15 Institutional Directions in Groundwater Management in Australia

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Now the stock have started dying, for the Lord has sent a drought;
But we're sick of prayers and Providence – we're going to do without; . . .
As the drill is plugging downward at a thousand feet of level,
If the Lord won't send us water, oh, we'll get it from the devil;
Yes, we'll get it from the devil deeper down.

From 'Song of the Artesi an Water' (1896)
by A.B. Banjo Paterson, Australian bush poet

Introduction

Australia is a large country, covering 7.69 million square kilometres, with a relatively small population of 20 million (Australian Bureau of Statistics, 2005). Agriculture accounts for a paltry 3% of gross domestic product (GDP) and only 6.88% of the land surface is under arable cropping, with 0.03% under permanent crops. In 1997, 5% of the labour force was directly engaged in agriculture (http://worldfacts.us/Australia.htm) compared with 22% in industry and 73% in services. These statistics set it a world apart from densely populated agrarian countries such as India and China.

Although agriculture has declined from being a major contributor to national wealth (>27% of gross national product (GNP) in the late 1980s), it still has a strong export focus. There have been considerable structural adjustments in agriculture in the last 20 years in response to Australia's commitment to free trade, removal of input and output subsidies and widespread application of 'user-pays' principles in service sectors. The recent strength of the mining sector with strong global demand for iron and aluminium has contributed to the relatively small contribution of agriculture to GNP.

Governance and Natural Resources Management

Australia is a democratic federation of six states and two territories, united by the Commonwealth government (federal government). Cohesion within this structure is cemented by centralization of income tax collection, the revenue of which is redistributed to the nine (central, state and territory) governments. There is a third layer of local government at the municipal (urban) and shire (country) levels. The state, territory and local governments can also contribute by raising some local revenue (e.g. states via petrol levies and local government via service levies).

Water is the responsibility of the state and territory governments (henceforth referred to as 'states' or jurisdictions) under the Australian Constitution, each having independent water laws and distinct policies. However, international issues, common jurisdictional concerns and Commonwealth leverage of Section 96 of the Australian Constitution (which allows the Commonwealth to grant financial assistance to any state on terms determined by the Commonwealth) have accelerated the development of a federal role in the national water policy (McKay, 2002).

Issues of national significance that concern the Commonwealth and all state governments are dealt with by the Council of Australian Governments (COAG). The COAG deals with a wide raft of issues through a number of ministerial councils. These councils facilitate development and implementation of national plans and proposals that would otherwise be impinged by the division of constitutional powers between the federal and state governments.

The Natural Resources Management Ministerial Council (NRMMC) was formed in 2001 'to promote the conservation and sustainable use of Australia's natural resources'. All Australian and New Zealand government ministers responsible for natural resource management issues are members. Decisions of the Council require consensus of the members. The reorganization through which the NRMMC evolved saw this Council absorb roles and responsibilities previously held by the Agricultural Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment and Conservation Committee (ANZECC). Many current national water policies were therefore developed through the ARMCANZ and ANZECC.

Within this structure, the National Groundwater Committee (NGC) is a senior intergovernmental network that shares information and provides insight into the national groundwater policies and resource management, research directions, priorities and programmes. It also provides advice on groundwater issues, including those pertaining to surface water–groundwater interactions. The subject of groundwater is dominated by two issues:

1. salinity management;
2. extractive use.

Salinity management is perhaps more important, given the significance of irrigation-induced salinity problems, particularly in the state of Victoria, and of the parallel but slower development of dryland salinity in the state of western

Australia. Irrigation-induced salinity largely occurs because of the rise in water table, due to progressive accessions from irrigated fields and water supply infrastructure, where the groundwater is naturally saline or intersects naturally saline soils and rock formations.

Dryland salinity is emerging as a widespread and serious problem in catchments that have been cleared for dryland agriculture and pasture (National Land and Water Audit (NLWA), 2001): shallow-rooted crops and grasses transpire less water each year than the native scrub and forest, resulting in small net annual accessions, which, over 50–100 years, have also contributed to the rise in water table and attendant local salinization, particularly near streams and inland water bodies. The most alarming estimates of potentially affected areas for 2030 run to approximately 20 million hectares.

Since the main focus of this chapter is on the use of groundwater in agriculture, with only a passing reference to other sectors, it is instructive to set the context of irrigation development and water resources management in Australia.

A Brief History of Irrigation Development in Australia

In the first decade of the 19th century, Australia's agriculture dealt mainly with sheep, wool, beef and wheat production. The comparatively slow development of the irrigation sector compared with that of dryland reflects the high river flow variability characteristic of Australia, and the associated prerequisite of securing water supply through dam development. Despite the greater water resources in northern Australia, the history of urban and market access have largely dictated the geography of the irrigation industry, which is today dominated by development in the southern half of the Murray–Darling Basin (MDB) (see case study 1).

From 1901 (since the Federation) to the early 1990s, Australian governments were determined to 'drought-proof' the continent through river development (Tisdell *et al.*, 2002). Development of water courses and provision of security of supply were seen as a public good, necessary for the development of the nation. As agents for water resources, the states were the primary developers of surface water infrastructure. This resulted in extensive dam building and associated engineering works, which are represented by the Snowy Mountains hydroelectric scheme, a huge engineering feat that captures and redirects 5044.5 l (1121 gallons) of water from its natural course down the Snowy River into the MDB system. The dam's construction (which spanned 25 years and involved more than 100,000 workers) illustrates the level of cooperation between governments, which was fuelled by the general optimism of the development era.

Irrigation development was associated with concentrated efforts to settle high potential areas following the two World Wars – normally discussed as 'soldier settlement'. Private irrigation trusts were also established in the late 19th century, but were relatively small scale compared to state-sponsored developments. Public investments for dam construction, channel infrastructure and promotion of expansion within the industry made for an industry dominated by the heavily subsidized surface water irrigation industry. In contrast, groundwater development has been sparse, privately financed and localized, with a greater emphasis on non-agricultural use, partly due to the extensive development of surface water resources.

The goodwill generated by shared development ambitions and successful collaborative social and engineering projects have served intergovernment communication through similar jargon and shared responsibilities. This history underpins the relatively cooperative endeavour of water reforms today.

The development agenda of the early and mid 20th century declined since the 1970s, with the realization that the resource base in key areas (notably the MDB) was being jeopardized. It was realized, in the late 1970s, that the licensed volumes within the MDB exceeded the available supply on which interstate water-sharing arrangements were based (Turral, 1998). It was clear that the value of building additional dams would therefore come at a cost of filling existing storages. Quite clearly, in the developed irrigation sites, there was no surface water to harvest and any further development would reduce the security of supply to existing users.

Furthermore, the irrigation industry was increasingly aware of the environmental overheads of their own practices. The expense and political sensitivities relating to the riverine impact of salinity were expanding, and there was growing pressure for irrigators to internalize these costs by improving farm management. Rivers and inland wetlands were impaired by reductions in in-stream flows and, in some cases, through inversion of flow patterns, as irrigation water is released from dams in summer, whereas natural flows are mostly concentrated in winter in south and east Australia.

In the early 1980s, issues surrounding the proposal to dam the Franklin River resulted in an explosion of public debate and environmental awareness relating to river development. The Franklin Dam was a Tasmanian proposal, which was successfully halted by the Commonwealth Government on the basis of the World Heritage listing.

In terms of water development, the significance of the Franklin Dam was twofold:

1. It confirmed (by precedent) a Commonwealth power to intervene in activities previously held to be state responsibilities.
2. It clearly demonstrated, through polls, the public priority of environmental sustainability.

Coincidentally, the state governments were also reluctant to continue to subsidize the operation, maintenance and replacement of irrigation systems. As a result they were corporatized (Victoria) or fully privatized (New South Wales, NSW) in the 1990s, and are now run by professional managers responsible for farmer-dominated management boards. The governments also recognized the full environmental and financial costs of water diversion and transmission, and maintenance overheads of the existing infrastructure. Tisdell *et al*. (2002) clearly summarize:

> [A] singular construct of water capture and reticulation, which traditionally reflected the primacy of national development, was increasingly seen as failing to capture the multiplicity of water outputs, ecosystem functions and the changing societal objectives of maintaining in-stream values and water quality.

Water Property Rights

Surface and groundwaters are both licensed by, or on behalf of, the state governments, under state-specific water legislation and policy; licence details therefore vary considerably across the states.

A level of security is normally applied to water licences. This is traditionally based on the purpose for which the licence was originally issued. The accepted priorities of water supplies (from highest to lowest) are: town supply, stock and domestic, perennial crop (e.g. vineyards and orchards) and annual crops (e.g. grains).

Most water licences are specified in volumetric terms as an entitlement, based on a certain level of historical security of supply (exceeding availability in 99% of years, in the case of Victoria). Volumetric measurement and charging for surface irrigation water have been the norm throughout most of the MDB since the 1960s and date back much longer in Victoria. The actual amount a licence-holder can obtain in 1 year is determined *pro rata* by the announced allocation, which is reviewed every month, based on different formulas that incorporate available storage, plus minimum (1:100 year) expected rainfall volume, less the volume required by high-priority uses. The precise formulation of the allocation and entitlement rules varies from state to state, particularly in relation to environmental reserve, environmental flow rules governing dam operations and the ability to carry over unused allocations from one year to the next.

To some extent, this ‘share’ approach was the result of an explicit rejection of the ‘prior appropriation’ doctrine practised by the western states in America (Tisdell, 2002). It could nevertheless be contended that environmental and some native water titles can claim priority at least partially by virtue of history. The capacity of a share approach to entirely avoid prior appropriation issues also rests heavily on sound definition and hydraulic understanding of the water resource being licensed, implicitly assuming that these licensing frameworks account for any hydraulic connectivity between institutionally independent resources (e.g. surface water and groundwater).

In the MDB, interstate water shares were agreed in 1915 and those limits were not tested by water resources developments until it was realized (in the late 1970s) that the licensed volume exceeded the available resource, notably in NSW (Turral, 1998).

Subsequently, it was realized that the existing licensed volume already exceeded the sustainable water resource and that, at the prevailing rates of irrigation expansion, the actual diversion would exceed sustainable limits by 2020 (MDBC, 1996) and possibly approach the volume of annual runoff to the sea. A Cap on diversions of surface water within the MDB was agreed in 1995, set not to exceed the volume diverted at the extent of agricultural development in 1994. It was left to each state to work out how to implement the Cap and it has been independently audited annually since then. The idea of a rolling cap was implemented de facto, which allows states to overrun the Cap in low allocation years provided they balance this in subsequent above-average years. Since 2000, 3–4 years of consecutive drought, with less than the previous 1:100 year water availability, have put some strain on this arrangement. The largest volume of unused licences is in NSW, due to the existence of sleeper and dozer[1] users and relatively conservative withdrawals by many farmers in response to the lower security of supply in NSW, where there is considerably less interannual storage volume than in Victoria.

Water trading has been activated through private, state and central initiatives since the mid-1980s, although temporary trading has a long and informal history. The liberalization of water trading since the mid-1990s has activated some of this unused volume, putting further strain on the security of supply to existing users (Panta *et al*., 1999). The market is dominated by temporary transfers of unused allocation within a season and activity reflects the general drought cycle and water resources availability, whilst permanent trades account for less than 1% of the licensed volume (Turral *et al*., 2005). Most of the water trade is between irrigators within a particular state, and interstate trading is currently limited by questions of exchange rate between upstream and downstream transfers (Etchells *et al*., 2004).

