A Review of the Existing Literature on the Environmental Effects of Wyangala Dam

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EXECUTIVE SUMMARY

The Lachlan Valley is one of the most important agricultural regions in Australia; it covers only 10% of New South Wales yet accounts for 14% of the state’s agricultural production. Lake Wyangala is the major water storage in the Lachlan Valley and is located downstream of the junction of the Abercrombie and Lachlan rivers, about 45 km south-west of Cowra. Wyangala Dam was originally built in 1935, but storage capacity was tripled in 1971 primarily to meet projected water demands from an expanding agricultural industry. Irrigated agriculture in the Lachlan Valley has increased substantially in the last 60 years, from a little over 13 000 ha in 1944 to about 88 000 ha in 2001.

State Water Corporation is currently reviewing safety and environmental improvement options for Wyangala Dam, as part of the Wyangala Dam Upgrade Project. Safety or remedial options are concerned with meeting ANCOLD requirements for dam safety and flood handling capacity. This report investigates the environmental effects of Wyangala Dam on the surrounding environment by reviewing all available relevant literature. The evaluation of current environmental condition enables the development of a conceptual model of how Lake Wyangala functions and identification of the major environmental effects of Wyangala Dam on the surrounding environment. This report recommends environmental improvement options aimed at ameliorating the current impacts of Wyangala Dam on the surrounding environment. We also recognise, in this report, that the operational constraints under the current Water Sharing Plan limit environmental improvement options for Wyangala Dam.

The literature review is a substantial and integral part of this report: it was the basis for the assessment of current condition and the development of the conceptual model. Over 110 documents are cited, most of which are ‘grey’ literature — agency reports — as very few peer-reviewed published papers specific to Lake Wyangala and/or the Lachlan River exist. Analyses of unpublished data provided important information regarding storage levels and water quality (pH, salinity, phosphorus, nitrogen) in Lake Wyangala, and fish communities in the lake and in the Lachlan River downstream. The development of the conceptual model was not possible without a number of assumptions. Most assumptions stem from the fact that many aspects of current environmental condition have not been adequately studied and exist as knowledge gaps.

For the most part, Lake Wyangala functions similarly to other headwater storages in the Murray–Darling Basin. There are, however, some aspects of environmental condition — namely aspects of water quality and the biological community — specific to Lake Wyangala and the Lachlan River downstream. The key functional aspects are:

- Nutrient enrichment of Lake Wyangala. The lake is a depositional zone for sediments to which nutrients are attached. Phosphorus and nitrogen levels, particularly in the deeper waters, are frequently above ANZECC default trigger levels for lakes and reservoirs.
• Stratification of Lake Wyangala. The lake stratifies during summer and autumn each year, reducing water temperature and dissolved oxygen levels in the deeper waters (hypolimnion).

• The flow regime of the Lachlan River has been dramatically altered by the operation of Wyangala Dam. Of particular consequence to the biological community are the reversal of seasonal trends and the removal of high and low flow events.

• Cold water pollution in the Lachlan River is caused by the combination of stratification of Lake Wyangala, the fixed-level intake tower in the lake and the timing of irrigation releases.

• Blue-green algal blooms occur frequently in Lake Wyangala between October and May each year. They are caused by the combination of high nutrient inputs, stratification, calm waters, low turbidity and warm water temperatures.

• Salinity levels in Lake Wyangala are rising and consistently exceed ANZECC trigger levels for lakes and reservoirs.

• pH levels in Lake Wyangala are increasing.

• Native fish populations have declined and introduced species dominate in Lake Wyangala and the Lachlan River.

• Macroinvertebrate diversity in the Lachlan River directly downstream of Wyangala Dam is lower than elsewhere along the river.

The depauperate condition of aquatic fauna, particularly native fish, in Lake Wyangala and the Lachlan River downstream is probably due to a combination of processes created by the existence and operation of Wyangala Dam. Cold water pollution in the Lachlan River, experienced from Wyangala Dam to downstream of Cowra, restricts the spawning period for some native fish and denies suitable spawning conditions for others (catfish and silver perch). Regulation of the Lachlan River also affects spawning cues and the extent and availability of nursery habitats critical for the recruitment of juvenile fish. Wyangala Dam is a significant barrier to the upstream and downstream movement of aquatic fauna; the impact on native fish is likely to be significant given that upstream movements are critical for the breeding of some species, and larvae of most species are distributed downstream by drift.

