

# Water 4

4.1	Water resources	134
4.2	River health	147
4.3	Wetlands	163
4.4	Groundwater	171
4.5	Marine waters and ecosystems	181
4.6	Estuaries and coastal lakes	190
	References	203



## 4.1 Water resources

After a period of protracted drought, widespread rains across New South Wales have increased river flows and the water available in storages. As of 2011–12, most major storages stood at over 90% capacity.

River flows have generally been higher than average in the major inland river valleys over the past two years and levels of extraction have been relatively low for the flow levels experienced.

The ongoing impacts of water extraction and flow regulation, together with the residual effects of the drought, remain significant pressures on the health of river systems.

Demand for the state's water resources is high and needs to be managed through water sharing plans to balance equity of access for users, while maintaining ecosystem health. Since 2004, a total of 63 water sharing plans have been implemented across NSW, covering about 95% of water use. Plans for the remaining water sources are being developed progressively with those for the Murray–Darling Basin to be completed in 2013 and for the rest of the state by 2014.

In June 2012, cumulative holdings of environmental water by the NSW Government stood at 357,141 megalitres (ML). In each of the past two years, just over a million ML (on average) of environmental water have been delivered to environmental assets, a substantial rise compared with the 123,000 ML delivered in 2009–10.

### NSW indicators

Indicator and status	Trend	Information availability
Available water supply (in storage)	Increasing	✓✓✓
Proportion of water extraction covered by water sharing plans	Increasing	✓✓✓
Environmental share of available water	Increasing	✓✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.

### Introduction

Water resources are critical for many human needs, such as the supply of town water, and stock and domestic water, the irrigation of crops, and for mining and industry. Most of these needs are satisfied by water held in storages or extracted from rivers and groundwater. Rainfall runoff is also collected in farm dams and floodwater is harvested from river floodplains.

The need to maintain a healthy environment as well as securing water resources to enable future economic growth depends on an adequate supply of good quality water. Water resources are needed to preserve the health of riverine, estuarine and wetland ecosystems and maintain the food chains that support fish and other aquatic species. Floods and river flows enrich floodplain soils and provide connectivity between different aquatic habitats and ecosystems. The health of riverine ecosystems is discussed in Water 4.2, wetlands in Water 4.3 and estuaries and coastal lakes in Water 4.6.

Planning for water use to meet socioeconomic demands and environmental needs must be balanced and take into account the long-term variability in water availability due to the extremes of climate, such as droughts and floods. To address this, NSW is developing statutory water sharing plans under the state's *Water Management Act 2000* to provide certainty for all users as well as the environment. These plans, which are discussed later in this section, aim to protect water for the environment and provide better security of entitlement for all water users.

## Status and trends

### Water use and sources of water in NSW

Long-term average water use in NSW is about 7000 gigalitres (GL) per year but use is quite variable and depends on rainfall and flow conditions. Around 80% of this water is extracted from regulated rivers, where flows are controlled by large rural water storages operated by the State Water Corporation. The remainder comes mainly from groundwater in the major inland alluvial systems (see Water 4.4), with the balance drawn from unregulated rivers.

**Figure 4.1** shows how this water was used by different sectors in three individual years (2000–01, 2004–05 and 2008–09). Total water use varies considerably from year to year. In the three years depicted it fell by 33% from an estimated 8800 GL used in 2000–01 just at the start of the drought to around 6000 GL in 2004–05 and then a further 23% to around 4500 GL in 2008–09.

In all three years agriculture was the largest user of bulk water, ranging from just under 80% during

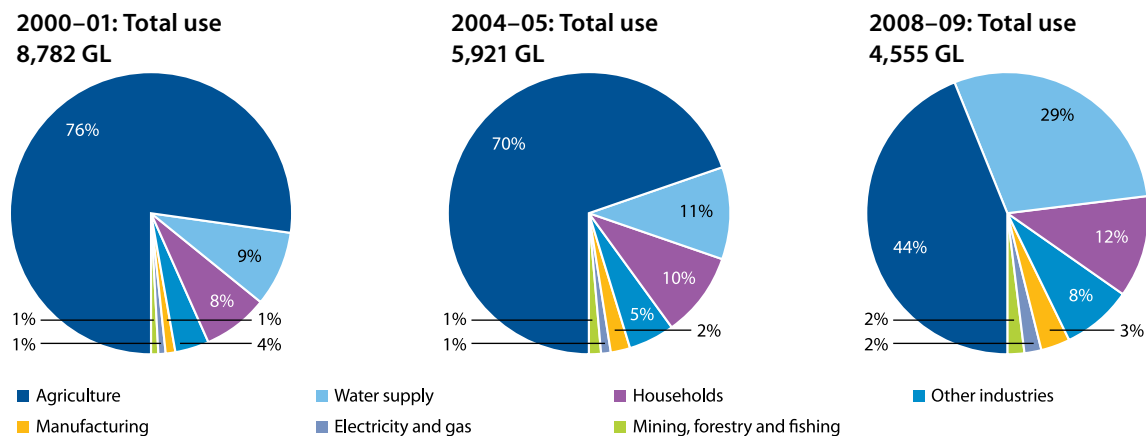
a period of relatively good water availability in 2000–01 to 44% towards the end of the drought in 2008–09. Water supply – which includes sewerage and drainage services, as well as water lost to evaporation and leakage during water delivery – was the next largest ‘user’. It accounted for almost 10% of total water use during periods of higher water availability, but increased considerably in both absolute and relative terms during the drier years of the drought. By contrast, the next highest water use – domestic household use – decreased in absolute terms as conservation measures were implemented during the drought, although its relative share increased.

### Water availability

The factors that most significantly influence water availability are climate (rainfall and temperature) and storage capacity. Water supply largely depends on the regulation and storage of river flows in large dams for human consumption as well as for agriculture and industry. The dams have the effect of ‘smoothing’ out the natural variability in water availability by storing large volumes during periods of high river flows and releasing water to meet demand and supplement periods of low rainfall or extended drought.

By contrast, much of the extraction on unregulated rivers tends to occur at low-flow levels as irrigators access water to supplement periods of low rainfall. This is particularly the case on the coast, tablelands and slopes. During high-flow periods in these areas, water demand and thus the volume pumped from a river tend to be lower. However, on the inland plains, where unregulated river flows are less reliable, users access higher flows and often pump water into off-river storages to meet needs through dry periods.

**Figure 4.1: Water consumption in NSW by sector, 2000–01, 2004–05 and 2008–09**



Source: ABS 2006; ABS 2010

Notes: ‘Water supply’ includes sewerage and drainage, as well as the water lost through evaporation and leakage in the process of water supply.

NSW has 19 major dams and storages. The largest dams are the Eucumbene, Hume, Warragamba, Blowering, Copeton, Wyangala and Burrendong. Menindee Lakes also operates as a major water storage through an interconnected lake system. Much of the public storage capacity was built between the mid-1950s and 1980. The combined capacity of these storages is over 18 million megalitres (ML) of water.

**Table 4.1** summarises water levels in major NSW water storages between 2006 and 2011. As of 2011–12, most of the major storages stood at over 90% of capacity. Early in the 2010–11 water year, an extended drought was broken by substantial and widespread rainfall across much of NSW, resulting in major flooding in many river valleys. Most of the major storages filled and spilled for the first time in about a decade. This provided substantial improvements to water availability in NSW and full water allocations

in most valleys. The flooding also caused substantial inundation of floodplains and the restoration of important wetlands.

## Water extraction

The major regulated river valleys in NSW are the Murray, Murrumbidgee, Lachlan, Macquarie, Border, Gwydir, Namoi and Hunter and these represent the bulk of water extraction in NSW. Significant extraction also occurs in the unregulated Barwon–Darling River. A large amount of water is also extracted from the Hawkesbury–Nepean for urban use in Sydney. Water from the Snowy River is stored and diverted inland to the Murray and Murrumbidgee rivers to supplement water extraction in those valleys.

**Table 4.1: Storage levels at major public water storages managed by the State Water Corporation in NSW, 2006–11**

Valley and storage	Storage volume (% of full capacity)					
	2006	2007	2008	2009	2010	2011
<b>Selected inland water storages of the Murray–Darling Basin</b>						
Border Rivers: Glenlyon Dam	28	13	35	24	22	99
Border Rivers: Pindari Dam	66	23	31	43	25	99
Gwydir: Copeton Dam	23	10	21	12	7	50
Namoi: Keepit Dam	17	4	21	36	28	98
Namoi: Split Rock Dam	19	3	5	5	3	21
Macquarie: Burrendong Dam	28	9	18	19	17	91
Lachlan: Wyangala Dam	21	11	10	6	7	92
Lower Darling: Menindee Lakes	16	5	31	31	91	116
Murrumbidgee: Blowering Dam	53	23	36	32	46	97
Murrumbidgee: Burrinjuck Dam	33	34	41	37	41	88
Murray: Hume Dam	21	13	16	11	27	92
<b>Coastal water storages</b>						
North Coast: Toonumbar Dam	100	84	100	101	101	102
Hunter: Glenbawn Dam	38	32	54	72	67	96
Hunter: Glennies Creek Dam	38	33	60	80	70	88
South Coast: Brogo Dam	68	103	99	29	101	101

Source: State Water Corporation data 2011

Notes: The total volume of water storage for NSW includes some storages not included in the table. Storage volumes are as recorded at 1 July each year.

The relative amount of water diverted by users from regulated rivers and the water available to the environment varies from year to year, depending on the prevailing weather conditions, water availability and the flow rules in water sharing plans (see 'Responses' below). At the beginning of each water accounting year and sometimes periodically throughout the year, water is allocated for consumption in the regulated river valleys, according to the security of entitlement and the water resources available. Water for town supply, major utilities, and domestic and stock use has the highest level of security over all other licensed purposes. Other high security licences receive allocations in all but the driest years and are typically used for irrigation of permanent plantings, such as horticulture and vines, as well as industries that require an assured supply of water.

Allocations to general security licences are more variable from year to year and are mostly used for irrigating annual crops, such as cereals, rice, cotton and pastures. Depending on water sharing plan rules, general security water can be carried over from year to year, if annual allocations are not fully used. Water that is not allocated for extraction each year is considered environmental water, along with that allocated specifically to the environment through the environmental flow rules of water sharing plans and environmental water licences.

### Long-term modelling of river flows and extractions

Long-term modelling of river flows is used to simulate flow behaviour in regulated rivers and the impact of water resource development on the natural flows of rivers. This modelling provides a basis for setting long-term diversion limits in water sharing plans.

The models are based on climate and flow data for the last 120 years. They describe the variation that can be expected in river flows and water extraction over the longer term and provide a context against which actual flows can be described and interpreted. As a general rule, the models show that the proportion of water remaining for the environment is higher during typical wet flows than during dry periods. By contrast, when flows are low, there is less water available in total and a greater proportion of it is allocated for consumption.

### Current river flows and extractions

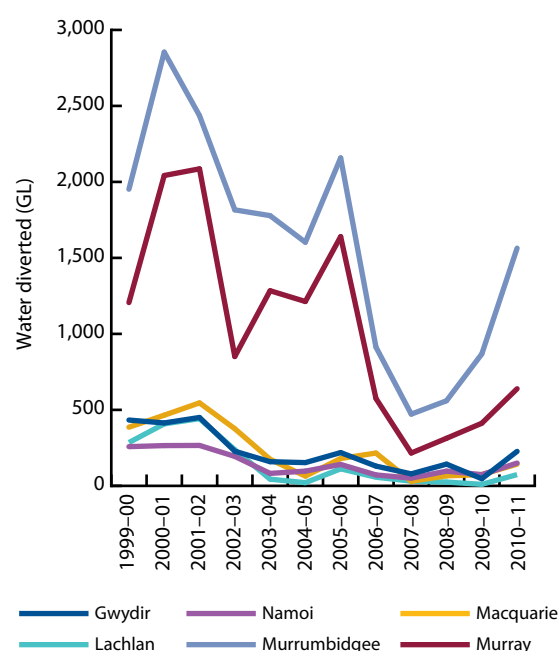
Up until 2010–11, water extractions over recent years have been substantially lower than average.

**Figure 4.2** shows that the overall quantity of water extracted from regulated rivers fell as the severity of drought conditions intensified up until 2009–10, and then rose in 2010–11 as the heavy rains across NSW increased surface water availability.

The proportion of water extracted and that remaining for the environment in the major regulated river valleys of NSW is shown in **Figure 4.3**. In all of the river valleys depicted over the 12 years shown, river flows only exceeded median flow levels in two years, except for the Macquarie (three years). In general terms, the higher flows were at either end of the 12-year period, with dry flow levels or worse being experienced in most of the intervening years.

The period described (1999–2011) was exceptionally dry and the usual patterns of river flows and water usage did not apply, with water sharing plans being suspended in some river valleys. However, the proportion of water retained in river systems was relatively high during the isolated wet years. During most of the dry years, extraction levels fluctuated around 50% of water available, except for the Murrumbidgee, where extraction levels were consistently higher, and the Lachlan, where they were generally lower.

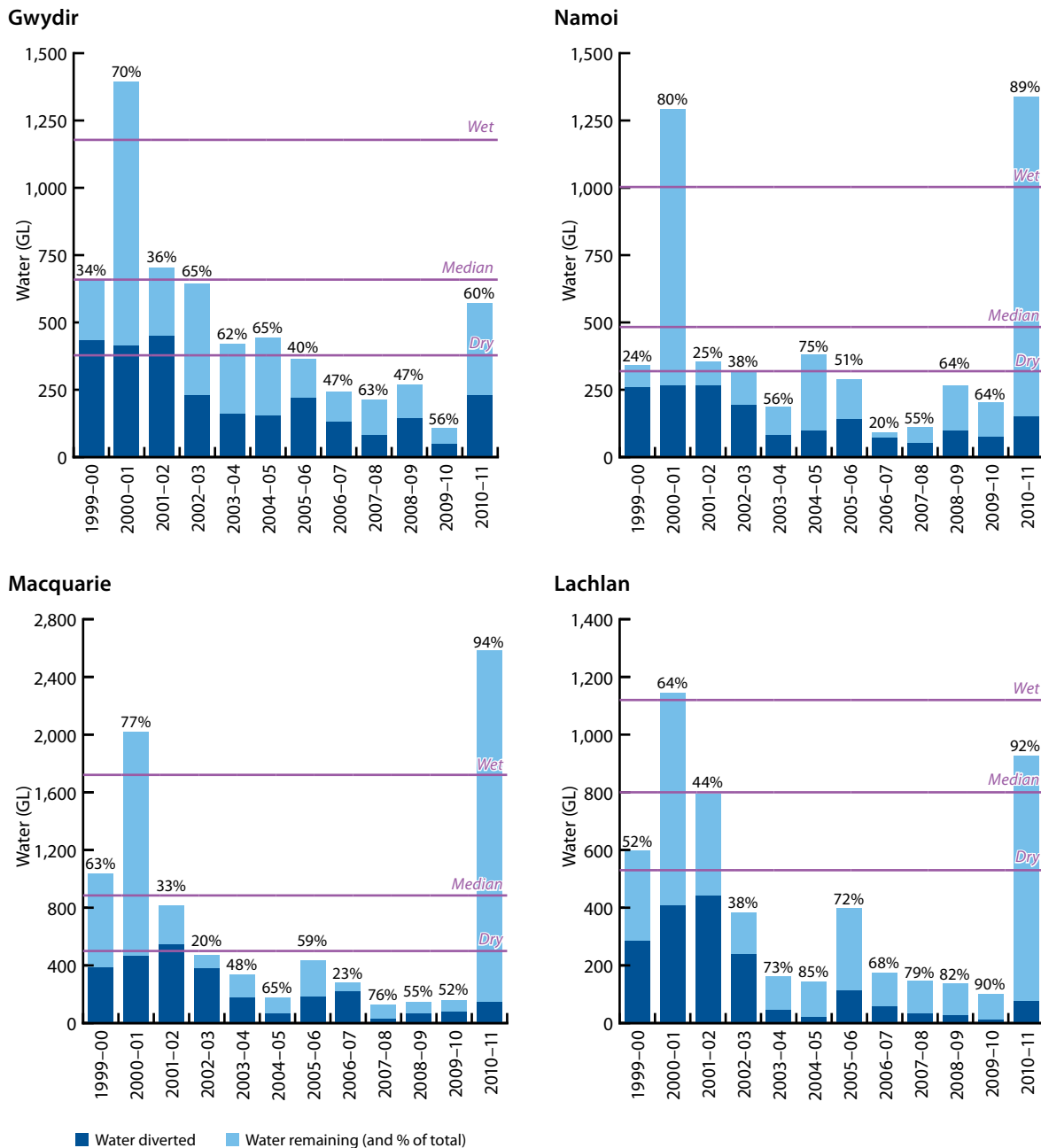
**Figure 4.2: Water diverted by licensed users in major NSW regulated valleys, 1999–2000 to 2010–11**



Source: NSW Office of Water (NOW) data 2011

Notes: Observed diversions are metered general security, high security and supplementary diversions.

**Figure 4.3: Diversions and water remaining after extraction in the major NSW regulated valleys, 1999–2000 to 2010–11**



Source: NOW data 2011

Notes: Some of the 'water remaining' is lost to evaporation, seepage and other transmission losses. While it is in the system, it provides some benefit to the environment, depending on how long it remains and the volume and timing of the flow. Observed diversions are metered general security, high security and supplementary diversions. Floodplain harvesting is not included and further reduces the volume of water remaining in the charts.

The data for each valley represents total water available and is taken from a representative gauging station downstream of major tributary inflows and upstream of major extractions.

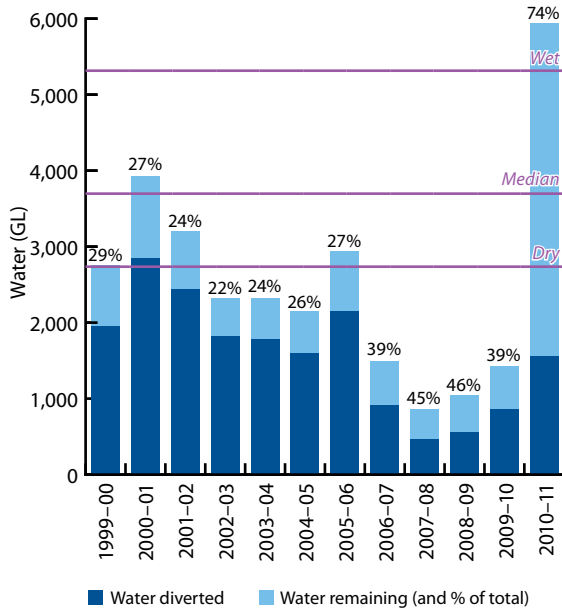
Total flow and observed diversions in the Murrumbidgee Valley are influenced by water released from the Snowy Mountains Scheme. In percentage terms the influence is greatest in dry years. Development in the valley reflects this inter-valley transfer.

Wet, median and dry flow levels are sourced from long-term (110-year) hydrological modelling of conditions for water sharing plans.

The typical dry year is the 80th percentile of total water available, the typical median year the 50th percentile and the typical wet year the 20th percentile. Percentile is the proportion of time the flow volume is equalled or exceeded.

**Figure 4.3: Diversions and water remaining after extraction in the major NSW regulated valleys, 1999–2000 to 2010–11 (continued)**

**Murrumbidgee**



Source: NOW data 2011  
Notes: See previous page.

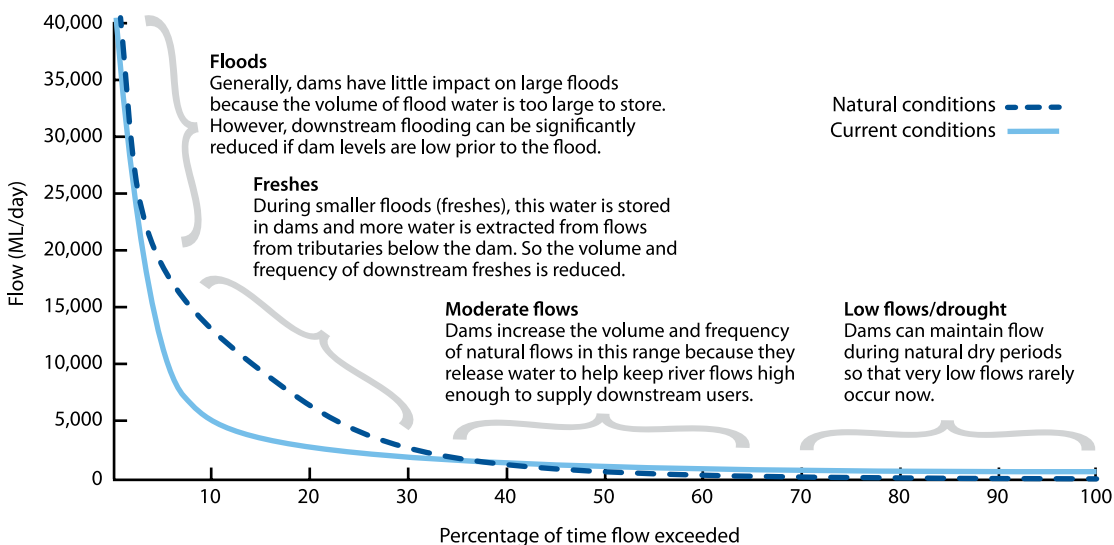
Floodplain harvesting is the collection, extraction, diversion or impoundment of water flowing across floodplains, a practice that further reduces the volume of the 'water remaining' shown in Figure 4.3. Extractions occurring through floodplain harvesting are not included in the extractions described in the figure as they have not yet been licensed. Floodplain harvesting is considered to be most significant in the valleys of the northern Murray–Darling Basin, including the Border, Gwydir and Namoi rivers.

**Effects of water storage and river regulation**

River flow regimes are characterised by the magnitude, timing and duration of various flow levels. How often a flow of a particular volume is likely to occur can be illustrated by a flow duration curve. A flow duration curve, such as shown in **Figure 4.4**, plots the volumes of flow (ML per day) against the percentage of days that such a flow will be equalled or exceeded. These curves can be used to illustrate the volumes of water typical for a given river for low flows, moderate flows, freshes and floods, as well as the changes to natural river flows (particularly volumes) that can occur as a consequence of building dams and regulating flows.

Dams generally have a minimal impact on large floods. During high flows or 'freshes' (flows that occur around 10% of the time), dams exert their greatest impact and flow levels can be significantly reduced. During moderate flows (median flows that occur 50% of the time), levels may be increased downstream of dams as operational releases for water supply to users lift flow levels. In regulated systems, low flows are increased artificially to maintain flows and continue providing water for users.

**Figure 4.4: Hypothetical flow duration curve showing the potential effect of major dams on natural river flows**



Source: DLWC 2000

Individual river systems have differently shaped flow duration curves and experience varying impacts according to their own specific flow levels and patterns of extraction. The data in Figure 4.3 provides a better indication of the actual extent of extraction in a particular river valley and its potential level of impact on river systems.

Flow regulation has two additional effects on natural ecosystems. Firstly, it causes a dampening of the seasonal fluctuations and natural flow variability of rivers that result in the boom and bust cycles in response to which many of Australia's aquatic ecosystems have evolved. Secondly, and less apparent from the flow duration curve, regulation has the effect of reversing the seasonality of flows by storing water during high winter flows and releasing it in summer when flows are naturally low.

## Environmental water

To offset the impact of water extraction and flow regulation and maintain the health of natural systems and water resources, a share of the water resource is set aside for environmental purposes. Two types of environmental water are recognised under the *Water Management Act 2000* and provided for in water sharing plans for regulated rivers in NSW: planned environmental water and adaptive environmental water.

'Planned environmental water' is committed to the environment by environmental water rules in water sharing plans. This is done by limiting overall water extraction to ensure that an agreed amount of water remains in the river and applying specific environmental flow allocations or 'rules'.

'Adaptive environmental water' is water that is committed to the environment through water access licences. This is equivalent to the environmental water described as 'held water' under Commonwealth legislation. It is generally purchased in water markets from willing sellers or through investment in water savings measures that convert previous water losses into an equivalent licensed entitlement. Adaptive environmental water is actively managed for specific environmental outcomes and can be used to supplement planned environmental water.

**Table 4.2** provides examples of some environmental water rules currently in use in the regulated river system.

Unregulated water sharing plans generally rely on rules that limit extraction of river flows to protect a share of water for the environment. In most cases, rules set out an annual extraction limit and a low-flow 'cease-to-pump' level. This threshold – when pumping stops – is intended to minimise impacts on low flows and protect water for basic ecosystem health and riparian water users.

**Table 4.2: Examples of environmental flow rules under water sharing plans in NSW regulated rivers**

Environmental flow rule	Purpose	Valleys where rule applies
Diversion limits	Precludes increases in the total volume of water extracted	All regulated rivers
End-of-system flows	Requires a certain minimum flow to be retained at the downstream end of the river, below the areas where major extraction occurs	Hunter, Murrumbidgee, Namoi
Transparent dam releases	Requires all reservoir inflows occurring at certain times to be passed immediately downstream, as though no dam were present	Murrumbidgee
Translucent dam releases	Requires part of a reservoir inflow to be passed immediately downstream	Lachlan, Macquarie
High flow access	Limits pumping and/or total extractions when reservoirs spill or high flows enter flow-regulated rivers from unregulated tributaries	Gwydir, Hunter, Lachlan, Namoi
Environmental allowances	Creates a 'bank' of reservoir water to be used for specific environmental purposes, such as flushing blue-green algal blooms, reducing salinity or supporting bird-breeding events	Gwydir, Hunter, Lachlan, Macquarie, Murray, Murrumbidgee

Source: Department of Environment, Climate Change and Water NSW 2009

## Environmental water delivery

Water purchased under programs such as The Living Murray and NSW RiverBank is used as adaptive environmental water and is additional to the planned environmental water protected through water sharing plans.

**Table 4.3** presents the volumes of water that were released from storages in different river valleys through specific environmental allowances between 2009–10 and 2011–12 or as a result of adaptive environmental licences. It does not include water made available to the environment through fixed rules, such as prescribed end-of-system flows or dam transparency.

From the first purchase of water for environmental use in 2004 until June 2012, NSW has acquired the equivalent of 357,141 megalitres (ML) in water holdings across the Gwydir, Macquarie, Murrumbidgee and the NSW portion of the Lower Murray–Darling river systems. Table 4.3 shows the result of increased water availability after the above-average rainfall in 2010 following the extended drought conditions. Around 937,000 ML of environmental water were delivered to environmental assets during 2011–12 and 1,141,000 ML in 2010–11, substantially more than the 123,000 ML delivered in 2009–10.

These environmental water deliveries included nearly 200,000 ML of environmental water to the

internationally important Macquarie Marshes and 400,000 ML to wetland systems in the Murrumbidgee, including the mid-Murrumbidgee wetlands and the Lowbidgee area of the lower Murrumbidgee floodplain. Delivery of this water after a decade of managing small amounts of environmental water to maintain core ecosystem processes produced significant ecological responses, including widespread and successful bird breeding events, and enabled the watering of large areas of highly stressed river red gum woodland.

## Pressures

### Drought

Droughts occur naturally in Australia and aquatic ecosystems are adapted to periods of dryness. However, severe, extensive or prolonged drought can have major repercussions for all water users and the environment. The most recent drought was among the worst on record for some river valleys – the cumulative stress of reduced water availability over a number of years had severe environmental and socioeconomic impacts. In five river systems, it was necessary to suspend water sharing plans and contingency plans were implemented to meet critical water needs.

**Table 4.3: Environmental water delivered, 2009–10 to 2011–12**

Water source	2009–10		2010–11		2011–12	
	Environmental water allowance	Adaptive environmental water	Environmental water allowance	Adaptive environmental water	Environmental water allowance	Adaptive environmental water
Gwydir	–	70	5,000	17,783	16,500	1,798
Macquarie	16,000	4,784	139,101	60,210	88,229	65,251
Lachlan	–	–	–	10,334	–	27,551
Murrumbidgee	30,372	56,146	185,249	233,926	132,003	91,394
Murray and Lower Darling	15,606	–	219,000	270,768	283,100	231,086
<b>Total</b>	<b>61,978</b>	<b>61,000</b>	<b>548,350</b>	<b>593,021</b>	<b>519,832</b>	<b>417,080</b>
<b>Total environmental water</b>	<b>122,978</b>		<b>1,141,371</b>		<b>936,912</b>	


Source: NSW Office of Environment and Heritage (OEH) data 2012

Notes: All values in megalitres


'Environmental water allowance' refers to water held in storage for release to assist in environmental watering.

'Adaptive environmental water' refers to water allocated to the environment under the conditions of water access licences and includes licences held by the Commonwealth Environmental Water Holder and water sourced through The Living Murray and coordinated by the Murray–Darling Basin Authority.

## Water extraction




Maintaining high levels of water extraction relative to total river flows over an extended period places stress on river health. Scientific evidence now shows that the total volume of water extracted from rivers in NSW has affected the health of aquatic ecosystems. For example, the *Macquarie Marshes Adaptive Environmental Management Plan* (DECCW 2010a) shows the decline and/or loss of wetland communities that has resulted from water extraction, combined with the effects of river regulation and drought. This finding necessitated a formal notification by the Australian Government to the Ramsar Convention of a likely change to the ecological character of this Ramsar-listed wetland caused by human disturbance.




The Sustainable Yields Assessment Project for the Murray–Darling Basin (CSIRO 2008a) modelled rainfall runoff and inflows to river systems for a range of scenarios and levels of water resource development. These analyses found that water resource development has caused major changes in the flooding regimes that support important floodplain wetlands in the basin and that climate change could have additional effects on the seasonal patterns and overall availability of flows.


## River regulation



Water storages and regulating structures have been built to provide greater security of supply, moderating the effects of variability in stream flows and enabling storage of water for release during dry periods, including the severe drought recently experienced. However, a consequence of river regulation is the modification of natural flow regimes, including reduced flow variability, altered seasonality of flows, and changes to river morphology.



Aquatic ecosystems, particularly inland rivers, are adapted to highly variable flow levels. To a significant extent, aquatic species are dependent on this variability to maintain or complete their life cycles. Over the longer term, modification of natural flow patterns contributes to a loss of biodiversity and declining health in aquatic ecosystems.



The Sustainable Yields Assessment Project assessed the degree of regulation of river flows due to water resource development in each valley of the Murray–Darling Basin, and the ratio of water releases to total water availability (CSIRO 2008a). The Murray, Murrumbidgee and Macquarie were found to be

highly regulated; the Lachlan, Gwydir and Namoi moderately regulated; and the Border Rivers subject to low levels of flow regulation. The Paroo is the only entirely unregulated river valley in the Murray–Darling Basin that also has no significant water extraction. These results show a strong pattern of conformity with the overall river ecosystem health outcomes described in Table 4.5 and Map 4.1 in Water 4.2.

## Climate change

Over the longer term, projected changes in rainfall due to climate change are expected to create risks for water availability (Climate Commission 2011; Vaze & Teng 2011). In addition, the frequency and intensity of heavy rainfall events is likely to increase as the climate continues to warm. A pattern of more severe droughts and intense rainfall events would increase the risk of severe flooding when rain does occur, particularly in low-lying areas, such as the Illawarra region (Climate Commission 2011). The impacts of climate change on rainfall events leading to flooding are likely to be different from the impacts on seasonal or average rainfalls (DECCW 2010b).

Analyses of modelled runoff projections indicate that a shift in the seasonality of patterns is virtually certain, with significantly more summer runoff (up to about 20% increase) and significantly less in winter (up to about 25% decrease). The projections also indicate some minor increases in autumn runoff and moderate to significant decreases in spring runoff. In northern NSW, which is dominated by summer rainfall and runoff, projections indicate a slight increase in mean annual runoff (DECCW 2010b; Vaze & Teng 2011). In the southern regions of the state, which currently experience winter-dominated rainfall and runoff, the projections indicate moderate to significant decreases in mean annual runoff (DECCW 2010b; Vaze & Teng 2011).

## Water pollution

The quality of water affects its suitability for human use and may affect the health of aquatic ecosystems. To a significant extent, water quality reflects the state of vegetation cover and land management practices in river catchments. The condition of riverine water quality and the effects of catchment disturbance and diffuse runoff from agricultural activities and urban expansion are discussed in Water 4.2.

## Responses

### Established responses

#### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Improve the environmental health of wetlands and catchments through actively managing water for the environment by 2021'. This includes the strategic recovery and management of water for the environment to improve the health of the most stressed rivers and wetlands.

Priority actions to protect waterways include:

- 'Completing the water sharing plans for surface and groundwater sources and reporting annually on environmental water use'
- 'Driving the Commonwealth to ensure it delivers a plan for the Murray–Darling Basin that protects the environment and regional, social and economic outcomes through investment in strategic water recovery, water efficiency and river health measures'.

Progress on achieving *NSW 2021* goals and targets is regularly reported on-line and through an annual report tabled in the NSW Parliament. *NSW 2021 Performance Report 2012–13* (NSW Government 2012a) sets out baseline performance data for the goals and targets which provide the foundation for future performance monitoring and public reporting and the technical context for each NSW 2021 target.