Institutional Reform in Water Resources Management in Australia

Reforms in water resources management in Australia have proceeded along three main lines, which have complementary origins in the community and in government: (i) state-driven water accounting and allocation reforms, pricing, cost recovery, removal of subsidies and administrative reform; (ii) a community-initiated movement for better land and water management – now commonly lumped under the banner 'LandCare'; and (iii) the development and specification of environmental flows, river flow rules and strategies to mitigate in-stream salinity and algal blooms. Land and water have been considered complementary factors in this process.

The Brundtland Report (World Commission of Environment and Development, 1987) highlighted the international importance of co-dependency between environmental and economic policy in achieving sustainability. Australia responded through the National Strategy for Ecologically Sustainable Development (NSESD, COAG, 1992) (http://www.deh.gov.au/esd/national/nsesd/strategy/index.html), which adopted the 'precautionary principle' as a guiding philosophy. This strategy had three broad objectives:

1. to enhance individual and community well-being by following a path of economic development that safeguards the welfare of future generations;
2. to provide equity between generations;
3. to protect biological diversity and maintain essential ecological processes and life-support systems.

Management of surface water has been high on the agenda and the laboratory has often been the MDB, due to the extent of irrigation and surface water development. Regulation of the river has allowed increased reliability in agricultural production through a combined dam storage volume equivalent to 2.8–3 years of mean annual flow, but this security has occurred at the expense of river health (MDMBC, 1996).

As a component of the NSESD, reform of the water industry was tied to microeconomic reforms via the National Competition Policy reform package (1995). Within this package, financial benefits of microeconomic reforms were distributed on the basis of performance against specific reform agendas, including that of water (Tisdell *et al*., 2002), through 'tranche' payments of central tax revenue to individual states on compliance with agreed targets. In tandem with reforms focused on the MDB, the COAG began a process of reform aimed at removing subsidies and ensuring competition and economic efficiency. COAG (1994) water reforms were intended to allow water to move to its most productive use by enabling water markets and full cost recovery of the operation and maintenance of irrigation systems. This incentive initiated rapid institutional changes, including significant legislative amendment. By the necessity of relevant time frames, these were implicitly driven by the dominant surface water issues.

Recognizing continuing resource issues and the need for further reform to fully develop and deliver full cost pricing policies (van Bueren and Hatton MacDonald, 2004), the COAG agreed to the National Water Initiative (NWI) in 2004 (COAG, 2004). The NWI objective explicitly identifies its application both to surface and groundwaters, and more specifically the issue of surface water–groundwater connectivity. This implies an inconsistent implementation of earlier COA OPG, 2004 (1994) reforms across surface and groundwaters, which is generally acknowledged as a lag between implementation of surface and groundwater reforms in most states.

In agreement with the NWI, the COAG delegated the following responsibilities to the NRMMC:

1. overseeing implementation of the NWI, in consultation with other minister ial councils as necessary and with reference to advice from the COAG;
2. addressing ongoing implementation issues as they arise;
3. providing annual reports to the COAG on the progress with actions being taken by jurisdictions in implementing the NWI;
4. developing a comprehensive national set of performance indicators for the NWI in consultation with the National Water Commission (NWC) (set up to implement the NWI).

Somewhat contentiously, the NWI proposed a fund to buy back surface water for the environment based on financial contributions from the state and central governments. This was derailed for some time due to the Commonwealth's intention to fund NWI from the Natural Heritage Trust, at the expense of previously agreed initiatives and payments to the states.

The story of LandCare is rich, varied and interesting and is well documented elsewhere (Ewing, 1996). It began with genuine, community-based initiatives in irrigated salinity management in Victoria and catchment management for dryland salinity in western Australia in the mid-1980s. LandCare became a national programme in 1992, following the historic joint initiative of the Australian Conservation Foundation (an environmental NGO) and the National

Farmers Federation. By 2001, there were 4500 LandCare groups incorporating 50% of farmers and 35% of land administrators. This phenomenal growth in community-based management of natural resources and associated investment went largely unevaluated until 2000, when the National Land and Water Audit (1999–2002) was established to set a benchmark on resource availability, use and condition, and allow future evaluation of the impacts of community and other initiatives on the resource base. Simultaneously, many felt that there were too many voices from the plethora of LandCare groups, sometimes working at too local a scale. This resulted in the creation of umbrella groups for coordinated community-based management, now well established, such as the Catchment Management Authorities (CMAs) in Victoria. Despite fears of a creeping bureaucratization of grass-roots initiative, CMAs have emerged as a central force in natural resources management, where essentially the community decides and partly self-funds management plans and their implementation, using state agencies and commercial companies as advisers and consultants.

In conjunction with the NWI, there are other state-level initiatives, such as the 2004 Victorian White Paper 'Securing our Water Future Together' (DSE, 2004), that move the focus of land and water management to be framed more tightly within the concepts of environmentally sustainable development. With that broad introduction to the setting and recent institutional reform in the water sector as a whole, we now turn to the specifics of groundwater.

National Groundwater Resources and Use

A series of water resources assessments were conducted in Australia, with a primary focus on surface water. These assessments included:

- a review of Australia's Water Resources (1975), Australian Water Resources Council (1976), resulting among other outputs in 'Australian Rainfall and Runoff', a key work on hydrological data and methods in the continent;
- first national survey of water use in Australia (1981), Department of National Development;
- a review of Australia's Water Resources (1985), Australian Water Resources Council (1987);
- Water and the Australian Economy (AATSE) (1999);
- Water Account for Australia, Australian Bureau of Statistics (2000);
- National Land and Water Resources Audit (NLWRA) (2000), update of AWRC (1985).

Most of these studies were complemented by detailed hydrogeological and water resources assessments in the states, but had historically focused on resource development, and there was little information on actual groundwater use. The NLWR. A provides the most comprehensive national overview of groundwater availability and use in Australia to date. It estimated that the national groundwater availability amounts to 25.78 billion cubic metres per year on average, of which 21 billion cubic metres is of potable quality (NLWRA, 2002). Total abstraction in 1996/97 amounted to less than 10% of this at 2.49 billion cubic metres. On the face of it, this does not look to be a problem. However, poor distribution of groundwater use across available resources has resulted in overallocation of many good-quality and readily accessible groundwater stores – often the alluvial plains of prior and existing riverbeds within which surface water irrigation districts lie. The sustainable yield of groundwater in each state is shown in Table 15.1 and is disaggregated by salinity status, showing that about 63% is of high quality. It shows that salinity concerns are greatest in Victoria, western Australia and south Australia (SA). Salinity problems are on the rise in specific localities in NSW.

Nationally, about 50% of total groundwater abstraction is for irrigated agriculture (Table 15.2), but this figure rises to 65% in Victoria and NSW and is highest in SA at 80%. Groundwater allocation is a little over one-fourth of the total national water resources availability and less than one-third of the surface water allocation. The available resource in Northern Territories (NT) (Table 15.2) is enormous compared with actual allocation, so the fact that actual use exceeds allocation is not necessarily significant in resource management terms. The same story is broadly true for Tasmania. Rural water use includes stock and domestic water provision, and the majority of water abstracted from the Great Artesian Basin (covering large parts of NSW, Queensland and NT) is for pastoral use. A detailed breakdown of groundwater use is available for 286 out of 538 groundwater management units across the nation, and summary data are available for 377 of them. Groundwater is the sole source of water for many rural towns, mines and associated settlements.

Many surface-irrigated properties in northern Victoria and throughout NSW also have bores as drought insurance and for supplementing surface water supplies. Generally they abstract from deeper, higher-quality aquifers, which are separated from saline layers by an aquitard. Nevertheless, some provide water of suboptimal quality which is mixed with surface water before being applied to the crop (known colloquially as 'shandying').

In many areas, actual use is significantly less than allocation (Table 15.3). However, the local balance of use and conservation can be highly variable between years.

Table 15.1. Sustainable yield, by salinity status, of groundwater in Australia. (From National Land and Water Audit, 2002.)

	<500	500–1,000	1,000–1,500	1,500–3,000	3,000–5,000	5,000–14,000	>14,000	Total
NSW	554	4,237	129	790	480	–	–	6,189
VIC	302	422	244	367	207	1,377	797	3,717
QLD	1,422	1,030	113	160	35	23	–	2,784
WA	514	1,162	1,150	1,500	766	841	371	6,304
SA	–	290	709	102	21	25	–	1,146
TAS	1,585	767	–	178	–	–	–	2,531
NT	5,785	186	324	141	5	–	–	6,441
ACT	103	–	–	–	–	–	–	103
Total	10,264	8,094	2,670	3,238	1,515	2,266	1,168	29,215
%	35	28	9	11	5	8	4	100

Table 15.2. Mean annual groundwater extraction by category of use (million). (From National Land and Water Audit, 2002.)

	Irrigation	Urban/industrial	Rural	*In situ*	Total
NSW	643	160	205	0	1008
VIC	431	127	54	10	622
QLD	816	265	541	0	1622
WA	280	821	37	0	1138
SA	354	23	42	24	430
TAS	9	7	4	0	20
NT	47	48	33	0	128
ACT	2	0	3	0	5
Total	2003	1370	788	34	4171

Table 15.3. Total annual water allocations in Australia, in MCM. (From National Land and Water Audit, 2002.)

	Surface water allocation	Ground water allocation	Total allocation	Total water use	Δ allocation – use	% difference allocation–use
NSW	9,825	2,665	12,490	10,004	2,486	25
VIC	5,469	780	6,249	5,788	–461	7
QLD	3,202	983	4,185	4,591	406	–9
WA	855	1,138	1,993	1,796	197	10
SA	740	630	1,370	1,266	104	8
TAS	403	20	423	471	–48	–11
NT	53	73	126	179	–53	–42
ACT	76	7	83	73	10	12
Total	20,623	6,296	26,919	23,280	3,639	16

While groundwater development in western Australia, NT and the Australian Capital Territory is dominated by priority (town supply, stock and domestic) uses, intermittent surface flows have resulted in the agricultural development of groundwater as a primary agricultural source in many parts of SA. SA is also distinguished by the security of its surface water supply via the Murray River, which is a volume secured in agreement with Victoria, NSW and the Commonwealth (case study 1). This allows SA much tighter accounting mechanisms than can be accommodated by the less certain water budgets of other states.

Characteristics of Groundwater Irrigation Development in Australia

Groundwater development for irrigation has not received the significant subsidies characteristic of surface water irrigation. The process for irrigation development of groundwater has evolved directly from policies put in place to ensure that groundwater development processes could readily accommodate the high priority of remote town, as well as stock and domestic, supplies. The typical process has been for an irrigator to nominate preferred bore sites on a property, and apply for a groundwater licence. Assessments of nominated sites are made, and licences issued according to bore yield and need. The full cost of infrastructure (installation, operation and maintenance) is borne by the irrigator. In practice, bore owners have generally been fairly free to go about their business. Lack of a linear supply system (river or channel) limits natural centralization, which encourages communication between groundwater stakeholders.

By the very nature of this decentralized development, groundwater users are characterized as being highly independent, autonomous and protected by:

1. ownership of infrastructure located on private land;
2. limited detail of scientific understanding of cause-and-effect relationships between resource availability and resource use.

The private investment and operation of infrastructure make changes to groundwater management difficult and highly dependent on social willingness to comply (see case study 2).

