosystems. Department of the Environment and Heritage, Canberra

Evans R, Richardson S, Hillier J, Bonte M, Dyson P, Ross J, Middlemis H (2003) Watermark: sustainable groundwater use within irrigation regions. Murray-Darling Basin Commission MDBC, Canberra

Evans R, Evans R, Jolly P, Barnett S, Hatton T, Merrick N, Simmons C (2006) National Groundwater Reform, Sydney, November. Available at http://www.ncgm.uts.edu.au/media/National_GW_Reform.pdf

Finlayson B, Ladson A, Nevill J (2008) Managing cumulative impacts on Australia's water resources. Paper presented to the Water Downunder Conference, Adelaide

GABCC Great Artesian Basin Consultative Council (2000) Great artesian basin strategic management plan. Department of Agriculture, Fisheries and Forestry Australia, Canberra

Goesch T, Hone S, Gooday P (2007) Groundwater management: efficiency and sustainability. ABARE Australian Bureau of Agricultural and Resource Economics, Canberra

Government of Australia (1992) National strategy for ecologically sustainable development. Australian Government Publishing Service, Canberra

GTRG Groundwater Technical Reference Group (2004) Estimated impact of groundwater use on streamflow in the Murray-Darling Basin. Murray-Darling Basin Commission, Canberra

Hafi A, Brownlowe N, Welsh W (2006) Groundwater and surface water use in the Dumaresq River Valley. Australian Bureau of Agricultural and Resource Economics ABARE, Canberra

Hardin G (1968) The tragedy of the commons. Science 162:1243–1248. doi:10.1126/science.162.3859.1243

Hatton T, Evans R (1998) Dependence of ecosystems on groundwater and its significance to Australia. Land and Water Australia, Canberra

Humphreys WF (2006) Aquifers: the ultimate groundwater-dependent ecosystems. Aust J Bot 54:115–132. doi:10.1071/BT04151
IAG Independent Audit Group (2007) Review of cap implementation 2005/06. Murray-Darling Basin Commission, Canberra
IAG Independent Audit Group (2008) Review of cap implementation 2006/07: report of the Independent Audit Group. Murray Darling Basin Commission, Canberra
IAHA International Association of Hydrogeologists Australia (2004) Guiding principles for sustainable groundwater management. Murray-Darling Basin Commission in collaboration with Resource and Environmental Management SA, Canberra
Jones G, Hillman T, Kingsford R, McMahon T, Walker K, Arthington A, Whittington J, Cartwright S (2002) Independent report of the expert reference panel on environmental flows and water quality requirements for the River Murray System. River Murray Project Board, Canberra
Kingsford R, Nevill J (2006) Urgent need for a systematic expansion of freshwater protected areas in Australia: a scientists consensus statement. Pac Conserv Biol 12(1):7–14
Ladson A, Finlayson B (2002) Rhetoric and reality in the allocation of water to the environment: a case study of the Goulburn River, Victoria Australia. River Res Appl 18:555–568. doi:10.1002/rra.680
Ludwig D, Hilborn R, Walters C (1993) Uncertainty, resource exploitation and conservation: lessons from history. Science 260(2):17. doi:10.1126/science.260.5104.17
LWA Land and Water Australia (2007) The impact of groundwater use on Australia's rivers: exploring technical, management and policy challenges. LWA, Canberra
MDBC Murray-Darling Basin Commission (2008) Water audit monitoring report 2006/07: report of the MDBC on the cap on diversions. MDBC, Canberra
MDBMC Murray-Darling Basin Ministerial Council (1998) Floodplain wetlands management strategy. Murray-Darling Basin Commission, Canberra
MDBMC Murray-Darling Basin Ministerial Council (2001) Integrated catchment management in the Murray-Darling Basin 2001-2010. Murray-Darling Basin Commission MDBC, Canberra
Nevill J (2001a) Freshwater biodiversity: protecting Australian freshwater ecosystems in the face of infrastructure development. Water Research Foundation of Australia, Canberra
Nevill J (2001b) Submission: Wy Yung groundwater supply protection area groundwater management plan draft for consultation Southern Rural Water. Available at http://www.tucs.org.au/~cnevill/Submission_Wy_Yung_groundwater.doc. Accessed January 3, 2007
Nevill J (2003) Managing the cumulative effects of incremental development in freshwater resources. Environ Plann Law J 20(2):85–94
Nevill J (2006) The precautionary principle in Australian ocean management, OnlyOnePlanet Australia. Available at http://www.ids.org.au/~cnevill/marinePrecautionaryPrinciple.doc. Accessed August 18 2007
Nevill J (2008) Comment on recent progress in water-balance planning and the supply of environmental flows to ground water-dependent ecosystems. Ecological Management & Restoration 9(2):145–148. doi:10.1111/j.1442-8903.2008.00407.x
Odum W (1982) Environmental degradation and the tyranny of small decisions. Bioscience 32(9):728–729. doi:10.2307/1308718
Preston, Justice CJ (2006) New South Wales land and environment court. Telstra Corporation Limited v Hornsby Shire Council, 133, 24 March 2006
Pringle CM (2001) Hydrologic connectivity and the management of biological reserves: a global perspective. Ecol Appl 11:981–998. doi:10.1890/1051-0761(2001)011[0981:HCATMO]2.0.CO;2
SCRRAT Senate Standing Committe on Rural and Regional Affairs and Transport (2006) Water policy initiatives: final report. Department of the Senate—Parliament House, Canberra
Sinclair Knight Metz SKM (2003) Projections of groundwater extraction rates and implications for future demand and competition for surface water. Murray-Darling Basin Commission, Canberra
Sinclair Knight Metz SKM (2006) Towards a national framework for managing the impacts of groundwater and surface water interaction in Australia. Department of Agriculture, Fisheries and Forestry Australia, Armadale Melbourne
Sommer B, Horwitz P (2001) Water quality and macroinvertebrate response to acidification following intensified summer droughts in a Western Australian wetland. Mar Freshw Res 52:1015–1021. doi:10.1071/MF00021
Sophocleous M (2000) From safe yield to sustainable development of water resources—the Kansas experience. J Hydrol 235(1–2):27–43
Sophocleous M (2002) Interactions between groundwater and surface water: the state of the science. Hydrogeol J 10:52–67. doi:10.1007/s10040-001-0170-8

Southern Rural Water SRW (2007) Draft water plan 2008-2013. SRW, Maffra Victoria
Tan P-L (2000) Conflict over water resources in Queensland: all eyes on the Lower Balonne. Environ Plann Law J 17:545–568
Turnbull M (2007a) New $52 million groundwater action plan. Press release. Parliament House, Canberra, 19 Sept
Turnbull M (2007b) Water bill 2007—second reading speech. Available at http://www.malcolmturnbull.com.au/news/Article.aspx?ID=898. Accessed February 9, 2007
Turral H, Fullagar I (2007) Institutional directions in groundwater management in Australia. In: Giordano M, Villholth KG (eds) The agricultural groundwater revolution: opportunities and threats to development. CAB International, London
Wentworth Group of Concerned Scientists (2003) Blueprint for a national water plan. WWF Australia, Sydney
WRON Alliance (2007) Australian water resources 2005: a baseline assessment of water resources for the National Water Initiative. National Water Commission Australia, Canberra
Zektser S, Loaiciga HA, Wolf JT (2005) Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States. Environ Geol 47:396–404. doi:10.1007/s00254-004-1164-3