The health and diversity of native fish populations in the Lachlan River is clearly a major priority of environmental improvement options for the management and operation of Wyangala Dam. Reducing the prevalence and severity of cold water releases will certainly improve conditions for native fish, but substantial improvements are not expected to occur unless some other issues are addressed; namely, altered hydrology, habitat restoration, control of alien species and Wyangala Dam as a barrier to fish movement. There is some uncertainty predicting the outcomes of environmental improvement options, such as the construction of a fish passage, given that rehabilitation measures of this magnitude have not been previously implemented in Australia. Also, in Australia at least, restoration ecology is a developing branch of ecology and the results of many restoration efforts are, as yet, unknown (Lake 2001). Predicting the outcomes of environmental improvement options is further compounded by the fact that much of the assessment of current
environment condition, of Lake Wyangala and the Lachlan River, is based on sketchy information.

The following are recommended as environmental improvement options for the management and operation of Wyangala Dam:

Recommendation 1
State Water develop a modified flow regimen, that fits within the current Water Sharing Plan, aimed at improving in-stream production, water quality and habitat diversity based on increased variability in flows over the whole year.

Recommendation 2
- A. Determine the status of the fish community in Lake Wyangala and the Lachlan River downstream of Wyangala Dam: collect data on presence/absence, breeding and recruitment of native species. It is critical to establish whether there is, or isn’t, a viable fish community before undertaking significant works.
- B. Before the potential benefits of any management action can be determined, a wider monitoring program is established that describes the current condition of the river: including fish, invertebrate, vegetation condition, hydrological assessment, geomorphic assessment. This monitoring program should continue after any changes to the management of Wyangala Dam are implemented.

Recommendation 3
Carry out a more detailed investigation into the suitability of localised destratification of Lake Wyangala compared to the construction of a multilevel offtake, taking into consideration not only thermal pollution but also the potential effects on water quality. Scenario testing (based on thermal dynamic models) should provide a solid basis for examining the relative merits of localised destratification compared to the construction of a multilevel offtake.

Recommendation 4
State Water does not undertake a feasibility study into the design and construction of a fish passage until other factors affecting downstream ecological condition have been addressed.

Recommendation 5
State Water commissions a study to determine the historical sources of sediments currently in Lake Wyangala.

Recommendation 6
State Water encourages the relevant catchment management agency to undertake an analysis of the major current sources of sediments and nutrients in the catchment (eg. SedNet modelling) and prioritise rehabilitation of those sites.

Recommendation 7
In addition to thermal modelling outlined above (Recommendation 3), the study be expanded to include the impacts of internal loading of nutrients on water quality in Lake Wyangala.
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ACRONYMS

ABS — Australian Bureau of Statistics
ANCOLD — Australian National Committee on Large Dams
ANZECC — Australian and New Zealand Environment and Conservation Council
CWP — Cold water pollution
CWRACC — Central West Regional Algal Coordinating Committee
DEC — Department of Environment and Conservation
DIPNR — Department of Infrastructure, Planning and Natural Resources
DLWC — Department of Land and Water Conservation
DSNR — Department of Sustainable Natural Resources
DWR — Department of Water Resources
ECA — Environmental Contingency Allowance
EPA — Environmental Protection Authority
FSL — Full storage level
IRN — Inland Rivers Network
LCMA — Lachlan Catchment Management Authority
LCMB — Lachlan Catchment Management Board
LRMC — Lachlan River Management Committee
MDB — Murray–Darling Basin
MDBC — Murray–Darling Basin Commission
MDBMC — Murray–Darling Basin Ministerial Council
NPWS — National Parks and Wildlife Service
NSW — New South Wales
SCC — Soil Conservation Service
TN — Total nitrogen
TP — Total phosphorus
WCIC — Water Conservation and Irrigation Commission
WSP — Water Sharing Plan
1 INTRODUCTION

1.1 Wyangala Dam Upgrade Project

The Wyangala Dam Upgrade Project has a number of objectives. The primary objective is to meet dam safety requirements for extreme flood events. The secondary objective is to investigate options for the operation and management of Wyangala Dam that will, potentially, lead to improved environmental outcomes.

Safety or remedial options for Wyangala Dam were investigated in an earlier report (Geo-Eng 2001). That report considered options for satisfying Australian National Committee on Large Dams (ANCOLD) requirements for dam safety — options to reduce risk of dam failure during flood and enhancing the flood handling capacity of the dam. To address the ANCOLD requirements, four options for augmenting the spillway’s capacity were investigated and the spillway gate mechanism was evaluated in terms of risk assessment (Geo-Eng 2001). Options to improve the temperature of water released from Wyangala Dam during the irrigation season were also investigated. State Water is currently refining potential dam safety options.