Australian groundwater irrigation development is a natural response to surface water availability, markets and the expanding politics and compliance overheads of surface water development. In many established irrigation areas, groundwater development has been characterized by a tangible trade-off between poorer water quality and enhanced supply security. Table 15.4 summarizes resource and institutional differences between surface and groundwater irrigation.

Table 15.4. Characteristics distinguishing surface water and groundwater.

Characteristic	Surface water	Groundwater
Primary nature of development	Centralized	Decentralized
Infrastructure funding	(Historically) publicly subsidized	Private
Management of flow	Linearly regulated	Unregulated
Public awareness	High	Low
Security of supply	Low	High
Water quality	High (managed)	Variable
Physical extraction limit	Volume in storage	Bore capacity, draw-down
Capacity to enforce legal limits	High (linearly regulated)	Variable (private infrastructure on private land)
Monitoring and reporting	Regulatory and centralized	Variable, generally less than surface water
Primary financial costs of water use and entitlement	Levies	Infrastructure installation, maintenance and operation
Markets	Well established and widely available	Wide range. Generally developing
Ease of monitoring and building resource data	Relatively high	Low

Salinity management and extractive use have dominated public awareness of groundwater. Salinity management has been the dominant issue to date, given the significance of irrigation-induced salinity problems, particularly in the state of Victoria. Irrigation-induced salinity largely occurs because of rise in water table due to progressive accessions from irrigated fields and water supply infrastructure, where the groundwater is naturally saline or intersects naturally saline soils and rock formations.

Drivers for Change in Groundwater Management

There has been an increasing realization that surface and groundwater resources are inextricably linked – which is obvious at one level and yet quietly under-recognized, perhaps due to the relatively low historical use of groundwater.

Groundwater exploitation has risen in tandem with competition for surface water resources. The development of groundwater as a 'back-up' supply for irrigation properties is additionally increasing the demand for groundwater development in existing irrigation areas, in NSW and Victoria. Table 15.5 shows that groundwater use has tripled between 1983/84 and 1996/97 in NSW, Victoria and western Australia. Abstraction in Queensland actually declined, largely as a result of a programme to cap all the bores in the Great Artesian Basin, many of which had been flowing freely for years, gradually reducing artesian pressure and causing concern about 'senseless' wastage.

Although western Australia and the NT have the greatest reliance on groundwater, the primary users in these jurisdictions are urban, rural (town, stock and domestic) and mining. The capital of western Australia, Perth (population 1.5 million), is the largest groundwater-dependent city in Australia.

Despite various earlier initiatives to quantify water resources in Australia, it was progressively realized that, as a lot of groundwater use was neither licensed nor measured, steps would have to be taken to bring this in line with surface water management. Historically, the British riparian tradition of landowner access to groundwater had continued long after surface water had been declared

Table 15.5. Changes in mean annual groundwater use, 1983/84 to 1996/97. (From National Land and Water Audit, 2002.)

	Total use 1983/84 MCM	Total use 1996/97 MCM	% change in groundwater use
NSW	318	1008	217
VIC	206	622	202
QLD	1121	831	–26
WA	373	1138	205
SA	542	419	–22
TAS	9	20	122
NT	65	128	97
ACT	n/a	5	–
Total	2634	4171	58

Table 15.6. The extent of metering of groundwater use in 2000 in Australia. (From National Land and Water Audit, 2002.)

	Not known	No	Yes	Total
NSW	–	39	11	50
VIC	8	66	5	79
QLD	28	57	22	107
WA	40	134	–	174
SA	15	27	11	53
TAS	–	17	–	17
NT	2	26	27	55
ACT	–	3	–	3
Total	93	369	76	538

a state (and peoples') resource to be allocated through licensing. Table 15.6 shows that only a small number of groundwater management units were metered before 2000, although it is important to note that the majority of large agricultural abstractors, especially those operating within the large surface irrigation schemes were licensed and metered by this time.

Coupled with the lack of detailed knowledge on abstraction, the rising trends in total groundwater use prompted the introduction of legislation and initiatives designed to respond to three major principles of ecologically sustainable development of groundwater:

- Water level and pressure should be maintained within agreed limits and should not diminish.
- There should be no degradation of water quality.
- Environmental water needs should be determined and sustained.

National Framework for Groundwater Management

The National Framework for Improved Groundwater Management in Australia in 1996 (ARMCANZ, 1996a) set in train subsidiary policies and legislation in the states. Core recommendations were to publicly identify sustainable yield, allocation and use of aquifers as well as limit allocations to sustainable yields. Others included the enablement of trading of groundwater licences; improved integration of surface and groundwaters; management and licensing of high-yielding wells and provision of all drilling data by contractors; provision of funding for investigation in high-priority areas; and the introduction of full recovery of the costs of managing groundwater.

This framework resulted in tangible outcomes in terms of the definition of 72 groundwater provinces, and 538 groundwater management units, with associated water resources assessments and the initiation of groundwater management plans. Preliminary definitions of groundwater provinces and some management units go back to definitions made in the Water Review (1985), but these had only been partially developed. Figure 15.1 shows a summary of the degree of abstraction relative to sustainable yield in the groundwater

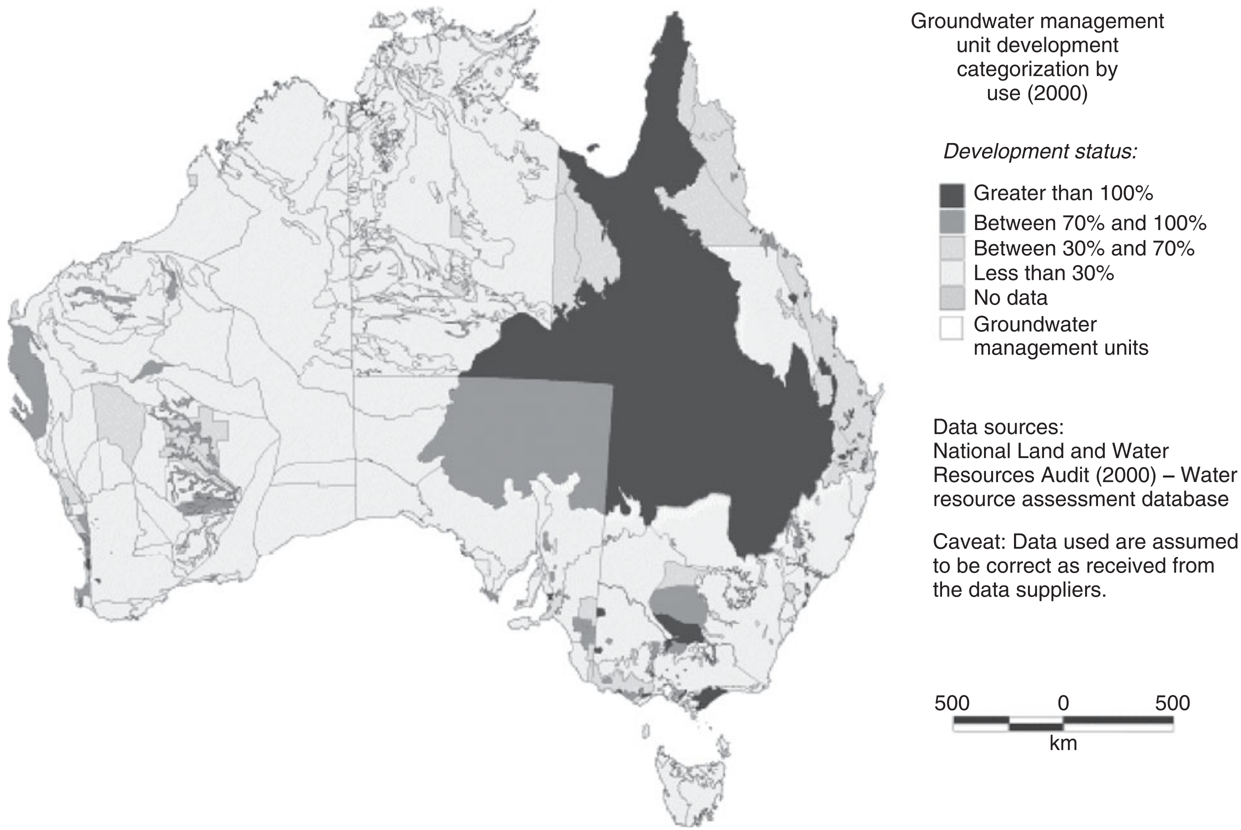

Fig. 15.1. Groundwater management units, categorized by use in 2000. (From NLWRA, 2002.)

management units of Australia. The management units are defined on the basis of water availability, water use and aquifer characteristics including depth, thickness and salinity. The NLWRA (2001) reported that more than 50% of the management units were extracting less than 30% of sustainable yield, with a further 19% between 70% and 100%, and 11% exceeding annual sustainable yield. Overall, 83 units (15%) were judged to be overallocated. Three management units, all in Victoria, had developed environmental allocation plans.

The framework is supported by two further national initiatives, and coordinated by the Department of Heritage and Environment – the National Principles for the Provision of Water for Ecosystems (ARMCANZ, 1996b) and the National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (ARMCANZ, 1995). A summary of groundwater-dependent ecosystems as envisaged in this and other work is given in Box 15.1.
There are two further supporting frameworks:

1. Overallocated Groundwater – A National Framework for Managing Overallocated Groundwater Systems has 13 recommendations designed to provide policy guidance for the states grappling with the serious issue of how to reduce the licensed volumes of overallocated groundwater aquifers. Associated with this policy paper is a Best Management Practice Manual, which suggests a broad range of approaches that are available to groundwater managers to reduce allocations and use (NRMMC, 2002a–c).
2. A National Framework for Promoting Groundwater Trading identifies the fundamental requirements for trading of groundwater as well as the impediments to groundwater trading.

The 13 recommendations address both the preconditions for trading and the requirement for a trading regime to operate. Methods to encourage trading are identified, as are the benefits of groundwater trading. The disadvantages of trading in overused systems are also identified. The document also asserts the following:

- The current level of monitoring of groundwater use (through the metering of bores) was low and more comprehensive data were required to correctly estimate sustainable yields.
- Commonly agreed methods for estimating sustainable yields and defining environmental water allocations for groundwater-dependent ecosystems were yet to be developed.
- Some states and territories have released new groundwater management policies; however, generally groundwater management reform was lagging behind those in surface water.

We will now turn to the central issue of *sustainable yield*: how this is defined, effected by groundwater-dependent ecosystems, and the characteristics of groundwater licensing and trade.

Box 15.1. Definitions of groundwater-dependent ecosystems in Australia. (Adapted from Hatton and Evans, 1998, 2003.)

- terrestrial ecosystems that show seasonal or episodic reliance on groundwater;
- river base flow systems, which are aquatic and riparian ecosystems in, or adjacent to, streams or rivers depending on the input of groundwater base flows, especially during dry seasons in seasonally dry climates or perennially in arid zones; hyporheic zones;
- aquifer and cave ecosystems, often containing diverse and unique fauna;
- wetlands dependent on groundwater influx for all or part of the year;
- estuarine and near-shore marine ecosystems that use groundwater discharge.

Sustainable Yield

Many countries (e.g. the USA and India) have widely adopted the concept of 'safe yield' (i.e. annual recharge) as a sustainable extraction limit. In many instances, this adoption is necessitated by high levels of groundwater development, but it has limited ability to account for hydraulic connectivity between water resources and environmental dependencies (Custodio, 2002; see also Llamas and Garrido, Chapter 13, this volume).