#### Water reforms

Significant progress has been made in water reform in NSW including:

- introduction and implementation of the *Water Management Act 2000*, which recognises the importance of transparent and controlled allocation of water to the environment and extractive uses
- implementation of the Murray–Darling Basin cap on water extractions in the basin
- establishment of environmental and water sharing rules in water sharing plans and of tradeable water property rights
- development of 63 water sharing plans (including for groundwater), with seven more covering the remaining inland water sources to be completed by 2013, and the remaining plans for coastal water sources by 2014
- implementation of the National Water Initiative and working in partnership with the Commonwealth Government to progress four State Priority Projects

- acquisition of additional water for the environment through water savings and buyback of water licences to address historical over-extraction.

#### Water Management Act 2000

The *Water Management Act 2000* provides for the sustainable and integrated management of the state's water through water sharing plans and rules for the trading of water in a particular water source. Since 2009, some amendments have been made to strengthen the Act's compliance and enforcement powers and comply with obligations imposed by market rules under the Commonwealth *Water Act 2007*.

#### National Water Initiative

The National Water Initiative (NWI) commits NSW to achieving sustainability in the use of its water resources. It facilitates the expansion of trade in water resources to promote the highest value uses of water and most cost-effective and flexible mechanisms of water recovery to achieve environmental outcomes. In tracking progress against the NWI, the National Water Commission has produced a report card assessing individual water sharing plans within each jurisdiction (NWC 2011).

#### Murray–Darling Basin Plan

A key role for the Murray–Darling Basin Authority (MDBA) is to prepare the Murray–Darling Basin Plan, a legislative instrument that will set a long-term sustainable limit on the use of both surface and groundwater in the basin. The MDBA released a draft basin plan for public comment in November 2011. NSW submitted a response to the draft (NSW Government 2012b) which outlined the state's position on the proposed plan as follows:

- the plan should balance the needs of the environment, communities and the economy
- unavoidable social and economic costs should be identified and mitigated through a Commonwealth structural adjustment package
- water recovery should be equitably shared between basin states
- water should be recovered through a combination of improved infrastructure, environmental works and measures, review of water rules, and strategic buyback.

Revised draft plans were subsequently produced by the MDBA in May and August 2012 (MDBA 2012) and provided to the Ministerial Council (which includes the NSW Minister) for a formal response by the council, both collectively and by individual members. The plan is now expected to be finalised in late 2012.



## Murray–Darling Basin cap

An audit of water use in the Murray–Darling Basin in 1995 concluded that the high level of use was a major factor in the decline in river health. As a result, a limit ('cap') on surface water extractions in the basin was introduced to prevent further growth in extractions and these are monitored to ensure that the amount of water taken by licence holders remains below the cap.

## Water sharing plans

Water sharing plans have been a significant development in improving the management of water resources in NSW. They can apply to rivers, groundwater (see Water 4.4) or a combination of water sources. These statutory plans provide a legislative basis for the sharing of water between the environment and extractive users. They bring certainty for both the environment and water users over their 10-year duration and provide the basis for the trading of water licences and water allocations.

Water sharing plans aim to:

- protect the fundamental health of the water source
- ensure that the water source is sustainable in the longer term
- provide water users with long-term certainty about access rules.

Environmental flow rules, implemented through the water sharing plans for each river valley, enable the equitable sharing of water between users and the environment.

Since 2004, a total of 63 water sharing plans have been implemented across NSW, covering about 95% of the water used. Plans for the remaining water sources are being developed progressively with those for the Murray–Darling Basin to be completed by 2013 and the rest of the state by 2014. Over the long term, the plans for regulated rivers will return on average an additional 220,000 megalitres (ML) of water per year to the environment, over and above the requirement under the Murray–Darling Basin cap.

Additional constraints or requirements may be imposed in the Murray–Darling Basin Plan being developed by the MDBA. Long-term average annual extraction limits (LTAAEL) established in water sharing plans are generally lower than the Murray–Darling Basin cap. These LTAAELs will become the Baseline Diversion Limits under the basin plan, which will set new Sustainable Diversion Limits.

Although environmental flow rules have been introduced, it may take some time before the aquatic ecosystems receiving environmental water are restored to an acceptable environmental condition. Until recently, the severity of drought conditions in

some regions of NSW has meant that insufficient water has been available for some water sharing plans to operate effectively.

Water sharing plans were suspended in the Lachlan from the time the plan commenced in 2004, and in the Murray and Murrumbidgee in September 2006, the Macquarie–Cudgegong in July 2007 and the Hunter Regulated Water Source in December 2006. During 2009–10, drought conditions eased and all plans have since been reactivated. While suspended, contingency arrangements were in place with the water available being prioritised for critical human uses, such as domestic requirements and high priority industry needs.

## Rural floodplain management plans

Rural floodplain management plans have been developed for 17 floodplains covering approximately 20,800 square kilometres. Completion of another four plans will bring the total coverage to more than 24,300 square kilometres. Plans have been developed for the floodplains of the Namoi, Gwydir, Macquarie, Lachlan, Murrumbidgee and Murray rivers and the Liverpool Plains. The objective of the plans is to enhance the health of flood-dependent ecosystems by increasing floodplain connectivity while also managing the risk from flooding by controlling floodplain development likely to block or redistribute flows during floods.

## Environmental water recovery

Water has been recovered for the environment in NSW through a number of programs including NSW RiverBank, the NSW Rivers Environmental Restoration Program, The Living Murray program (see Water 4.2), the NSW Wetland Recovery Program (see Water 4.3) and Water for Rivers. The cumulative total for all adaptive environmental water at June 2012 was 357,141 ML.

**Table 4.4** summarises the amount of licensed water purchased collectively by NSW from these programs by river valley. However, it does not include water purchases by the Australian Government.

Adaptive environmental licences are also being created through water savings from infrastructure efficiency projects. These licences include over 93,000 ML of entitlement through Water for Rivers projects in NSW (see Water 4.2), as well as 63,000 ML from The Living Murray (TLM) in the state. For example, about 47,000 ML per year of water will be saved and committed as an adaptive environmental licence through TLM's Darling Anabranch Pipeline project.

**Table 4.4: Cumulative holdings of adaptive environmental water recovered to 30 June 2012 by program and valley (ML)**

Regulated water source	NSW RiverBank				Rivers Environmental Restoration Program			NSW Wetland Recovery Program		The Living Murray	Subtotal per valley
	HS	GS	SA	UR	GS	SA	UR	GS	SA	LTCE	
Gwydir	–	7,798	–	–	7,104	441	–	2,190	–	n/a	17,533
Macquarie	–	19,926	28	–	22,602	122	2,980	5,891	1,302	n/a	52,851
Lachlan	1,000	24,097	–	–	472	–	184	–	–	n/a	25,753
Murrumbidgee	–	27,676	5,679	6,162	–	–	–	–	–	n/a	39,292
NSW Southern Murray–Darling Basin <sup>6</sup>	–	–	–	–	–	–	–	–	–	221,487	221,487
Subtotal per program	1,000	79,497	5,707	6,162	30,178	563	3,164	8,081	1,302	221,487	
Cumulative total											357,141

Source: OEH 2011a; OEH data 2012; Water for the environment (water purchase programs)

Notes: The Rivers Environmental Restoration Program and NSW Wetland Recovery Program were jointly funded by the NSW and Australian Governments.

HS = High security – Shares are likely to receive close to 100% of their allocation in most years.

GS = General security – Allocation varies depending on inflows and storage levels.

SA = Supplementary access – is subject to event-based announcements

UR = Unregulated entitlement – Available water is not regulated by a major storage. For many valleys, water sharing plans for unregulated water sources have not yet been completed and licences are administered under the *Water Act 1912*.

LTCE = Long-term cap equivalent – Units of measure for entitlement purchased under The Living Murray (TLM) which approximates long-term water availability and includes all entitlement categories (HS, GS, SA, Conveyance). A breakdown of TLM water purchase and recovery is available at the website.

NSW Southern Murray–Darling Basin includes water recovered from the Murray, Murrumbidgee and Lower Darling valleys for the benefit of the Murray River (The Living Murray).

Water recovery is also occurring under the following programs:

- Pipeline NSW is a joint NSW and Commonwealth Government project to improve the efficiency of delivering rural stock and domestic water by substituting channels and dams with piped systems, tanks and troughs. The project is due for completion in 2012 and will recover about 5000 ML per year of water from reduced system and operational losses.
- The Darling River Water Savings Project was established to improve the water supply and management of the entire Darling River system, in particular for the Menindee Lakes.
- Sustaining the Murray–Darling Basin is a State Priority Project focused on improving water efficiency, particularly the investment in metering works in the basin.

- Hawkesbury–Nepean River Recovery Program: The Hawkesbury–Nepean catchment is the most developed catchment for water use in coastal NSW. This program includes the following projects aimed at water efficiency: metering of water users; water-smart and nutrient-smart farms; water recycling; reducing water use from the tap; more efficient irrigation; and purchase of water licences.

## Developing responses

### Floodplain Harvesting Policy

Floodplain harvesting works and water extractions fall under the scope of the *Water Management Act 2000*. The NSW Office of Water (NOW) has released a draft *NSW Floodplain Harvesting Policy* for community consultation (NOW 2010). It foreshadows that all floodplain harvesting activities will require a water supply work approval and a water access licence to harvest water, both issued under the Act. Floodplain harvesting extractions will be managed within long-term average annual extraction limits under water sharing plans.

## Future opportunities

Over the next few years, water sharing plans will be completed for all river valleys, floodplain management plans will be produced, and the harvesting of water from floodplains is likely to be regulated, all with the aim of enhancing the sustainable and equitable management of water resources in NSW.

The 2008 Intergovernmental Agreement on Murray–Darling Basin Reform established a framework for greater coordination and a whole-of-basin focus for the management of basin water resources. When finalised, the Murray–Darling Basin Plan will set a new sustainable diversion cap on water extractions for each valley and any water sharing plans developed after this will need to be consistent with the plan.

With the referral of powers relating to water management in the Murray–Darling Basin through the basin plan, the Commonwealth will play a more prominent role in determining water extraction levels, coordinating environmental water management and developing future initiatives to improve water resources and river health. The NSW Government will ensure that the Commonwealth delivers a plan that protects the environment as well as the social and economic wellbeing of regional communities.

Better information on the relationship between surface water and groundwater is desirable to facilitate more integrated and holistic management of all water resources.



## 4.2 River health

The stresses on New South Wales inland rivers have eased after a period of protracted drought as widespread rains have led to high flows and enhanced the productivity of aquatic ecosystems. Coastal river systems have also experienced good flows that have enhanced the condition of riverine ecosystems and downstream estuaries.

The condition of macroinvertebrate communities in inland rivers is moderate, though this was recorded during low flows. Native fish populations remain in poor condition and have shown little response to higher flows. Nine out of 25 native fish species found in inland rivers were not sighted at all in recent surveys and exotic species accounted for 68% of the fish biomass sampled. Recruitment rates of native fish in coastal rivers were also very low. Large algal blooms that occurred in inland river systems during drought conditions in 2008–10 have since dissipated with increased river flows.

Most major inland river systems are still affected by pressures, including the ongoing impacts of water extraction and altered river flows, degradation of the riparian zone, catchment disturbance, invasion by exotic species and changes to water quality. As a result, most inland rivers remain in poor ecosystem health. By contrast, coastal rivers are less affected by flow regulation and, with the exception of fish communities, are generally in better ecological health.

The extent of use of water resources is a major determinant of the condition of freshwater riverine systems. Areas where the flow regime has changed the most (where river regulation and water use are highest) are generally showing the greatest signs of ecosystem stress.


Water sharing plans are being implemented for all major rivers in NSW to ensure a balance between human uses of water and the environment, with all plans for the Murray–Darling Basin to be completed by the end of 2013.

### NSW indicators


Indicator and status	Trend	Information availability
Health of aquatic macroinvertebrate communities	Stable	✓✓
Health of fish assemblages	Decreasing	✓✓
Hydrological condition	Increasing	✓✓
SRA overall health index of Murray–Darling Basin rivers	Stable	✓✓
Salinity levels	Stable	✓✓
Phosphorus levels	Stable	✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.


## Introduction




Healthy riverine ecosystems, comprising rivers and their riparian zones, floodplains and wetlands, are vital for the maintenance of aquatic and terrestrial biodiversity. However, while aquatic ecosystems have their own intrinsic value, healthy rivers are also critical to provide the ecosystem services necessary to maintain good water quality and supply, and enable opportunities for future economic growth. Rivers support a variety of beneficial uses of water by humans, including activities such as agriculture, aquaculture, fishing, recreation and tourism.



NSW has approximately 58,000 kilometres of rivers and major streams. These can generally be categorised as either short, high-gradient coastal streams or long, low-gradient inland rivers. The flow of these rivers is highly variable and often unpredictable. Streams and creeks may flow permanently or only intermittently after heavy rainfall and floods. About 97% of river length in NSW has been substantially modified (NLWRA 2002). Typical changes include the removal of riverine vegetation, the regulation of river flows, sedimentation from erosion of land and river banks, and the introduction of exotic species.




A river is in good health if it is resilient in the face of environmental change, including changes in climate patterns, resource exploitation and other human impacts. A primary objective is to achieve a long-term balance, whereby the integrity of natural systems is preserved while providing for a range of beneficial human uses. Factors that affect the resilience of river systems include river geomorphology, riparian vegetation, natural flow regimes, water quality and exotic species.



This section focuses on inland and coastal freshwater riverine ecosystems, including floodplains which are essential for connecting many types of freshwater wetlands and associated ecological processes to the rivers. Other ecosystem types are discussed elsewhere in this report: freshwater wetlands in Water 4.3 and estuaries in Water 4.6.

## Status and trends



The health of NSW coastal and inland rivers is likely to have improved following the breaking of a prolonged drought. In 2010, NSW had its third-wettest year on record and the wettest in over 50 years. It was also the wettest year on record for the Murray–Darling Basin (BoM 2011a). In 2010, a number of major flood events occurred in inland and coastal catchments across NSW, with significant flooding in southern NSW (BoM 2011a). Another wet year in 2011 caused further widespread flooding, particularly in northern NSW, and the flushing of most NSW river systems.

Most of the sampling of macroinvertebrates outlined in this report was, however, undertaken during drought conditions so any improvements as a result of the drought breaking will not be observed or reported until the next SoE report. For fish communities, some post-drought sampling has occurred in most valleys, excluding the Gwydir, Lachlan, Macquarie and Murrumbidgee rivers.

## River health

The Sustainable Rivers Audit (SRA) has developed a methodology to assess the health of rivers in the Murray–Darling Basin (MDB) based on indexes for hydrology, fish and macroinvertebrates. More recently, measures of riparian vegetation and physical form have been added. A set of rules is used to combine the indexes for fish, macroinvertebrates and riparian vegetation to determine an overall rating of ecosystem health (Davies et al. 2012). These are reported alongside index scores for hydrology and physical form, which provide additional information on some of the drivers of ecosystem health.

Overall results for the inland river systems of the Murray–Darling Basin are summarised in **Table 4.5** and described in greater detail below. Data recorded for the three years up to the end of 2010 were available for the SRA analysis, collected mainly during drought conditions. No assessment has been conducted for those rivers in far western NSW beyond the MDB.

Development of a complementary assessment process for coastal rivers in NSW has now commenced. Coastal rivers were assessed using similar, but not directly comparable methodologies, with an extra year of data recording available for the wet conditions of 2011. However, data for the condition of macroinvertebrates in coastal rivers was not available for this report. The results for the other indicators are summarised in **Table 4.6**.

## Hydrology

River flow influences virtually every facet of river ecosystem health and is therefore an indicator of river condition. The SRA hydrology condition index for inland NSW compares measured flows with reference conditions for each river using modelled data based on flow variability over the longer term (110 years of recording). The index reflects the overall effects of water resource development on historical flow patterns or the naturalness of the flow regime. However, the results are less indicative of shorter term variability or current flows, and therefore do not directly reflect the effects of either the recent drought or the subsequent flooding that has occurred in much of the Murray–Darling Basin over the past two years.

The SRA hydrology component has been broadened to assess most of the river network, not just individual locations within the regulated components and now includes:

- improved hydrological modelling and broader assessment within valleys
- the hydrological effects of farm dams and historical changes to land cover
- measures of hydrological condition for both the channel and near and far floodplain environments (with four additional measures to characterise the overbank flooding regime)
- assessments of temporal changes over the previous 12 years, alongside the condition assessment based on a longer term (30-year) record.

As a result of these changes, the condition scores for hydrology presented in Table 4.5 cannot be directly compared to those presented in *SoE 2009* (DECCW 2009).

For coastal rivers, an approach consistent with that used to calculate hydrological stress for water sharing plans was used. This approach compares peak daily demand estimates with the 80th percentile flow to develop a low-flow hydrological index. It was adopted because the vast majority of licences issued for water extraction on the coast are for unregulated flows, which are generally accessed during dry conditions when river flows are low. The exceptions to this are those valleys with major storages for town water supply and river regulation, such as the Hunter, Hawkesbury–Nepean, Shoalhaven and Snowy rivers. In these valleys, dam releases are made to allow low flows to continue, but the dams capture most high-flow events.

**Table 4.5: Summary of ecosystem health and condition assessments for NSW Murray–Darling Basin rivers, 2010**

Valley	Hydrology	Physical form	Fish	Macro-invertebrates	Riparian vegetation	Ecosystem health rating
Border Rivers	Good	Moderate	Moderate	Moderate	Poor	Poor
Condamine-Culgoa	Poor	Moderate	Moderate	Moderate	Good	Moderate
Warrego River	Good	Good	Poor	Good	Good	Moderate
Paroo River	Good	Good	Good	Good	Good	Good
Gwydir River	Poor	Moderate	Poor	Moderate	Moderate	Poor
Namoi River	Good	Moderate	Very poor	Moderate	Poor	Poor
Castlereagh River	Good	Good	Very poor	Moderate	Good	Poor
Macquarie–Bogan Rivers	Moderate	Moderate	Extremely poor	Moderate	Moderate	Very poor
Darling River	Moderate	Moderate	Poor	Poor	Good	Poor
Lachlan River	Moderate	Good	Extremely poor	Moderate	Poor	Very poor
Murrumbidgee River	Poor	Good	Extremely poor	Good	Moderate	Poor
Upper Murray River	Poor	Good	Extremely poor	Good	Moderate	Poor
Central Murray River	Poor	Moderate	Very poor	Poor	Good	Poor
Lower Murray River	Very poor	Moderate	Poor	Moderate	Poor	Poor

Source: Davies et al. 2012

**Inland rivers:** The SRA found that most sites in the Murray–Darling Basin were in moderate to good hydrological condition (Table 4.5). Those valleys that fell short of reference condition were the Condamine–Culgoa, Gwydir, Murrumbidgee and Upper, Central and Lower Murray valleys. For the Condamine, Gwydir, Murrumbidgee and Upper Murray valleys, the montane and upland zones were in good condition,

with the poor rating resulting from changes to the hydrology of the main river channels. The Central and Lower Murray valleys are dominated by the regulation of the Murray River which was in very poor condition. The Border Rivers, Warrego, Paroo, Namoi and Castlereagh were rated as being in good hydrological condition (Davies et al. 2012).

**Table 4.6: Summary of ecosystem health and condition assessments for NSW coastal rivers, 2011**

Valley	Hydrology	Physical form	Fish	Riparian vegetation
Tweed River	Moderate	Very poor	Very poor	Poor
Brunswick River	Poor	Very poor	Poor	Poor
Richmond River	Poor	Poor	Poor	Moderate
Clarence River	Good	Moderate	Poor	Moderate
Bellinger River	Good	Moderate	Poor	Good
Macleay River	Good	Moderate	Poor	Poor
Hastings River	Moderate	Moderate	Very poor	Good
Manning River	Moderate	Moderate	Very poor	Good
Karuah River	Moderate	Moderate	Poor	Good
Hunter River	Moderate*	Very poor	Very poor	Moderate
Macquarie–Tuggerah Lakes	Poor	Moderate	Poor	Good
Hawkesbury–Nepean River	Good*	Poor	Very poor	Not assessed
Sydney Coast–Georges River	Not assessed	Poor	Very poor	Poor
Illawarra Coast	Not assessed	Moderate	Very poor	Good
Shoalhaven River	Good*	Moderate	Very poor	Moderate
Clyde River–Jervis Bay	Good	Good	Poor	Good
Moruya River	Good	Good	Very poor	Good
Tuross River	Good	Good	Very poor	Good
Bega River	Moderate	Moderate	Very poor	Moderate
Towamba River	Moderate	Moderate	Very poor	Good
Genoa River (NSW)	Not assessed	Good	Very poor	Good
Snowy River (NSW)	Good*	Poor	Extremely poor	Poor

Source: NSW Office of Water (NOW), NSW Office of Environment and Heritage and NSW Department of Primary Industries data 2012

Notes: Hydrological condition uses an assessment based on hydrological stress at low flows. Entries marked \* do not have low-flow stress as they receive regulated flows which are greater than natural low-flow levels, so stress mainly occurs as extractions during high levels.

Fish condition uses the same methodology as the SRA with some minor adjustments. Fish results are very low due to a new measure for recruitment, which was found to be poor in coastal rivers. The measures for 'nativeness' and 'expectedness' gave relatively better ratings.

**Coastal rivers:** The coastal rivers of NSW were mostly rated as being in good condition (Table 4.6). Only the condition of the Brunswick, Richmond and Macquarie–Tuggerah Lakes was rated as poor, reflecting the high peak demand during low flows in these rivers. The Tweed, Hastings, Manning, Karuah, Hunter, Bega and Towamba rivers had moderate levels of low-flow hydrological stress, reflecting a moderate impact at low flows as a result of extraction. All other valleys assessed were rated as good.

### Physical form

The SRA's new physical form component has been developed and implemented since the first SRA report (MDBC 2008a). Assessment of physical form for the SRA uses remotely sensed data obtained from airborne laser altimetry (LiDAR) surveys, sediment data modelled by SedNet (a catchment-based sediment model) and empirical models of reference condition.

**Inland rivers:** Based on the SRA methodology, all inland rivers were rated as being in moderate or good physical form (Table 4.5). The Warrego, Paroo,

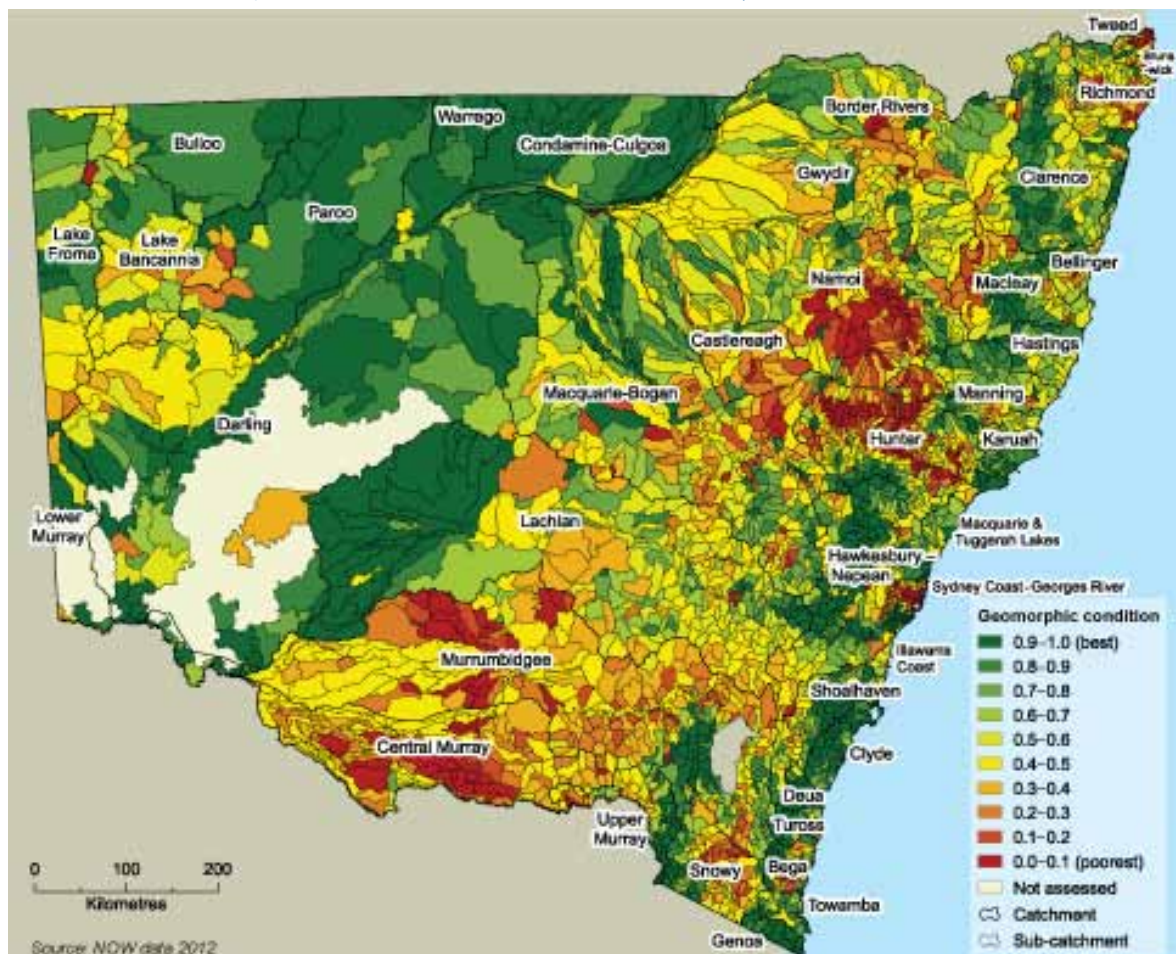
Castlereagh, Lachlan, Murrumbidgee and Upper Murray valleys all received a good rating compared to reference. However, there are substantial areas of moderate and poor geomorphic condition in the Murray and Murrumbidgee catchments at the reach level.

A more elaborate system for assessing physical form is provided by the Riverstyles® framework, based on river type, condition and recovery potential (Brierley & Fryirs 2005).

Mapping of geomorphic condition using the Riverstyles methodology has recently been completed for most of NSW and the outcomes are shown in **Map 4.1**. The results have been used to describe physical form for coastal rivers.

Riverstyles captures data at the river reach scale and therefore provides a more detailed analysis of geomorphic condition than the SRA in inland NSW. As a result, the outputs from Riverstyles mapping may be different from those derived using the physical form component of the SRA.

**Map 4.1: Statewide geomorphic condition based on Riverstyles®**



Notes: Areas coloured off-white have not yet been assessed.

Riverstyles mapping also captures a stream's recovery potential, which is a measure of the capacity of a stream reach to return to a good or realistically rehabilitated condition, given the limiting factors of the reach. These factors are based on hydraulics and the ability of vegetation and sediment to facilitate geomorphic evolution (Outhet & Young 2004).

**Coastal rivers:** Most coastal valleys are in good to moderate condition with three – the Tweed, Brunswick and Hunter – having a condition score of very poor (Table 4.6). The Tweed and Brunswick both have large areas of coastal plains relative to the size of their catchments with significant scope for lateral channel movement across the floodplain. The likelihood for this to occur has increased following extensive changes to riparian vegetation and large woody debris which constrained this movement in the past. The Hunter River has also undergone major change since European settlement. On the south coast, the Clyde, Moruya, Tuross and Genoa rivers had ratings of good.

## Fish

The fish component of the SRA has been broadened since the last report to include a measure for native fish recruitment. The recruitment indicator is weighted to have an intermediate influence on the overall fish condition score, relative to the existing 'expectedness' and 'nativeness' indicators. Data analysis also incorporates a more comprehensive quantification of native fish distributions in reference condition. As a result, the condition ratings for fish presented in this report are not directly comparable to those used in *SoE 2009* (DECCW 2009).

Ratings of expectedness and nativeness showed a slight improvement since 2009 in both inland and coastal rivers so what appears to be a decline in overall condition is mainly due to the influence of the new indicator for fish recruitment.

**Inland rivers:** Overall, fish condition index scores indicate that condition was poor to extremely poor in most inland valleys (Table 4.5). Only the Paroo Valley received a rating of good while the Border Rivers and Condamine–Culgoa were rated moderate. The valleys in the worst overall condition were the Macquarie–Bogan, Lachlan, Murrumbidgee and Upper Murray.

'Expectedness' (an indicator of the proportion of species historically found in each valley that are still present) was good in the Border Rivers and moderate in the Gwydir and Darling valleys. In some valleys many native fish species expected to occur were not recorded at all. Of 25 native fish species inhabiting inland rivers, nine were not recorded at any site sampled, including four that are threatened: the flat-headed galaxias, Murray hardyhead, trout cod and southern pygmy perch. Native fish recruitment was rated good in the Condamine–Culgoa and Paroo

valleys and moderate in the Border Rivers, Castlereagh and Lower Murray, and was worst in the Lachlan, Murrumbidgee, and Upper and Central Murray valleys.

While data available for the SRA river health analysis and the outcomes described in this report was sampled wholly during drought conditions, an extra year of unpublished data recorded during flood conditions in 2011 has since become available, but reveals little change to the overall results described here. Fish sampling was also undertaken in the far west of NSW, outside the Murray–Darling Basin. Results for Lake Bancannia were very poor and those for Cooper Creek, Lake Frome and the Bulloo River extremely poor.

**Coastal rivers:** Overall, fish condition index scores indicate that condition was poor to extremely poor in all coastal valleys with none rated as being in moderate or good condition (Table 4.6). Valleys in the best condition (poor) were the Brunswick, Richmond, Clarence, Bellinger, Macleay, Karuah, Macquarie–Tuggerah Lakes and Clyde River–Jervis Bay. The only coastal valley in extremely poor condition was the Snowy.

'Nativeness' of fish assemblages was generally very good, but this is the lowest weighted indicator for fish. Expectedness scores in coastal rivers were slightly better than for inland rivers, but much of the species diversity that should be present was not detected. Five freshwater species expected to be present in coastal catchments were not sampled at all during the reporting period, including the threatened Oxleyan pygmy perch and southern purple-spotted gudgeon, as well as jungle perch, spangled perch and the Darling River hardyhead.

Recruitment was lower in coastal valleys than in inland rivers with many of the species present not recruiting or recruits not being very abundant. The exact cause for this is not known but the impacts of fish barriers on the movement upstream of estuarine species and the recent spate of flooding in coastal catchments may be contributing factors.

## Macroinvertebrates

The SRA macroinvertebrate index (MDBC 2003) describes the condition of macroinvertebrate communities in rivers. The index integrates indicators for observed macroinvertebrate families (compared with reference conditions) and sensitivity to disturbance. The macroinvertebrate component of SRA has been refined by improving the assessment of reference condition for macroinvertebrate communities and the calculation of indicator values. As a result, the condition ratings for macroinvertebrates presented in this report are not directly comparable to those reported in *SoE 2009* (DECCW 2009).

**Inland rivers:** Overall, macroinvertebrate condition was best in the Warrego, Paroo, Murrumbidgee and Upper Murray systems which all had ratings of good (Table 4.5). This reflects relatively fewer stressors, such as water extraction or flow regulation, in these valleys. With the exception of the Darling and Central Murray valleys, which were in poor condition, all other valleys rated moderate.

### Riparian vegetation

A new riparian vegetation index has been developed and implemented since the first SRA report (MDBC 2008a). Because no reference condition could be established for fringing riparian vegetation, scores for SRA analysis of inland rivers are based on the near-riparian zone, which describes vegetation occurring beyond the high river bank. For coastal rivers, riparian vegetation condition was assessed by analysing the extent of native woody vegetation that occurred within a 30-metre buffer applied to the stream line.

**Inland rivers:** For near-riparian vegetation, the Condamine–Culgoa, Warrego, Paroo, Castlereagh, Darling and Central Murray valleys had good condition ratings, while the Border Rivers, Namoi, Lachlan and Lower Murray valleys were in poor condition. The remaining valleys rated moderate.

**Coastal rivers:** Ratings of the condition of riparian vegetation for coastal rivers are closely related to physical form, with most valleys in moderate to good condition.

### Ecosystem health

**Map 4.2** shows the SRA ecosystem health ratings by river valley for the inland rivers of the Murray–Darling Basin only. The rating of river ecosystem health is a combined assessment based on the indexes for fish, macroinvertebrates and riparian vegetation shown in Table 4.5. Overall, the Paroo was the only river found to be in good ecosystem health, with the Condamine–Culgoa and Warrego rivers being in moderate health. Most other rivers received ecosystem health ratings of poor or very poor.

**Map 4.2: SRA assessment of ecosystem health in the Murray–Darling Basin, 2010**



Notes: The SRA catchment ecosystem health rating is based on fish, macroinvertebrates and riparian vegetation.

Due to the relatively recent commencement of broadscale coastal monitoring, it is not yet possible to make an overall assessment of ecosystem health for coastal rivers.

## Threatened species

Declining biodiversity and the number of threatened species in Australia is of serious environmental concern. While it may be more widely recognised that many mammals, birds and other terrestrial species are threatened, some aquatic species are also under threat.

In NSW, seven of the 25 native freshwater fish species found in inland rivers and nine in total are listed as threatened with extinction under the *Fisheries Management Act 1994*. Three freshwater invertebrates have also been listed as endangered species under the Act and the status of many other species is of concern for conservation purposes.

Three aquatic ecological communities have been listed as endangered under the Act:

- the Lowland Murray River ecological community
- the Lowland Darling River ecological community
- the Lowland Lachlan River ecological community.