Australia's relatively recent development of groundwater allows a more conservative approach to sustainable yield. As any significant development of an aquifer will alter the water balance and have some impact, 'sustainability' must be interpreted as 'social acceptability of impacts' (Herczeg and Leaney, 2002). The central role of community in defining sustainable yield was noted by ARMCANZ (1996a):

> As any definition of sustainable yield embraces a range of technical as well as social, environmental and economic factors, it is necessary for considerable community input to make judgement of what is sustainable.

The NGC (2004) agreed the following definition of sustainable groundwater yield ('sustainable yield'):

> The groundwater extraction regime, measured over a specified planning timeframe, that allows acceptable levels of stress and protects dependent economic, social, and environmental values.

In adopting this definition, the NGC requested it be used with the explanatory notes provided, abridged in Box 15.2.

While implication within this definition and accompanying explanatory notes is to adopt a conservative approach to sustainable yield, the definition has been designed to allow for groundwater 'mining'. The willingness of the states to accept 'mining' – 'the exploitation of groundwater at a rate that is much greater than recharge' (Custodio, 2002) – as 'sustainable' has resulted in differences in the application of sustainable yield across the states. SA, in particular, accepts the notion of controlled depletion on the basis that (assuming no groundwater-dependent ecosystems) the groundwater is of no benefit if unused.

Box 15.2. Explanatory notes to accompany the nationally accepted definition of sustainable groundwater yield. (From NGC, 2004.)

Extraction regime

It is recognized that sustainable groundwater yield should be expressed in the form of an extraction regime, not just an extraction volume. The concept is that a regime is a set of management practices that are defined within a specified time (or planning period) and space. Extraction limits may be expressed in volumetric quantity terms and may further specify the extraction or withdrawal regime by way of accounting rules and/or rates of extraction over a given period and/or impact, water level or quality trigger rules. The limits may be probabilistic and/or conditional.

An oft-used means of defining the extraction regime has been by way of a maximum volume that may be taken in any single year. In some cases, where drawdown beyond the rate of recharge may be acceptable, it may be only for a specified period, after which time the rate may be less than the rate of recharge to compensate. In some cases and under specific circumstances (e.g. high or low rainfall years), the amount of water that may be taken may be greater or lesser than the longer-term value, and the conditions for this can be specified.

Acceptable levels of stress

The approach recognizes that any extraction of groundwater will result in some level of stress or impact on the total system, including groundwater-dependent ecosystems. The concept of acceptable levels of stress as the determining factor for sustainable yield embodies recognition of the need for trade-offs to determine what is acceptable. How trade-offs are made is a case- and site-specific issue and a matter for the individual states to administer.

The definition should be applied in recognition of the total system. That is, it should recognize the interactions between aquifers and between surface and groundwater systems and associated water dependent ecosystems.

In calculating sustainable yield, a precautionary approach must be taken with estimates being lower where there is limited knowledge. Application of the calculated sustainable yield as a limit on extractions must be applied through a process of adaptive management involving monitoring impacts of extraction. Sustainable yields should be regularly reassessed and may be adjusted in accordance with a specified planning framework to take account of any new information, including improved valuations of dependent ecosystems.

Storage depletion

The approach recognizes that extraction of groundwater over any time frame will result in some depletion of groundwater storage (reflected in a lowering of water levels or potentiometric head). It also recognizes that extracting groundwater in a way that results in any *unacceptable* depletion of storage lies outside the definition of sustainable groundwater yield.

Where depletion is expected to continue beyond the specified planning time frame, an assessment needs to be made of the likely acceptability of that continuation and whether intervention action might be necessary to reduce extraction. If intervention is likely to be necessary, planning for that action should be undertaken so that it can be implemented at the end of the specified time frame.

Major considerations in determining the acceptability of any specific level of storage depletion should be ‘intergenerational equity’, and a balance between

Box 15.2. *Continued*

environmental matters identified in the *National Principles for Provision of Water for Ecosystems* and social and economic values.

Protecting dependent economic, social and environmental values
The definition recognizes that groundwater resources have multiple values, some of which are extractive while others are *in situ* (e.g. associated water-dependent ecosystems) and all have a legitimate claim on the water resource.

The national definition of sustainable yield does not identify a standard planning time frame. The cumulative nature of extraction impacts and temporal response of aquifers can make the planning time frame a critical component of groundwater planning. These attributes of groundwater make sustainable yield estimations particularly subject to changes in social values and technical knowledge (see case study 2). Community understanding of groundwater availability can be difficult to progress with regard to the differences between the amount of water stored in an aquifer and the rate of recharge of that storage.

Groundwater Licensing, Management and Trade

Before the identification of groundwater management units and adoption of sustainable yield philosophies, it was not uncommon for water licences to provide access to a volume of water that could be taken as either surface water or groundwater ('conjunctive licences'). As a result of the COAG (1994) agreements to establish accounting mechanisms able to facilitate trade, conjunctive licences are progressively being separated into surface water and groundwater licences and this separation is considered complete in most states.

The identification of groundwater management units and adoption of sustainable yield practices within these management boundaries has allowed issue and management of groundwater licences to reflect that of surface water licensing. Thus groundwater licences comprise a share (still considered a volume in many areas) and an allocation. The introduction of groundwater management plans in overallocated areas alters the previously assumed 1:1 relationship between share and volume.

Where groundwater licences have been translated from volume to share through introduction of groundwater management plans, forecast of allocation is provided across the lifespan of the plan (typically 5–10 years). Thus, groundwater users have forewarning and can adapt if the plan requires a decrease in allocation. This is fundamentally different to the security offered by surface water and is of great importance to regional economies during drought where the storage/share ratio is low (e.g. NSW).

In locations where groundwater mining is not advocated, groundwater sharing plans typically address overallocation through an adjustment period by successively reducing the value of groundwater shares each year over the duration of the plan. In some areas where significant reduction was required (e.g. the Namoi, see case study 2), governments have provided financial support to assist regional communities to adjust to lower water availability. The other common practice to assist economic viability of communities in such instances is to develop carry-over capacities. As with surface water, this capacity allows unused (volumetric) allocation from 1 year to be transferred into the following year. Two primary constraints affect the capacity for such carry-over: (i) the physical limitation of bore yield; and (ii) the institutional limitations identified in the relevant groundwater management plan. While carry-over does not increase the net volume of available water over duration of a plan, it does allow for individuals to 'save' groundwater entitlements for drought years when surface water is not available.

The implementation of sustainable yield as an extraction regime rather than just a volume has generally been facilitated by the subdivision of groundwater management units into zones. They may be subject to different management constraints and practices (including trade) depending on zone-specific characteristics such as aquifer dynamics, level of development, water quality objectives, water level objectives and/or water pressure objectives. Case study 2 provides some insight into the manner in which zones can be used.

In accordance with COAG (1994) water reforms, groundwater management trade is progressively being enabled. Groundwater trade typically develops in fully allocated systems once enabled through institutional arrangements dictated via groundwater management plans.

Groundwater markets are geographically defined by groundwater management plans, and often restricted by institutional, technical and practical constraints applicable to zones subject to those plans. Generally speaking, groundwater trade in overallocated systems is considered a problem, and limited until overallocation has been addressed. Thus (nationally), groundwater trade is somewhat influenced by the priority development of groundwater management plans for overallocated resources and therefore tends to be localized (and can be restricted to zones within management areas).

The isolated nature of groundwater infrastructure and high costs of bore construction provide for narrow water market. Groundwater trade involves accessing more water from a bore rather than supplying more water via a channel. In practice, the high private overhead and risk of stranded assets associated with groundwater development for irrigation have limited the practical separation of groundwater property rights and land property rights

A national overview of groundwater markets was compiled in 2003 (Fullagar and Evans, 2003). This overview found that established rural groundwater trade markets existed only in SA and southern Victoria, for both temporary and permanent transfers. Prices for temporary trade ranged from AUS\$0/m^3 to AUS\$2.80/m^3. Prices for permanent trade ranged from AUS\$0.325/m^3 to AUS\$21.50/m^3. The broad range in prices is a direct reflection of the nature of markets within different groundwater management units: the niche wine markets in SA (notably McLaren Vale) allow far greater prices than do dominant crops in other states. Although only about 150 groundwater trades were estimated to occur annually in Australia (more than 50% of these in SA), expansion of groundwater trade is anticipated (Boyd and Brumley, 2003; Fullagar and Evans, 2003) as it is progressively enabled through implementation of the water reform process.

Integrating the Management of Surface and Groundwaters

As observed earlier, the focus of Australian public discussion and political interest in groundwater has now progressed from salinity management per se to recognizing the need for improved management across the surface and groundwater components of flow systems as well as the impact that limited surface water availability is having on groundwater development of adjacent aquifers. Thus, while saline base flows have been increasing, there is a risk that good-quality base flows will decrease.

Institutional (planning and management) separation of surface and groundwaters has allowed potential double allocation across a flow system (i.e. allocating the same yield once as surface water and again as groundwater).

In response to this issue, a national workshop addressing the management of hydraulically connected surface and groundwaters (Fullagar, 2004) recommended the adoption of five principles (see Box 15.3), the first of which was subsequently adapted and adopted as a component of the NWI objective. These principles are consistent with the issues and knowledge gaps that are handled by the NGC (2004).

Behind this work is the general belief that the sustainable productive capacity across a flow system (surface and/or groundwater) can be maximized by taking the 'right water, from the right place, at the right time' – this is the essence of the Australian interpretation of conjunctive water management.[2]

Managed aquifer recharge (including artificial groundwater recharge) is one aspect of surface and groundwater integration that has an interesting, if particular, history in Australia. There is increasing interest in capturing storm water, flood water and reclaimed or recycled water and diverting it to an aquifer either to recover lost storage or to enhance aquifer yield.

Before the 1960s, excessive private groundwater development for irrigation in the Burdekin delta, Queensland, led to sea water intrusion. In the mid-1960s, management of the Burdekin River was revised to provide for the replenishment of the delta aquifer through artificial recharge. The Burdekin became the largest groundwater-dependent irrigation scheme in Australia, with more than 35,000 ha of sugarcane and vegetables, adjacent to a surface-irrigated scheme of roughly the same area. Groundwater levels and yield have been systematically managed

Box 15.3. Recommended principles for managing hydraulically connected surface water and groundwater.

1. Where physically connected, surface water (including overland flows) and groundwater should be managed as one resource.
2. Allocation regimes should assume connectivity between surface water (including overland flows) and groundwater unless proven otherwise.
3. Overallocation of systems comprising connected surface water, groundwater and/or overland flows should be identified and eliminated by 2014.
4. Water users (surface water and groundwaters) should be treated equally.
5. Jurisdictional boundaries should not prevent management actions.

through artifical recharge from the Burdekin Falls dam since then. Recent economic analysis indicates that effective recharge may be adequately provided from irrigation return flows alone, with better benefits from the primary use of the irrigation water compared to direct recharge (see e.g. Hafi, 2003).

This example illustrates an unusual Australian development of surface water to respond to groundwater depletion, which contrasts with the more common problem of surface water depletion and increasing reliance on groundwater for drought management, whilst at the same time groundwater faces increasing degradation through salinity.

It is primarily economic costs of aquifer storage and recovery that have to date restricted practical interest to the high-value niche markets of SA. Noting the water values in McLaren Vale (see previous section on groundwater trade), it is not surprising that artificial recharge has created some interest. Water management in McLaren Vale involves the (privately initiated and funded) relocation and use of reclaimed water from an off-site treatment system (Grasbury, 2004). Interest in recharge has largely related to the need to secure winter storage in order to optimize use of this alternative water supply (10,000 million litres per year). In this instance, artificial recharge is economically viable and funding is not a primary issue. Trials have shown it to be a technically viable option (Hook *et al*., 2002); however, obtaining necessary regulatory approvals have proven to be difficult: there are few precedents to build on, and obtaining approval thus requires a significant degree of government commitment.

Addressing surface water–groundwater interaction requires an understanding of the geographic distribution and volumes involved. Braaten and Gates (2003) made a statewide assessment of river systems in NSW, overlaying major streams with groundwater depth data and the locations of irrigation bores. The results demonstrated that river losses and/or gains are most closely correlated to groundwater levels in the mid-sections of the major rivers where alluvial systems are well developed, narrow and constricted, and groundwater depths are shallow.

Case study 1: managing groundwater in the Murray–Darling Basin

The profile of issues associated with surface water–groundwater interactions is perhaps best represented by the interjurisdictional activities that are in progress in context of the MDB (the catchment for the Murray and Darling rivers; Fig. 15.2). The MDB covers 1,061,469 km^2, and includes almost three-quarters of Australia's total irrigated land. About 70% of water used for agriculture in Australia is for irrigation in the MDB. The MDB extends over three-quarters of NSW, more than half of Victoria, significant portions of Queensland and SA and includes the whole of the Australian Capital Territory.

States retain responsibilities for natural resource management. The Murray–Darling Basin Commission (MDBC) is an interjursidictional institution established 'to promote and coordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and other environmental resources of the Murray–Darling Basin' (MDBMC, 1992). The Commission reports to a ministerial council comprising ministers from each of the jurisdictional governments (including the Commonwealth) and a representative of the MDB community. Resolutions of the council require a unanimous vote.

The story of surface water allocation, the Cap on surface water in the MDB, has been presented earlier in this chapter; these policies were based specifically on river management and as such took no account of groundwater (MDBMC, 1996). Concerns relating to irrigation-induced salinity had been registered as early as 1911 within the MDB (Wilkinson and Barr, 1993). Accordingly, initial MDBC interest in groundwater was associated with water quality management and the impact of salinity to in-stream water quality – this interest subsequently expanded to encompass concerns regarding the mobilization of salts from dryland farming areas.

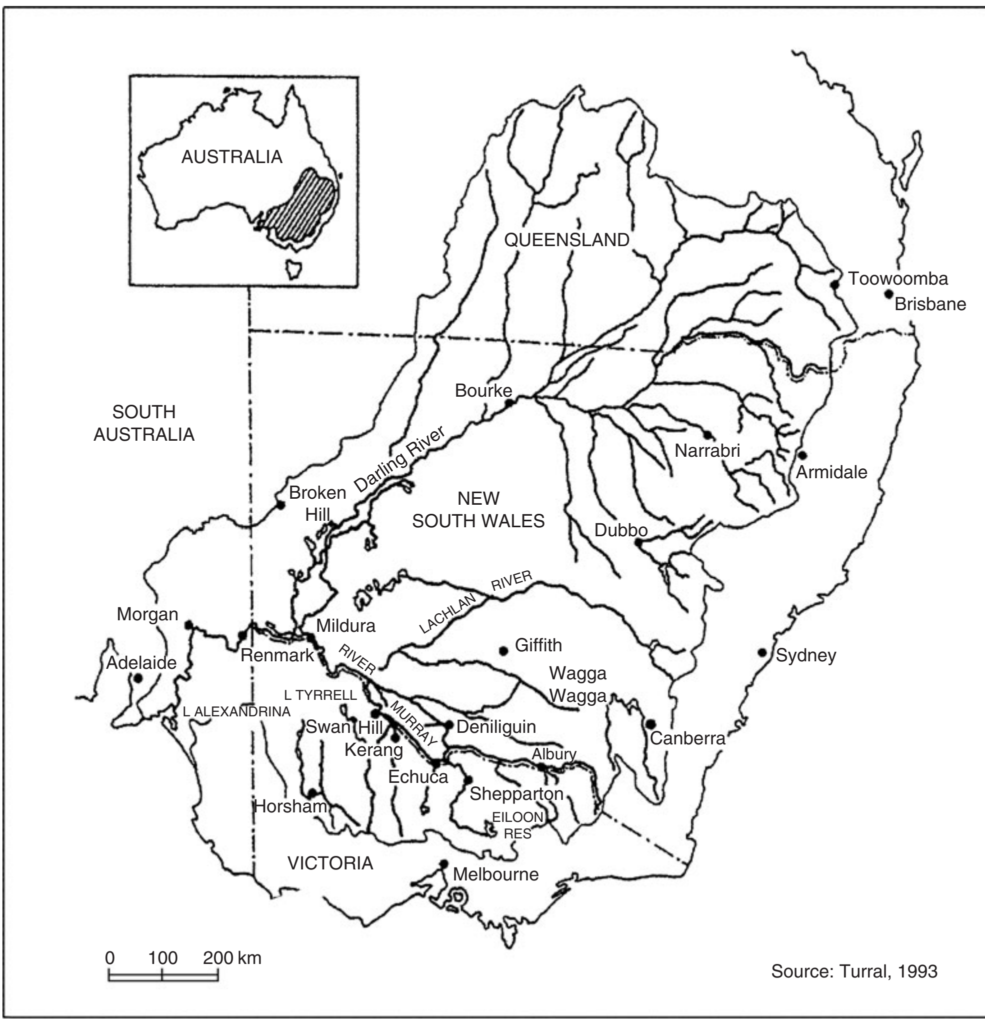

Fig. 15.2. The Murray–Darling Basin.

In 1996, a technical report (MDBC Groundwater Working Group, 1996) was released with the aim of 'progressing the setting of policy and programs to achieve a higher utilization of groundwater within the Basin's water resource allocation'. This report was followed in 1998 by another, which specifically outlined the impact that limited access to surface water would have on demand for groundwater, and the need to manage potential hydraulic impacts between surface and groundwaters (MDBC Groundwater Working Group, 1998). This report fed into general concerns that groundwater development could threaten river base flows – an impact with potential to thrust groundwater management into the central quantitative concerns of Cap agreements. The three means by which groundwater management may threaten the integrity of the Cap are (Fullagar, 2001):

1. reduced quantity of base flows through interception;
2. reduced quality of base flows through poor salinity management;
3. reduced capacity for governments to remain committed to the Cap in the event where viable alternative water supplies are lost.

A number of strategic studies were initiated to assess associated risks. These studies looked at: (i) the projection of groundwater extraction rates and implications for surface water; (ii) estimation of base flow in unregulated catchments of the MDB; and (iii) a review of groundwater property rights in Australia.

To provide a more comprehensive picture of water consumption within the MDB, the annual MDB Water Audit Monitoring Report (1999) began including groundwater consumption statistics in 1999/2000. Subsequent records (see Table 15.7) show a general increasing trend in groundwater consumption within the MDB, which peaked in response to the critical drought conditions of 2002/03.

The Review of the Operation of Cap (MDBCMC, 2000) found that the Cap had been a critical 'first step' in sustainable management of river resources in the MDB. The report included a recommendation to develop a groundwater management strategy for the MDB based on:

- jurisdictional management of sustainable yields;
- investigations clarifying how groundwater management practices may impact upon the integrity of the Cap in the future.

MDBC (2003) publicly released a report estimating an average reduction in surface water flow of 600 million litres for every 1000 million litres of groundwater use (Sinclair Knight Merz, 2003). Under groundwater development of the time, this amounted to a 2% undermining of the Cap, which was projected to increase to 7% in 50 years.

While the geological history of alluvial aquifer development implies some hydraulic relationship between groundwater and surface water, quantifying the potential for 'double allocation' is complicated by management and planning time frames, and time lags between groundwater flows and streams. Perhaps the most significant aspect of this work is the proactive manner in which the multiple jurisdictions have acknowledged and agreed to progress with a highly technical and political issue. This cooperation highlights the political importance

Table 15.7. Reported water use (GL) in the MDB 1999–2004.

Year	1999/ 2000	2000/01	Annual growth	2001/02	Annual growth	2002/03	Annual growth	2003/04	Annual growth	Growth 1999–2004
Ground water	1,103	1,240	12.4%	1,329	7.2%	1,632	22.8%	1,476	–9.6%	33.8%
Surface water	8,973	11,369	(capped)	10,960	(capped)	7,445	(capped)	8,780	(capped)	(capped)
Total	10,076	12,609	NA	12,289	NA	9,077	NA	10,256	NA	NA
Ground water % total	10.9	9.8	NA	10.8	NA	18	NA	14.39	NA	NA

given to ensure the long-term viability of existing surface water agreements underpinning management of the MDB. More broadly, groundwater interest within the MDBC structure is indicative of a wider interest in recognizing and realizing any potential environmental and/or productive opportunities associated with conjunctive water management.

Investigations associated with the development of an MDB groundwater management strategy continue. Consistent with broader water reforms, the primary focus of this research is to:

- establish consistent approaches to calculating sustainable yields for aquifers within the basin;
- build a framework for managing the combined use of surface and groundwaters;
- develop tools to help manage external groundwater impacts from irrigated areas;
- develop an approach to manage groundwater systems that have been overallocated;
- establish an evaluation process to help monitor and report progress against benchmarks and targets for managing groundwater resources.

In the following section, we focus on the development of groundwater policy at state level, with the case of NSW, and then take a more detailed look at an interesting example of efforts to bring an overexploited aquifer system back to sustainable levels in the Namoi Valley, which lies in NSW to the north of the MDB.

New South Wales: An Example of Integrating State and National Groundwater Policy

The total NSW groundwater resource is estimated at 5110 billion cubic metres, which is an enormous quantity of water, approximately 200 times the storage capacity of all dams in the state (DLWC, 2003). However, it has highly variable characteristics in terms of depth, yield, quality and spatial and temporal recharge. The sustainable yield is a tiny fraction of this (0.12%) at 6.19 billion cubic metres, of which 15% is too saline to use for most purposes. It is however a large resource and has been thought of as an effective buffer in drought.

In 1990, there were 70,000 licensed bores operating in the state of NSW, extracting 530 million cubic metres per year for irrigation, 15 million cubic metres per year for industry, commerce, mining and recreation and 60 million cubic metres per year for rural towns. Through the 1990s there has been increasing emphasis on high-value agriculture, with vegetables and fruits (grapes) leading the value table, and attracting higher-technology irrigation inputs (micro-sprinkler and drip irrigation) and accounting for a significant proportion of groundwater use. There has also been rapid development of groundwater since the early 1980s for conjunctive use on cotton and other commercial crops in the northern part of the state. There are few large dams in the northern river valleys and river flows are directly diverted, or harvested and stored in large on-farm dams known as 'ring-tanks' or 'turkey's nests'. Although cotton prices fluctuate considerably, the values shown in Table 15.8 indicate the price drivers for higher-value and intensified agriculture and the corresponding irrigated areas for each major crop.

The NSW Water Administration Act (1986) gave the minister of water resources the right to control, manage and use groundwater via the Department of Land and Water Conservation (DLWC), principally through licensing of use. Land use planning has been seen as crucial to the maintenance of groundwater quality and has been administered by the Department of Urban Affairs and Planning, working in cooperation with local government authorities under the remit of the Environmental Planning and Assessment Act of 1979. The protection of surface and groundwaters is governed by the Clean Waters Act of 1970 and the Environmental Offences and Penalties Act of 1989, both of which are administered by the Environmental Protection Authority (EPA).