## Water quality

Parameters for describing water quality include:

- salinity, where the electrical conductivity (EC) of water is used as a surrogate measure for total concentration of all salts in water
- nutrients, represented by total phosphorus and nitrogen content of the water, both measured in milligrams per litre (mg/L)
- turbidity, where the light-scattering properties of water measured in nephelometric turbidity units (NTU) is a surrogate measure for the amount of suspended particles in water.

In NSW, the current water quality guidelines for ecosystem protection use the default trigger values in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) which were prepared under the National Water Quality Management Strategy (ANZECC & ARMCANZ 1994). The extent and frequency with which water quality monitoring data exceeds these trigger values provides an indication of the potential risk that environmental disturbance is occurring.

## Salinity

Geology, climate, groundwater interactions and land-use practices all affect the level of salinity in NSW streams. High salt concentrations can degrade freshwater aquatic ecosystems while irrigation water with high salt loads can increase soil salinity.

Electrical conductivity is used as a measure of the level of salts in water. Continuous monitoring of electrical conductivity has been established at a number of sites across NSW. **Table 4.7** shows mean daily salinity levels for a three-year period (2008–2011) and a 10-year period (2001–11). The table also shows the maximum salinity level measured during the latest three-year period of record at each stream measuring point. Mean daily salinity levels are well below the World Health Organization desirable upper limit for drinking water of 800 EC units. However the maximum spot readings in Table 4.7 indicate that the limits for drinking water have been exceeded in many systems for short periods.

Compared with the 10-year mean, the latest three-year reporting period shows a relatively stable or slightly lower mean daily electrical conductivity in the streams surveyed. Only the Hunter River at Greta showed a substantial increase (over 70 EC units) while five sites showed a decrease of the same magnitude or greater. This is likely to be due to major flooding that occurred in the latter part of 2010 and into 2011 as drought conditions broke across large areas of NSW.

## Nutrients

Nutrients, especially nitrogen and phosphorus, can have a significant effect on water quality when present in excess of ecosystem needs. The current guidelines for water quality (ANZECC & ARMCANZ 2000), along with NSW River Flow Objectives, provide default trigger values for water quality parameters designed to protect potential uses of water. Trigger values are conservative and where they are exceeded indicate the need to investigate possible causes, but they do not necessarily signify poor river health.

Table 4.7: Electrical conductivity in selected NSW rivers

Stream measuring point	Daily river salinity levels (EC units) for specified period			
	Period of record	July 2001–June 2011 mean	July 2008–June 2011 mean	Maximum spot readings: July 2008–June 2011
Macintyre at Holdfast	2002–2012	281.1	255.0	475.5
Mehi at Bronte*	2001–2012	436.0	331.2	167.8
Barwon–Darling at Collarenebri	2002–2012	283.7	214.6	330.7
Namoi at Goangara*	1995–2012	415.7	383.9	783.0
Namoi at Gunnedah	1995–2012	454.4	463.0	932.0
Castlereagh at Gungahlin Bridge*	2001–2012	600.9	574.4	1,527.3
Macquarie at Carinda*	1999–2012	577.2	480.1	734.2
Macquarie at Barooka	1999–2012	450.1	425.5	1,057.9
Bogan at Gongolgon*	2000–2012	377.4	281.3	843.6
Hunter at Greta	1992–2012	713.5	784.9	1,447.0
Lachlan at Booligal*	1999–2012	593.6	520.7	858.8
Lachlan at Forbes	1999–2012	497.8	490.0	1,017.1
Murrumbidgee at Wagga Wagga	1993–2012	139.2	149.5	318.0
Murrumbidgee at Balranald*	1992–2012	149.1	158.3	329.0

Source: NOW data 2012

Notes: 'Maximum spot readings' (not means) cover the latest three-year period of record

\* End-of-valley site

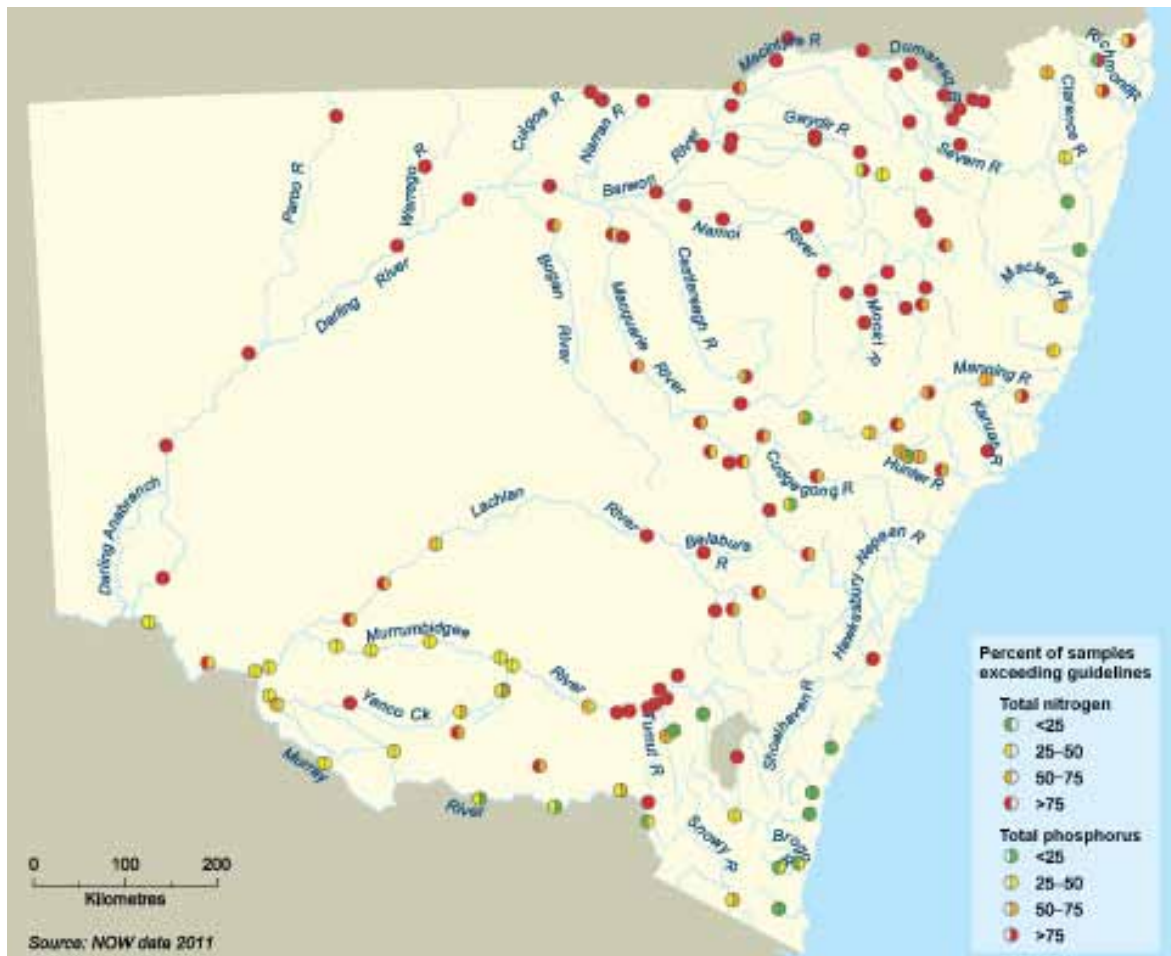
**Map 4.3** shows the percentage of water samples from streams across NSW that had nitrogen and phosphorus concentrations above the ecosystem protection trigger values (ANZECC & ARMCANZ 2000). The results show that the northern inland and western drainages of NSW – the Border Rivers, Gwydir, Namoi, Macquarie, Darling and intersecting streams – regularly exceed trigger values for nutrients. In the central and southern inland drainages of NSW (the Lachlan and Murrumbidgee valleys), nitrogen and phosphorus levels are also elevated in mid-catchment locations, but trigger values are exceeded less frequently in the lower reaches of these drainages and in the Murray. In the coastal regions of NSW, trigger values are generally exceeded less frequently than in inland regions, with some exceptions around the Hunter Valley and north coast.

### Turbidity

Water clarity decreases – or becomes more turbid – as the amount of sediment and other particles in the water column increases. Turbidity levels vary according to the geology, soil type and cover, climate and intensity of disturbance to the landscape through land clearing and the erosion of agricultural land, stream banks and channels. High turbidity can decrease the amount of light that sustains plant growth, suppress the growth of aquatic organisms and choke habitat. It can also carry with it pesticides and other chemicals.

In NSW there is generally a pattern of low turbidity in upland areas and higher turbidity in lowland areas, reflecting the progression of rivers through the landscape and the effects of geology and topography. However there is also a tendency for higher levels of turbidity in river basins in the north-west of the state, such as the Paroo and Warrego, due to the naturally occurring dispersive soils found there.

**Map 4.3: Exceedences of ecological trigger levels for total nitrogen and total phosphorus, 2009–11**



## Water quality by river valley

Nationally, an assessment of the water quality of river valleys (SKM 2011) was prepared for the *Australian State of the Environment 2011* (ASoEC 2011). The NSW component of this assessment consisted of site and overall ratings for the inland river valleys of NSW, evaluated against the ANZECC default trigger values. The overall results for rivers are presented in **Table 4.8**.

The results show that the low-gradient, far western streams have a tendency to poor water quality, particularly turbidity but also nitrogen and phosphorus, with only the Mallee and Murray–Riverina recording good ratings. These results for water quality display some inconsistency with the outcomes of the SRA ecosystem health assessments shown in Table 4.5, most markedly for the Paroo River, but also the Warrego and Condamine–Culgoa. While these rivers have high levels of natural turbidity and therefore lower ratings for water quality, their ecosystems are adapted to these conditions and, being relatively undisturbed, they remain in better ecosystem health than the other rivers assessed.

These outcomes demonstrate the need for regional guidelines which better reflect natural variability in water quality and the influence of soil types and flow patterns on water quality at the regional level. Work is now progressing on the development of regional water quality guidelines for NSW. This involves modelling reference (natural) water quality and currently observed water quality, based on the characteristics of individual catchments and their levels of disturbance to develop more appropriate guidelines for water quality that are not uniform across the state.

## Algal blooms

Most freshwater algal blooms in NSW are caused by blue-green algae (or ‘cyanobacteria’), some of which produce toxins that are harmful to humans, livestock and aquatic fauna. However, non-toxic blooms can also have significant impacts on the health of aquatic ecosystems by depleting dissolved oxygen (which can cause fish kills), changing pH levels, reducing light penetration, and smothering habitat.

Drought conditions in 2008–09 and 2009–10 led to major blue-green algal blooms in many inland waters across NSW. In particular, warm conditions and low water availability caused major blooms in the Murray River in the autumns of both 2009 and 2010 that extended for over 1000 kilometres downstream of Lake Hume. In contrast, the 2010–11 period was much wetter with higher water levels and good flows in many NSW rivers and significantly fewer blooms reported.

## Pressures

### Water extraction and altered flow regimes

The drought in NSW, which lasted for over eight years in many river valleys, was replaced by wetter than average rainfall in 2010 and 2011. Water availability to the environment has improved in most inland rivers and wetlands following flooding events that have flushed river systems. However, natural flows continue


to be modified by the effects of water extraction and flow regulation and control, through the dams built on most large river systems (see Water 4.1). Altered flow regimes also affect the seasonality and variability of flows, dampening both the peaks and troughs in water levels. This has an impact on the critical ecological processes that trigger breeding cues for bird and fish species, and has been a significant factor in the loss of biodiversity and decline of aquatic ecosystems over the longer term.

'Alteration to the natural flow regimes of rivers and streams and their floodplains and wetlands' has been listed as a Key Threatening Process (KTP) under the *Threatened Species Conservation Act 1995*. A related process, 'the installation and operation of in-stream structures and other mechanisms that alter natural flow regimes of rivers and streams' is also listed as a KTP under the *Fisheries Management Act 1994*. Alteration to natural flows has impacts on the habitat of native species, their dispersal and breeding, and encourages the establishment of introduced pest species.

**Table 4.8: Water quality assessment for NSW river basins from the National Water Quality Assessment, 2007–11**


River basin	Sites	Salinity	Total nitrogen	Total phosphorus	Turbidity	pH
Border Rivers	33	Fair	Very poor	Very poor	Fair	Fair
Moonie River	1	Good	Very poor	Very poor	Very poor	Good
Condamine–Culgoa Rivers	7	Good	Very poor	Very poor	Very poor	Good
Warrego River	1	Good	Very poor	Very poor	Very poor	Good
Paroo River	1	Good	Very poor	Very poor	Very poor	Good
Gwydir Lakes	24	Poor	Very poor	Very poor	Fair	Poor
Namoi River	38	Poor	Very poor	Very poor	Fair	Poor
Castlereagh River	1	Very poor	Poor	Very poor	Good	Good
Macquarie–Bogan Rivers	17	Poor	Very poor	Very poor	Good	Fair
Darling River	26	Fair	Very poor	Very poor	Poor	Poor
Lachlan River	15	Fair	Very poor	Poor	Fair	Good
Benanee River	4	Good	No data	No data	Good	Good
Murrumbidgee River	70	Good	Poor	Fair	Good	Good
Upper Murray River	16	Good	Poor	Poor	Good	Good
Murray–Riverina	20	Good	Good	Good	Good	Good
Lower Murray River	2	Good	Good	Good	Good	Good

Source: SKM 2011




The alteration to natural flow regimes encompasses a range of changes or disturbances within rivers and associated floodplains, including to the frequency, duration, magnitude, timing and variability of flow events, altered surface water levels and seasonality of flows, and changes to the rates at which water levels rise and fall. Water resource development, while necessary to provide resource security and access, is the main cause of alterations to natural flows through the building of dams and weirs, diversion or extraction of in-stream flows, and the alteration of flows on floodplains by levees and other structures.


## Drought



Australia is a land prone to drought and many of its native plants and animals, as well as most inland aquatic ecosystems, are adapted to drought conditions and recover quickly when rain falls and flows increase. Many species depend on the natural variability in river flows to complete critical stages in their life cycles. However prolonged drought is a major disturbance to riverine systems and can place severe stress on aquatic ecosystems.




Where the cumulative effects of drought conditions and water extraction continue over an extended period, critical thresholds in life cycles may be exceeded, placing prospects for recovery at risk. Due to long-term changes in river condition, many native fish populations are now much reduced in numbers and hence less resilient to change, such as the additional stress placed on them during the recent decade-long drought.



Following the end of the drought, several major rivers experienced new threats from 'blackwater events'. These occur after a dry spell when accumulated debris is washed into the river during a flood, lowering levels of dissolved oxygen as microbes in the water break down the organic matter. While blackwater events have occurred naturally in the past, changes to river hydrology have decreased their frequency but increased their intensity in lowland river floodplains. Blackwater events are now more likely to lead to complete oxygen starvation in rivers, resulting in more devastating fish kills and further ecosystem deterioration (Hardwick 2011).

## Floodplain fragmentation and harvesting



Floodplains are the areas of land that would naturally receive waters during floods, while floodplain harvesting is the collection, extraction, diversion or impoundment of water flowing across a floodplain. Historic settlement on floodplains has changed natural flow patterns and the behaviour of floods through

associated structures, such as levee banks built to harvest water or protect property, as well as bridges, roads and railway lines. The redirection of floodwaters and reduction in flow levels have significant impacts on the health of riverine and wetland ecosystems.

## Catchment disturbance

Activities in river catchments can have a significant impact on riverine ecosystems, primarily through a reduction in water quality and changes to river geomorphology. Agriculture, urban stormwater and effluent can introduce nutrients, pollutants, suspended sediments and other contaminants into rivers and streams, reducing water quality during both high- and low-flow events. Changes in the land cover of catchments, such as the clearing of riparian and terrestrial vegetation and drainage of wetlands, have altered river geomorphology, including the widening of channels, headcut incisions in headwater streams, and increased sediment loads that smother aquatic habitats (Brierley & Fryirs 2005).

Pollution from a variety of sources has impacts on water quality and riverine ecosystem health. Point-source pollution has largely been addressed through regulatory processes, but pollution from diffuse sources is still an issue that affects water quality in some catchments (DECC 2009). The most significant pollutants from diffuse sources are sediments and nutrients, which are washed into streams by runoff from surrounding catchments. The quality and quantity of water pollution within a catchment largely depends on the extent of vegetation cover and local land management practices including agriculture and urban development. Generally, the more intensive the development, the greater the impact on riverine ecosystems.

Riparian vegetation provides habitat and food for aquatic communities so its disturbance is of particular significance for river health. Riverbank integrity is also critical because many species use overhanging banks and vegetation for habitat. Healthy fringing riparian vegetation is valuable for maintaining healthy aquatic ecosystems. It provides structural integrity for river banks to protect against erosion, as well as being a complex habitat and source of food and nutrients. The loss or degradation of the riparian zone through vegetation clearing and trampling by stock causes significant impacts.

Other forms of catchment disturbance that can influence river health include bushfires, roads, large dams and industrial activities such as mining.

## Water temperature

Cold water pollution is caused by low-temperature water being released into rivers from the bottom of large thermally stratified dams during summer. Cold water releases can prevent the natural seasonal changes in river temperature and reduce the range of temperature variation, both seasonally and diurnally, sometimes for hundreds of kilometres downstream. These variations may affect fragile ecosystems, fish breeding, the hatching of fish eggs and ecosystem productivity (Astles et al. 2004).

Discharge of cold water from dams is believed to be one of the main factors behind severe declines in native warm-water fish species in the Murray–Darling Basin (Phillips 2001). Nine dams in NSW are likely to cause severe cold water impacts: the Blowering, Burrendong, Burrinjuck, Copeton, Hume, Keepit, Khancoban, Pindari and Wyangala storages (Preece 2003). Over 3000 kilometres of NSW rivers are estimated to be affected by cold water pollution.

## Invasive species

Alien fish compete for food and space with native fish and frogs. They also prey on fish and frog eggs, tadpoles and juvenile fish, fundamentally altering food webs and habitats. Surveys of freshwater fish species by the NSW Department of Primary Industries (DPI) over the past three years found only 31% of the sites sampled were free from introduced fish, mainly in coastal rivers. A small number of sites – 6.7% – contained only introduced fish.

Averaged across all sites, introduced taxa accounted for 33% of the fish species collected at each site, 34% of the total fish abundance and 45% of the total fish biomass (DPI data 2011). The impact of introduced species is much greater in the inland rivers of the Murray–Darling Basin, with introduced fish present at 90% of all sites, and accounting for 40% of all species collected, 44% of total fish abundance and 68% of total fish biomass (see Biodiversity 5.4).

## Climate change

According to the findings of the CSIRO Sustainable Yields Assessment (CSIRO 2008a), the impacts of climate change on environmentally beneficial flooding in most regions of the Murray–Darling Basin, especially the highly developed regions, will be smaller than the impacts already brought about by water resource development. However, when the incremental impacts of climate change are superimposed on the existing pressures on water availability, the ecological consequences could be substantial as important ecological thresholds may be crossed (CSIRO 2008a).

Under a median climate change scenario, impacts by 2030 are expected to include:

- extended dry periods between important flood events and reduced flood volumes for the Murray icon sites identified in The Living Murray program (CSIRO 2008a)
- a 10% increase in the interval between beneficial flood events in the Macquarie River (CSIRO 2008b)
- a 24% increase in the flood interval in the Lachlan River (CSIRO 2008c).

## Responses

### Established responses

#### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Improve the environmental health of wetlands and catchments through actively managing water for the environment by 2021'. This includes the strategic recovery and management of water for the environment to improve the health of the most stressed rivers and wetlands. Further details on Goal 22 are provided in Water 4.1.


#### Water sharing plans

Water sharing plans are a significant tool in water management for addressing river health in NSW, by improving the management of river flows and water extraction practices to protect a proportion of flows for the environment. They are described in greater detail in Water 4.1.

#### Water recovery

Improving the condition of aquatic ecosystems is a high priority for NSW. The Australian and NSW Governments have recovered water through the purchase of water entitlements and infrastructure works under a number of programs, including NSW RiverBank, The Living Murray program, Water for Rivers and the NSW Wetland Recovery Program. Further information on water recovery is available in Water 4.1.







**The Living Murray program:** This program is a major investment by the NSW, Victorian, South Australian, ACT and Commonwealth Governments to recover water and improve the environmental health of the Murray River at six significant ecological sites along the river. In NSW, these include the Millewa Forest, Koondrook–Perricoota Forest, Chowilla Floodplain, and the river channel itself.

The NSW target is to recover 249,000 megalitres (ML) of water for the environment. By June 2012, the program had recovered 221,000 ML of water.

Projects completed in NSW include:


- 
- the Great Darling Anabranch Pipeline scheme, which saw the removal or modification of water regulation structures that previously created a series of pools, and replacing them with pumps, a pipeline and a filtration system to restore more natural flows to the Great Darling Anabranch, saving 47,000 ML of water per year
  - the purchase of 12,000 ML of irrigation entitlement from the Poon Boon Irrigation Trust
  - wetland rehabilitation works on the Edward River through construction of 18 regulators to stop the unwanted flooding of the Millewa Forest, saving 7100 ML of water a year
  - construction of a regulator to better manage flows and prevent unnatural flooding of Croppers Lagoon, providing an annual saving 8000 ML of water.

### NSW Rivers Environmental Restoration Program:




This program was completed in 2011. It targeted important wetlands in the Macquarie Marshes and the Gwydir, Lachlan and Murrumbidgee river systems to arrest their decline by purchasing water for the environment and improving the management and delivery of environmental flows. The achievements of this program are described in greater detail in Water 4.3.

### NSW Weir Review



The 2006 Weir Review identified more than 3300 dams and weirs on NSW rivers. A central issue for water sharing plans is the degree to which any management recommendation to remove or modify weirs affects water resource availability and water sharing arrangements. While weirs create impediments to fish passage and cause impacts on water quality, they can provide valuable ‘compensatory’ refuge areas for fauna during drought times. These factors need to be carefully weighed when considering management intervention.



### Rural floodplain management plans

Rural floodplain management plans have been adopted for 17 floodplains covering approximately 20,800 square kilometres. Completion of another four plans currently being developed will bring the total coverage to more than 24,300 square kilometres. Plans have been adopted or are being prepared for floodplains associated with rural sections of the Namoi, Gwydir, Macquarie, Lachlan, Murrumbidgee and Murray rivers and the Liverpool Plains.

The objective of the plans is to enhance the health of flood-dependent ecosystems by increasing floodplain connectivity while also managing the risk from flooding through control of development that is likely to block or redistribute flows during floods. This is achieved by mapping floodway networks based on historical flood information to allow for the unimpeded passage of floodwaters. Floodplain management plans are statutory plans under the *Water Act 1912* and *Water Management Act 2000* and form the basis for assessing floodplain work approvals.

### Water releases for the Snowy River

Water for Rivers was established to achieve significant improvements in environmental flows into the Snowy and Murray river systems. Targets include returning 212,000 ML or 21% of average annual natural flows to the Snowy River and 70,000 ML to the Murray River in a staged approach over 10 years. In the 2010–11 water year, a total of 24,200 ML of water was committed for additional environmental flows by the NSW, Victorian and Commonwealth Governments. The first release of 16,600 ML occurred in 2010 and was the largest environmental release to the Snowy River since the Jindabyne Dam was built in 1967. This was followed by an additional 7600 ML in April 2011 and 84,000 ML during October 2011.

### Pipeline NSW

Under Pipeline NSW, old and wasteful open channels that deliver stock and domestic water from NSW rivers are being replaced with piped systems modelled on the successful Cap and Pipe the Bores program in the Great Artesian Basin. New pipelines will pump water from rivers or groundwater sources and deliver it directly to farm storage tanks and stock troughs via a network of underground pipes in three locations:

- the Barwon Channel Association stock and domestic pipeline, saving 1488 ML per year
- the Lower Gwydir domestic pipeline, saving 2544 ML per year
- the Lower Lachlan Noonamah Water Authority stock and domestic pipeline, saving 795 ML per year.

The water saved by Pipeline NSW will be reallocated and managed through environmental water licences held by the NSW and Commonwealth Governments to benefit the rivers.

### NSW Diffuse Source Water Pollution Strategy

Pollution from diffuse sources accounts for the majority of pollutant loads in the state's waterways. The objective of this strategy (DECC 2009) is to reduce diffuse source water pollution in all NSW surface and groundwaters. The strategy's primary focus is on sources of priority pollutants that are not currently regulated. The three main pollutants to be addressed are sediments, nutrients and pathogens, which can arise from a multitude of sources, including agricultural land uses, sealed and unsealed roads, and urban stormwater.

### Cold Water Pollution Strategy

The Cold Water Pollution Strategy adopted in 2004 aims to reduce the significant effect that major dams have on the ecology of many of the large rivers across NSW. The strategy is being implemented in five-year stages: outcomes achieved in the first stage included major infrastructure works at Jindabyne and Tallowa Dam, investigations at Keepit and Burrendong dams, integration of cold water pollution conditions in State Water works approvals and identification of high priority dams for possible action in Stage 2. *Guidelines for Managing Cold Water Releases* became available in April 2011 (NOW 2011) and a *Report on the implementation of Stage 1* of the strategy was released in July (NOW 2012).

### Native Fish Strategy for the Murray–Darling Basin 2003–2013

The *Native Fish Strategy for the Murray–Darling Basin 2003–2013* (MDBMC 2003) has the long-term goal of rehabilitating native fish communities back to 60% of estimated pre-European fish populations by the year 2050 (MDBC 2006). It covers a range of initiatives designed to reduce the threats to native fish and engage the local community in improving river health across the basin. Actions taken so far have included placement of over 5100 snags in rivers and improving the condition of over 90 km of riparian vegetation. In addition, over 14,800 people across the state have attended community engagement events promoting activities and an understanding of native fish issues.

### Fishways

Remediation of fish passage at weirs, dams and road crossings by constructing fishways or fish ladders and redesigning existing barriers plays an important role in improving the health of fish communities.

Improvements have been delivered through three major projects. The Sea to Hume Dam Fishway Program involves the construction of 19 fishways on the Murray and adjacent waterways, improving fish access to over 2000 km of waterway. The program is nearing completion, with 14 fishways now completed.

The Fish Superhighways Program is a strategic initiative to improve fish passage at State Water Corporation assets across NSW. Fishways have been completed at 15 weirs, allowing improved passage to over 1700 km of river, while a further 17 fishways in the planning and design phase will improve connectivity to another 1600 km. Six weirs have been removed since 2002 and the removal of another 18 is being investigated.

The Bringing Back the Fish Project concluded in 2009, improving migratory fish access to over 1200 km of waterways in coastal NSW.

## Developing responses

### Water shepherding project

The NSW and Commonwealth Governments signed a Memorandum of Understanding (MoU) on shepherding environmental water in July 2010. The MoU sets out the principles for how water purchased for environmental purposes in one location will be protected from extraction or 'shepherded' to a downstream location. Submissions on proposed arrangements for shepherding environmental water in NSW were received until July 2012.

### Draft Floodplain Harvesting Policy

A draft *NSW Floodplain Harvesting Policy* (NOW 2010) to provide a framework for managing licensing and approvals for the harvesting of water from floodplains has been released for public consultation. More detail is available in Water 4.1.



## Future opportunities

The monitoring of habitat and ecosystem responses to environmental flows will allow knowledge to be refined so that adaptive management can optimise the benefits of flows and better target high-value ecosystems.

Many native fish species have been under severe stress during the extensive drought that broke in 2010. The recovery of species as more typical flow patterns resume will be monitored and supplementary measures, such as selective restocking considered, where appropriate.

While point sources of water pollution are generally well-managed, there is still scope to improve the management of diffuse-source pollution, primarily from agricultural runoff and urban stormwater. Stormwater harvesting developments, runoff controls and initiatives to promote revegetation and better land management practices in catchments are being implemented to improve water quality.

Further research is desirable to determine the likely effects on the health of aquatic ecosystems of changes in water availability and possible shifts in community composition due to the altered seasonality of flows.



## 4.3 Wetlands

The condition of wetlands in inland New South Wales has improved markedly since 2009, mainly due to increased rainfall and river flows following a prolonged drought. Despite their resilience, wetland systems require careful management of water inflows to maintain or improve their condition.

The majority of inland floodplain wetlands are presently undergoing a cycle of enhanced productivity with increases in extent and vegetation, and more waterbird breeding than has been experienced in over 10 years. The highest level of breeding activity and the second largest area of wetlands in 30 years of monitoring were recorded in 2010, followed by the second highest number of waterbirds in 2011.

Long-term surveys demonstrate a general pattern of decline in the extent and productivity of inland wetlands over the longer term due to the effects of water extraction and altered flow regimes.

Reduced water availability and changed patterns of river flows remain the principal causes of wetland decline. Habitat degradation as the result of changes in catchment land use, clearing and modified drainage patterns are other significant pressures.

Many important wetlands occur within regulated catchments and are dependent on careful management of environmental water and river flows to maintain ecosystem health. Around 7% of inland wetlands and 19% of coastal wetlands are now protected within the terrestrial reserve system of NSW.

### NSW indicators

Indicator and status	Trend	Information availability
Wetland extent	Stable	✓
Wetland condition	Increasing	✓✓
Waterbird abundance and diversity	Increasing	✓✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.



## Introduction

Wetlands are dynamic by nature and an important part of the natural environment. They are 'hot spots' for plant and animal biodiversity and integral to landscape processes at regional and larger scales. Wetlands moderate the impacts of floods and contribute to regional economies by providing nurseries for estuarine commercial fisheries and also supporting grazing, apiary and tourism. They provide a regional focus for many communities, including ones based on Aboriginal culture.

NSW has 12 'Ramsar' wetlands recognised as internationally important for their biodiversity and ecosystem values under the Ramsar Convention. Wetlands provide vital habitat for the migratory bird species protected under various bilateral international agreements, such as the Japan–Australia Migratory Bird Agreement (JAMBA), China–Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea–Australia Migratory Bird Agreement (ROKAMBA).

## Status and trends

### Wetland extent and condition

Little new statewide or systematic mapping of the extent and condition of wetlands in NSW has become available recently. However, catchment-specific studies clearly demonstrate that, despite significant declines in extent over the long term (**Table 4.9**), wetlands are resilient to climatic variability and have responded to recent drought-breaking rains.

The first statewide map of wetland extent in NSW was published in 2004 (Kingsford et al. 2004). It found that wetlands then covered 4.3 million hectares or 5.6% of the state. The map used satellite imagery from 1984 to 1993 to delineate inland wetlands and satellite imagery from 1994 to 1995 to delineate coastal wetlands.

While no update of the statewide extent of wetlands is available, inundation frequency and extent have recently been mapped for the Macquarie Marshes, Gwydir wetlands and Lowbidgee floodplain using satellite imagery (Landsat MSS and TM data). This mapping shows that the frequency of inundation of these key wetlands has declined over the past 30 years and the areas that are frequently inundated have also declined over this time (Thomas et al. 2012)

The condition of wetland vegetation has also been assessed in the Macquarie Marshes, Gwydir wetlands and Lowbidgee, in relation to the frequency, duration and extent of inundation. *SoE 2009* (DECCW 2009) noted that between 2001 and 2009 reduced flooding in the Macquarie Marshes resulted in a decline in condition and extent of characteristic wetland vegetation communities there (Bowen & Simpson 2010b). The condition of river red gum forests and woodlands and semi-permanent wetland vegetation in the marshes improved in response to floods in 2010–11, which inundated more than 80% of all wetland vegetation communities (Spencer et al. 2011). A substantial waterbird breeding event was also stimulated by the floods.

In 2010, it was estimated that only 25% of the original extent of the Gwydir wetlands still remained (Bowen & Simpson 2010a), with much of the wetland area converted to cropping. In 2008, the remaining area of wetland was mostly in poor condition (Bowen & Simpson 2010a). However, in response to prolonged natural flows of about 117,000 megalitres (ML) and environmental releases of 20,000 ML into the Gwydir wetlands from mid-2010 to March 2011, the health of wetland vegetation in areas receiving this inundation improved markedly and an increase in waterbird abundance, species diversity and breeding occurred (GECAOAC 2011).

Extensive flooding in the Lowbidgee wetlands in 2010–11 significantly increased the extent of wetland habitat and created breeding opportunities for waterbird species when compared with 2008 and 2009 (Spencer et al. 2011). Scientific studies found that, during the flood, wetlands that had previously been intermittently flooded (in at least 5–6 years of the last 10) supported the greatest abundance and diversity of waterbirds. This large-scale flood event also facilitated the re-colonisation of wetlands formerly occupied by threatened frog species, including the vulnerable southern bell frog (*Litoria raniformis*) (Spencer et al. 2011).

Mapping of the extent and condition of river red gum communities in the Millewa Forest in June 2010 found that 78% of those reserved were in intermediate condition and 17% in good condition. This provides a benchmark for adaptive management within the new Murray Valley National Park and State Conservation Area (Bowen et al. 2011).

Table 4.9: Declines in significant NSW wetlands

Significant wetlands	Long-term changes	Causes	Source
Murray River wetlands	72% of river red gum forests and woodlands in the Living Murray icon sites in stressed condition in 2009	Drought Flow regulation	Cunningham et al. 2009
Sydney region	50% of freshwater wetlands lost	Land clearing Locally changed hydrologic regimes	Adam & Stricker 1993
Gwydir River wetlands	75% decline in area	River regulation Clearing Changed flow regimes Water extraction	Keyte 1994 Mawhinney 2003 Bowen & Simpson 2010a
Macquarie Marshes	40–50% decline in area Sharp decline in bird and fish populations Sharp decline in area of reed, cumbungi and water couch Invasion of wetland communities by chenopod shrubland during drought	River regulation Clearing Changed flow regimes Water extraction	Kingsford & Thomas 1995 Kingsford & Johnson 1998 Kingsford & Auld 2005 Bowen & Simpson 2010b
Mid-Murrumbidgee River	Impacts on 62% of the total area of open water wetlands	Locally changed hydrologic regimes	Finlayson & Rea 1999
Border Rivers region	Probably substantially altered by water resource development	Water resource development	Kingsford 1999 Thoms & Sheldon 2000
New England Tablelands	80% of freshwater wetlands destroyed Remaining 20% nearly all drained or dammed	Land clearing Locally changed hydrologic regimes	Brock et al. 1999
Narran Lakes Ramsar site	75% reduction in median natural flows Wetland vegetation highly stressed with 54% of river red gums classified as dead in 2007	Water extraction in the Condamine–Balonne catchment	DNR 2000 Sheldon et al. 2000 Thoms 2003 MDBC 2008b MDBA 2010
Lower Murrumbidgee floodplain	76% of floodplain lost or degraded 80% decline in waterbird populations	Water resource development	Kingsford & Thomas 2001 Kingsford 2003 Kingsford & Thomas 2004
Wingecarribee Swamp	Collapse after peat mining caused sedimentation of a downstream water reservoir with resulting long-term changes to soil and vegetation	Remaining swamp stable but under severe threat from further invasion of weeds and inappropriate fire episodes	SCA 2001
Lachlan River wetlands	Decline in the condition of river red gums in Booligal wetlands and Cumbung Swamp Decreased river flows to Booligal wetlands by at least 50% from 1894–2007 levels Increase in maximum period between winter–spring flood events in Cumbung Swamp from 7 years to 16 years	River regulation	Capon et al. 2008 CSIRO 2008c Armstrong et al. 2009
Thirlmere Lakes	Major drop in lake levels in recent years	Drought from 2000–10	Jankowski & Knights 2010 Russell et al. 2010



## Waterbird surveys

The best long-term data on changes in wetland extent in NSW is provided by the annual aerial waterbird surveys conducted since 1983 (Porter & Kingsford 2011). These estimate the area of available wetland habitat and also the abundance and diversity of waterbirds, which are useful indicators of wetland condition because waterbirds are sensitive to environmental changes (Kingsford 1999; Baldwin et al. 2005).

Following a prolonged drought over the past decade, widespread and extensive rains occurred across most areas of inland NSW during 2010 and 2011. The long-term aerial monitoring program found that the area of wetlands rose sharply in response to the inundation, exceeding the long-term average for the first time in 10 years. Wetland habitat was widely available with many large areas in the Murray–Darling Basin, including the Paroo overflow lakes, Cuttaburra channels, Macquarie Marshes, Lowbidgee wetlands and Menindee Lakes all holding water.

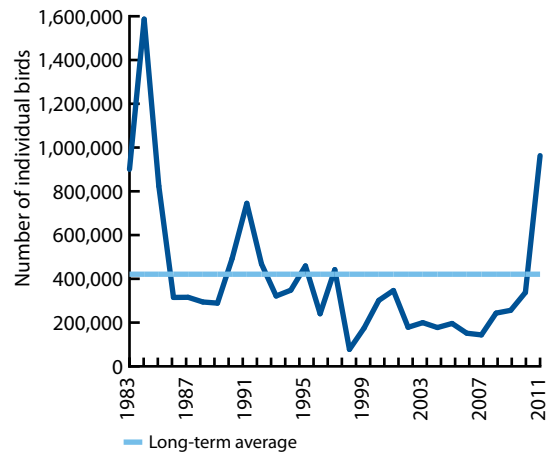
Total breeding for all waterbird species, based on the number of nest sites, was the highest on record in 2010, but then declined in 2011 to below the long-term average (Figure 4.5). However, following the successful breeding season in 2010, total waterbird numbers in eastern Australia during 2011 were the second-highest on record and the highest recorded since 1984 (Figure 4.5).

Breeding in 2011 was concentrated in the Lowbidgee and Murray River wetlands. Three species of ibis (glossy, straw-necked and white) accounted for more than 80% of total breeding abundance in the Lowbidgee wetlands during the 2011 survey.

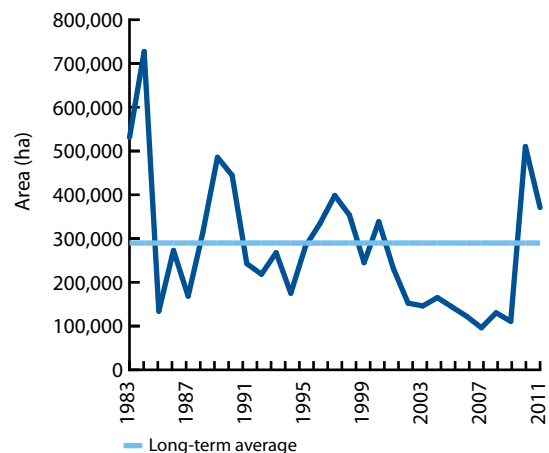
Although total waterbird abundance and wetland area were above the long-term average in 2011, these increases have not reversed long-term declines. Trend analyses indicate long-term declines in waterbird abundance, wetland area and breeding species richness remain significant (Porter & Kingsford 2011).

**Figure 4.5: Estimated number of waterbirds, wetland area and breeding in eastern Australia, 1983–2011**

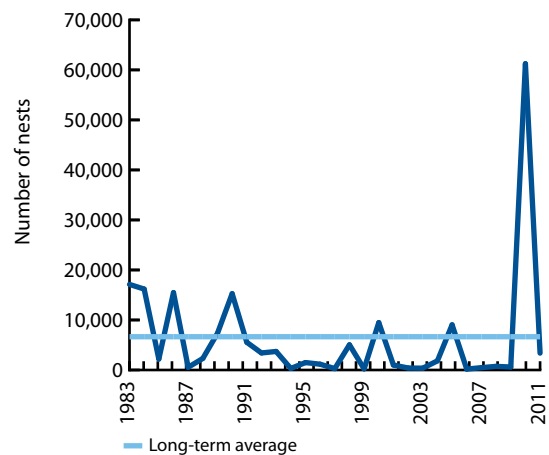
### Number of waterbirds



### Wetland area



### Breeding index (number of nests)



Source: Porter & Kingsford 2011

Notes: Aerial survey along 10 aerial survey bands, 1983–2011

## Reservation of wetlands


Protection of wetlands under the *National Parks and Wildlife Act 1974* or through Ramsar listing or other means is desirable to achieve effective conservation of these areas over the longer term. Studies suggest that the size of the protected area and the management of the surrounding catchment are critical for effectively protecting aquatic biodiversity (Nevill 2004; Kingsford et al. 2005). However, the sustainability of wetlands within the reserve system still depends heavily on the provision of adequate environmental flows, as well as sympathetic management of land and water resources by government agencies and surrounding landowners (see Water 4.1).

**Table 4.10** shows that, at December 2011, 7% of the area of inland wetlands in NSW was managed within the national parks estate, an increase in area of 4% over the preceding three years. Coastal wetlands are better represented, with nearly 19% of their area in the formal reserve system, a 1% increase since 2008. This analysis is based on a wetlands compilation map drawn from satellite imagery for the period 1986–95 which is presently the best available statewide representation of wetland distribution in NSW (Kingsford et al. 2004).


**Table 4.10: Extent of wetland types and their inclusion in the NSW national parks estate, 2011**

Wetland type	Total area in NSW (ha)	Total area in NSW parks estate (ha) (% of total)	Additions to NSW parks estate in 2009–11 (ha)	Examples of new areas declared or added to NSW parks estate in 2009–11
<b>Coastal wetlands</b>				
Floodplain wetlands	11,890	2,476 (21%)	27	Curracabundi National Park Oxley Wild Rivers National Park
Freshwater wetlands	1,926	221 (11%)	–	
Estuarine wetlands	110,791	14,735 (13%)	826	Hunter Valley National Park Gaagal Wanggaan (South Beach) National Park Limeburners Creek National Park
Coastal lakes and lagoons	66,103	18,480 (28%)	766	Limeburners Creek National Park Clybucca Aboriginal Area Meroo National Park
<b>Total</b>	<b>190,710</b>	<b>35,912 (19%)</b>	<b>1,619</b>	
<b>Inland wetlands</b>				
Floodplain wetlands	4,008,834	267,505 (7%)	168,231	Gwydir Wetlands State Conservation Area Lachlan Valley National Park and Nature Reserve Lachlan Valley State Conservation Area Macquarie Marshes State Conservation Area Murrumbidgee Valley National Park and State Conservation Area Murray Valley National Park Murray Valley Regional Park Toorale National Park and State Conservation Area
Freshwater lakes	296,071	21,034 (7%)	2,247	Murrumbidgee Valley National Park Murray Valley National Park
Saline lakes	18,542	–	–	
<b>Total</b>	<b>4,323,447</b>	<b>288,539 (7%)</b>	<b>170,479</b>	

Source: NSW Office of Environment and Heritage data 2012




Significant wetlands have been added to the NSW parks estate with the creation in July 2010 of the Murray Valley and Murrumbidgee Valley national parks by combining a number of former state forests. The Murray Valley National Park protects most of the largest remaining river red gum forest in Australia (with the section located in Victoria also being protected). The reserve also includes freshwater wetlands in the former Millewa State Forest that are Ramsar-listed. In July 2010, responsibility for the Ramsar-listed Werai Forests wetlands was vested in the Minister for the Environment and will be transferred to traditional owners for conservation purposes.



In 2010, the Gwydir Wetlands State Conservation Area became the first wetland reserve to be created in the Gwydir Valley. Part of this reserve is also Ramsar-listed.


## Pressures

### Flow modification (and drought)



Water availability is the most significant pressure on the health of wetland ecosystems. In NSW, the stresses caused by altered flow regimes due to water resource development over the longer term were most prevalent during the drought of 2000–10. Current conditions have improved as a result of flooding rains in 2010 and 2011.

Scientific studies of the response of water-dependent ecosystems to changes in the flow regime show that variability in stream flow and flooding is critical for maintaining and improving ecological health (Roberts & Marston 2000; Rogers & Ralph 2010). Essentially, different characteristics of a river's flow regime support specific flora, fauna, ecological functions and processes in the river channel and across its floodplains. Major dams modify flow patterns by storing inflows then releasing stored water when downstream water needs exceed downstream flows or on the few occasions when they overflow during flood periods. The overall effect of this is to smooth out flow variability and remove the 'boom and bust' patterns that many wetland plants and animals require to reproduce.



The impacts of water extraction, altered flow regimes and drought on water availability are discussed in greater detail in Water 4.1, while Water 4.2 outlines the implications of flow modification and drought for aquatic ecosystems.

## Habitat degradation

A number of processes are responsible for habitat degradation. Clearing of wetlands for development and/or cropping may result in irreparable damage to wetland ecosystems and the loss of biodiversity. Modifications to natural patterns of drainage are often difficult to detect or monitor, particularly during dry spells when the changes are less visible. Over-draining of coastal landscapes is a particular threat to freshwater wetlands that may create acid discharges to rivers.

More diffuse impacts to wetland habitats can be caused by surrounding land uses, pests and weeds. Increased nutrient and sediment loads and turbidity are particular threats to submerged aquatic vegetation in wetlands. Subsidence and cracking of watercourses and upland swamps resulting from long-wall mining can also pose problems for water quality and aquatic ecosystems.

In rural and semi-rural areas, grazing of wetland plants by livestock and pest species, such as rabbits and goats, can have a serious impact on the diversity, distribution and health of wetland plants. Grazing of stock may also lead to the compaction of soils, increased nutrient levels, the introduction of weed species, trampling of native plants, and the ringbarking of mature trees.

## Invasive species

Introduced plants, which can change wetland structure and function, are favoured by disturbances such as altered flow regimes, clearing or draining of wetlands, and increased nutrient loads. Significant weed species in NSW wetlands include lippia, salvinia, alligator weed and water hyacinth, which can all rapidly clog waterways when conditions are favourable for recruitment and spread (see Biodiversity 5.4).

Lippia has taken over thousands of hectares of the state's inland watercourse country and has had a major impact on the condition of the Gwydir wetlands. Lippia can out-compete all native vegetation, including tree seedlings, and it poses a severe threat to watercourses and adjacent grazing lands.

Introduced aquatic species, such as European carp and gambusia (commonly known as mosquito fish or plague minnow), can decimate native fish populations in wetlands and affect water quality. Introduced herbivores, such as pigs and goats, have caused extensive damage to the condition of wetland vegetation and soils through grazing, trampling and digging and are also capable of altering the channel and bank structure of watercourses (see Biodiversity 5.4).

## Water quality

Water quality plays an important role in wetland health. Runoff from towns, cities and farms may contain toxic substances or high levels of nutrients and sediments. Where excessive levels of nutrients enter wetlands, they can cause problems, such as eutrophication (the severe depletion of dissolved oxygen levels), fish kills or excessive plant growth. Increased turbidity affects the productivity of submerged vegetation and leads to siltation, which may have an impact on the composition and habitat of many dependent species. Increased salinity can affect other characteristics of water quality, contribute to the development of acid sulfate sediments, and adversely affect biodiversity.

## Acid sulfate soils

Acid sulfate soils are generally regarded as an issue for coastal waterways. If left undisturbed and covered with water, sulfidic material poses little or no threat of acidification. However, when it is exposed to oxygen in the air, the sulfides react to form sulfuric acid which can contaminate waterways. See Land 3.1 for more detail.

River regulation has seen some wetlands used as water storages, causing the loss of their dry phase. Where these wetlands are associated with saline groundwater that is high in sulfur, sulfidic sediments may accumulate in the inundated wetland. The drought conditions (2000–10) led to the drying of many otherwise permanently inundated wetlands in the Murray–Darling Basin, exposing sulfidic material with the potential to cause the acidification of some inland wetlands, as occurred at Bottle Bend on the Murray River. While some investigations have been conducted (Hall et al. 2006), the full extent of the threat posed by acid sulfate soils to inland wetlands is still unclear. The Murray–Darling Basin Commission has done a rapid assessment of the acid sulfate soil risk across the basin and identified key areas along the Murray and Murrumbidgee in NSW for detailed assessment.

## Climate change

Climate change is likely to affect wetlands through changes in water availability and higher temperatures and rates of evaporation. These are expected to affect wetland condition and productivity and potentially lead to shifts in wetland distribution or ecosystem types (CSIRO 2008c). For further consideration of this issue, see Water 4.1 and Water 4.2.

## Responses

### Established responses

#### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Improve the environmental health of wetlands and catchments through actively managing water for the environment by 2021'. This includes the strategic recovery and management of water for the environment to improve the health of the most stressed rivers and wetlands. Further details on Goal 22 are provided in Water 4.1.

#### NSW Wetlands Policy

The NSW Wetlands Policy (DECCW 2010c) updates the 1996 NSW Wetlands Management Policy to reflect developments in natural resource management and planning that affect wetlands. It promotes the sustainable conservation, management and wise use of wetlands in NSW and the need for all stakeholders to work together to protect wetland ecosystems and their catchments.

#### Water sharing plans

Water sharing plans provide for flows of environmental water to inland and coastal wetlands to improve wetland health. The amount of water received by the environment depends on the share specified in the water sharing plan and water availability. For example, with the end of the drought, the 2010–11 water year was the first time that the Macquarie Marshes received 100% of its environmental water allowance since the introduction of the water sharing plan in 2004–05. Water sharing plans are discussed in Water 4.1.

For inland water sources, the proposed Murray–Darling Basin Plan requires the development of long-term environmental watering plans that identify assets within each valley, their water requirements and targets for their management. Once developed, these long-term plans will be taken into account when water sharing plans are reviewed.

#### Purchase of water licences

The purchase of water licences has increased the share of water available for the environment and its active management under programs such as NSW RiverBank has enhanced the levels and patterns of flows to wetlands. Water 4.1 describes water purchases for the environment.



## Adaptive environmental water plans

These plans facilitate the delivery of available environmental water to key wetlands. Adaptive environmental water plans have been approved for the Lachlan, Macquarie and Gwydir valleys and a draft plan prepared for the Murrumbidgee.

## NSW Wetland Recovery Program

The NSW Wetland Recovery Program was completed in 2010. Management plans were developed for environmental watering of the Gwydir wetlands and Macquarie Marshes. In addition, infrastructure projects were delivered, including the Gingham pipeline project, providing water savings of 958 megalitres (ML) to water ecological assets in the Gwydir wetlands, and the upgrade of Gradgery Lane, upstream of the Macquarie Marshes, to remove a system choke and allow the passage of increased volumes of environmental water.

## NSW Rivers Environmental Restoration Program

The NSW Rivers Environmental Restoration Program was completed in 2011. This program to arrest the decline in iconic rivers and wetlands in NSW delivered the following outcomes:

- the purchase of 108,000 ML of water entitlement across the Lowbidgee floodplain, Lachlan wetlands, Macquarie Marshes, Gwydir wetlands and Narran Lakes
- preparation of decision support systems and hydrologic and hydrodynamic models for the Gwydir Valley, Macquarie Marshes, Lowbidgee floodplain and Narran Lakes to assist in managing environmental flows
- completion of major infrastructure works, including 10 regulating structures, 10 floodways and the breaching of 40 pre-existing embankments in Yanga National Park to improve environmental flows
- engagement of Aboriginal communities to reconnect to culturally significant wetlands on private land and the identification of over 1200 new sites of cultural significance
- negotiation of 15 land management agreements with landholders to improve management of over 3200 hectares of wetlands of high conservation value
- acquisition of 14,000 hectares of significant wetlands for inclusion in the National Reserve System, including Booligal Station (Lachlan), Old Dromana (Gwydir), and parts of Pillicawarrina (Macquarie) and Geramy (Lachlan).

## Change in ecological character: Macquarie Marshes

The notification of a 'likely change in ecological character' under the Ramsar Convention was made in August 2009 for the Macquarie Marshes Ramsar site. The key driver of change was identified as water management. The NSW Office of Environment and Heritage is currently taking action and preparing a response strategy consistent with the *Adaptive Environmental Management Plan for the Macquarie Marshes* (DECCW 2010a).

## Coastal wetland rehabilitation

In 2012, four major coastal wetland areas were restored at Darawakh Swamp (929 hectares – Great Lakes region), Yarrahapinni (600 ha – Macleay River), Ash Island (500 ha – Hunter River) and Hexham Swamp (2000 ha – Hunter River). These large-scale rehabilitation projects will benefit fish and other species that were lost due to drainage changes associated with flood mitigation schemes, improving the breeding of fish targeted by commercial and recreational fishers.

## Future opportunities

Assets such as priority wetlands will be identified for each Water Resource Plan area within the Murray–Darling Basin so that environmental water can be directed to them.

The monitoring of environmental flows will facilitate adaptive management so that these flows better replicate natural conditions and optimise the benefits to the health of wetland ecosystems.

Inland rivers and wetlands are not well represented within the national parks estate. The *NSW National Parks Establishment Plan 2008* (DECC 2008) identified wetlands as a key priority for building the reserve system over the 10 years to 2018.

Better scientific information on the location and types of wetlands found in NSW is desirable, particularly the conservation values of the smaller and less well-studied wetland types that may have unique values and inadequate protection.

A better understanding of the processes and factors affecting the health and resilience of floodplain wetlands will enhance their management, given the intermittent and unpredictable nature of inundation patterns which vary substantially over longer time frames.

## 4.4 Groundwater

Demand for assigned groundwater resources in New South Wales has eased significantly in recent years as more surface water has become available following high rainfall. Water sharing plans continue to be implemented for groundwater aquifers, with 34 now completed and all NSW sources in the Murray–Darling Basin to be covered by the end of 2012.

Overall groundwater use fell considerably during the 2010–11 water year, with extraction from most groundwater sources well below the long-term sustainable extraction limit. Groundwater levels have risen in most areas in response to the higher rainfall, enabling aquifers to recharge and usage levels to drop.

During 2010–11, the Lower Gwydir and parts of the Upper Namoi groundwater sources experienced the highest levels of groundwater demand, due to the relatively drier conditions being experienced in northern inland NSW.

The most significant fall in groundwater use occurred in the Lower Murrumbidgee and Lower Murray Groundwater sources due to the flooding experienced in southern NSW in late 2010–early 2011.

Water sharing plans set annual extraction limits for groundwater use. Extraction from some groundwater sources has been above the long-term sustainable yield in the recent past, but use is now being managed to align with the sustainable yield through the implementation of water sharing plans.

### NSW indicators

Indicator and status	Trend	Information availability
Extent and condition of groundwater-dependent ecosystems	Unknown	✓
Long-term extraction limit: use	Decreasing	✓✓
Long-term extraction limit: entitlement	Decreasing	✓✓✓
Aquifer integrity	Stable	✓✓
Groundwater quality	Stable	✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.

## Introduction

Where surface water is available, groundwater is generally seen as a supplementary water resource. However, for many communities in regional NSW, groundwater is the primary source of water for drinking, domestic and stock use, and it is also used in agriculture and industry.

A range of ecosystems also depend on groundwater for their continued survival, including some highly specialised and endemic subterranean systems, as well as surface water bodies (wetlands, rivers and lakes) that are connected to groundwater and some terrestrial ecosystems.

Significant changes in the quality and quantity of groundwater available have the potential to degrade ecosystems and affect human uses of water. Because of the hidden nature of many groundwater-dependent ecosystems, the impacts on these systems are likely to be less obvious and understood.

## Status and trends

### Extent and major uses of groundwater in NSW

Approximately 11% of all water used in NSW comes from groundwater sources. It is used for drinking water, irrigation, watering stock, and domestic and industrial purposes. For more than 200 towns in NSW, groundwater is the principal source of water supply. An estimated 13% of the groundwater used in NSW goes to domestic and stock purposes.

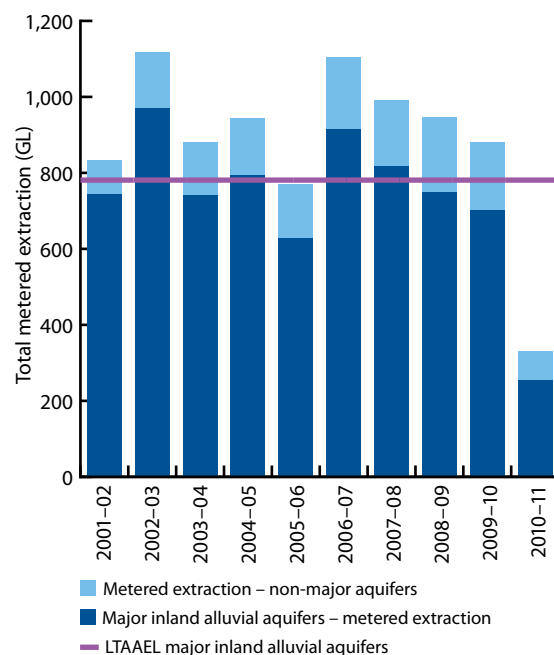
However, agriculture is the largest user of groundwater in NSW with the greatest volume of use being for irrigation in the areas of the main inland alluvial aquifers. This is followed by mining, with groundwater being the only available source of water for some inland mining operations, although it can also be an obstruction or hazard that must be removed for mining to proceed.

### Levels of extraction and recharge

Variability in climatic conditions affects the amount of groundwater used. Extraction may increase substantially in times of drought to offset the lack of surface water, while in periods of high rainfall and associated recharge less groundwater is used. Due to high rainfall and an increase in surface water availability, demand for groundwater resources has decreased over the past three years, following an extended period of high demand.

Figure 4.6 shows groundwater extraction from all metered aquifers in NSW and the major inland alluvial aquifers over the 10 years to 2010–11. Two peaks in extraction occurred in 2002–03 and 2006–07 when drought conditions were particularly acute. A gradual decline in extraction has occurred since 2006–07 as the effects of the drought eased, but also due to the introduction of water sharing plans in several of the large inland alluvial groundwater sources since 2006. A further substantial reduction occurred in the 2010–11 water year, due to very high rainfall and flooding in many areas. Overall only 350 gigalitres (GL) was extracted in 2010–11, around a third of the volume used when demand was at its peak.

**Figure 4.6: Annual levels of groundwater extraction from metered aquifers in NSW and the major inland alluvial aquifers, 2001–02 to 2010–11**



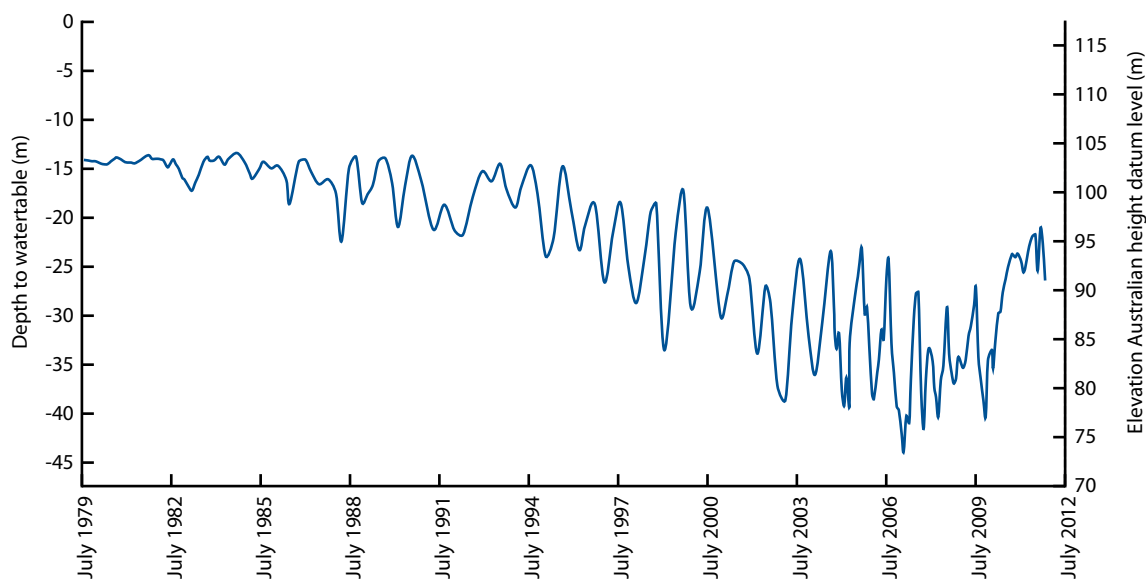
Source: NSW Office of Water (NOW) data 2011

Notes: The major inland alluvial aquifers are the basins of the Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee and Murray rivers.

The purple line is the long-term average annual extraction limit (LTADEL) for these major groundwater sources only, which is the level of water that can be extracted annually on a sustainable basis over a longer time frame. The LTADEL does not apply to all metered extraction in NSW.

Extraction limits are being reduced gradually to align with the LTADEL by the final year of relevant water sharing plans in 2016–17, so extraction levels for the major inland alluvial aquifers are permitted to exceed the LTADEL until then.

**Figure 4.7: Groundwater hydrograph for a monitoring bore in the Lower Murrumbidgee deep groundwater source (GW036358)**



Source: NOW data 2011

Around 80% of metered groundwater use in NSW occurs in the six major inland alluvial aquifers of the Gwydir, Namoi, Macquarie, Lachlan, Murrumbidgee and Murray River valleys as shown in Figure 4.6. The overall volume of groundwater extracted in NSW is higher as extraction is not metered in many areas of NSW where groundwater demand is low, particularly on the coastal side of the Great Dividing Range.

A groundwater hydrograph from a monitoring bore located in the largest groundwater source in NSW – the Lower Murrumbidgee deep aquifer – illustrates the general pattern of groundwater response to climatic conditions and variations in groundwater demand (**Figure 4.7**).

Groundwater use in this area began in the late 1970s and early 1980s, with an annual pattern of drawdown over the spring and summer, followed by recovery during autumn and winter, restoring previous levels by late winter. However, as demand grew and water pumping increased, drawdowns became deeper and seasonal recovery incomplete. As drier conditions set in, very deep drawdowns occurred, with the most acute in the summer of 2006–07 when it became clear that such levels of extraction could not be sustained in the longer term. In the years that followed, a reduction in use coincident with higher rainfall resulted in some recovery of levels, until 2010–11 when groundwater levels rose significantly. However, levels have not returned to pre-development levels and are not expected to do so.

### Long-term average annual extraction limits

The intent of water sharing plans for groundwater (see 'Responses' below) is to manage the resource sustainably so that groundwater levels do not decline excessively, causing unacceptable impacts on the aquifer or groundwater-dependent ecosystems, and extraction remains in balance with recharge over the longer term. This means that extraction above sustainable levels in times of drought, for one or several years, will result in a decline in groundwater levels with recovery occurring during wetter periods when recharge is much greater than extraction. This natural variability of groundwater systems provides for a reliable and secure water resource.

The long-term average annual extraction limit (LTAEL) is the average level of groundwater that can be extracted sustainably on an annual basis over a longer term from the groundwater sources defined in water sharing plans. It is effectively the plan 'limit'. Where data is available, the extraction limit is based on numeric models which relate rainfall and river leakage to recharge over a period of 20 to 30 years. Where insufficient data is available, it is based on a percentage of the annual average rainfall being captured as recharge. The final extraction limit is then set after a portion of groundwater is allocated to the environment, based on the environmental assets identified as requiring protection.

In large areas of NSW the potential to extract groundwater is low because of hydro-geological factors or the quality of the water is not suitable for use. At the state scale, therefore, the overall level of entitlement compared with the LTAEL is quite low, at around 25%.

The inland alluvium geological provinces lie in the flat lands of north-western and south-western NSW and provide high-yielding, good quality water supplies which are able to be used extensively for irrigation. About 98% of all metered groundwater extraction in NSW is from these aquifers, including the six major aquifers referred to in Figure 4.6, which provide 80% of extraction. As a consequence, it is mainly in the inland alluvium that there is pressure to manage groundwater sustainably as extraction is close to the LTAAEL.

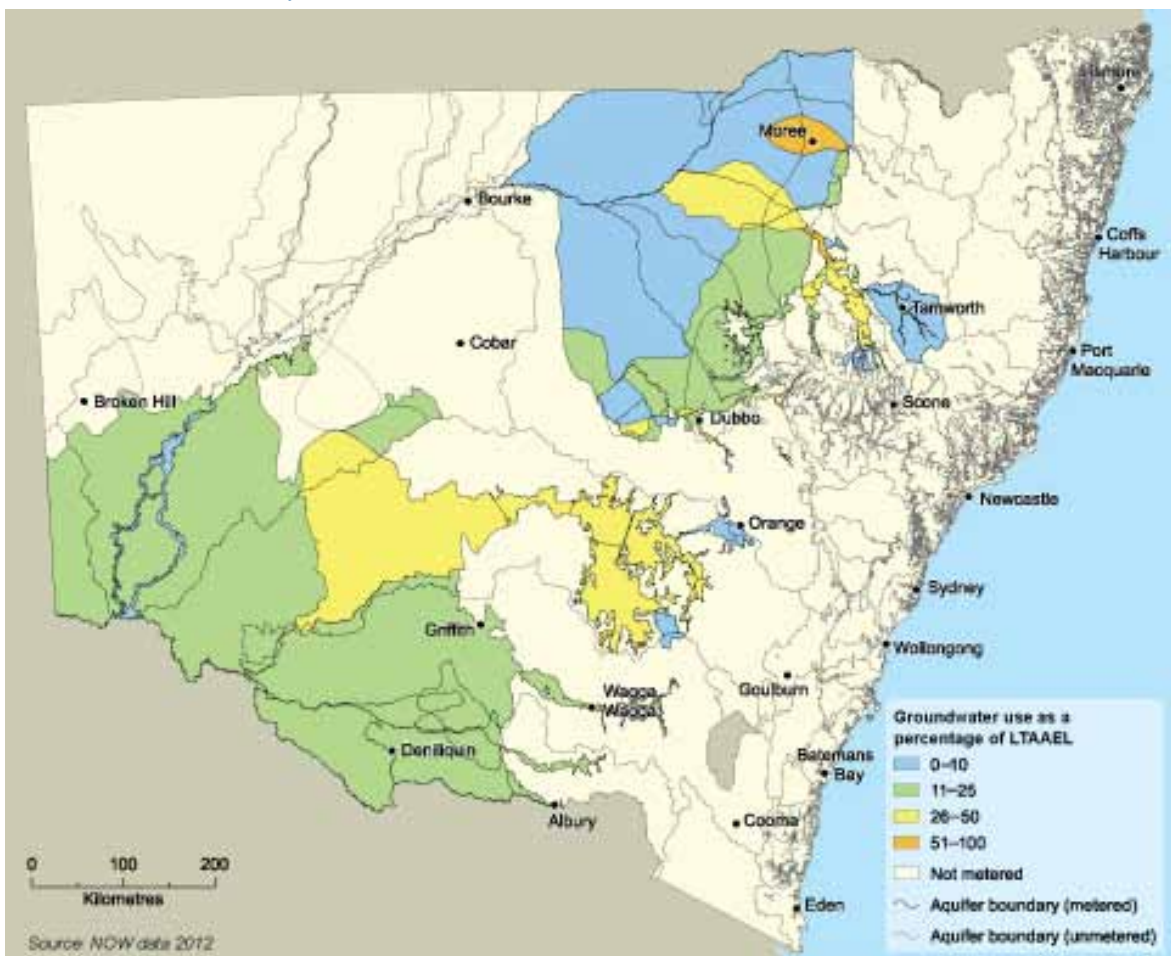
From the early 1980s, embargos have been imposed on the issue of further licences in the inland alluvial aquifers and annual limits have been placed on extractions. Since 2006, water sharing plans have placed a formal limit on extraction enforced through regulation. The implementation of these plans has expanded to areas beyond the six major inland alluvial aquifers, with all inland NSW groundwater sources to be covered by the end of 2012 (see below under 'Responses').