In 1997, the government of NSW released its State Groundwater Policy Framework (DLWC, 1997), which was then supported by three subsidiary policies on: (i) groundwater quality protection (1999); (ii) groundwater quantity management (2000); and (iii) groundwater-dependent ecosystems (2000). The guiding principles of the policy framework are given in Box 15.4.

In 1998, a risk assessment was conducted for 98 aquifers across the state by the DLWC and 36 were found to be at high levels of risk. Of these, 4 aquifers suffered from water quality degradation and 32 from overallocation, and consequently 14 were embargoed from further development. The remaining potential for further groundwater development was judged to be limited to aquifers in some of the smaller inland river tributaries and valleys, some of the coastal sand and alluvial aquifer systems and 'unincorporated areas' (those within a groundwater province, but outside a designated groundwater management unit).

Implementation was also to be guided by risk assessment, so that increased focus and levels of management would be applied to more stressed aquifers on a priority basis. The management tools envisaged in the framework document included (DLWC, 1997):

Table 15.8. Value of water use in agriculture in Australia. (From National Land and Water Audit, 2002.)

	Gross value (million $)	Net water use (million m^3)	Irrigated Area (ha)	Value/ha ($/ha)	Value/million m^3 (million $/million m^3)
Livestock, pasture, grains, etc.	2,540	8,795	1,174,687	2,162	0.3
Vegetables	1,119	635	88,782	12,604	1.8
Sugar	517	1,236	173,224	2,985	0.4
Fruit	1,027	704	82,316	12,476	1.5
Grapes	613	649	70,248	8,726	0.9
Cotton	1,128	1,841	314,957	3,581	0.6
Rice	310	1,643	152,367	2,035	0.3
Total	7,254	15,503	2,056,581		

Box 15.4. Principles of the NSW Groundwater Policy Framework. (From DLWC, 1997.)

- An ethos for the sustainable management of groundwater resources should be encouraged in all agencies, communities and individuals who own, manage or use these resources, and its practical application facilitated.
- Non-sustainable resource uses should be phased out.
- Significant environmental and/or social values dependent on groundwater should be accorded special protection.
- Environmentally degrading processes and practices should be replaced with more efficient and ecologically sustainable alternatives.
- Where possible, environmentally degraded areas should be rehabilitated and their ecosystem support functions restored.
- Where appropriate, the management of surface and groundwater resources should be integrated.
- Groundwater management should be adaptive, to account for both increasing understanding of resource dynamics and changing community attitudes and needs.
- Groundwater management should be integrated with the wider environmental and resource management framework, and also with other policies dealing with human activities and land use, such as urban development, agriculture, industry, mining, energy, transport and tourism.

- groundwater management plans where necessary;
- supporting guidelines for local government and industry;
- creation of aquifer resources and vulnerability maps;
- an education strategy;
- legislative mechanisms for groundwater management;
- licensing tools and conditions for users that better reflect resource protection objectives;
- economic instruments applicable to groundwater management.

At the time the framework was released, there were already 13 groundwater management plans in existence, and a further 5 in preparation, and the experience gained thereby was effectively incorporated into the policy. Groundwater management plans are to be reviewed on a 5-year basis and reporting is undertaken by community-staffed Groundwater Management Committees, supported where necessary by state funds. Reporting is biennial, and requires comparison of measurable indicators against the plan's targets.

Much of the ensuing debate in NSW has hinged on the definition of sustainable yield, and within this, determination of volumes available for development. Statewide this has been defined as 100% of the long-term average recharge with further reductions advised to reserve water for groundwater-dependent ecosystems. A pilot process was undertaken in the Namoi Valley to reduce abstractions to sustainable levels – through consultative processes and committees – and defining sustainable yield was at the core of the negotiations.

Since different formulas are used in different states and territories, and in many the amount of data is increasing and the reliability of assessment is improving, there are some cases where the estimate of sustainable extraction has actually risen since 2000.

Case study 2: the Namoi River

The Namoi River catchment lies in north-east–central NSW and covers approximately 42,000 km^2, as shown in Fig. 15.3. The river flows 350 km from east to west and there are three major storages on the main stem and its tributaries: Keepit, Chaffey and Split Rock dams. The catchment includes part of the Liverpool Plains that has been subject to long-term investigations of fertilizer and agrochemical pollution of groundwater. Rain generally occurs in summer but is highly variable between years and seasons, from as high as 1100 mm/year over the Great Dividing Range in the east (upper catchment) to as little as 470 mm/year in the downstream area in the west. As in the rest of south-eastern Australia, potential evaporation generally exceeds rainfall rising from 1000 mm/year in the east to more than 1750 mm/year in the west.

Groundwater is generally sourced from quaternary alluvial aquifers running along the major stream lines, but there are also two low-yielding sandstone aquifers. The total volume of groundwater storage is estimated to be 285 billion cubic metres, of which 89% is of low salinity (less than

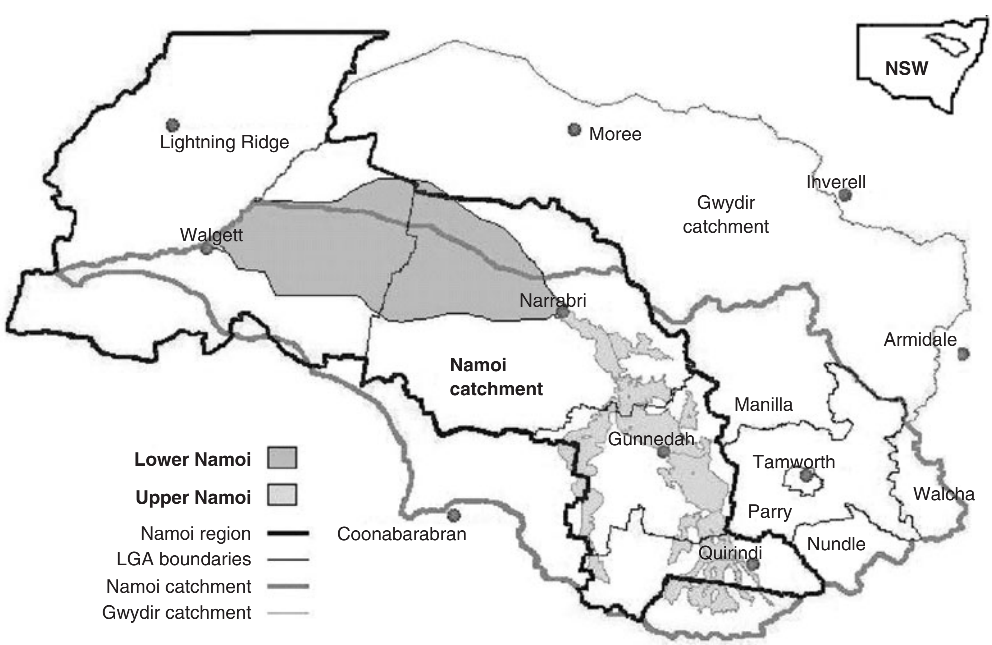

Fig. 15.3. Namoi river catchment. (From Ivkovic *et al*., 2004.)

1000 mg/l total dissolved solids (TDS)). In 1988, there were 1639 high-yielding tube wells, mainly in the paleo-channels or alluvium adjacent to the river, with maximum yields as high as 200 l/s. Average groundwater use at this time was 200 million cubic metres per year, which was equivalent to recharge these aquifers. Small volumes are also sourced from porous sandstone aquifers of the Great Artesian Basin, which stores the bulk of the groundwater in the Namoi Valley (243 billion cubic metres) at depths of 520–810 m below ground level. Although TDS are generally less than 1200 mg/l, the water has high sodium content and is not suitable for irrigation, but is used for stock watering and for town and rural drinking water. Groundwater in fractured rocks (basalt) is sometimes sourced for stock and domestic supplies, but yields are low and success in drilling is variable.

The Namoi accounts for about 40% of NSW's total groundwater use and is one of the most intensively developed irrigation areas in the state, with largely private investment through agri-business (e.g. Auscott and Twynhams) and large landholders who have moved into intensive irrigation development. Cotton is essentially a 'young industry', with highly mechanized large-scale layouts, mainly using furrow and bed irrigation. Substantial research has been undertaken into tightly scheduled irrigation and irrigation agronomy, coupled with trials on micro-irrigation and drip tape, but the consensus is that furrow and bed irrigation is best suited to the vertisol soils and has cheaper capital and operational costs, which attract less risk with volatile cotton prices.

Groundwater has been extensively monitored since the 1970s, with 560 piezometers at 240 sites in 1995, and a further 470 licensed bores monitored on 175 properties (Johnson, 2004). This data allowed the completion and calibration of a groundwater model of the Lower Namoi in 1989 and its subsequent refinement.

The chart in Fig. 15.4 shows the rapid development of groundwater, principally to irrigate cotton, lucerne and wheat since the late 1970s, increasing from less than 15,000 ha to around 35,000 ha. The surface-irrigated area in 1988 was marginally larger at 36,544 ha. The Commonwealth Scientific and Industrial Research Organization (CSIRO) undertook the first assessment of groundwater use in 1991, and recharge was estimated to be just over 200 million cubic metres per year. After community consultation, a contentious agreement was brokered to implement a policy of 'controlled depletion' of 220 million cubic metres per year on average, in the full knowledge that the economic life of the aquifer would then be only 30 years (i.e. till 2020). The idea of controlled depletion meant that an annual average recharge plus a further 10% or so annual depletion would be allowed.

However, it was not long before many people in the community as well as in public administration decided that a more sustainable long-term solution would be preferable, and that mining the aquifer was in very few peoples' interest. Further assessment and modelling studies indicated that average usage in the Namoi was below recharge, but at the same time it was overallocated with sleepers and dozer licences and punctuated by periodic overuse, corresponding to low surface water allocation years (Fig. 15.5). However, at this stage, the

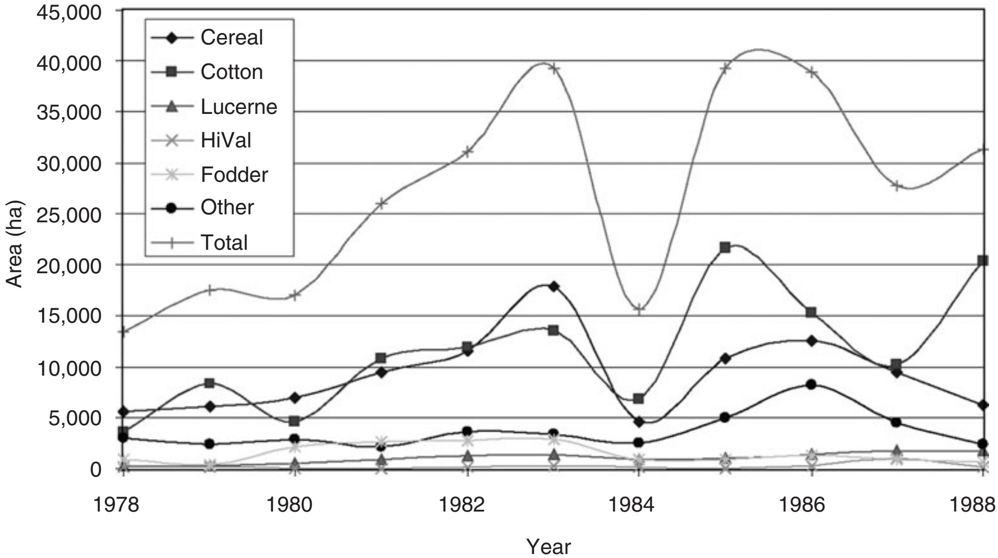

Fig. 15.4. Groundwater-irrigated area development in the Namoi Valley, 1978–1988.