## Extraction compared to extraction limits

Groundwater use can be quite variable, both within and between groundwater sources. In some years and some groundwater sources, extraction can exceed the LTAAELs that are set in water sharing plans. To address historical over-allocation, water sharing plans provide for a progressive reduction in water allocations over their 10-year term. At the end of their terms, water sharing plans will ensure that average annual groundwater use will be within the LTAAEL.

Map 4.4 shows groundwater use during the 2010–11 water year as a percentage of the LTAAEL, which provides an indication of sustainable use in areas where groundwater use is metered and monitored. The very wet water year caused groundwater demand to fall significantly with use at, or well below, the LTAAEL in most areas. The highest levels of extraction were from the Lower Gwydir groundwater source around Moree at 102% of LTAAEL. This level is within the acceptable buffer allowed in the water sharing

**Map 4.4: Extraction from NSW groundwater aquifers as a percentage of the long-term average annual extraction limit, 2010–11**



Notes: Only those areas of NSW where groundwater use is metered are shown on the map. LTAAELs for the six major inland alluvial water sources are being reduced during the life of their respective water sharing plans. Usage is compared with the LTAAEL applicable for the 2010–11 water year, not the LTAAEL specified for the end of the plan (at year 10).

plan and does not exceed the interim extraction limit set annually while long-term levels of use are adjusted to align with the LTAAEL. The only other area where use was greater than 50% of the LTAAEL was in some groundwater sources of the Upper Namoi around Narrabri. Usage was highest in these areas due to the relatively lower rainfall in northern inland NSW during 2010–11. The greatest falls in demand were in the groundwater sources of the Lower Murrumbidgee (around Hay) and Lower Murray (around Deniliquin) because of very high rainfall and flooding which occurred in southern NSW.

Some areas outside the six major alluvial groundwater sources have entitlements higher than the extraction limit, but use is currently at or below the limit. Where use approaches the extraction limit due to the activation of previously unused entitlements, the water sharing plan allows for usage to be moderated by determining the water levels available for extraction.

## Groundwater-dependent ecosystems

Groundwater-dependent ecosystems (GDEs) are described in water sharing plans for groundwater as those where species composition or natural functions depend on the availability of groundwater. Dependence may be complete or partial, such as during periods of drought. The degree and nature of dependency influences the extent to which ecosystems are affected by changes to water quality or quantity in groundwater aquifers.

GDEs occur across a broad range of environments, from highly specialised subterranean ecosystems to more generally occurring terrestrial, aquatic and marine ecosystems. GDEs were first identified and classified in Australia in the late 1990s (Hatton & Evans 1998) and were subsequently recognised in NSW by the *NSW State Groundwater Dependent Ecosystems Policy* (DLWC 2002). Since the release of this policy, the number of GDE types has grown as knowledge has improved.

There are two main groupings of GDEs – subsurface ecosystems and surface ecosystems – and seven broad types overall based on ecological, geomorphic and water chemistry criteria, as described below.

### Subsurface ecosystems

The most significant, diverse and potentially sensitive groundwater-dependent organisms are those found underground within aquifers and cave ecosystems. These organisms are totally reliant on groundwater and are adapted to these environments (Gibert et al. 1994).

**Karsts and caves** are defined as ‘natural cavities in rock which act as a conduit for water flow between input points, such as stream sinks, and output points, such as springs or seeps’ (White 1984). Karsts are a specific form of cave terrain with distinct landforms and drainage characteristics. The aquatic ecosystems within these subterranean environments consist of communities of organisms, mainly microorganisms and invertebrates that are adapted to live in perpetual darkness and are totally dependent on groundwater (Ward et al. 2000). Life forms that exist in caves and aquifers are considered to be highly endemic.

### Subsurface phreatic aquifer ecosystems:

The free water within the pore spaces and cracks of unconsolidated sand and gravel and fractured rock aquifers can also support communities of diverse, endemic, highly specialised, and often relict life forms. These can include microorganisms, invertebrates and, occasionally, vertebrate species. Due to their adaptation to a relatively narrow natural range of water chemistry, these communities may be of interest as indicators of groundwater health and water quality.

**Subsurface baseflow streams:** Many river reaches have a baseflow component derived from groundwater discharge which is vital to the character and composition of in-stream and near-stream ecosystems. By providing a permanent water source, baseflow streams support ecosystems that are able to live in subsurface sediments (Evans 2007).

### Surface ecosystems

**Surface baseflow streams** also support surface ecosystems through surface flows or permanent pools that provide refuges in times of low flows.

**Wetland ecosystems** may depend on groundwater to maintain seasonal patterns of waterlogging or flooding. Wetlands provide the most extensive and diverse set of potential GDEs in Australia (Hatton & Evans 1998). Examples include paperbark swamp forests and woodlands, swamp sclerophyll forests and woodlands, swamp scrubs and heaths, swamp shrublands, sedgelands and mound spring ecosystems.

### Estuarine and near-shore marine ecosystems:

Many of these systems depend on groundwater discharges to provide suitable habitats for a diverse group of flora and fauna. These include coastal lakes, mangroves, saltmarshes and seagrass beds (Hatton & Evans 1998; SKM 2001; Burnett et al. 2003). Groundwater discharges may be in the form of direct off-shore discharge zones called ‘wonky holes’, diffuse discharges through sandbeds, or baseflow streams that discharge to the ocean.



## Groundwater-dependent or phreatophytic vegetation:

This is terrestrial vegetation that depends on the subsurface presence of groundwater, often accessed via the capillary fringe – the subsurface layer just above the watertable that is not completely saturated (SKM 2001; Eamus et al. 2006). This vegetation may be dependent on groundwater to sustain transpiration and growth through a dry season or maintain perennially lush ecosystems in otherwise arid environments.

Although not a specific GDE type, terrestrial fauna may also depend on groundwater as a source of drinking water.

## Identification of groundwater-dependent ecosystems

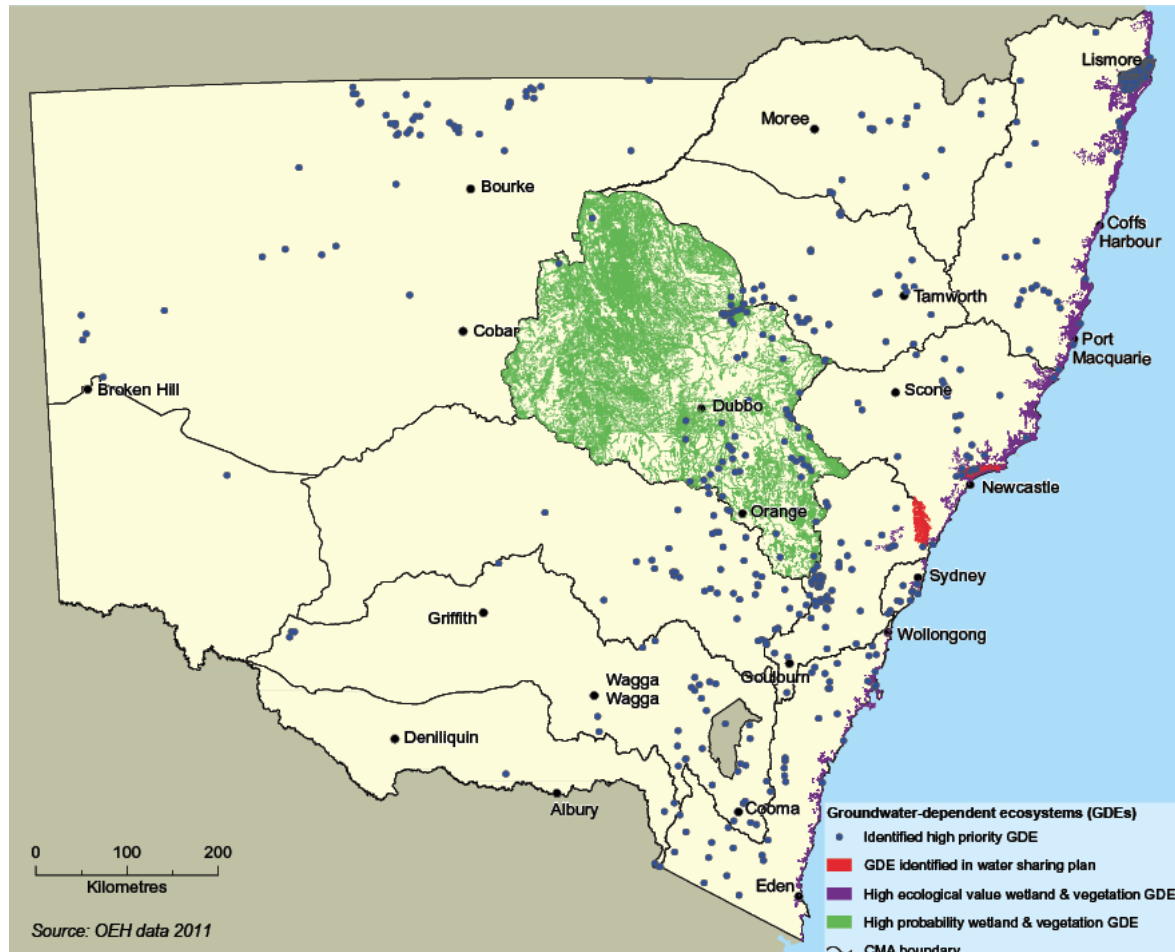
Interest in GDEs and their sustainability is relatively recent and little is known about their location or condition (Eamus & Froend 2006). However, the NSW Government has been actively engaged in identifying GDEs across the state in recent years. A preliminary desktop study identified a range of GDEs and sites where they could potentially occur. Areas of terrestrial vegetation that are potentially

groundwater-dependent are being mapped using satellite imagery (MODIS). Follow-up field survey work will establish the extent of their natural values and the condition of these sites, as well as their level of dependence on groundwater.

Risk assessment guidelines to provide methods for identifying and valuing GDEs and their associated aquifers (Serov et al. 2012) have now been developed during assessment of the coastal sands and floodplain alluvium on the NSW coast. The guidelines enable the development of management strategies for aquifers and GDEs and assessment of the potential and actual impacts of proposed activities on GDEs.

High priority GDEs shown in **Map 4.5** have high ecological value and are mostly associated with springs and karsts, but may include other GDEs identified as high priority in water sharing plans. At this stage, mapping of GDEs with high ecological value has only occurred along the coast. Map 4.5 also displays high probability GDEs within the Central West Catchment Management Authority area but the ecological value of many of these communities is yet to be determined. Current mapping is still limited and will be expanded in future.

**Map 4.5: Mapped NSW groundwater-dependent ecosystems at December 2011**



## Pressures

### Excessive demand and extraction

Over the longer term, reducing the storage levels of an aquifer or permanent mining of the resource will affect its stability and integrity, as well as having permanent consequences for all dependent ecosystems and beneficial uses. Competition for groundwater resources can place the long-term security of these resources at risk.

NSW groundwater sources have been assessed for risk due to groundwater demand using a standard developed under the National Framework for Compliance and Enforcement Systems for Water Resource Management, agreed to by COAG in December 2009. The areas at highest risk are characterised by high consumption with entitlements close to or above extraction limits and actively protected water rights. The areas of lower risk are those where demand is low and entitlements are significantly below sustainable levels.

The outcome of the risk assessment is shown in **Map 4.6**. The areas at highest risk are:

- Lower Murrumbidgee around Hay
- Mid-Murrumbidgee around Wagga Wagga
- Lower Namoi, west of Narrabri
- Lower Gwydir around Moree
- parts of the Lower Macquarie, west of Dubbo
- Orange basalt
- alluvial valleys of the Hunter catchment
- coastal sand beds north of Newcastle.

Although the risk assessment was intended to guide the prioritisation of water compliance resourcing, it has also highlighted the most important and sensitive areas for broader decision-making on groundwater management. The aim of water sharing plans is to ensure that water is managed sustainably and plans will shortly be in place in all these areas to protect the long-term security of groundwater supplies.

**Map 4.6: Risk posed to groundwater due to groundwater demand**



## Saline intrusion

Where the level of extraction of groundwater is high and the aquifer is overlain by saline aquifers or near the coast, there is a risk of saline water intrusion into the depleted aquifer. This will have a detrimental effect on water quality and related uses. The intrusion of sea water is relevant particularly to the coastal sand beds north of Newcastle, which are an important source of water for the Greater Newcastle area.

Studies have recently been completed to assess the risks caused by high volume groundwater extraction on groundwater quality in the six major inland alluvial aquifers. Localised areas of water quality decline have been discovered and strategies are being developed to address those areas of risk. The water sharing plans contain provisions to ensure groundwater quality does not change to a less beneficial risk class.

## Chemical contamination

Groundwater contamination by chemical pollutants can significantly reduce the value of water to users or the environment and increase the cost of water treatment. It may prevent some types of water use altogether. Once an aquifer is polluted, it is extremely difficult and expensive to restore. Groundwater contamination is largely associated with long-standing existing or former industrial areas and tends to be in urbanised areas concentrated around Sydney, Newcastle and Wollongong.

## Climate change

The Sustainable Yields Assessment Project for the Murray–Darling Basin (CSIRO 2008a) identified that the current and probable future levels of groundwater extraction will have a greater impact on inland aquifer systems than a likely reduction in recharge from rainfall and river systems due to climate change. Along the coast, the potential impacts of sea level rise and climate change on coastal aquifers will be more significant with saline intrusion on freshwater coastal aquifers affecting associated groundwater-dependent ecosystems.

## Responses

### Established responses

#### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Improve the environmental health of wetlands and catchments through actively managing water for the environment by 2021'. Further details on Goal 22 are provided in Water 4.1.

#### Water Management Act 2000

The *Water Management Act 2000* requires all groundwater aquifers to be managed sustainably and this is occurring through the implementation of statutory water sharing plans for groundwater.

#### Groundwater-dependent Ecosystems Policy

The *NSW State Groundwater Dependent Ecosystems Policy* (DLWC 2002) provides guidelines on how to protect and manage groundwater-dependent ecosystems. Further work will help to establish the location of these ecosystems and how heavily they rely on groundwater.

#### Water sharing plans for groundwater

The intent of water sharing plans for groundwater is to manage the resource so that extraction remains in balance with the capacity to replenish them over the longer term.

The environmental provisions in the groundwater sharing plans are centred on:

- protecting the long-term storage component of the aquifer
- reserving a proportion of the average annual recharge for the environment.

In some NSW groundwater systems, the level of entitlement is greater than the sustainable yield of the aquifer. The implementation of water sharing plans for all groundwater sources includes a process to manage groundwater use to align with the sustainable yield of aquifers.

This is being achieved by reducing allocations in the six major inland alluvial groundwater sources over the 10-year period of the water sharing plans. **Figure 4.8** shows the effect of these reductions in the early years of the plans.

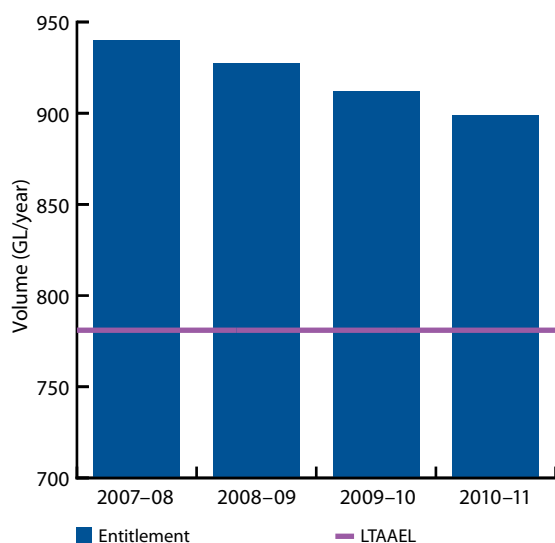
There were 34 gazetted water sharing plans which covered groundwater sources as of July 2012, with another six for the remaining inland aquifers to be completed by the end of 2012 and a further 12 plans for coastal aquifers expected to be completed by 2014. In time, all groundwater in NSW will be regulated by water sharing plans made under the *Water Management Act 2000* and the *Water Act 1912* will no longer apply to groundwater use. The making of these plans will ensure that water entitlements are brought into equilibrium with the sustainable yields of all aquifers throughout NSW.

In the interim, the issue of further entitlements has been embargoed in many areas not covered by a water sharing plan. This is to minimise the risk of resource over-allocation and lessen potential impacts on surface water resources ahead of the making of water sharing plans.

### Achieving Sustainable Groundwater Entitlements program

Under this program the Australian and NSW Governments are providing financial assistance to groundwater licence holders and regional communities to help them adjust to reduced groundwater entitlements.

**Figure 4.8: Entitlements to groundwater under water sharing plans**



Source: NOW data 2011

### Cap and Pipe the Bores Program

Since the 1990s, various programs have been in place to cap and pipe bores across the Great Artesian Basin, which underlies parts of NSW, Queensland, the Northern Territory and South Australia, to reduce water wastage and improve groundwater pressure. The Cap and Pipe the Bores Program provides financial incentives to landholders to offset the cost of rehabilitating bores and installing efficient piped systems to replace open bores. The pipeline systems provide water to properties, prevent large quantities of salt from entering drainage systems, and help drought-proof properties. These measures have produced savings of 63,000 megalitres (ML) per year and there has now been an increase in water pressure across the basin.


### Aquifer protection and research

Great care needs to be taken to ensure that the rapid expansion of mining and coal seam gas developments does not result in permanent damage to aquifers. A new interim aquifer interference regulation took effect on 30 June 2011, which requires new mining and petroleum exploration activities that extract more than 3 ML per year from groundwater sources to hold a water access licence. The *NSW Aquifer Interference Policy* (DPI 2012) has been developed by the NSW Office of Water as a component of the NSW Government's Strategic Regional Land Use Policy. The new policy details how potential impacts to aquifers, such as those posed by mining and coal seam gas activities, should be assessed and licensed to strike a balance between the water requirements of towns, farmers, industry and the environment.


Significant effort in groundwater research has occurred over the past three years. With the assistance of industry and government partners, NSW has undertaken studies to better understand the dynamics and chemistry of NSW aquifer systems, their hydraulic interaction with rivers, and learn more about groundwater-dependent ecosystems. Some of these studies have been completed and are already influencing decision-making for groundwater management.

This research has been supported by an expansion of groundwater monitoring and improved data management. Monitoring of groundwater levels has increased in sophistication with the roll-out of instruments which measure water levels and transfer the data continuously making it available on the internet.


## Future opportunities




In many groundwater management areas, meter readings are not reported. Current knowledge of groundwater recharge and availability is based on estimates using the limited data available and conceptual models of groundwater recharge. Better monitoring of extraction will improve these models and enable greater accuracy when setting extraction limits.




The connections between groundwater and surface water systems should also be better understood. The potential for holistic management of closely linked systems as a single integrated resource needs further development. There is a risk that more stringent limits on the use of surface water will place greater pressure on groundwater as a substitute source of water.



In making new water sharing plans, the sustainable extraction limit for each water source has been determined for the first time. However, many water sources that are deep or contain brackish groundwater have water that is unassigned. A process is being formulated for the controlled allocation of a proportion of this water where its use would not adversely affect surface water flows, other groundwater users or the environment.



Knowledge of groundwater-dependent ecosystems is still at an early stage and better understanding is needed of their location, characteristics and levels of dependency. Little is also known about the fauna and flora that live within, or are dependent on, groundwater aquifers and this makes it difficult to manage groundwater systems to protect them.



## 4.5 Marine waters and ecosystems

The overall health of the New South Wales marine environment and ecosystems is considered to be good, as is recreational water quality.

While instances of contamination from stormwater runoff, sewage overflows and outfall emissions do occur, their impacts tend to be localised and of limited effect. Beach suitability, based on levels of stormwater and sewage contamination, is rated as good or very good at 83% of all beaches in NSW and at over 99% of ocean beaches. It is lower at around 60% of beaches in the enclosed waters of coastal lakes, estuaries and rivers.

Forty-one species found in NSW coastal waters are listed as threatened or extinct, around half of them ocean birds and most of the rest higher order species, such as marine mammals and large fish.

The listing of some marine species as threatened indicates that external pressures are having an impact on some species and, by implication, on ecosystems.

The main pressures on marine species include destruction of vital habitats, chemical contamination, overfishing, and entanglement in disused fishing gear and refuse, such as plastic bags and ring pulls.

### NSW indicators

Indicator and status	Trend	Information availability
Percentage of beaches with beach suitability grades for swimming of good or better	Stable	✓✓✓
Frequency of algal blooms	Stable	✓✓
Distribution of rocky reef-covering biota	Unknown	✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.

### Introduction

NSW marine waters contain high levels of biodiversity because of their wide range of oceanic, shoreline and estuarine habitats and the strong influence of both subtropical and temperate currents. These varied environments provide many important ecosystem services, including preventing coastal and seabed erosion, maintaining coastal water quality, and acting as critical habitats for fish and other marine life. The community values and uses provided by the NSW marine environment include healthy aquatic ecosystems, recreation, visual amenity and aquatic food production.

The state's marine jurisdiction extends three nautical miles (5.6 kilometres) off the 1900-kilometre NSW coast. Marine waters and ecosystems adjacent to urban and industrial areas are more susceptible to the effects of pollution from urban runoff, stormwater and sewage discharge.

### Status and trends

To meet the requirements of the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d), indicators have been developed to assess the status of the marine environment but information is still quite limited. Information on marine protected areas is addressed in more detail in Biodiversity 5.3.

## Water quality

Marine waters are generally considered to be in good condition as currents, wave action and tides are usually able to dilute pollution, making marine systems less vulnerable to degradation. Nonetheless, even in well-flushed systems, pollutants can bind to organic material and sediments and accumulate in filter feeders and higher order predators with adverse effects on ecosystems and human health.

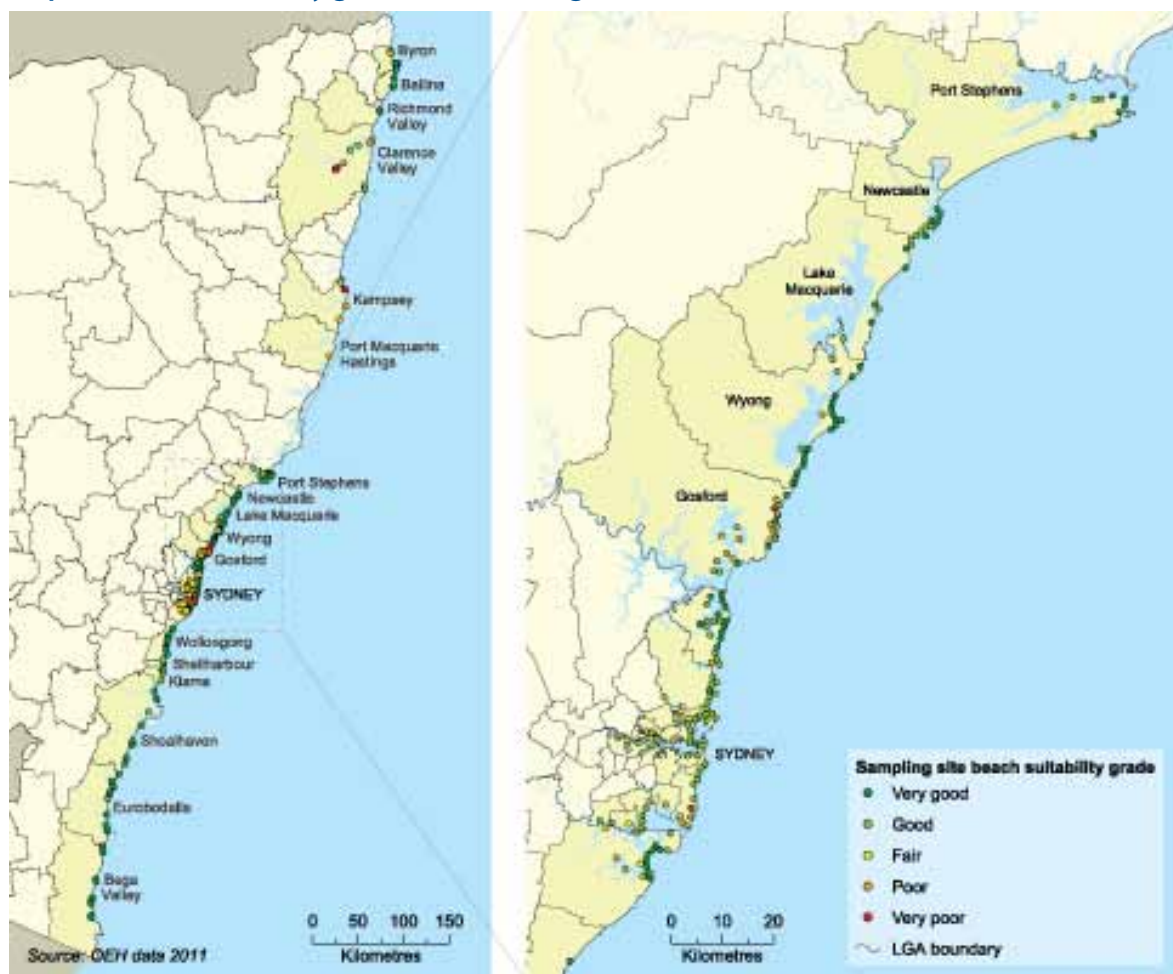
Sedimentation and local pollution from sewage and stormwater overflows associated with urban development can have an impact on water quality. *Marine Water Quality Objectives for NSW Ocean Waters* (DEC 2005) simplify and streamline the consideration of water quality in coastal planning and management. These objectives reflect the environmental values the community places on marine waters and their uses. Together with the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000), the objectives identify the steps required to protect these values and uses, now and in the future.

## Recreational water quality

Information on the recreational water quality in marine and estuarine waters is provided by the Beachwatch programs. The Beachwatch program conducted by the NSW Office of Environment and Heritage (OEH) monitors 127 swimming sites in the Sydney, Hunter and Illawarra regions, while coastal councils also monitor beaches in their areas under the Beachwatch Partnership Program. In the 2010–11 swimming season, 14 local councils participated in this program, monitoring 132 swimming sites, including beaches, coastal lagoons, tidal pools, estuaries and rivers.

Both programs provide information on the risks of sewage and stormwater pollution at beaches. Swimming sites are assigned a beach suitability grade ranging from 'very good' to 'very poor' based on a risk assessment of pollution sources affecting the beach and the level of the bacterial indicator enterococci, in accordance with the *Guidelines for Managing Risks in Recreational Water* (NHMRC 2008). **Map 4.7** shows the beach sustainability grades at NSW sites in 2010–11.

**Map 4.7: Beach suitability grades at swimming sites in NSW, 2010–11**



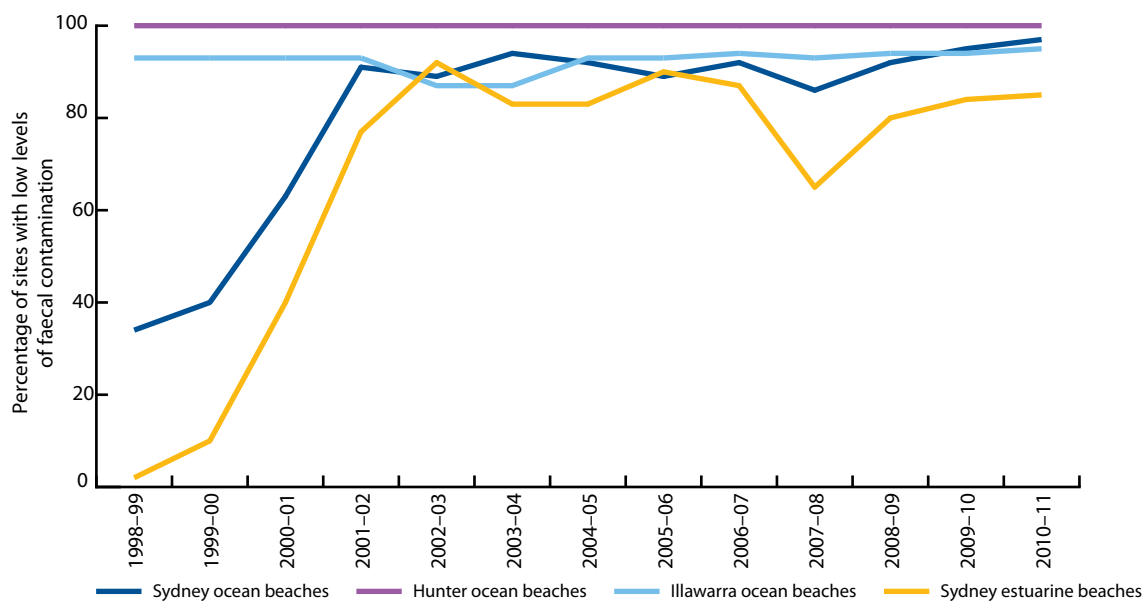
This system for grading beaches is based on new guidelines that were adopted in NSW in May 2009, replacing the earlier 1990 guidelines. Although monitoring water for recreational use does not provide an assessment of overall water quality and waterway health, changes over time enable the effectiveness of stormwater and wastewater management to be assessed.

In 2010–11, 83% of the 259 swimming locations monitored were graded as 'very good' or 'good'. However, there are differences between swimming sites with over 99% of all ocean beaches achieving ratings of very good or good, compared with around 60% of sites in coastal lagoons, estuaries and rivers due to the lower dilution and tidal flushing capacities of these waterways (Map 4.7). Overall, this is a strong result which was achieved despite the NSW coast experiencing its wettest spring and fifth-wettest summer on record. High rainfall causing stormwater discharges and sewerage overflows is recognised as the principal factor in the contamination of water at NSW beaches. Detailed results for all swimming sites monitored in NSW can be found in the *State of the Beaches* reports (OEH 2011b).

**Figure 4.9** shows the proportion of sites with low levels of faecal contamination over the past 13 years at ocean and estuarine beaches in the greater Sydney area. Less than a decade ago wet weather had a much greater impact on swimming locations in Sydney. During 1998–99, when almost as much rain fell as in 2007–08 and 2010–11, only 35% of Sydney's ocean beaches and 2% of Sydney's estuarine swimming areas recorded low levels of faecal contamination (Microbial Assessment Categories A and B defined by NHMRC 2008). These results are based on the measure used prior to 2009 and they are therefore not directly comparable to the outcomes displayed in Map 4.7. Improvements in stormwater and wastewater management over the past decade have resulted in significant reductions in bacterial levels at swimming locations in the Sydney region.

While significant progress has been achieved in controlling point sources of pollution and some diffuse sources, such as stormwater, diffuse source water pollution remains one of the biggest challenges in improving water quality for government, industry and the community (DECC 2009).

**Figure 4.9: Sydney, Hunter and Illawarra beach and estuary monitoring sites graded as having low levels of faecal contamination, 1998–99 to 2010–11**



Source: OEH data 2011

Notes: Beach suitability grades are only available from 2009–10 onwards. To report on trends through time, Microbial Assessment Categories have been back-calculated using historical enterococci data. Microbial Assessment Categories A and B indicate generally low levels of faecal contamination and are required for a swimming site to achieve a 'very good' or 'good' beach suitability grade.

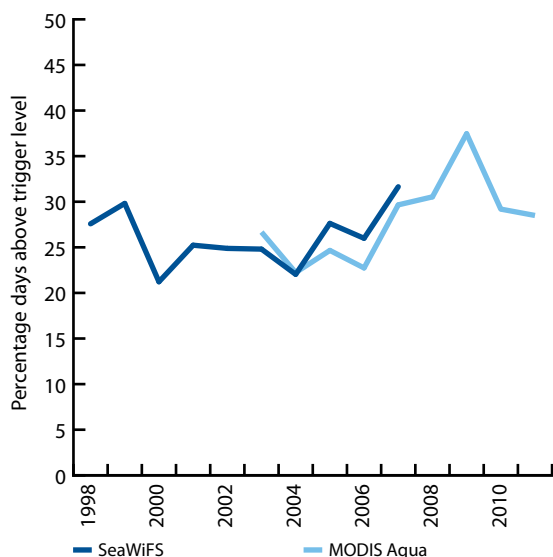
Data from the Beachwatch Partnership Program is not included.

## Algal blooms

While algal blooms occur naturally in the marine environment, some species such as dinoflagellates can be harmful to aquatic organisms (DEH 2005). Less harmful blooms can cause odours or discolouration, such as the red tides that affect visual amenity. The nutrients which promote the growth of algal blooms come from ocean upwellings, which have a close association with El Niño weather cycles, and from the outflows of estuaries. Ocean outfalls, rainfall runoff and stormwater discharges may also boost local nutrient levels in waters close to urban areas.

Satellite data from 1998 onwards is being used to derive information on the occurrence of marine algal blooms in NSW waters. This data allows for a broad and systematic assessment of the frequency and type of blooms and improves on the largely reactive reporting of the past which relied on testing of water quality in affected areas after algal blooms were sighted. Following the failure of the SeaWiFS satellite initially used, it has been necessary to transition to the MODIS Aqua satellite to monitor blooms. As there are some differences between the characteristics of the two sensors, the results recorded are similar but not directly equivalent as shown in **Figure 4.10**.

**Figure 4.10: Sampling days when chlorophyll-a levels indicate an algal bloom, 1998–2011**



Source: OEH data 2012

Notes: An algal bloom is indicated when the water concentration of chlorophyll-a is greater than or equal to the ANZECC trigger value of 1 µg/L.

Figure 4.10 shows the frequency of algal blooms at 17 sites covering the length of the NSW coast between 1998 and 2011. An algal bloom is considered to have occurred when the concentration of chlorophyll-a in the water is equal to or exceeds a trigger value of 1 microgram per litre (1 µg/L) (ANZECC & ARMCANZ 2000). Overall, the frequency of algal blooms appears to be relatively stable, allowing for some differences in the characteristics of the two satellite sensors. Trigger levels were generally reached on fewer days in the southern part of the state. Higher rates of exceedence at some sites may be caused by natural upwellings, while others may be influenced by river discharges. Further analysis is probably needed to identify algal blooms outside their natural range with confidence.

## Ecosystem health

### Rocky reef biota

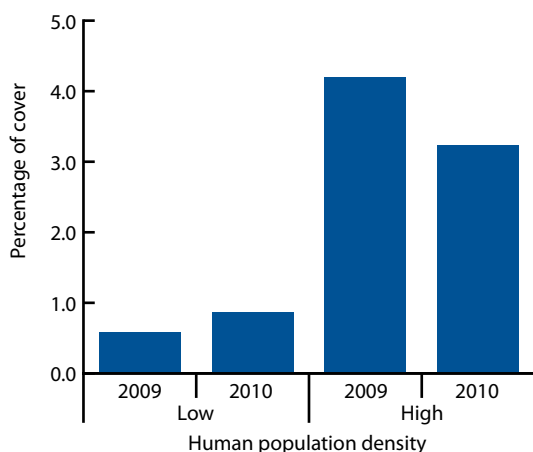
Previous SoE reports relied on commercial harvest data to report on the condition of rocky reef biota. Since 2009, a statewide program has been sampling the dominant biota covering near-shore rocky reefs. Each year, approximately 40 sites associated with a range of nearby human population levels are sampled. Over time, it will be possible to assess the impact of anthropogenic (human-derived) disturbances on rocky reef biota, as an indicator of marine condition. With only two years of monitoring, the data collected so far only allows an estimate of condition and not trend.

The sampling of near-shore rocky reefs indicates that there is considerable variation in covering biota in permanently submerged (subtidal) habitats along the NSW coast. However, there appears to be no significant association between human population level and either condition or patterns of change in condition. The indicators suggest that subtidal habitats are in similar condition throughout NSW.

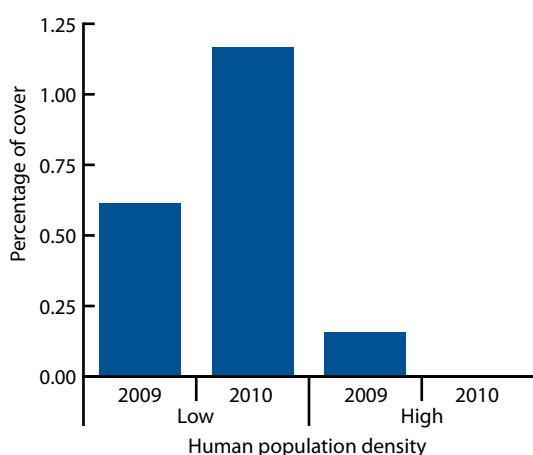
Similar surveys of periodically exposed (intertidal) rocky shore habitats where specific habitat categories can be distinguished indicate that various species may be responding in different ways to human disturbances. For example, the green seaweed, *Caulerpa filiformis*, is significantly more abundant when located near large human populations than smaller ones. This pattern was consistent in 2009 and 2010 (Figure 4.11). For the smaller brown seaweed, *Hormosira banksii*, this pattern appears to be reversed (**Figure 4.11**). Increased disturbance (such as elevated levels of nutrients) could favour the growth of this green seaweed, while more human activity (such as an increase in trampling) could adversely affect the brown variety. Other species show no clear patterns associated with population level.

**Figure 4.11: Changes in biota covering rocky reefs**

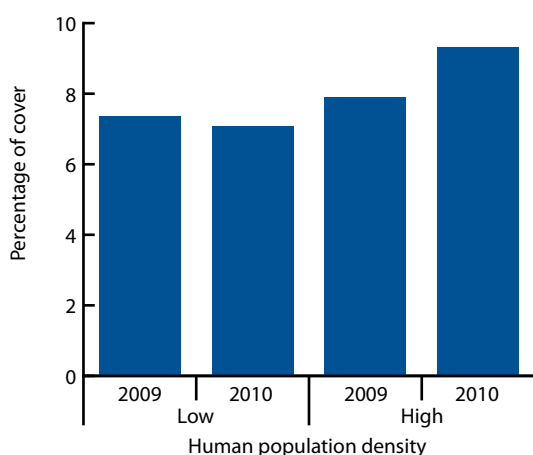
***Caulerpa filiformis***



***Hormosira banksii***



***Pyura stolonifera***



Source: NSW Department of Trade and Investment, Regional Infrastructure and Services data 2012

It had also been predicted that fewer cunjevoi (*Pyura stolonifera*) would be associated with large human populations, since fishers use cunjevoi for bait, but this pattern was not observed in the surveys undertaken (Figure 4.11).

While there are some indications that certain intertidal species may be affected by human activities, at this stage there is no strong overall association between the rocky reef biota sampled and human population levels.

### Threatened species

Information on the status of marine species is not generally as good as that for terrestrial species. However 41 marine species and one population are currently listed as extinct or under threat by the *Fisheries Management Act 1994* (FM Act) and *Threatened Species Conservation Act 1995* (TSC Act).

Around half of the listings are marine seabirds (19 species), the majority of which are classed as vulnerable. Marine mammals (7 species), fish (6), reptiles (3), marine invertebrates (4), macroalgae (2) and one marine vegetation population make up the remaining listings. The four invertebrates were added over the past three years and two – Haswell's caprellid (*Metaprotella haswelliana*) and the marine worm, *Hadrachaeta aspeta* – are presumed extinct.

As information improves, more species may be recognised as being extinct or under threat than are currently known and the number of species listed may also grow as pressures on the marine environment increase. Higher order species, such as sharks, tuna and whales, remain the most vulnerable to external pressures.

Eight key threatening processes are listed under the FM Act. Four relate to the marine environment:

- Introduction of non-indigenous fish and marine vegetation to the coastal waters of NSW
- The current shark meshing program in NSW waters
- Hook and line fishing in areas important for the survival of threatened fish species
- Human-caused climate change.

Climate change and shark meshing are also listed as threats under the TSC Act along with 'Entanglement in or ingestion of anthropogenic debris in marine and estuarine environments' (see Biodiversity 5.1).

The Fisheries Management (General) Regulation 2010 lists seven protected marine or estuarine species, the entire zoological families of seahorses and pipefish (Syngnathidae), ghostpipefish (Solenostomidae) and seamoths (Pegasidae), and four marine or estuarine species protected from commercial fishing, including southern bluefin tuna.

## Marine protected areas

Marine protected areas, which include six marine parks and 12 aquatic reserves, aim to conserve biodiversity by protecting representative habitats and reducing pressures on the marine environment, particularly from certain fishing activities. Marine parks and aquatic reserves cover approximately 347,000 hectares or around 34% of the state's waters.

Multiple-use zoning within marine parks restricts activities in line with conservation and management priorities while permitting reasonable use and providing protection for the diverse marine ecosystems found within park boundaries (NSW Government 2001). There are four types of zones: sanctuary, habitat protection, special purpose and general use. The role of marine protected areas and the areas under each zoning category are discussed further in Biodiversity 5.3.

The report from an independent scientific audit of marine parks in NSW, undertaken at the request of the NSW Government, was released in February 2012 (Beeton et al. 2012) with the public invited to comment until 30 June 2012.

## Pressures

### Pollution

Pollutants have a range of impacts on biodiversity in the marine environment (NBSRTG 2009) including:

- degrading habitats
- changing the distribution and density of species
- increasing the levels of contaminants in some species (which can accumulate up the food chain)
- reducing the relative abundance of top-order predators.

Most of the pollution in coastal and marine waters comes from land-based activities. The main pressures arise from human settlement, population growth and urbanisation in the coastal zones adjacent to marine waters and include sewage and stormwater discharges, diffuse sources of pollution (such as runoff from agricultural land), outflows from estuaries and marine debris.

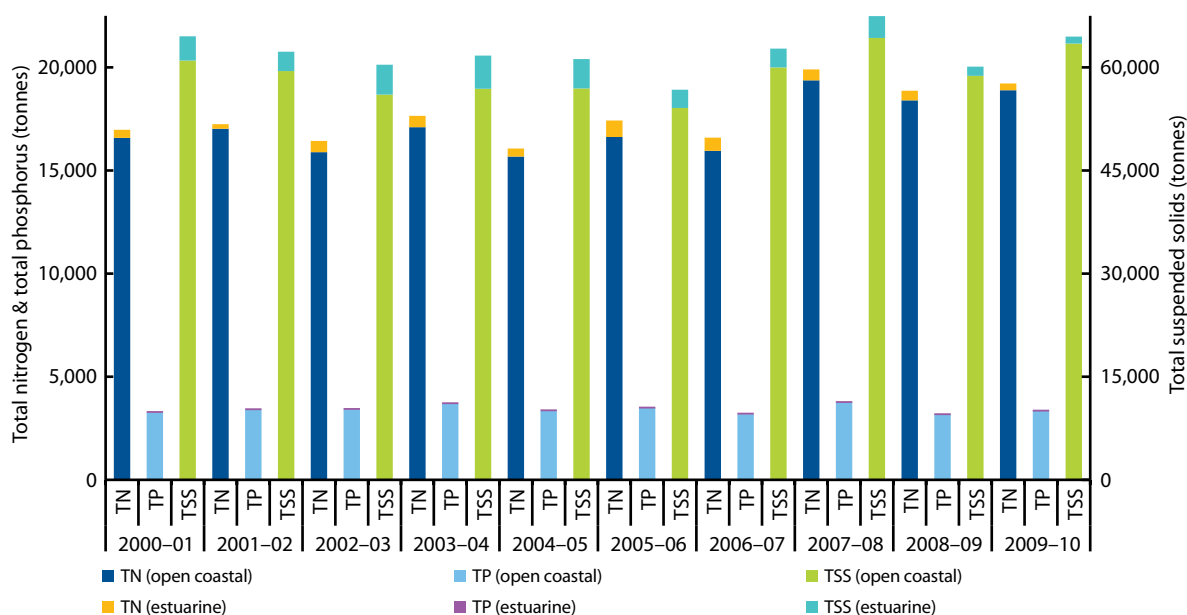
Sediments, nutrients and other pollutants in freshwater from rivers, creeks and coastal lagoons are discharged into the ocean through estuaries. Modelling indicates that each year 135 NSW estuaries discharge an average 23,000 tonnes of nitrogen, 2400 tonnes of phosphorus and around 835,000 tonnes of sediment into marine waters (Roper et al. 2011). Excess sediments, phosphorus and nitrogen in the marine environment, usually delivered by flooding, can have significant impacts on marine water quality and habitats, including seagrass beds and reefs.

**Figure 4.12** shows licensed discharges of total nitrogen, total phosphorus and total suspended solids to open marine waters and estuaries. Nitrogen and phosphorus discharges to the marine environment have been relatively stable over the period shown. These are largely the outputs of sewage treatment plants. Discharges of suspended solids into marine waters increased in 2006–07 and 2007–08 primarily due to the increase in average yearly rainfall in coastal areas in those years following a dry period (SWC 2008). High levels of iron, steel and coke production also contribute to discharges of suspended solids into marine waters.

On average, licensed discharges of suspended solids to the marine environment represent less than 7% of the overall load of total suspended solids to the marine environment. Licensed discharges of nitrogen and phosphorus are predominantly restricted to waters off Sydney and Wollongong. Diffuse source discharges to the marine environment are more significant than point source discharges in most coastal waters, excluding the waters off Sydney, where ocean outfalls contribute the majority of nutrients to marine waters.

Some marine pollution is not from land-based sources. This generally includes material from shipping-related incidents, such as oil or chemical spills, ballast water discharges and sewage released from vessels. Many of these incidents are minor and usually occur around ports and harbours. No major pollution incidents have been recorded in NSW marine waters over the last three years.

**Figure 4.12: Licensed discharges to NSW open marine waters and estuaries, 2000–01 to 2009–10**



Source: Environment Protection Authority data 2012

Notes: Data covers all licensees discharging into the marine environment under the Load-based Licensing Scheme.

## Refuse and habitat disturbance

The Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* lists 'Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris' as a key threatening process. Harmful marine debris consists of garbage washed or blown from land into the sea, fishing gear abandoned by recreational and commercial fishers, and solid non-biodegradable floating materials (such as plastics) disposed of by ships at sea (DEH 2003). Entanglement and ingestion of debris, such as plastic bags, cigarette butts, lolly wrappers and discarded fishing gear, can be fatal to marine species, particularly listed threatened species, such as seabirds, turtles and whales. Grey nurse sharks in NSW waters have also been found to have fishing hooks snared in both their mouths and stomachs, with the potential to cause death. Recovery in the populations of threatened species, such as humpback whales, is likely to result in a greater number of accidental entanglements.


Demersal trawl nets used in the NSW Ocean Trawl Fishery are dragged along the seabed in suitable fishing areas (DPI 2004). Gear restrictions, area closures and a reduction in licence holders in the fishery have helped reduce the impacts of trawling on marine habitats. The mapping of habitat and trawl grounds presently under way should provide for improved management of trawling into the future.

## Fishing

Commercial and recreational fishing occurs in the marine waters of NSW. Commercial fish landings and overall numbers of recreational anglers are currently relatively stable in NSW, although the number of commercial catch returns, which can be used as an indicator of fishing effort, has been steadily decreasing over the last 10 years. The decrease in the number of submitted catch returns indicates an increase in the average catch per return.


The number of commercial fishing licences has decreased over recent years. This is the result of licence buybacks for marine parks or to restructure fisheries, the introduction of 'recreational fishing havens', commercial closures in Sydney Harbour and other areas, as well as a reduction of effort in Commonwealth fisheries that would have had an impact on dual Commonwealth and NSW licence holders. High fuel prices and low product prices have also affected fishing effort in NSW commercial fisheries.

## Invasive species




Marine invasive species are plants or animals, often introduced from overseas, that can have a significant impact on marine industries and the environment, by taking over habitats and directly competing with native species for food. Marine pests include mussels, crabs, seaweeds, sea stars and other marine species. Some marine pests are native to other regions of Australia but have been transported into NSW through shipping or the aquarium trade (see also Biodiversity 5.4).

## Climate change




The potential impacts of climate change on the marine environment are not well understood but predicted increases in sea surface temperature and ocean acidification (Guinotte & Fabry 2008) are likely to have the most significant impacts.

## Sea surface temperature and salinity



Over the past 40 years, average sea surface temperatures in NSW coastal waters have increased by 0.5°C in the north of the state and up to 0.8°C in the south (OEH 2011c). The temperature in the Tasman Sea off the east coast of NSW has risen markedly. Climate change predictions for NSW include higher sea surface temperatures (by possibly up to 4°C), stronger currents and more frequent storms (Hobday & Lough 2011). Changes to currents, regional wind patterns and mixed layer depths are also likely to affect upwellings with an associated impact on primary productivity (Hobday et al. 2006).



To illustrate this, the East Australian Current now extends 350 kilometres further south, making southern waters warmer and saltier than previously (Ridgway 2007). An observed impact of this change has been the spread of the black spiny sea urchin from NSW into Tasmania, where it was not previously found. The urchin is a voracious predator of important algal species and threatens fisheries (Ling et al. 2009). In addition, it has been found that 45 species of fish have changed their distribution in south-eastern Australia over recent years, with the change corresponding to warming observed in the marine environment (Last et al. 2010).

## Marine acidification

The world's oceans currently absorb about 25% of the carbon dioxide (CO<sub>2</sub>) generated by humans, with about 40% of this absorbed in the Southern Ocean (CSIRO & BoM 2010). The CO<sub>2</sub> absorbed by the ocean increases its acidity, which is registered as a decrease in pH. Since 1750, the pH of the world's oceans has decreased by an average of 0.1 (McNeil & Matear 2007; Riebesell et al. 2009).

Any measurable change in pH is significant and has a potential impact on the marine environment. Ocean acidification will decrease the ability of calcitic organisms such as molluscs to form shells and corals (Fabry et al. 2008; CSIRO & BoM 2010). These effects are now being observed in the Southern Ocean where it was predicted they would first become evident. Since these organisms play an important role in food webs and the natural cycling of carbon, this will have far-reaching implications for the future health of ocean ecosystems.

## Responses

### Established responses

#### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Protect rivers, wetlands and coastal environments'. Further details on Goal 22 are provided in Water 4.1.

#### Legislation

The *Fisheries Management Act 1994* and supporting regulations provides for conservation of fish stocks, key fish habitats, threatened species, populations and ecological communities of fish and marine vegetation. This includes the regulation and management of recreational and commercial fisheries, including licence, gear and species restrictions, application of commercial catch quotas for some species, recreational bag limits and habitat protection through the establishment of aquatic reserves and closures.

The *Protection of the Environment Operations Act 1997* aims to protect the sea and certain waters from pollution by oil and other noxious substances discharged from ships through such mechanisms as protection of the environment policies and licensing, including the regulation of point source discharges into the marine environment.

The *Marine Parks Act 1997* aims to conserve marine biological diversity, habitats and ecological processes in marine parks (see also Biodiversity 5.3). All six NSW marine parks have their own zoning plan, which specifies the activities that are allowed in each zone (such as where fishing is allowed).

### Water quality objectives

*Marine Water Quality Objectives for NSW Ocean Waters* (DEC 2005) describe the water quality needed to protect the community's values for, and uses of, the marine environment. The objectives simplify and streamline the consideration of water quality in coastal planning and management.

### Policy and programs

The *NSW Diffuse Source Water Pollution Strategy* (DECC 2009) provides a framework for coordinating efforts to reduce diffuse source water pollution across NSW. The strategy promotes partnerships and provides a guide for investment and an avenue to share information on projects and their outcomes across the state. Reducing diffuse sources of pollution in upstream catchments will help to improve the quality of the marine waters into which they discharge.

### Future opportunities

NSW marine waters and ecosystems are currently considered to be in good condition. However, pressures from urban, industrial and recreational development are growing. NSW will need to continue to implement suitable management and adaptation strategies to prevent a decline in the quality of the marine environment.

Apart from commercial fishing and sea surface temperature records, little ongoing monitoring has occurred to determine the impacts of the key pressures on the marine environment. Improved information on marine water quality, species diversity and abundance, and marine habitats through remote sensing and aerial helicopter and underwater video surveys will improve our understanding of the marine environment and enable it to be managed more effectively.

A mix of pollution control, fishing management and conservation measures will continue to be required to maintain the condition of marine waters and ecosystems. This mix of approaches is likely to evolve in response to our understanding of how best to adapt to the changing marine environment.



## 4.6 Estuaries and coastal lakes

New South Wales estuaries and coastal lakes continue to come under increasing pressure from coastal development. While many estuaries are resilient to some level of change and remain in reasonably good condition, the condition of more vulnerable estuaries or those subject to greater pressures is poorer.

The condition of NSW estuaries is highly variable. Many remain in good condition but a small number are considered to be in poor condition. The overall condition of individual estuaries generally reflects their level of resilience to change caused by disturbances to their waterways and catchments.

The pressures facing NSW estuaries are also highly variable. Most have been modified to some extent, but around 20% have experienced little or no clearing of their immediate catchments, especially those along the south coast. However a significant proportion are considered to be under high pressure due to a range of intensive catchment and waterway activities, particularly in more settled areas.

Catchment and waterway disturbance results in habitat modification, including changes in runoff characteristics which increase the loads of sediments and nutrients that affect estuarine water quality and ecosystem health.

Continuing population growth and urban development along the NSW coast are expected to intensify pressures on estuaries and coastal lakes.

### NSW indicators

Indicator and status	Trend	Information availability
Chlorophyll-a levels in seawater	Stable	✓
Turbidity levels in seawater	Stable	✓
Percentage of estuaries with beach suitability grades for swimming of good or better	Stable	✓✓✓
Distribution of estuarine macrophytes	Stable	✓
Levels of catchment disturbance	Increasing	✓✓
Levels of riparian disturbance	Increasing	✓✓
Rate of sea level rise	Increasing	✓✓✓

Notes: Terms and symbols used above are defined in *About SoE 2012* at the front of the report.

## Introduction

Estuaries are semi-enclosed bodies of water with an open or intermittently open connection with the ocean, where water levels vary in a predictable and periodic way in response to the ocean tide at the entrance. Coastal lakes are a relatively common estuary type in NSW; many have only intermittent connections to the ocean often referred to as 'intermittently closed and open lakes and lagoons'.

Estuaries occupy the transition zone between the freshwater and marine environments. They are highly productive natural systems that form the basis of complex food webs and underpin life in near-shore waters and marine environments.

The desirability of coastal lifestyles and increasing settlement along the coast are placing estuaries and coastal lakes under ever greater levels of stress. The attendant pressures of development and urbanisation, and disturbance of the natural values of surrounding catchments need to be carefully managed in order to protect the health and preserve the condition of estuarine environments.

Systematic data has generally been lacking on the overall condition and long-term health of estuaries and the important ecosystems they support. However in implementing the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d), relevant data from a range of stakeholders was collected, consolidated and analysed for the *State of the Catchments Reports* series (DECCW 2010e). Data is still not available on the condition of all NSW estuaries but data collection and analysis is ongoing and reporting coverage is improving over time.

## Status and trends

### Estuary types

The types of estuaries found along the NSW coast vary according to their geophysical setting. The north coast is generally characterised by broad coastal floodplains that have been extensively cleared and settled. The Sydney Basin is highly urbanised with drowned river valleys that cut through a sandstone plateau. Much of the south coast is less developed and characterised by many coastal lakes and lagoons with relatively small catchments and often intermittent connections to the ocean.

## Water quality

The health of estuarine ecosystems and the food webs they support is heavily influenced by water quality. While water quality is naturally variable across different estuaries, pressures on it over time can lead to a reduction in ecosystem health, including changes in the distribution and abundance of species, the loss of biodiversity, and reduced recreational value and amenity.

Turbidity and chlorophyll-a are monitored in NSW to assess estuary condition as part of the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (MER Strategy) (DECCW 2010d). Two datasets are available for comparison: the first a baseline dataset compiled from a variety of sources for the period July 2005–June 2008, the second containing monitoring data from July 2008 to June 2011. Both datasets include estuaries from the three regions (north, central and south) and the range of estuary types, but the specific estuaries monitored vary. However, the same estuaries were used to monitor both turbidity and chlorophyll-a in the second dataset.

Trigger values and compliance intervals for turbidity and chlorophyll-a have been derived for the MER Strategy program using an approach consistent with the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000). Exceeding the guidelines' trigger levels does not automatically indicate that estuarine conditions are poor, but any pattern of exceedences is regarded as a cue for further investigation to determine whether water quality issues exist. Further details on site selection, monitoring procedures and data analysis are available in the MER Strategy technical report for estuaries (Roper et al. 2011).

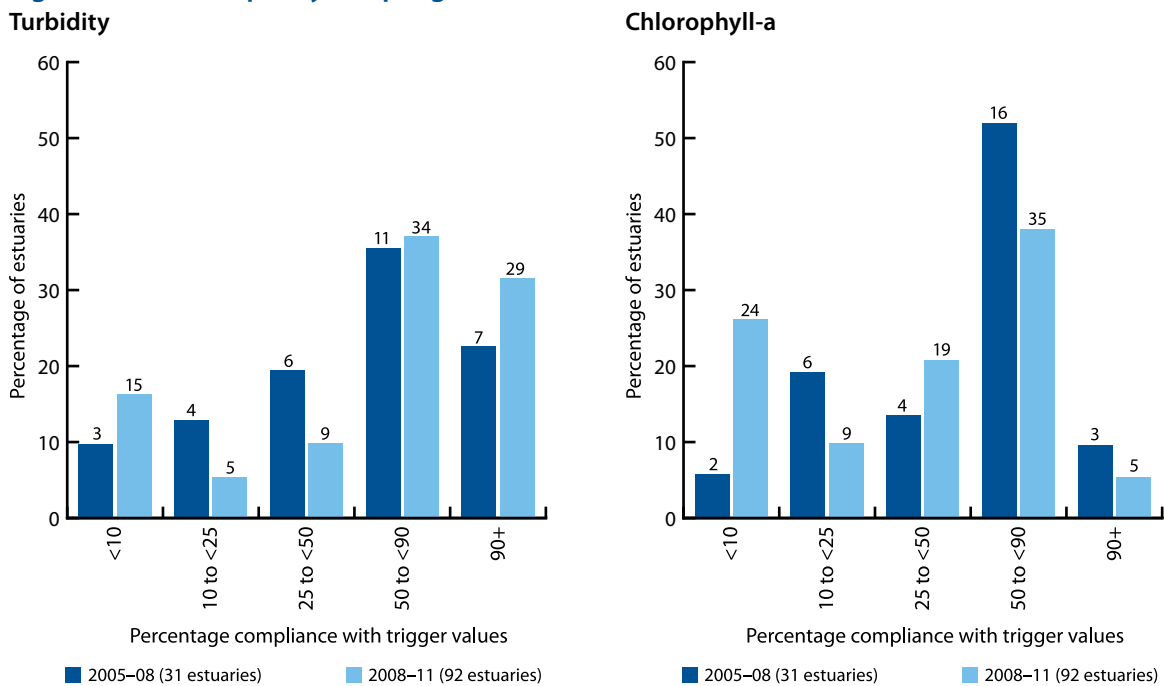
### Turbidity

Water clarity is an indication of the amount of particulate matter in the water, which may consist of clay and silt particles, phytoplankton or natural tannins. Measuring turbidity provides an indication of the amount of light available for aquatic plants and other benthic organisms that inhabit the water column and substrate of estuaries.

Turbidity data is available for 92 estuaries for the period July 2008–June 2011 and 31 estuaries between July 2005 and June 2008. Results were generally similar for the two periods of monitoring (**Figure 4.13**). During 2008–11, compliance with trigger values was very good (over 90% of sampling occasions) in 29 estuaries (32% of those monitored) and good (50–90% compliance) in 34 (37%); for 2005–08, compliance was very good in seven estuaries (23% of those monitored) and good in 11 estuaries (35%) (Figure 4.13).



**Figure 4.13: Water quality sampling from selected NSW estuaries, 2005–08 and 2008–11**



Source: Department of Environment, Climate Change and Water data 2010 and NSW Office of Environment and Heritage (OEH) data 2012

Notes: The values shown above the bars in the graphs are the number of estuaries in each compliance category.

These estuaries are generally under relatively little pressure with low to moderate sediment inputs (Roper et al. 2011). However, it appears that some estuaries may receive larger sediment inputs from catchment disturbance than are reflected in this turbidity data possibly because the sediment is delivered by rainfall outside the summer sampling period.

Fifteen estuaries (16%) had very poor compliance with trigger levels, complying on less than 10% of sampling occasions during 2008–11 and three estuaries (10%) in 2005–08. Many of these estuaries receive relatively large sediment inputs because of the scale and nature of disturbance in their catchments (Roper et al. 2011).

### Chlorophyll-a

Abnormally high levels of chlorophyll-a indicate high phytoplankton levels or algal blooms and are a symptom of eutrophication, the over-enrichment of a water body with nutrients. High levels of algae may lead to reduced levels of dissolved oxygen in the water column and some algal species may produce toxins which have serious implications for fish, shellfish and humans coming into contact with the water.

Increased levels of chlorophyll-a are generally recorded in the warmer months when higher temperatures and more light provide better growing conditions. The generally higher rainfall over the warmer months

is also when nutrient inflows to an estuary are greatest. This combination of conditions gives a better indication of the potential for eutrophication to occur.

Chlorophyll-a data is available from 92 estuaries for the period 2008–11 and 31 estuaries during the period 2005–08. For 2008–11, compliance with trigger values was very good (more than 90% of sampling occasions) in five estuaries (5% of those monitored) and good in 35 (38%); for 2005–08, it was very good in three estuaries (10% of those monitored) and good in 16 estuaries (52%) (Figure 4.13). These estuaries are generally under low to moderate pressure (Roper et al. 2011).

While there are generally similarities in monitoring results for chlorophyll-a across the compliance categories, the largest difference between 2005–08 and 2008–11 was the increase in the proportion of estuaries with very poor ratings (<10% compliance with the trigger values) in the second sampling period. The majority of these estuaries receive relatively high loads of nutrients from catchment disturbance which probably explains the findings (Roper et al. 2011), although two exceptions on the south coast – Baragoot Lake and Tuross River – receive relatively low nutrient loads and require further investigation.

### Recreational water quality

Beachwatch programs monitor recreational water quality at swimming beaches in NSW. While not an assessment of overall water quality, the results provide an indication of sewage and stormwater pollution which affects the fitness of water bodies for human recreational use as well as the effectiveness of stormwater management.

In the Sydney region, 55 estuarine beaches are monitored for the bacterial indicator enterococci, in accordance with the *Guidelines for Managing Risks in Recreational Water* issued by the National Health and Medical Research Council (NHMRC 2008). Sites are located in Pittwater, Sydney Harbour, Botany Bay, Lower Georges River and Port Hacking. **Map 4.8** shows the outcomes of this monitoring.

Rainfall during 2010–11 was extremely high and only 38 of the 55 swimming locations (69%) received a beach suitability grading of 'very good' or 'good' (Map 4.8). The poorest performing swimming sites were generally those located in the upper reaches of tributaries. These sites have less capacity to dilute pollution sources and lower levels of tidal flushing.

While the results for 2010–11 indicate that there is still a need to improve the management of stormwater inflows to estuaries in urban catchments, they are a significant improvement compared with a similarly wet period in 1998–99 (assessed under an older measurement system). When the data for 1998–99 is converted to the assessment system currently used, only 2% of estuarine swimming sites in that year recorded low levels of enterococci (Microbial Assessment Category A or B) compared with 85% of sites in 2010–11.

Water 4.5 has further information on Beachwatch monitoring programs.

### Estuarine macrophytes

Estuarine macrophytes include seagrass, mangroves and saltmarsh communities. The distribution of macrophytes in NSW estuaries has been systematically mapped several times, firstly in the 1980s (West et al. 1985), then as part of the Comprehensive Coastal Assessment (CCA) (Williams et al. 2006) and the Seabed Mapping Project which filled in some gaps not mapped in the CCA. This data was compiled in Creese et al. 2009.

Estuarine macrophyte mapping continues under the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d) with 26 estuaries now remapped. These represent a range of estuary types from large river systems, such as the Clarence and Shoalhaven, to small coastal lake systems, such as Dalhousie Creek and Dee Why Lagoon.

**Map 4.8: Beach suitability grades at estuary swimming sites in the Sydney area, 2010–11**



### Distribution of seagrass

Seagrasses occur in the subtidal zones of estuaries. They are particularly important because of their role in maintaining sediment stability and water quality, and providing shelter and food to a wide variety of aquatic biota. Causes of seagrass decline include:

- impaired water quality due to increased sediment and nutrient levels, which reduces the light that enables their growth
- physical disturbance through such activities as dredging and reclamation
- changes to hydrologic flows
- natural phenomena such as storms.

Four estuaries account for more than 60% of the total area of seagrass in NSW. However the distribution and area of seagrass and of the species represented is highly variable. Three of the four main species of seagrass found in NSW often display substantial variations in distribution over time with cyclical patterns of loss followed by slower periods of regeneration and regrowth. The fourth, *Posidonia australis*, is the exception.

The natural variability of seagrass communities and lack of consistent mapping prior to the 1970s makes it difficult to assess their overall status or trends in distribution over the longer term. It is believed that there has been an overall decline in the extent of seagrasses since European settlement, but this is difficult to quantify. Based on the historic evidence available, the total loss has been estimated at less than 30% (Keith 2004). However, many major estuaries in NSW lost as much as 85% of their seagrass beds in the 30–40 years prior to the commencement of systematic mapping in the 1970s (DPI 1997).

Reference to the most recent seagrass mapping indicates a slight overall decline (<4%) in the total area of seagrass since 2009 (Figure 4.14), with significant total loss of seagrass in several of the smaller estuaries in the northern part of NSW. The distribution of seagrass increased in four estuaries, where the dominant species is *Zostera capricorni*, which has highly dynamic distribution patterns that may relate to localised climatic events, such as high rainfall and flooding, rather than direct human impacts. The cause of specific declines requires further investigation.