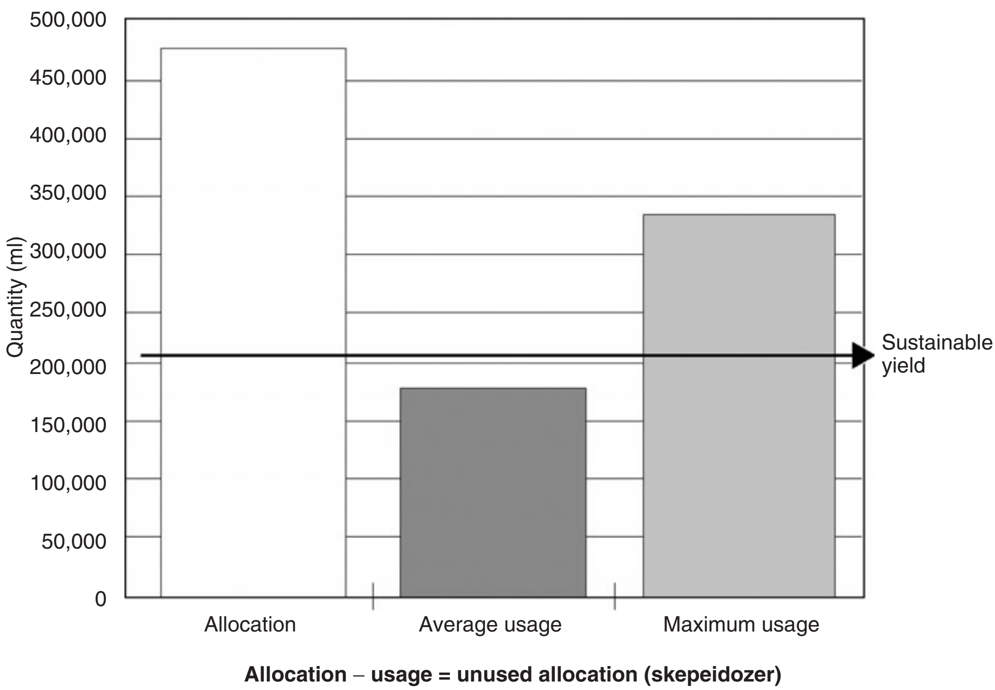

Fig. 15.5. Comparison of allocation and use in the Upper and Lower Namoi groundwater systems, 1998 (DLWC).

assumption was still that sustainable extraction equated to 100% long-term average annual recharge and that there were no groundwater-dependent ecosystems in the valley.

Even at this most optimistic formulation of sustainable extraction, some subsystems were 3–4 times overallocated, and no further development was allowed in all zones (see Table 15.9) except zone 6 where the water table continued to rise. There was an in-principle agreement to phased reductions in allocations to 35% of existing values during 1996–1998, but in practice this proved very difficult to agree and implement. Following national and state initiatives for groundwater management reforms, a series of modelling assessments were undertaken and then supported by a Social Impact Study, conducted by CSIRO with, and on behalf of, the community. Initial stakeholder assessments on fair reallocation and the definition of environmental flows were made to develop the full process (Nancarrow *et al.*, 1998a,b). The main focus of the assessment was to understand differential treatment of active and unused licences, as well as the likely impacts on the community and their expressed priorities. The consultation was conducted in 1999, and the main characteristics are summarized in Box 15.5.

The results were incorporated into the Water Sharing Plan, seeded in 1999, which was expected to be formalized in 2000 and followed by swift implementation. The Namoi study was effectively a pilot for other groundwater management units in NSW, but in the end, the final plan was not agreed and published until 2003, and began implementation only in 2004, having progressed through one of the most severe and extended droughts on record (2000–2004).

The principle source of contention concerned the definition of sustainable extraction and the preference of many in the community to maintain this at 100% annual average recharge. In 1999, DLWC supported the continued abstraction of 100% annual average recharge and proposed a 10- to 15-year period to determine and implement a transition to incorporating an environmental share of the resource. In response to the paper 'Perspectives on the Sustainable Development of Groundwater in the Barwon Region', presented to the Namoi Groundwater Management Committee, the Nature Conservation Council of NSW drafted a hard-hitting response (http://www.nccnsw.org.au/water), and suggested the immediate and precautionary implementation of 70% as an environmentally sustainable yield in underused zones, with a 10-year transition for the overexploited zones. They proposed formulas to cut back allocations to sustainable limits for each zone, which were eventually adopted in the water sharing plan after some modification (2003).

Simultaneously, combined surface and groundwater assessment studies were undertaken with hydraulic and social impact models linked together (Letcher and Jakeman, 2002). The investigators noted that many such studies require approximately 3 years for model completion, by which time the initial key issues might no longer be relevant. They commended the development of models to be sufficiently flexible for reapplication to other problems, and to emphasize the difference between outcomes and policy developed from models, compared to accurate prediction. Despite considerable community involvement, they note that great effort is required to explain model outputs and accept

Box 15.5. Community consultation and participation in development of the water sharing plan in the Namoi Valley: the NSW socio-economic assessment. (Adapted from Nancarrow *et al*., 1998a.)

1. Understanding the catchment:
   (a) community water profile – socio-economic characteristics and history, water use profile;
   (b) identifying change processes in the catchment;
   (c) identifying key issues.

2. Goal setting (principle of balance of benefits and costs):
   (a) understanding government goals and objectives;
   (b) understanding community expectations of the water reform process;
   (c) communities' aspirations and concerns for the future.

3. Generating management options:
   (a) development of a range of appropriate options.

4. Identifying effects:
   (a) on different uses, population groups, industry sectors, communities and over time;
   (b) extractive and non-extractive uses – matrix of sectoral uses and options;
   (c) socio-economic effects – checklist of financial effects inside and outside catchment, socio-demographic structure, community institutions and vitality, heritage values, environment.

5. Assess effects:
   (a) preliminary and detailed;
   (b) extent, likelihood, intensity, timing and duration;
   (c) impacts of no-change – development of a common reference scenario;
   (d) detailed studies – clear statement of assumptions; quality assurance principles – focus, long-term horizon and equity; targeted sensitivity analysis; identification of appropriate methods and techniques; identification of data sources.

6. Determining preferred option:
   (a) impact display table;
   (b) trade-offs – weighting strategies to cope with differential benefits;
   (c) risk and uncertainty analysis.

7. Developing impact management strategy.

8. Reporting:
   (a) required reporting on important steps (i.e. all the foregoing).

9. Monitoring:
   (a) monitoring for management, feedback and adjustment;
   (b) review of objectives and actions;
   (c) generation of monitoring questions;
   (d) identification of key factors or variables to be monitored.

10. Evaluating and adjusting.

uncertainty and iterative solutions. They also noted that stakeholders must be encouraged and assisted to have more realistic expectations on the appropriate and inappropriate uses of models and their outputs, and implied that gaining feedback through public seminars and discussions was insufficient.

The final Water Sharing Plan (MLWC, 2003) documents the agreed reductions in allocation and the rules associated with allocation and monitoring. The plan defines 13 separate groundwater management zones within the Namoi Valley and determines the long-term average recharge for each one (Table 15.9). The largest zone, in terms of geographic area, water resources and use, is the Lower Namoi, a contiguous near-stream alluvial aquifer. However, wells that were drilled deeper through unconsolidated sediments of the Lower Namoi and into the Great Artesian Basin were not included in the plan. The crux of the matter is the process by which allocations will be reduced to address current overallocation (Box 15.6).

Previous drafts of the plan were consistently opposed by the Nature Conservation Council of NSW (see Report Card on Water Sharing Plans), which recommended against gazetting the Namoi Water Sharing Plan in 2003 on the grounds of insufficient allocation for the environment.

The final assessment of extractable water for agriculture was undertaken on the basis of environmental health requirements (taken at approximately 30% of annual recharge) and other high-priority uses (utility licences and native title use), and considers the long-term aspects of climate variability. The domestic and stock rights were calculated separately, and then the actual agricultural demand was also determined (Table 15.9). In fact native title rights in the Namoi amounted to zero and so had no impact in this case, and it can be seen that the stock and domestic and utility licence volumes are generally modest. A simple formula that pro-rated new licensed volume in proportion to available resources, reserved licence and prior licence volumes resulted in the revised figures and the percentage reductions in zonal allocations summarized in Table 15.9. It can be seen that there are no reductions in zones 6, 9

Table 15.9. Summary table of groundwater allocations by zone in Namoi, water sharing agreement 2003 (in thousands m^3). (From Water Sharing Plan 2003.)

Zone	Estimated annual average recharge	Stock and domestic rights	Estimated water requirement	Local utility access licence	Reductions in access licence (% volume)
1	2,100	39	8,510	1,716	87
2	7,200	359	23,810	59	70
3	17,300	470	56,017	199	69
4	25,700	667	82,590	4,660	73
5	16,000	262	36,042	56	45
6	14,000	274	11,448	97	0
7	3,700	89	6,321	4,407	41
8	16,000	166	48,204	–	67
9	11,400	187	11,342	–	0
10	4,500	36	1,420	–	0
11	2,200	210	8,740	–	75
12	2,000	73	7,487	–	73
Lower Namoi	86,000	3,304	172,187	–	51
Total	208,100	6,136	474,118	11,194	

Box 15.6. Objectives and performance indicators for the groundwater sharing plan, Namoi.

The objectives of the plan include:

- protection maintenance and enhancement of ecosystems dependent on groundwater;
- protection of the structural integrity of the aquifers and of their water quality;
- management of extraction so that there is no long-term decline in water levels;
- preservation of basic landholder rights access to the groundwater sources and assurance of fair, reliable and equitable access through management of local impacts and interference effects;
- contribution to the protection, maintenance and enhancement of the economic viability of groundwater users and communities;
- assurance of sufficient flexibility in account management to encourage efficient use of groundwater resources and to account for the effects of climate variations.

The performance indicators selected to monitor the objectives include:

- change in groundwater level and climate adjusted levels;
- change in groundwater level adjacent to dependent ecosystems;
- change in groundwater quality;
- change in economic benefits derived;
- extent to which domestic, stock, water utility and native title rights have been met;
- change in structural integrity of the aquifer.

and 10, and water levels have been rising in zone 6 due to recharge from surface irrigation and other surface water–groundwater interactions.

The plan makes allowance for future revision of estimates of sustainable extraction volumes and sets limits on the maximum (over)abstraction within 1 accounting year, compared to the longer-term (3 years) average extraction as reported to the minister. Typically, the maximum 1-year overabstraction limit is 25% greater than the nominal long-term value given in Table 15.9.

Water availability is determined by continuous monitoring and compares the average abstraction with the extraction limit over the current and preceding 2 years, with some upper limits set on water availability in some zones. Water accounting is conducted annually over a water year that runs from 1 July to 30 June. To minimize interference between adjacent bores, no new agricultural bores can be approved within 100 m of an existing well or 200 m from an existing property boundary, and are subject to further expert hydrogeological findings as appropriate. They must also be more than 400 m from an existing monitoring well and 500 m from an existing domestic water supply well. Finally the plan was scored by the DLWC on how well it met the 38 targets of the State Water Management Outcomes Plan. The transition period allowed for the full implementation of environmental allocation was finalized at 10 years. It will be implemented through re-specification of licences, such that the sustainable licence volume is now formally allocated with supplementary water allocations that will be gradually reduced to zero over the transition period.