## Distribution of mangroves

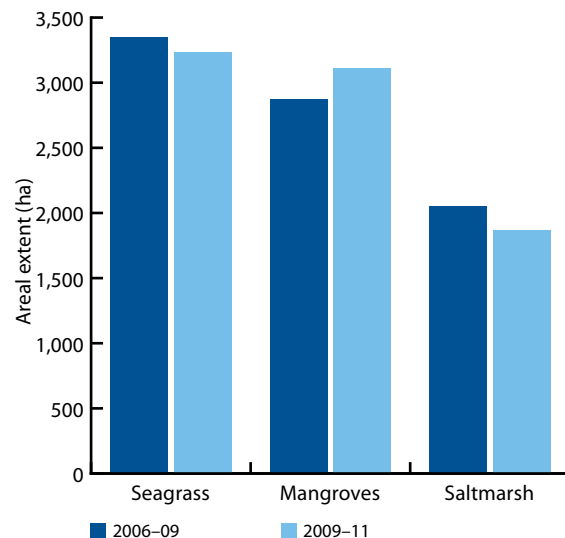
Mangroves grow along the intertidal shores of many NSW estuaries, in some places forming extensive forests. They are absent from many intermittently closed and open lakes and lagoons, particularly those where entrances are frequently closed.

Although five mangrove species occur in NSW, only the grey mangrove and river mangrove are found extensively. The diversity of mangroves decreases southwards along the coast with only grey mangroves found beyond Merimbula Lake on the far south coast. Three major estuaries – Port Stephens and the Hunter and Hawkesbury rivers – account for approximately 50% of the total distribution of mangroves in NSW.

Mangroves are quite resilient and are able to rapidly colonise favourable areas. Expansion may be due to a range of factors, including:

- regrowth in areas of past clearing
- expansion into areas of saltmarsh

**Figure 4.14: Change in macrophyte distribution**



Source: Department of Primary Industries data 2012

- colonisation of areas where sedimentation has occurred and altered hydrology and tidal regimes favour them, such as coastal lakes where artificial entrance regimes have increased tidal inundation.

A lack of consistent mapping over the longer term has made it difficult to assess overall trends in the status and extent of mangroves. It is believed that there has been an overall decline in their extent since European settlement, but this is difficult to quantify. Based on the historic evidence available, Keith 2004 has estimated the loss of mangroves at between 30 and 70%.

The most recent surveys indicate that the total area of mangroves across 26 estuaries has increased by about 8% since 2009 (Figure 4.14). The distribution of mangroves in the majority of estuaries expanded or remained similar. The largest expansion was recorded in the Clarence River, while two estuaries – Darkum Creek and Lake Macquarie – registered a slight decline. Given the relatively small area of mangroves around Darkum Creek, these changes may relate to the resolution of mapping, whereas the losses around Lake Macquarie occur in a number of areas and require further investigation.

The overall distribution of mangroves, however, is still greater than that mapped in the 1980s (West et al. 1985).

### Distribution of saltmarsh

Saltmarsh communities grow to the highest tide levels, meaning that they are only inundated by larger tides or extremes in water levels. Where saltmarsh occurs in conjunction with mangroves, it occupies the landward area. Saltmarsh can also occur around coastal lakes where conditions do not favour mangroves. Typically vegetated by low shrubs, herbs and grasses, they can range from narrow fringes on steep shorelines to nearly flat expanses.

There has been a substantial decline in the extent of saltmarsh since European settlement, but this is difficult to quantify. However, based on the historic evidence available, the loss has been estimated at 30–70% (Keith 2004). Losses of saltmarsh have been particularly severe in the Sydney region and on the central coast (Wilton 2002; Williams & Meehan 2004; Kelleway et al. 2007). Saltmarsh has been listed as an endangered ecological community in NSW due to the nature of ongoing losses. The processes threatening saltmarsh include infilling, modified tidal flows, weed invasion, human disturbance and climate change (Adam 2002).

An overall loss of saltmarsh of around 9% was found across the 26 estuaries recently remapped (Figure 4.14). An increase in saltmarsh distribution was mapped in 13 estuaries: 10 had distributions similar to the previous mapping and three had reduced saltmarsh distributions.

The largest area of change was in Cathie Creek where saltmarsh species have been replaced by freshwater wetland species (a reduction of 412 hectares or 22% of the saltmarsh distribution mapped by Williams et al. 2006). This change is likely to be in response to varying hydrologic conditions as the entrance to the creek has become constricted over recent years and water levels have increased, submerging saltmarshes and favouring freshwater species.

Excluding Cathie Creek from the analysis, the overall trend for NSW is an increase in saltmarsh distribution of about 230 ha or 16%.

### Pressures

Pressures influencing the condition of NSW estuaries originate in the surrounding catchment, in the area immediately adjacent to the estuary known as the foreshore or riparian zone, and within the estuarine waterway itself.

Many of the pressures on estuaries are associated with the growth in population along the coast and the land clearing and development this entails. These activities increase the volume and change the nature of rainfall runoff and stormwater which carries sediment and

other pollutants to coastal environments with impacts on water quality. Areas of mangroves, saltmarsh and coastal wetland have been cleared or reclaimed for port infrastructure, recreation, housing and rubbish disposal. Aquatic communities, such as seagrasses, have been disturbed by waterway activities and infrastructure, including boat ramps, jetties and moorings, and affected by changes in water quality.

### Catchment disturbance

Changes in land use and the removal of vegetation in coastal catchments are good indicators of the pressures affecting water bodies from increased loads of diffuse source nutrients and sediments. Where vegetation has been cleared, the nature of the subsequent land use will determine the extent of the increase in runoff transporting nutrients and sediment from the catchment to estuaries. For example, increasing urbanisation leads to greater runoff from the hard non-porous surfaces found in built-up areas.

The level of disturbance affecting the catchments of NSW estuaries has been mapped as part of the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d). The area of the catchment can be divided into the 'estuary catchment' where runoff drains directly to the estuary below the tidal limit and the 'fluvial catchment' where drainage is to areas above the tidal limit, including freshwater tributaries. The largest fluvial catchments tend to be associated with larger estuaries which have significant tributaries. The catchments of 30 NSW estuaries have no mapped fluvial component due to their small size and absence of major freshwater tributaries draining to the estuary.

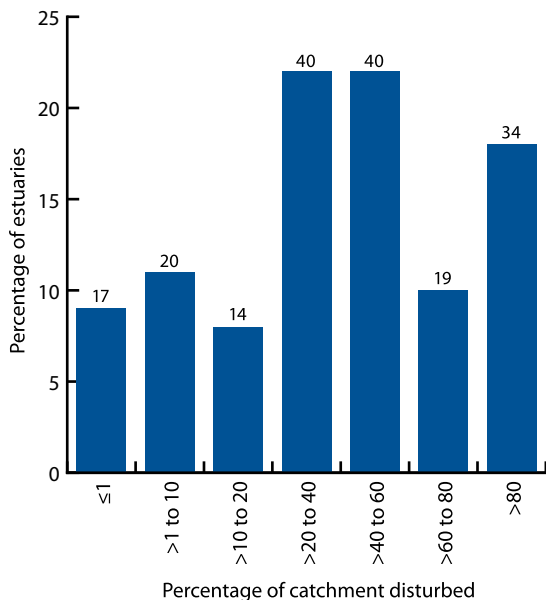
The average rate of vegetation clearance in the catchments of NSW estuaries is approximately 38%. For that part of the catchment that drains directly to the estuary, the average rate of disturbance increases to 44%. It is possible that pressures originating nearer to waterways have a greater influence on condition.

Thirty-seven estuaries (about 20%) have experienced little or no clearing of their direct catchments (less than 10% of vegetation cover), while for the total catchment the figure is 40 estuaries (22%) (Figure 4.15). The majority of these are within the public reserve system of national parks or other public lands.

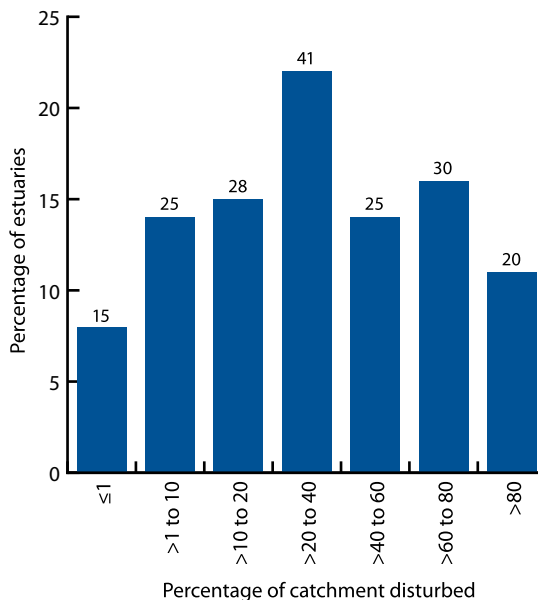


**Figure 4.15: Level of catchment disturbance (vegetation clearing) in NSW estuaries**

### Disturbance of estuarine catchment only



### Disturbance across the whole catchment



Source: OEH data 2012

Notes: The data covers 184 estuaries and the values shown above the bars in the graphs are the number of estuaries in each disturbance category.

Thirty-four estuaries (around 18%) have experienced extensive clearing of 80% or more of their immediate catchment areas, while 20 estuaries (11%) have experienced this level of disturbance throughout the whole catchment (Figure 4.15). Many of these estuaries are considered to be in a fair to poor state, particularly the smaller systems with intermittent connections to the ocean. The smaller number of larger, well-flushed estuaries that have been extensively cleared are generally considered to be in better condition.

An ongoing shift of population to the coast occurred across the three Censuses. The proportion of the NSW population living in estuary and coastal catchments increased from 80.6% of the total NSW population in 1996 to 82.1% in 2006. Population density across all coastal catchments has increased from 38.3 to 42.2 people/km<sup>2</sup> or an increase of 9.2% for the period (Roper et al. 2011). A continuation of this trend is likely to increase the pressures on NSW estuaries and coastlines that are adjacent to population centres.

## Population and demographic change

The majority of the NSW population lives close to the coast and this places considerable pressure on coastal and estuarine ecosystems through increased development and disturbance of the catchments.

Population density data has been calculated from data collected by the Australian Bureau of Statistics in the 1996, 2001 and 2006 Censuses. The population density of estuary catchments ranges from nil for estuaries with catchments located wholly within national parks to very high densities for estuaries in metropolitan Sydney, where Port Jackson and Dee Why catchments support over 5000 people per square kilometre (km<sup>2</sup>). The average population density for NSW estuary catchments is 211 people/km<sup>2</sup>.

## Nutrient and sediment loads

Many NSW estuaries face the threats of eutrophication (excessive nutrient enrichment) and sedimentation.

Increases in nutrient loads to estuaries are associated with a range of land uses and activities, such as urban development, agricultural land-use practices and effluent discharges. Increases in nutrient loads may lead to excessive production of algae and aquatic plants, with flow-on effects up the food chain. System productivity may increase temporarily but, because excessive levels of nutrients tend to favour a smaller number of species, overall biodiversity and ecosystem health is reduced.

Sediment loads entering estuaries can increase as a result of disturbance to soils, erosion in catchments, and riverbank, shoreline and in-stream erosion. Following its transport by rainfall, coarse sediment settles out, smothering sensitive species, while finer sediment may remain suspended and limit primary production by reducing water clarity.

Direct measurement of the sediment and nutrient loadings to coastal lakes and estuaries from a range of diffuse sources in a catchment is difficult and costly. Therefore sediment and nutrient loads are estimated using models of the surface flows across catchments associated with a range of land uses.

Point source discharges from sewage treatment plants (STPs) directly into estuaries or their tributaries are another source of sediment and nutrient inputs. Discharges from STPs and sewage overflow points are licensed by the NSW Environment Protection Authority. Combining the annual discharge loads with the diffuse source loads from modelling provides an estimate of the annual loads for total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP).

The percentage increase above natural levels of TSS, TN and TP in NSW estuaries has been estimated using this approach. **Figure 4.16** shows the combined results for TSS and demonstrates that while some estuaries still have nearly natural loads, in many others the loads are well above natural, undisturbed levels. An estimated 54% of NSW estuaries have undergone a doubling (or greater) of loads of TSS.

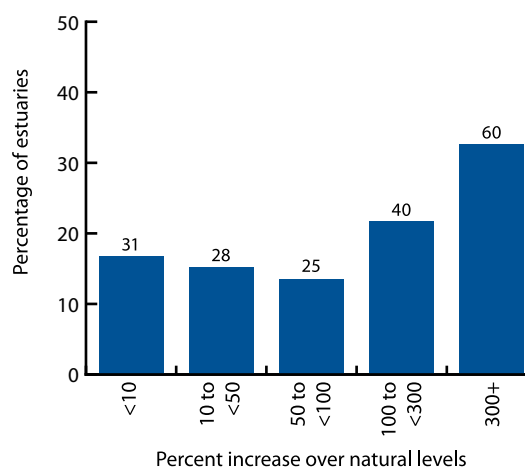
The modelled results for nutrients are similar with an estimated 48% of NSW estuaries experiencing a doubling (or greater) of TN levels, while TP levels in 73% of estuaries have at least doubled (Figure 4.16). With a small number of exceptions, estuaries determined to be in a fair to very poor condition (DECCW 2010e) are generally within this group of estuaries.

### Riparian disturbance

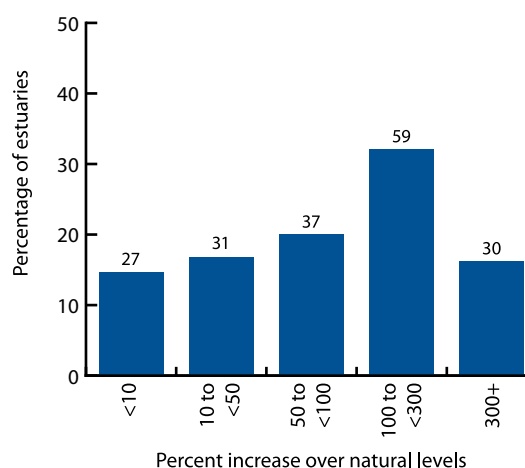
Riparian zones are the areas directly adjacent to a waterway, often referred to as 'foreshores' in estuaries. Disturbance within this zone is of particular interest as riparian vegetation acts as a barrier or filter to protect the water body and minimise erosion. Pressures originating in this area are likely to have a more direct impact on estuary condition than the same pressure acting further away.

**Figure 4.16: Modelled loads of total suspended solids and nutrients to NSW estuaries**

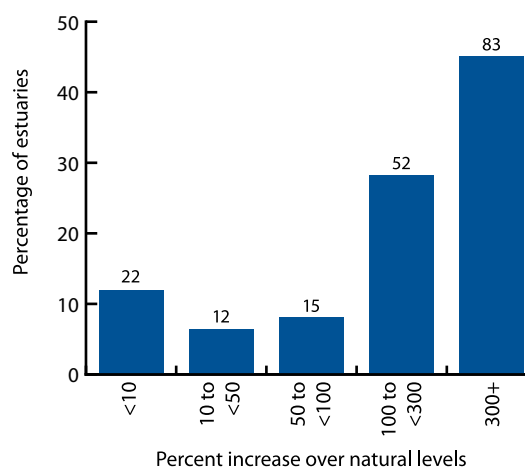
#### Total suspended solids



#### Total nitrogen



#### Total phosphorus



Source: Roper et al. 2011

Notes: The data covers 184 estuaries and the values shown above the bars in the graphs are the number of estuaries in each increase category.

The riparian zones around each of the 184 estuaries in NSW have been mapped. These cover the area that is within 100 metres of the waterway and less than 0.6 m above mean sea level, an area that generally defines the outer edge of seagrass, mangrove or saltmarsh communities. Within this zone, land-use mapping identifies the areas of disturbance based on the same land-use classes used to determine catchment disturbance and diffuse nutrient and sediment loads (Roper et al. 2011).

Similar to the patterns of disturbance within the estuary catchments, 11% of estuaries have riparian zones with little or no disturbance and a further 9% have disturbance levels of less than 10% (Figure 4.17). Around 11% of estuaries have experienced disturbance to 80% or more of their riparian zone, a similar proportion to estuaries with the same level of disturbance throughout the whole catchment.

## Waterway disturbance

Change in estuarine habitats, water quality and estuarine processes can also occur as the result of disturbance directly to the waterway itself, including:

- the removal of vegetation
- competition from introduced species

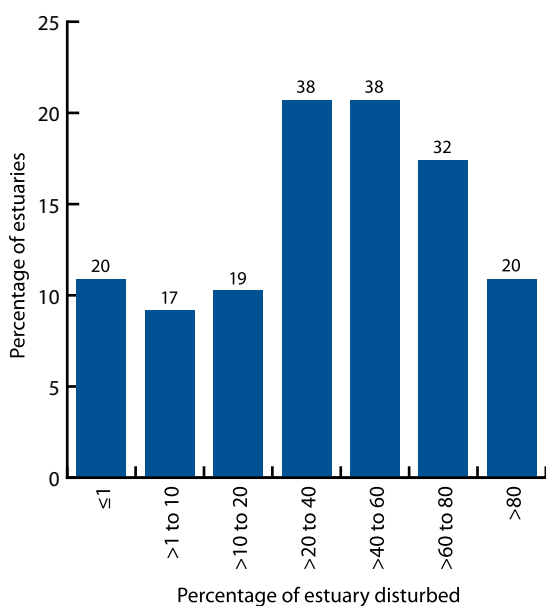
- the building of structures, such as marinas, boat ramps, foreshore reclamation, hard erosion control structures, weirs, training walls and artificial entrance openings
- activities such as fishing, trawling and aquaculture.

One measure of direct waterway disturbance is the percentage of the estuary perimeter that is occupied by foreshore structures on Crown land above or below the mean high water mark. Structures include buildings, jetties and wharves, boat ramps, foreshore reclamation and seawalls. Another measure is the percentage of estuary area leased for waterway-based aquaculture, such as oyster and mussel farming. The levels of these disturbances in NSW estuaries are shown in Figure 4.17.

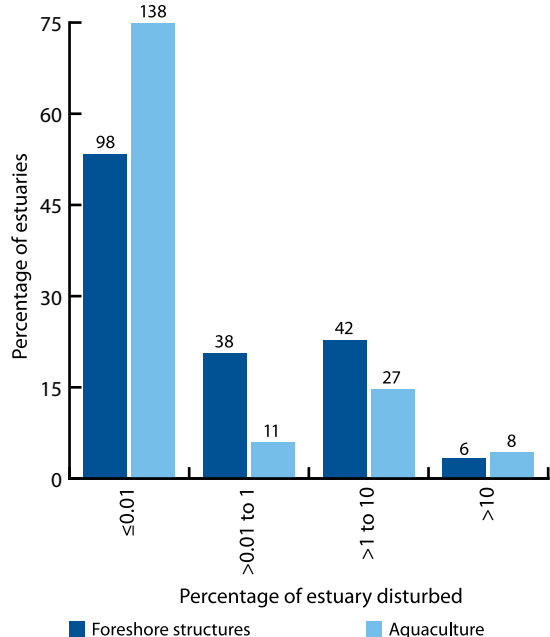
Just over 50% of estuaries have few, if any, foreshore structures and 75% of estuaries contain no aquaculture leases. Estuaries in the metropolitan area with higher percentages of their perimeters occupied by foreshore leases tend to be waterways with a proliferation of boating infrastructure associated with urban development. As such, these estuaries are generally subject to catchment, riparian and waterway pressures and determining the dominant pressures influencing their condition can be difficult.

**Figure 4.17: Levels of disturbance to riparian vegetation and waterways in NSW estuaries**

### Riparian disturbance



### Waterway disturbance



Source: OEH data 2012

Notes: The data covers 184 estuaries and the values shown above the bars in the graphs are the number of estuaries in each disturbance category.

Estuaries with over 10% of their waterway area occupied by aquaculture leases are all located on the south coast of NSW in waterways that are generally in good condition, have moderate to low levels of catchment development and consistent patterns of tidal variation, all conditions that favour a productive aquaculture industry.

## Climate change

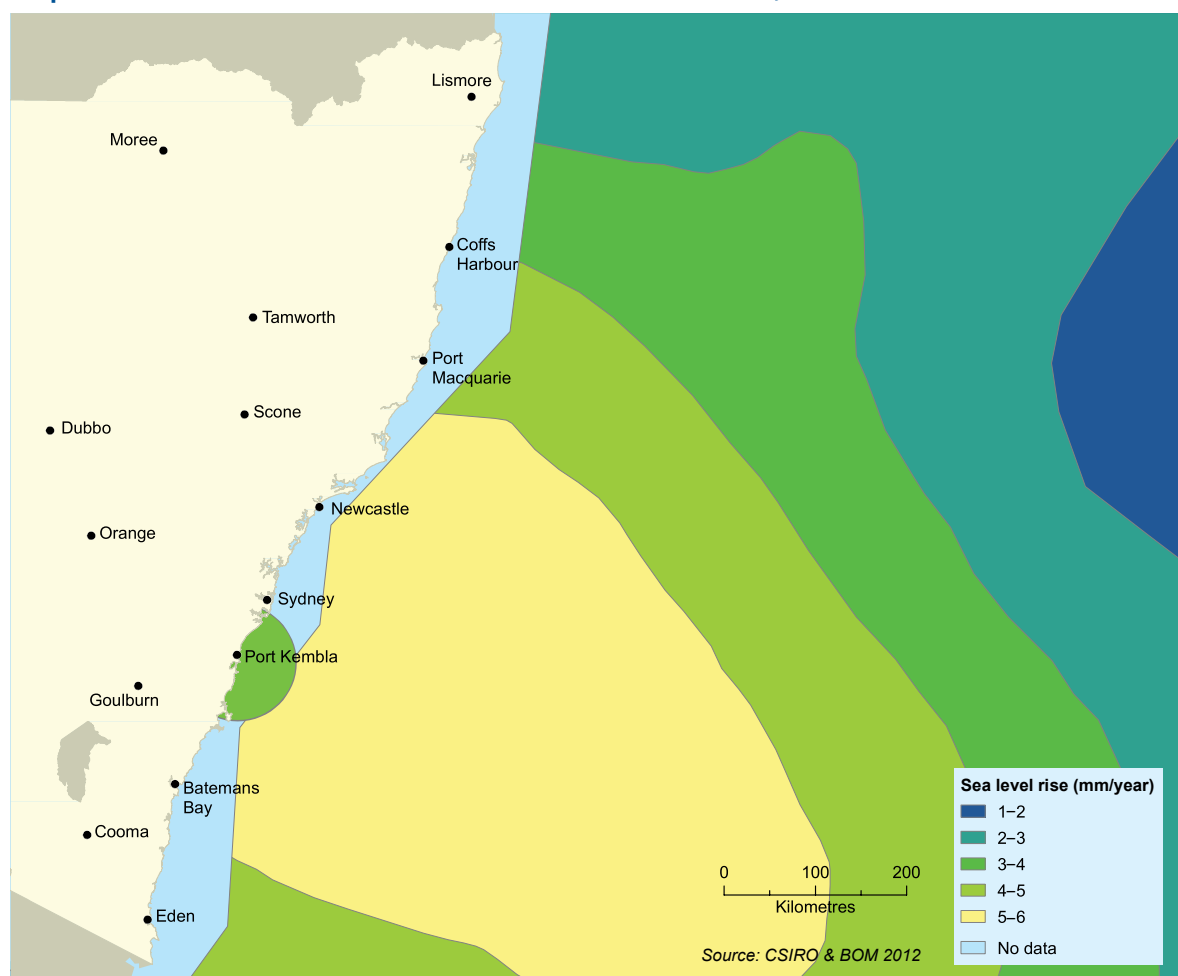
Variations in climate and sea level are inextricably linked (BoM 2011b). Warming temperatures lead to sea level rise for two main reasons: water expands as it warms and, as average temperatures rise, the polar ice sheets begin to melt (IPCC 2007). Sea level rise is not uniform around the world or in Australia as climatic cycles such as El Niño-Southern Oscillation and the Indian Ocean Dipole create further variations that can mask or enhance changes due to global warming.


Such variations will only become evident over the longer term and it is not possible to identify changes

over a relatively short time frame such as the three-year cycle of SoE reporting. Since 1993, sea levels around Australia have risen 7–10 millimetres per year in the north and west and about 4 mm per year in the south and east. Off the east coast of NSW, warm water currents have elevated sea levels by about 6 mm per year as demonstrated by tidal gauge readings from Port Kembla shown in **Map 4.9** (CSIRO & BoM 2012).


Sea level rise is virtually certain to increase tidal levels, enlarging the areas of low-lying land near coastal waterways that are exposed to more frequent tidal inundation (DECCW 2010b). Due to the combined influence of sea level rise and higher rainfall events, the frequency, height and extent of floods are expected to increase in the lower parts of coastal floodplains (DECCW 2010b). With 63% of the NSW population living in Sydney – a coastal city – and a further 20% living in the non-metropolitan coastal strip (ABS 2012), rising sea levels are likely to have a significant effect on human settlements in coastal NSW.

**Map 4.9: Sea level rise between 1993 and 2011 at Port Kembla, NSW**






Most coastal dunes and some beach-barrier systems and estuaries are expected to be affected by an increased threat of erosion from a combination of sea level rise, changes in wave direction, and greater storm intensity. A number of sites along the NSW coast have already experienced heightened coastal erosion (DECCW 2010b).




The effect of rising sea levels on natural systems is demonstrated by mangrove swamps encroaching on areas previously occupied by saltmarsh. In 70% of estuaries surveyed in Queensland, NSW, Victoria and South Australia, the area of saltmarsh taken over by mangroves has been greater than 30% and in some cases mangroves have completely replaced saltmarsh. This change has largely been attributed to subsidence and sea level rise (Saintilan & Williams 1999; Saintilan & Williams 2000; Rogers et al. 2006). As water levels rise, the ability of some communities, such as saltmarsh, to colonise new areas at more suitable elevations may be impeded by the presence of coastal development (Goudkamp & Chin 2006).


## Other pressures



A range of other pressures also affect waterway health, but their cumulative impact is more difficult to measure or assess. Tidal flows may be affected by rock training walls designed to keep estuary entrances open, the artificial opening of lagoon entrances to alleviate flooding, and other flood mitigation structures. Changes to hydrology and flows can have a significant impact on water and salinity levels and the distribution and composition of estuarine ecosystems.



Changes in the volume of freshwater flows entering estuaries can arise from upstream water storages, extraction of water for agriculture, and barriers such as weirs. A reduction in freshwater flows to estuaries can influence the location of the tidal limit and the salinity profile, as well as affect the distribution and composition of ecosystems.



Commercial and recreational fishing place pressures on the fisheries they target as well as the broader estuarine environment. Impacts from fishing and trawling can include damage to habitat, bycatch, waste and infrastructure pressures.

## Responses

### Established responses

Management of the NSW coastal zone is the responsibility of all levels of government. The expected growth in population in coastal areas is likely to increase the importance of integrated coastal zone management and strategies that enable communities to adapt to changing environmental conditions.

Local government plays a key role in protecting the health of estuarine ecosystems through a variety of mechanisms including land-use and strategic planning, development controls and a range of policies affecting water utilities and water quality management, including sewage and stormwater management strategies and estuary management plans.

### NSW 2021

*NSW 2021: A plan to make NSW number one* (NSW Government 2011) is the Government's 10-year plan for NSW. Under Goal 22 – 'Protect our natural environment', the plan contains the following target: 'Protect rivers, wetlands and coastal environments'. Further details on Goal 22 are provided in Water 4.1.

### Legislation

The NSW *Environmental Planning and Assessment Act 1979* sets the framework for land-use planning decisions. The *Coastal Protection Act 1979* and *NSW Coastal Policy 1997* (NSW Government 1997) provide the strategic direction and legislative framework for managing the NSW coastal zone, including the requirement for coastal zone management plans and the matters these plans should consider. Mangroves and seagrass habitats are protected under the *Fisheries Management Act 1994*.

### State environmental planning policies

State environmental planning policies (SEPPs) address specific planning issues in NSW.

*State Environmental Planning Policy No. 71 – Coastal Protection* ensures that:

- development in the NSW coastal zone is appropriate and suitably located
- there is a consistent and strategic approach to coastal planning and management
- there is a clear framework for assessing development in the coastal zone.

*State Environmental Planning Policy No. 14 – Coastal Wetlands* ensures that coastal wetlands are preserved and protected for environmental and economic reasons. The policy applies to coastal local government areas outside the Sydney metropolitan area and identifies over 1300 wetlands of high natural value from Tweed Heads to Broken Bay and Wollongong to Cape Howe. All land clearing, construction of levees, and drainage work or filling within wetland boundaries requires consent and the preparation of an environmental impact statement.

Other SEPPs relevant to coastal development include:

- *State Environmental Planning Policy No. 26 – Littoral Rainforests*
- *State Environmental Planning Policy No. 50 – Canal Estate Development*
- *State Environmental Planning Policy No. 62 – Sustainable Aquaculture.*

### Review of coastal protection and NSW Sea Level Rise Policy

A Coastal Ministerial Taskforce has been established to review coastal protection arrangements. Stage 1 coastal reforms were announced in October 2012. These included the removal of sea level rise benchmarks, which will no longer apply to coastal zone planning in NSW. Further developments will be announced in stage 2 of the reforms.

### Coastal zone and estuary management plans

The *Guidelines for Preparing Coastal Zone Management Plans* (DECCW 2010f) provide advice to local councils, their consultants and coastal communities on the preparation of Coastal Zone Management Plans. The primary purpose of these plans is to address priority management issues in the coastal zone including:

- managing risks to public safety and built assets
- pressures on coastal ecosystems
- community uses of the coastal zone.

Plans for estuaries should include:

- a description of the condition of estuaries within the plan's area
- details of the pressures affecting estuary condition and their relative magnitude
- proposed actions to respond to pressures on estuary condition
- an entrance management strategy for intermittently closed and open lakes and lagoons
- an estuarine monitoring program consistent with the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d).

Coastal zone and estuary management plans are being prepared and implemented by local councils for over 90 estuaries in order to achieve integrated, balanced and ecologically sustainable management.

### Regional strategies

Regional strategies are in place for six coastal areas of regional NSW: Central Coast, Lower Hunter, Far North Coast, Mid North Coast, Illawarra and South Coast.

The strategies set a strategic direction for these rapidly growing coastal regions on issues including management of the high rates of population growth in a sustainable manner, while protecting valuable natural and cultural assets. The strategies require local environmental plans to protect and zone lands with aquatic, riparian and wetland conservation values.

### Catchment action plans

Catchment action plans are developed by catchment management authorities and represent the key process that coordinates and drives natural resource management at the regional level. The plans describe the approaches to be adopted for addressing statewide targets at the regional scale and also specify the regional targets and the programs of investments and works that are needed to deliver outcomes at the regional and local levels.


### Management of water quality

The main responses aimed specifically at improving estuarine water quality by reducing pollution include:


- planning strategies covering land use and catchment management, which set water quality objectives
- licensing or management of pollution from major point sources
- works to manage stormwater and diffuse runoff
- programs to prevent and manage pollution incidents
- tools to assist in managing estuaries.

The Coastal Catchments Initiative is the Australian Government's primary vehicle to deliver significant reductions in the discharge of pollutants to 'hot spots' identified through agreement with relevant state jurisdictions. The Great Lakes (Wallis, Smiths and Myall Lakes) and Botany Bay have been identified as hot spots in NSW. Implementation of the initiative included the preparation of water quality improvement plans for hot spots to guide investment in water quality projects.





NSW Water Quality Objectives set out the agreed environmental values and long-term goals for NSW surface waters. The objectives are consistent with the agreed national framework for assessing water quality described in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000). They set out a range of water quality indicators and criteria to determine whether water quality in estuaries and coastal lakes is able to support healthy ecosystems and a range of beneficial uses, including recreational activities. Consistent with the Water Quality Objectives and the process recommended in the ANZECC Water Quality Guidelines, the NSW Natural Resources Monitoring, Evaluation and Reporting Strategy (DECCW 2010d) provides further advice on estuarine water quality indicators and monitoring and has derived a number of water quality trigger values that can be used in lieu of the default values provided.



The *NSW Diffuse Source Water Pollution Strategy* (DECC 2009) recognises that diffuse source pollution accounts for the majority of the pollution load in NSW waterways. The strategy aims to coordinate the NSW Government's approach to the management of diffuse water pollution and identifies a list of actions to be implemented.



## Future opportunities

The strong preference of many Australians to live near the coast means that it is likely that pressures on the NSW coastal zone will continue to grow, due to expanding population and development.

The poor condition of water quality in some highly urbanised estuaries suggests that stormwater runoff and new urban development can be managed better in order to maintain the health of estuaries and coastal lakes and the desirability of coastal lifestyles.

Due to a lack of consistent and reliable data, there are still many uncertainties in assessing the status of estuaries and coastal lakes and any related trends.

Susceptibility to inundation and coastal erosion should be a significant consideration in the location and planning of all future settlements in catering for an expanding population and development needs.

# References

- ABS 2006, *Water Account Australia 2004–05*, catalogue no. 4610.0, Australian Bureau of Statistics, Canberra [www.abs.gov.au/Ausstats/abs@nsf/mf/4610.0]
- ABS 2010, *Water Account Australia 2008–09*, catalogue no. 4610.0, Australian Bureau of Statistics, Canberra [www.abs.gov.au/Ausstats/abs@nsf/mf/4610.0]
- ABS 2012, *Regional Population Growth, Australia, 2011*, catalogue no. 3218.0, Australian Bureau of Statistics, Canberra [www.abs.gov.au/AUSSTATS/abs@nsf/mf/3218.0]
- Adam, P. 2002, 'Saltmarshes in a time of change', *Environmental Conservation*, 29(1), pp.39–61 [dx.doi.org/10.1017/S0376892902000048]
- Adam, P. & Stricker, J. 1993, 'Wetlands of the Sydney Region', National Estates Grants Program, Project no.51, unpublished report by the Nature Council of NSW, Sydney
- ANZECC & ARMCANZ 1994, *National Water Quality Management Strategy*, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra [www.environment.gov.au/water/publications/quality/nwqms-outline-of-policies.html]
- ANZECC & ARMCANZ 2000, *Australian and New Zealand Guidelines for Fresh and Marine Water Quality*, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra [www.environment.gov.au/water/publications/quality/nwqms-guidelines-4-vol1.html]
- Armstrong, J.L, Kingsford, R.T. & Jenkins, K.M. 2009, *The Effect of Regulating the Lachlan River on the Booligal Wetlands: The floodplain red gum swamps*, Wetlands & Rivers, School of Earth & Environmental Sciences, University of NSW, Sydney [www.wetrivers.unsw.edu.au/wp-content/uploads/2010/11/Booligal\_Lachlan\_River\_Report.pdf]
- ASoEC 2011, *Australia State of the Environment 2011*, an independent report to the Australian Minister for Sustainability, Environment, Water, Population and Communities by the Australian State of the Environment Committee, Canberra [www.environment.gov.au/soe/2011/index.html]
- Astles, K.L., Winstanley, J.H., Harris, J.H. & Gehrke, P.C. 2004, *Regulated Rivers and Fisheries Restoration Project: Experimental study of the effects of cold water pollution on native fish*, Fisheries Final Report Series No. 44, NSW Department of Primary Industries, Cronulla [www.dpi.nsw.gov.au/\_\_\_data/assets/pdf\_file/0003/137478/output-317.pdf]
- Baldwin, D.S., Nielsen, D.L., Bowen, P.M. & Williams, J. 2005, *Recommended Methods for Monitoring Floodplains and Wetlands*, Murray–Darling Basin Commission, Canberra [download.mdba.gov.au/archived/mbc-tlm-reports/2\_Recommended\_methods\_monitoring\_floodplains\_wetlands.pdf]
- Beeton, R.J.S., Buxton, C.D., Cutbush, G.C., Fairweather, P.G., Johnston, E.L. & Ryan, R. 2012, *Report of the Independent Scientific Audit of Marine Parks in New South Wales*, NSW Department of Primary Industries and NSW Office of Environment and Heritage, Sydney [www.marineparksaudit.nsw.gov.au/audit-report]
- BoM 2011a, *Annual Australian Climate Statement*, Australian Bureau of Meteorology, Canberra [www.bom.gov.au/announcements/media\_releases/climate/change/20120104.shtml]
- BoM 2011b, *The Australian Baseline Sea Level Monitoring Project: Annual sea level data summary report July 2010–June 2011*, National Tidal Data Centre, Australian Bureau of Meteorology, Canberra [www.bom.gov.au/ntc/IDO60202/IDO60202.2011.pdf]
- Bowen, S. & Simpson, S.L. 2010a, *Changes in Extent and Condition of the Vegetation Communities of the Gwydir Wetlands and Floodplain 1996–2008: Final report to the NSW Wetland Recovery Program*, Department of Environment, Climate Change and Water NSW, Sydney
- Bowen, S. & Simpson, S.L. 2010b, *Changes in Extent and Condition of the Vegetation Communities of the Macquarie Marshes Floodplain 1991–2008: Final report to the NSW Wetland Recovery Program*, Department of Environment, Climate Change and Water NSW, Sydney
- Bowen, S., Powell, M., Cox, S.J., Simpson, S.L. & Childs, P. 2011, *Riverina Red Gum Reserves Mapping Program: Stage 1*, NSW Office of Environment and Heritage, Sydney



Brierley, G.J. & Fryirs, K.A. 2005, *Geomorphology and River Management: Applications of the river styles framework*, Blackwell Publications, Oxford, UK

Brock, M.A., Smith, R.G.B. & Jarman, P.J. 1999, 'Drain it, dam it: alteration of water regime in shallow wetlands on the New England Tableland of New South Wales, Australia', *Wetlands Ecology and Management*, 7(1–2), pp.37–46 [dx.doi.org/10.1023/A:1008416925403]

Burnett, W.L., Bokuniewicz, H., Huettel, M., Moore, W.S., & Taniguchi, M. 2003, 'Groundwater and pore water inputs to the coastal zone', *Biogeochemistry*, 66(1–2), pp.3–33 [dx.doi.org/10.1023/B:BIOG.0000006066.21240.53]

Capon, S., Reid, M., Thoms, M. & Parsons, M. 2008, *Ecological Character Description of Lower Lachlan Floodplain Wetlands*, report to NSW Department of Environment and Climate Change by Riverine Landscapes Laboratory, University of Canberra [www.lachlan.cma.nsw.gov.au/downloads/Reports/Uni\_of\_Canberra\_2008.pdf]

Climate Commission 2011, *The Critical Decade: Illawarra/NSW South Coast Impacts*, Canberra [climatecommission.gov.au/wp-content/uploads/4246-CC-Wollongong-Key-Messages\_web.pdf]

Creese, R.G., Glasby, T.M., West, G. & Gallen, C. 2009 *Mapping the Habitats of NSW Estuaries*, Fisheries Final Report Series 113, Industry & Investment NSW, Department of Primary Industries, Port Stephens [www.dpi.nsw.gov.au/research/areas/aquatic-ecosystems/outputs/2009/1575]

CSIRO 2008a, *Water Availability in the Murray–Darling Basin: A report to the Australian Government from the CSIRO Murray–Darling Basin Sustainable Yields Project*, Commonwealth Scientific and Industrial Research Organisation, Canberra [www.csiro.au/files/files/po0n.pdf]

CSIRO 2008b, *Water Availability in the Macquarie–Castlereagh: A report to the Australian Government from the CSIRO Murray–Darling Basin Sustainable Yields Project*, Commonwealth Scientific and Industrial Research Organisation, Canberra [www.csiro.au/files/files/pj7z.pdf]

CSIRO 2008c, *Water Availability in the Lachlan: A report to the Australian Government from the CSIRO Murray–Darling Basin Sustainable Yields Project*, Commonwealth Scientific and Industrial Research Organisation, Canberra [www.csiro.au/files/files/pj81.pdf]

CSIRO & BoM 2010, *State of the Climate*, CSIRO and Australian Bureau of Meteorology, Canberra [www.bom.gov.au/inside/eiab/State-of-climate-2010-updated.pdf]

CSIRO & BoM 2012, *State of the Climate 2012*, CSIRO and Australian Bureau of Meteorology, Canberra [www.bom.gov.au/announcements/media\_releases/ho/stateClimate2012.pdf]

Cunningham, S.C., MacNally, R., Griffioen, P. & White, M. 2009, *Mapping the Condition of River Red Gum and Black Box Stands in The Living Murray Icon Sites*, report to the Murray–Darling Basin Authority, Canberra [www.mdba.gov.au/services/publications/more-information?publicationid=57]

Davies, P.E., Stewardson, M.J., Hillman, T.J., Roberts, J.R. & Thoms, M.C. 2012, *Sustainable Rivers Audit: A report on the ecological health of rivers in the Murray–Darling Basin 2008–2010*, Report 2, Vol. 1-3, Murray–Darling Basin Authority, Canberra

DEC 2005, *Marine Water Quality Objectives for NSW Ocean Waters*, Department of Environment and Conservation NSW, Sydney [www.environment.nsw.gov.au/water/mwqo/index.htm]

DECC 2008, *NSW National Parks Establishment Plan 2008*, Department of Environment and Climate Change NSW, Sydney [www.environment.nsw.gov.au/resources/protectedareas/0852npestplan.pdf]

DECC 2009, *NSW Diffuse Source Water Pollution Strategy*, Department of Environment and Climate Change NSW, Sydney [www.environment.nsw.gov.au/resources/water/09085dswp.pdf]

DECCW 2009, *New South Wales State of the Environment 2009*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/soe/soe2009]

DECCW 2010a, *Macquarie Marshes Adaptive Environmental Management Plan*, Department of Environment, Climate Change and Water NSW, Sydney [www.wetlandrecovery.nsw.gov.au/download/10224MacquarieMarshAEMP.pdf]

DECCW 2010b, *NSW Climate Impact Profile*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/resources/climatechange/10171climateimpactprof.pdf]

DECCW 2010c, *NSW Wetlands Policy*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/wetlands/nswwetlandspolicy.htm]

DECCW 2010d, *NSW Natural Resources Monitoring, Evaluation and Reporting Strategy 2010–2015*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/resources/soc/10977nrmmerstrat1015.pdf]

DECCW 2010e, *NSW State of the Catchments Reports*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/soc/stateofthecatchmentsreport.htm]

DECCW 2010f, *Guidelines for Preparing Coastal Zone Management Plans*, Department of Environment, Climate Change and Water NSW, Sydney [www.environment.nsw.gov.au/resources/coasts/101019GdlinsCZMPs.pdf]

DEH 2003, *Harmful Marine Debris: Key threatening processes information sheet*, Department of the Environment and Heritage, Canberra [www.environment.gov.au/biodiversity/threatened/publications/marine-debris.html]

DEH 2005, *Frequency of Algal Blooms in Estuarine, Coastal and Marine Waters*, Department of the Environment and Heritage, Canberra [www.nrm.gov.au/publications/factsheets/me-indicators/estuarine/pubs/algae.pdf]

DLWC 2000, *Hunter, Karuah, Manning: State of the Rivers and Estuaries Report 2000*, NSW Department of Land and Water Conservation, Sydney

DLWC 2002, *The NSW State Groundwater Dependent Ecosystems Policy*, Department of Land and Water Conservation, Sydney [www.water.nsw.gov.au/ArticleDocuments/34/groundwater\_dependent\_ecosystem\_policy\_300402.pdf.aspx]

DNR 2000, *Condamine–Balonne WAMP Environmental Flows Technical Report*, Queensland Department of Natural Resources, Brisbane

DPI 1997, *Fish Habitat Protection Plan No. 2: Seagrasses*, NSW Fisheries, Department of Primary Industries, Cronulla [www.dpi.nsw.gov.au/\_\_\_data/assets/pdf\_file/0019/202744/Fish-habitat-protection-plan-2--Seagrass.pdf]

DPI 2004, *Environmental Impact Statement on the Ocean Trawl Fishery in NSW: Public consultation document*, Department of Primary Industries, Cronulla [www.dpi.nsw.gov.au/fisheries/commercial/ea/eis/otf-eis]

DPI 2012, *NSW Aquifer Interference Policy*, NSW Department of Primary Industries, Sydney [www.water.nsw.gov.au/Water-management/Law-and-policy/Key-policies/Aquifer-interference/Aquifer-interference]

Eamus, D. & Freund, R. 2006, 'Groundwater-dependent ecosystems: the where, what and why of GDEs', *Australian Journal of Botany*, 54(2), pp.91–96 [dx.doi.org/10.1071/BT06029]

Eamus, D., Freund, R., Loomes, R., Murray, B.R. & Hose, G.S. 2006, 'A functional methodology for determining the groundwater regime needed to maintain health of groundwater-dependent vegetation', *Australian Journal of Botany* 54(2), pp.97–114 [dx.doi.org/10.1071/BT05031]

Evans, R. 2007, *The Effect of Groundwater Use on Australia, Technical Report*, Land and Water Australia, Canberra [lwa.gov.au/products/pr071283]

Fabry, V.J., Seibel, B.A., Feely, R.A. & Orr, J.C. 2008, 'Impacts of ocean acidification on marine fauna and ecosystem processes', *ICES Journal of Marine Science*, 65, pp.414–32 [dx.doi.org/10.1093/icesjms/fsn048]

Finlayson, C.M. & Rea, N. 1999, 'Reasons for the loss and degradation of Australian wetlands', *Wetland Ecology and Management*, 7(1), pp.1–11 [dx.doi.org/10.1023/A:1008495619951]


GECAOAC 2011, *Gwydir Environmental Watering Annual Report: 2010/2011 Water Year*, Gwydir Environmental Contingency Allowance Operations Advisory Committee, Gwydir Catchment Management Authority, Inverell [brg.cma.nsw.gov.au/uploads/ECA/GwydirECAOACAnnualReport2010-2011.pdf]

Gibert, J., Danielopol, D. & Stanford, J.A. (eds) 1994, *Groundwater Ecology*, Academic Press, San Diego, USA

Goudkamp, K. & Chin, A. 2006, 'Mangroves and saltmarshes' in Chin, A. (ed.), *The State of the Great Barrier Reef On-line*, Great Barrier Reef Marine Park Authority, Townsville [www.gbrmpa.gov.au/\_\_\_data/assets/pdf\_file/0020/3971/SORR\_Mangroves\_Saltmarshes.pdf]

Guinotte, J.M. & Fabry, V.J. 2008, 'Ocean acidification and its potential effects on marine ecosystems', *Annals of the New York Academy of Sciences*, 1134, pp.320–42 [dx.doi.org/10.1196/annals.1439.013]






Hall, K., Baldwin, D.S., Rees, G.N. & Richardson, A. 2006, *Distribution of Sulfidic Sediments in Inland Wetlands of NSW*, Murray–Darling Freshwater Research Centre, Wodonga


Hardwick, L. 2011, 'Murrumbidgee black water monitoring: preliminary report to March 2011, unpublished report, NSW Office of Water, Sydney

Hatton, T. & Evans, R. 1998, *Dependence of Ecosystems on Groundwater and its Significance to Australia*, Occasional Paper No. 12/98, Land and Water Resources Research and Development Corporation, CSIRO Australia [lwa.gov.au/products/pr980270]



Hobday, A.J. & Lough, J.M. 2011, 'Projected climate change in Australian marine and freshwater environments', *Marine and Freshwater Research*, 62(9), pp.1000–14 [dx.doi.org/10.1071/MF10302]


Hobday, A.J., Okey, T.A., Poloczanska, E.S., Kunz, T.J. & Richardson, A.J. (eds) 2006, *Impacts of Climate Change on Australian Marine Life: Part B Technical Report*, report to the Australian Greenhouse Office, Canberra [eprints.utas.edu.au/2534]



IPCC 2007, *Climate Change 2007: Synthesis Report*, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Core Writing Team, Pachauri, R.K & Reisinger, A. (eds.)], IPCC, Geneva, Switzerland, 104 pp. [www.ipcc.ch/publications\_and\_data/publications\_ipcc\_fourth\_assessment\_report\_synthesis\_report.htm]

Jankowski, J. & Knights, P. 2010, 'Surface water-groundwater interaction in the fractured sandstone aquifer impacted by mining-induced subsidence: 1. Hydrology and hydrogeology', *Proceedings of the International Association of Hydrogeologists Symposium*, Krakow, Poland, 441, pp.33–42

Keith, D. 2004, *Ocean Shores to Desert Dunes: The native vegetation of New South Wales and the ACT*, Department of Environment and Conservation NSW, Sydney [www.environment.nsw.gov.au/publications/ostdd.htm]



Kelleway, J., Williams, R.J. & Allen, C.B. 2007, *An Assessment of the Saltmarsh of the Parramatta River and Sydney Harbour*, final report to NSW Maritime Authority, Fisheries Final Report Series No. 90, Department of Primary Industries, Orange [www.dpi.nsw.gov.au/research/areas/aquatic-ecosystems/outputs/2007/848]

Keyte, P.A. 1994, *Lower Gwydir Wetland Plan of Management: 1994 to 1997*, prepared by NSW Department of Water Resources for the Lower Gwydir Wetland Steering Committee, Sydney

Kingsford, R.T. 1999, 'Managing the water of the Border Rivers in Australia: irrigation, government and the wetland environment', *Wetlands Ecology and Management*, 7(1–2), pp.25–35 [dx.doi.org/10.1023/A:1008452423586]

Kingsford, R.T. 2003, 'Social, institutional and economic drivers for water resource development: a case study of the Murrumbidgee River, Australia', *Aquatic Ecosystem Health and Management*, 6(1), pp.69–79 [dx.doi.org/10.1080/14634980301480]


Kingsford, R.T. & Auld, K.M. 2005, 'Waterbird breeding and environmental flow management in the Macquarie Marshes, arid Australia', *River Research and Applications*, 21(2–3), pp.187–200 [dx.doi.org/10.1002/rra.840]

Kingsford, R.T. & Johnson, W. 1998, 'Impact of water diversions on colonially nesting waterbirds in the Macquarie Marshes in arid Australia', *Colonial Waterbirds*, 21(2), pp.159–70 [www.jstor.org/stable/1521903]

Kingsford, R.T. & Thomas, R.F. 1995, 'The Macquarie Marshes in arid Australia and their waterbirds: a 50-year history of decline', *Environmental Management*, 19(6), pp.867–78 [dx.doi.org/10.1007/BF02471938]

Kingsford, R.T. & Thomas, R.F. 2001, *Changing Water Regimes and Wetland Habitat on the Lower Murrumbidgee Floodplain of the Murrumbidgee River in Arid Australia*, report to Environment Australia, NSW National Parks and Wildlife Service, Sydney [www.environment.nsw.gov.au/resources/water/lowerMurrumbidgeeReport.pdf]

Kingsford, R.T. & Thomas, R.F. 2004, 'Destruction of wetlands and waterbird populations by dams and irrigation on the Murrumbidgee River in arid Australia', *Environmental Management*, 34(3), pp.383–96 [dx.doi.org/10.1007/s00267-004-0250-3]



Kingsford, R.T., Brandis, K., Thomas, R.F., Crighton, P., Knowles, E. & Gale, E. 2004, 'Classifying landform at broad spatial scales: the distribution and classification of wetlands in New South Wales, Australia', *Marine and Freshwater Research*, 55, pp.17–31 [www.publish.csiro.au/?act=view\_file&file\_id=MF03075.pdf]

- Kingsford, R.T., Dunn, H., Love, D., Nevill, J., Stein, J. & Tait, J. 2005, *Protecting Australia's Rivers, Wetlands and Estuaries*, Department of the Environment and Heritage, Canberra [www.environment.gov.au/water/publications/environmental/pubs/protecting-rivers.pdf]
- Last, P.R., White, W.T., Gledhill, D.C., Hobday, A.J., Brown, R., Edgar, G.J. & Pecl, G. 2010, 'Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices', *Global Ecology and Biogeography*, 20(1), pp.58–72 [dx.doi.org/10.1111/j.1466-8238.2010.00575.x]
- Ling, S.D., Johnson, C.R. & Ridgway, K. 2009, 'Climate-driven range extension of a sea urchin: inferring future trends by analysis of recent population dynamics', *Global Change Biology*, 15(3), pp.719–31 [dx.doi.org/10.1111/j.1365-2486.2008.01734.x]
- Mawhinney, W.A. 2003, 'Restoring biodiversity in the Gwydir Wetlands through environmental flows', *Water Science and Technology*, 48(7), pp.73–81 [www.iwaponline.com/wst/04807/wst048070073.htm]
- McNeil, B.I. & Matear, R.J. 2007, 'Climate change feedback on oceanic pH', *Tellus-B*, 59B, pp.191–98 [dx.doi.org/10.1111/j.1600-0889.2006.00241.x]
- MDBA 2010, *Assessing Environmental Water Requirements: Chapter 2 Narran Lakes*, prepared as part of the *Guide to the Basin Plan*, Murray–Darling Basin Authority, Canberra [download.mdba.gov.au/2010-HIS-report-02-narran.pdf]
- MDBA 2012, *Proposed Basin Plan: A revised draft*, Murray–Darling Basin Authority, Canberra [www.mdba.gov.au/proposed-basin-plan/proposed-basin-plan-revised]
- MDBC 2003, *Macroinvertebrate Theme Summary Pilot Audit Technical Report*, Murray–Darling Basin Commission, Canberra [www2.mdbc.gov.au/\_\_\_data/page/64/summary\_macroinvert\_theme.pdf]
- MDBC 2006, *Native Fish Strategy: Annual implementation report 2005–2006*, Murray–Darling Basin Commission, Canberra [www.mdbc.gov.au/subs/fish-info/NFS\_Annual\_implementation\_report2005-06/index.htm]
- MDBC 2008a, *Murray–Darling Basin Rivers: Ecosystem health check – 2004–2007*, report by the Murray–Darling Basin Commission to the Murray–Darling Basin Ministerial Council, Canberra [www2.mdbc.gov.au/\_\_\_data/page/2260/34373\_MDBC\_SRA\_Report\_Web.pdf]
- MDBC 2008b, *Narran Ecosystem Project: The response of a terminal wetland system to variable wetting and drying, final report to the Murray–Darling Basin Commission*, Canberra [www2.mdbc.gov.au/\_\_\_data/page/15/MDBC\_12800\_Narran\_Ecosystem\_sm.pdf]
- MDBMC 2003, *Native Fish Strategy for the Murray–Darling Basin 2003–2013*, Murray–Darling Basin Ministerial Council, Murray–Darling Basin Commission, Canberra [www2.mdbc.gov.au/\_\_\_data/page/65/Fish-Strat\_ful.pdf]
- NBSRTG 2009, *Australia's Biodiversity Conservation Strategy 2010–2020: Consultation draft*, National Biodiversity Strategy Review Task Group, Department of the Environment, Water, Heritage and the Arts, Canberra [www.environment.gov.au/biodiversity/strategy/pubs/biodiversity-conservation-strategy2010-2020.pdf]
- Nevill, J. 2004, *Assessing the Effects of Freshwater Protected Areas*, OnlyOnePlanet, Hampton, Melbourne
- NHMRC 2008, *Guidelines for Managing Risks in Recreational Water*, National Health and Medical Research Council, Canberra [www.nhmrc.gov.au/guidelines/publications/eh38]
- NLWRA 2002, *Australian Catchment, River and Estuary Assessment 2002: Volume 1*, National Land and Water Resources Audit, Canberra [www.anra.gov.au/topics/coasts/pubs/estuary\_assessment/est\_ass\_introduction.html]
- NOW 2010, *NSW Floodplain Harvesting Policy: Draft for community consultation*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Law-and-policy/Key-policies/Floodplain-harvesting/Floodplain-harvesting/default.aspx]
- NOW 2011, *NSW Cold Water Pollution Strategy: Guidelines for managing cold water releases from high priority dams*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Water-quality/Temperature/Temperature/default.aspx]
- NOW 2012, *NSW Cold Water Pollution Strategy: Report on the implementation of stage I*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Water-quality/Temperature/Temperature/default.aspx]
- NSW Government 1997, *NSW Coastal Policy 1997: A sustainable future for the New South Wales coast*, Sydney [www.planning.nsw.gov.au/plansforaction/pdf/PPARTA.PDF]
- NSW Government 2001, *Developing a Representative System of Marine Protected Areas in NSW: An overview*, Marine Parks Authority, Sydney [www.mpa.nsw.gov.au/pdf/developing-representative-mpa.pdf]



NSW Government 2011, *NSW 2021: A plan to make NSW number one*, Sydney [www.2021.nsw.gov.au]

NSW Government 2012a, *NSW 2021 Performance Report 2012–13*, Sydney [2021.nsw.gov.au/sites/default/files/pdf/NSW\_2021\_Performance\_Report\_2012-13.pdf]

NSW Government 2012b, *NSW Government Submission on the Proposed Murray–Darling Basin Plan*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Law-and-policy/National-reforms/Murray-Darling-Basin-Plan/murray-darling-basin-plan]

NWC 2011, *National Water Planning Report Card 2011*, National Water Commission, Canberra [www.nwc.gov.au/publications/topic/planning/national-water-planning-report-card-2011]

OEH 2011a, *Environmental Water Use in NSW: Annual report 2010–11*, NSW Office of Environment and Heritage, Sydney [www.environment.nsw.gov.au/resources/environmentalwater/20110930envtalwater1011.pdf]

OEH 2011b, *State of the Beaches 2010–2011*, NSW Office of Environment and Heritage, Sydney [www.environment.nsw.gov.au/beach/Reportann.htm]

OEH 2011c, *Observed Changes in New South Wales Climate 2010*, NSW Office of Environment and Heritage, Sydney [www.environment.nsw.gov.au/resources/climatechange/20110203obsnswclim2010.pdf]

Outhet, D. & Young, C. 2004, 'Riverstyles geomorphic fragility', unpublished internal draft paper for use throughout NSW by the Department of Infrastructure, Planning and Natural Resources, Sydney

Phillips, B. (ed.) 2001, *Thermal Pollution of the Murray–Darling Basin Waterways*, workshop held at Lake Hume 18–19 June 2001, World Wide Fund for Nature Australia and Inland Rivers Network, Sydney

Porter, J.L. & Kingsford, R.T. 2011, *Aerial Survey of Wetland Birds in Eastern Australia: October 2011*, Annual Summary Report, Australian Wetlands and Rivers Centre, University of NSW, Sydney [www.wetrivers.unsw.edu.au/media]

Preece, R.M. 2003, *Cold Water Pollution Below Dams in NSW: A desktop assessment*, NSW Department of Infrastructure, Planning and Natural Resources, Sydney [www.water.nsw.gov.au/Water-management/Water-quality/Temperature/Temperature/default.aspx#read]

Ridgway, K.R. 2007, 'Long-term trend and decadal variability of the southward penetration of the East Australian Current', *Geophysical Research Letters*, 34, L13613 [dx.doi.org/10.1029/2007GL030393]

Riebesell, U., Körtzinger, A. & Oschlies, A. 2009, 'Sensitivities of marine carbon fluxes to ocean change', *Proceedings of the National Academy of Sciences*, 106(49), pp.20602–09 [dx.doi.org/10.1073/pnas.0813291106]

Roberts, J. & Marston, F. 2000, *Water Regimes of Wetland and Floodplain Plants in the Murray–Darling Basin: A source book of ecological knowledge*, Technical Report 30/00, CSIRO Land and Water, Canberra [www.clw.csiro.au/publications/technical2000]

Rogers, K., Saintilan, N. & Wilton, K. 2006, 'Vegetation change and surface elevation dynamics of the estuarine wetlands of southeast Australia', *Estuarine, Coastal and Shelf Science*, 66(3–4), pp.559–69 [dx.doi.org/10.1016/j.ecss.2005.11.004]

Rogers, K. & Ralph, T. 2010, *Floodplain Wetland Biota in the Murray–Darling Basin: Water and habitat requirements*, CSIRO Publishing, Collingwood [www.publish.csiro.au/pid/6464.htm]

Roper, T., Creese, B., Scanes, P., Stephens, K., Williams, R., Dela-Cruz, J., Coade, G., Coates, B. & Fraser, M. 2011, *Assessing the Condition of Estuaries and Coastal Lake Ecosystems in NSW*, Monitoring, Evaluation and Reporting Program Technical Report, NSW Office of Environment and Heritage, Sydney [www.environment.nsw.gov.au/soc/socTechReports.htm]

Russell, G.N., Green, R.T., Spencer, J. & Hayes, J. 2010, *Thirlmere Lakes Groundwater Assessment*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Water-availability/Groundwater/Groundwater/default.aspx#lakes]

Saintilan, N. & Williams, R.J. 1999, 'Mangrove transgression into saltmarsh environments in southeast Australia', *Global Ecology and Biogeography*, 8(2), pp.117–24 [dx.doi.org/10.1046/j.1365-2699.1999.00133.x]

Saintilan, N. & Williams, R.J. 2000, 'Short note: the decline of saltmarsh in southeast Australia – results of recent surveys', *Wetlands (Australia)*, 18(2), pp.49–54 [ojs.library.unsw.edu.au/index.php/wetlands/issue/view/60/showToc]

SCA 2001, *Wingecarribee Swamp and Special Area Plan of Management 2001*, Sydney Catchment Authority and NSW National Parks and Wildlife Service, Sydney [www.sca.nsw.gov.au/publications/publications/29]

Serov, P., Kuginis, L. & Williams, J.P. 2012, *Risk Assessment Guidelines for Groundwater Dependent Ecosystems: Volume 1 – The conceptual framework*, NSW Office of Water, Sydney [www.water.nsw.gov.au/Water-management/Water-availability/Risk-assessment/Groundwater-dependent-ecosystems/Risk-assessment-guidelines-for-groundwater-dependent-ecosystems#vol1]

Sheldon, F., Thoms, M.C., Berry, O. & Puckridge, J.T. 2000, 'Using disaster to prevent catastrophe: referencing the impacts of flow changes in large dryland rivers', *Regulated Rivers: Research and Management*, 16(5), pp.403–20 [dx.doi.org/10.1002/1099-1646(200009/10)16:5<403::AID-RRR593>3.0.CO;2-3]

SKM 2001, *Environmental Water Requirements to Maintain Groundwater Dependent Ecosystems: Environmental flow initiatives technical report number 2*, Sinclair Knight Merz Pty Ltd for Environment Australia, Canberra [www.environment.gov.au/water/publications/environmental/rivers/nrhp/groundwater.html]

SKM 2011, *National Water Quality Assessment 2011*, prepared for the Australian Department of Sustainability, Environment, Water, Population and Communities on behalf of the State of the Environment 2011 Committee, Canberra [www.environment.gov.au/soe/2011/report/inland-water/supporting-material.html]

SWC 2008, *Sydney Water Annual Report 2008*, Sydney [www.sydneywater.com.au/Publications/Reports/AnnualReport/2008/Sustainabilityindicators/Clean\_waterways.cfm]

Spencer, J.A., Thomas, R.F., Wassens, S., Lu, Y., Wen, L., Bowen, S., Iles, J., Hunter, S., Kobayashi, Y., Alexander, B. & Saintilan, N. 2011, 'Testing wetland resilience: monitoring and modelling of flows in the Macquarie Marshes and Lowbidgee wetlands in 2009–11', final unpublished report for the NSW Catchment Action Program, NSW Office of Environment and Heritage, Sydney, and Charles Sturt University, Wagga Wagga

Thomas, R.T., Lu, Y., Cox, S.J. & Hunter, S.J. 2012, *Inundation Mapping in Significant Floodplain Wetlands: The Macquarie Marshes and Gwydir Wetlands*, final report to the NSW Wetland Recovery Program, NSW Office of Environment and Heritage, Sydney [download.mdba.gov.au/proposed/EWR-Macquarie-Marshes.docx]

Thoms, M.C. 2003, 'Floodplain-river ecosystems: lateral connections and the implications of human interference', *Geomorphology*, 56(3–4), pp.335–49 [dx.doi.org/10.1016/S0169-555X(03)00160-0]

Thoms, M.C. & Sheldon, F. 2000, 'Water resource development and hydrological change in a large dryland river: the Barwon–Darling River, Australia', *Journal of Hydrology*, 228(1–2), pp.10–21 [dx.doi.org/10.1016/S0022-1694(99)00191-2]

Vaze, J. & Teng, J. 2011, 'Future climate and runoff projections across New South Wales, Australia – results and practical applications', *Hydrological Process*, 25(1), pp.18–35 [dx.doi.org/10.1002/hyp.7812]

Ward, J.V., Malard, F., Stanford, J.A. & Gonser, T. 2000, 'Interstitial aquatic fauna of shallow unconsolidated sediments, particularly hyporheic biotopes' in Wilkens, H., Culver, D.C. & Humphreys, W.F. (eds), *Ecosystems of the World*, Vol. 30, Subterranean Ecosystems, Elsevier, Amsterdam

West, R.J., Thorogood, C.A., Walford, T.R. & Williams, R.J. 1985, *An Estuarine Inventory for New South Wales, Australia*, Fisheries Bulletin 2, NSW Department of Agriculture, Sydney [www.canri.nsw.gov.au/nrdd/records/ANZNS0364000065.html]

White, W.B. 1984, 'Rate processes: chemical kinetics and karst landform development' in La Fleur, R.G. (ed.), *Groundwater as a Geomorphic Agent*, Allen & Unwin, Boston

Williams, R.J. & Meehan, A.J. 2004, 'Focusing management needs at the sub-catchment level via assessments of change in the cover of estuarine vegetation, Port Hacking, NSW, Australia', *Wetlands Ecology and Management*, 12, pp.499–518 [dx.doi.org/10.1007/s11273-005-3948-y]

Williams, R.J., West, G., Morrison, D. & Creese, R.G. 2006, *Estuarine Resources of New South Wales*, CCA toolkit: project summaries, CCA 03, prepared for the Comprehensive Coastal Assessment by the Department of Primary Industries, Port Stephens [summary at www.planning.nsw.gov.au/cca-toolkit]



# Water

Wilton, K.M. 2002, 'Coastal wetland habitat dynamics in selected New South Wales estuaries', PhD thesis, School of Arts and Sciences, Australian Catholic University, Fitzroy, Victoria [[dlibrary.acu.edu.au/digitaltheses/public/adt-acuvp29.29082005](http://dlibrary.acu.edu.au/digitaltheses/public/adt-acuvp29.29082005)]