A socio-economic evaluation of the plan was conducted by the University of New England, Armidale, NSW, in late 2003 (Institute for Rural Futures (IRF), 2003). This was preceded by a number of studies undertaken generally for water sharing plans in NSW by Australian Consultants International Limited (ACIL) in 2002, and by the DLWC in conjunction with the CSIRO-conducted exercise. A number of expert commentaries were also written by other observers, including the Australian Bureau for Agriculture and Resource Economics (Topp, 2000), which illustrates not only the importance and pioneering nature of the Namoi case, but also the pluralistic and broader interests and perspectives brought into play by the state, the water users and the environmental lobby groups. It also shows that different studies are employed at different times for different purposes, even if they seem to cover the same territory – for example, dealing with public or users' perception and priorities in the evolution of a plan and a more dispassionate, objective assessment of the impacts of that plan after it has been declared.

The IRF study looked in detail at the economic impacts by commodity and zone, using primary data, secondary data and a farm modelling analysis. The farm analysis was extended to regions, and complemented by industry and social impacts. It was conducted at a time when an earlier version of the Water Sharing Plan was deferred for 6 months, and simplified water allocation reductions, similar to those voluntarily agreed by the user community, had been reinstated.

Some farmers indicated that they would acquire, or try to acquire, increased surface water supplies to substitute for 'lost' groundwater allocation, and set their future farming strategies accordingly; hence various scenarios of future water use were investigated, including the impact of trading. However, the authors lamented the lack of reliable information on the interaction between streams, irrigated fields and aquifers and the extent to which surface water could be substituted for groundwater.

Groundwater-irrigated farms were estimated to contribute AUS$384 million or 56% of the gross value of agricultural production in 2000–2001. The analysis of all zones indicated a future loss of production of AUS$26.7 million in 0–9 years (under the plan) and a further AUS$42.3 million in 10–20 years (post plan), considerably more than the structural adjustment compensation of AUS$18 million proposed by the NSW government. An alternative plan of AUS$120 million compensation had also been proposed, but cut back to this value, amounting to an average of about AUS$70,000 per affected property. As a result, it was felt that some owner-operators would be forced to amalgamate and expand or to cease operation due to reduced net income of reduced water allocation. The mitigating impacts of new enterprises, new technology and possible higher-price regimes in the future were all positive. Overall, it was expected that irrigated production would contract, with cereals reducing far more than irrigated cotton, and would be partially compensated by an increase in rain-fed wheat and sorghum. Lucerne production would decline and there would be an increase in feedlot cattle production and a corresponding reduction in open grazing. Little change in high-value cropping was anticipated.

At a regional scale, it was estimated that gross regional product would decline by 2% in 0–9 years and by 4% thereafter (10–20 years), with corresponding reductions in household income of 2% and reductions in employment of 2%. Social impacts were not quantified, but explained in qualitative terms, such as loss of employment, reduction in school population, reduced local spending and knock-on effects on service industries. The report identified the town of Gunnedah as the focal point of declining cotton production, which was expected to concentrate closer to existing service centres in Narrabri.

Although the Water Sharing Plan was developed in close consultation with the community over a long period, individual property owners are reported to have spent as much as AUS$ 250,000 in trying to challenge the plan in court (Rural Reporter, 30 August 2003).

The story continues to unfold with the same pressures from users, environmental groups and resource managers coming into play. The plan was due to be implemented towards the end of 2004, but was delayed and is now scheduled for implementation in 2006. In the current iterations, research continues on surface water–groundwater interactions and the resulting effects on water allocation policy (Ivkovic *et al.*, 2004). Preliminary conclusions indicate localized reductions in stream base flow, likely to be attributed to groundwater use. More extensive investigation continues, but it is likely that there will be further pressure on limiting both surface and groundwater abstraction, until a balance that is acceptable to the community has been achieved. This will no doubt continue to be a robust and noisy process.

Lessons for Groundwater Management in Other Countries

Although there are obvious structural differences between Australia and developing countries such as those in South Asia and China using groundwater, there are still useful insights to be gained. The contextual differences include population, particularly the farm population (20 million well users in India vs. 70,000 in NSW) and corresponding farm size, where Australian holdings range from hundreds to thousands of hectares. As a result, the number of wells in Australia is relatively modest and licensing and metering are *not* the daunting tasks presented in, for example, the Indian subcontinent. The lessons for Australia itself can be briefly summarized as follows:

1. Ensure that groundwater and/or surface water reforms happen in tandem to avoid lags in policy development and implementation.
2. Recognize groundwater–surface water interactions and aim to use these proactively rather than reactively.
3. Ensure that sustainable yield takes into account the temporal and geographic distribution of water use as well as the sustainable volumes available for development.
4. Zonal approaches can be used to fine-tune sustainable yield management.

5. Ownership of policies is critical to compliance, especially where overallocation or isolated infrastructure is involved.
6. Interindustry and interjurisdictional issues relating to aquifer development should be pre-empted – economic inequities between industries can complicate resolution.
7. Regular monitoring and reporting underpin management, understanding and compliance – groundwater issues can only be managed if they are recognized or addressed early enough.

However, Australia shares a common heritage of a philosophy of state-sponsored development of agriculture and irrigation in particular. This has been focused particularly on the development of a commercial agricultural economy with a major focus on exports. As the world market has become more competitive and rural sector's economic share of GNP has declined, the state has been less inclined to support the agriculture and has plunged it into global free trade with an enthusiasm and commitment seen in few other parts of the world. Coupled with the rising conviction that environmental management is of crucial importance, the federal government, through the COAG, has pursued reform objectives, based on clearly defined economic, environmental and social principles. These have been developed by state leaders and explained, sold and forced on the states' populations through combinations of incentives and penalties.

This has occurred against a background of genuine (if expensive) public participation in natural resources management, which has been transformed from disparate local initiatives into a national movement, and then rationalized to some extent through catchment-based management organizations that retain a strong community ownership and membership. Politically, the environmentally conscious urban electorate has become significantly more powerful than the rural lobby, whilst at the same time the true guardians of the rural environment are those who live and work there – predominantly farmers. In contrast, there is probably no broad-based consensus on economic reform and national competitiveness (masked at the ballot box by other issues), and this has allowed the central government to take the lead on potentially unpopular reforms with much less public participation and discussion.

Public participation involves genuine dialogue and often rancorous discussion supported by publicly available information. Although some information is recognized to be still far from perfect, there is a good general understanding of the resource base and its constraints, if less than perfect knowledge of actual groundwater use. With respect to groundwater, there has been a big step forward in the understanding of allocation in relation to sustainable resource use and this has led to hard-to-negotiate adjustment programmes to reduce overallocation, which is intrinsically easier than dealing with overconsumption, which in India is the real problem in absentia of rational energy pricing and any form of allocation system (see Shah, Chapters 2 and 11, this volume). On the inside, the debate is noisy and fragmented, giving a very different impression to the 'contestants' on the ground compared with observers trying to synthesize experience and progress from the outside. However, noise and dispute are welcome signs of a dynamic and healthy process, and in the end contribute to more balanced sets of outcomes than administration by fiat, whether it is honoured in practice or in the breach.

Public availability of data, commitment to find more when it is insufficient and access to modelling and other impact assessments, commissioned by the community, by the state or in collaboration, all contribute to a more transparent and better-argued politics in natural resources management.

There is an increasing tendency to look at structural differences between developed and developing countries and then say 'obviously this cannot be done' or 'that does not apply'. There is an increasing body of literature questioning integrated water resources management, especially its more prescriptive formulations (Biswas *et al.*, 2005). However, sound principles and practices need to be applied if we wish to achieve sustainable development of water resources and not overdevelop or degrade the resources for future generations.

This chapter shows that groundwater management is a complex, multifaceted process that is dynamic and has continually changing contexts, problems and challenges, just as with surface water. It also illustrates clearly that surface and groundwater management needs to be integrated in many cases, although this adds further complexity, more stakeholders, greater need for data and so on.

However, structural differences between Australia and, say, India mask differences in the size and importance of groundwater as a sector. In India, it is a much more significant contributor to both the economy and the individual welfare and, as such, should be accorded serious attention concerning its future sustainability. The recognition of this importance has either escaped the government's notice (by now, unlikely) or has been submerged by other conflicting short-term agendas and solutions. The Australian experience shows that initiative and active involvement by different interest groups working at different levels and for different ends can move towards a longer-term agenda, for broadly similar reasons of welfare and stability that confront developing countries.

An important point is that an effective process, based on a combination of policy, economics, science and participation can be, and has been, established. Attention to detail has been a fundamental plank in groundwater reforms, considering resource availability, use, environmental consequences, economic benefits and losses, and accounting for the range of stakeholders' perspectives and views. This does not mean that all stakeholders' needs and concerns are satisfied – far from it – but they are ultimately negotiated and cajoled towards what is believed to be a better position. A commitment to monitoring should ensure that results can be evaluated and the effectiveness of different policies and positions determined in a continuing and dynamic cycle of 'adaptive management'.

Countries such as India can learn from broader federal mechanisms of carrot and stick policies, applied to their own contexts. The Australian case shows how a strong and purposive government can rub shoulders with true public participation. There are positive lessons in the detailed development of process, interagency cooperation and genuine participation at state level. In India, managing approximately 20 million tube well owners looks like an impossible issue even though they represent only 1/50th of the whole population. At state level this number may reduce to a million tube well owners, amongst other millions of citizens – and becomes immediately more tractable, although daunting. Guiding and resourcing local authorities to manage jointly and locally with the community require commitment, clear direction and professional and service-oriented public agencies.

None of these reforms have happened overnight in developed countries and have a backdrop of a long history of changes in technology, management, ideology and public institutions. Change does not happen rapidly and cannot be expected to do so, miraculously, in developing countries. Solutions adapt to problems through the simple and pragmatic business of trying them out and gaining experience, confidence and trust. Exact models of management cannot be expected to be transplanted and made to work in different contexts, but different components offer potential to provide solutions if there is the broad policy and incentive structure to maintain commitment to learn and adapt on the ground.

To find solutions it is necessary to define problems, and there is great potential to do this more effectively, thoroughly and in more detail from a range of stakeholders' perspectives. How to do this with large numbers of stakeholders remains a challenge, which is only partly solved by increasing education and awareness.

Notes

1 Sleepers and dozers are licence-holders who pay for their entitlement annually, but use little or none of it. Typically they run mixed farms with rain-fed crops and substantial livestock holdings, for which they keep water entitlement as insurance in drought years, either for fodder production or direct stock watering. There are no 'use-it or lose-it' provisions (as in the US prior appropriation doctrine) for water licences in Australia.

2 'Conjunctive water management' encompasses both productive and environmental objectives, and some account of any hydraulic interdependency between surface and groundwaters is generally implicit to Australian use of the term. Consistent with the notion of sustainable yield as a 'regime' rather than volume and a rejection of 'prior rights', Australian terminology assumes fairly specific 'flow system' connotations and thus may be distinguished from aggregation of conjunctive use (e.g. according to Raju and Brewer, 2000) and activating use of aquifer storage services (e.g. characteristic of conjunctive water management in the USA, Blomquist *et al.*, 2004).

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