This report, *A Review of the Existing Literature on the Environmental Effects of Wyangala Dam*, is focused on the second objective of the Wyangala Dam Upgrade Project: options for environmental improvement. This part of the upgrade project involves a determination of the environmental effects of the dam on the surrounding environment including an assessment of current condition. From this basis of knowledge — of environmental effects and condition — it will be possible to identify desirable environmental outcomes and provide recommendations for future management. Recommendations for environmental improvement options are based on the assessment of current environmental condition, the identified drivers of current condition and the consultant’s (Murray–Darling Freshwater Research Centre) experience in freshwater ecology.

1.2 Operational constraints and responsibilities

Whilst the construction of a large dam across a waterway automatically modifies the surrounding environment, upstream and downstream, the operational procedures of that dam may have a greater environmental impact. The operational procedures of Wyangala Dam are determined largely by the Water Sharing Plan (WSP) — a framework for water-use in the Lachlan Valley, first gazetted in February 2003 and amended in July 2004 (Department of Infrastructure, Planning and Natural Resources [DIPNR] 2004a). Ameliorating the effects of Wyangala Dam on the surrounding environment is partially constrained by the legislative rules of ‘water sharing’ provided in the WSP for the Lachlan Valley.

The WSP contains provisions for water for the environment and the sharing of water among extractive users. It sets out the rules for ‘…management of water access licenses, water allocation accounts, the trading of or dealings in access licenses and water allocations, the extraction of water, the operation of dams and the management
of water flows’ (DIPNR 2004b, p. 1). The environmental component of the WSP was developed from recommendations made by the Lachlan River Management Committee (LRMC) — a committee comprised of representatives from the irrigation industry, conservation groups, the indigenous community, the Lachlan Catchment Management Board (LCMB), independent members of the community, and various government agencies (NSW Fisheries, National Parks and Wildlife Service [NPWS], Environmental Protection Authority [EPA], NSW Agriculture, Department of Land and Water Conservation [DLWC]). The environmental flow rules in the 2004 WSP differ slightly from the original rules implemented in 1998/99 (Section 3.2.2) as there is greater protection for the irrigation industry during dry years (DIPNR 2004b) — a legacy of low rainfall and storage levels in Lake Wyangala since 2002.

A number of agencies are involved, directly or indirectly, in the management and operation of Wyangala Dam. DIPNR is the ‘regulator’ and defines when and how water should be distributed under the stipulations of the WSP. State Water is the ‘operator’ and delivers water to downstream users based on the rules and constraints of the WSP. The Lachlan Catchment Management Authority (LCMA) is the ‘resource manager’ and is responsible for overseeing environmental management in the catchment.

The environmental flow rules in the WSP for the Lachlan River, as summarised in DIPNR (2004b, pp. 4–5), are:

1. Reserve all water above the Plan extraction limit for the environment:
   - This ensures that there is no erosion of the long-term average volume of water available to the environment during the life of the Plan.
   - This means that, on a long-term average basis, approximately 75% of yearly flows in the river are protected for the maintenance of environmental health.

2. Improve lower system flows and winter/spring flow variability:
   - This is achieved by passing some inflows through Wyangala Dam (called ‘translucent’ releases) and prohibiting extraction of some tributary inflows or the diversion of flows into Lakes Brewster or Cargelligo. This cannot occur until 250 000 ML has entered Wyangala Dam, commencing from 1 January each year.
   - The rules apply from mid-May to mid-November at Wyangala and the start of June to the end of November at Lake Brewster.
   - The Lake Brewster flow targets vary between 3 500 ML day\(^{-1}\) and 8 000 ML day\(^{-1}\), depending on the inflows that are occurring at the time, the volume of water in Wyangala Dam, the volume of flows that have entered Wyangala Dam and that have already passed Lake Brewster so far that year.
   - Total volume of translucent and tributary flows is up to 350 000 ML year\(^{-1}\) measured at Brewster Weir.

3. Provide reserves of water for environmental purposes:
• Reserve 10 000 ML of water in Wyangala Dam and 10 000 ML in Lake Brewster whenever the total volume of water available to general security licenses exceeds 50% of the access license share volume at the beginning of a water year or reaches 75% during a water year.
• Release this water to support waterbird or fish breeding, wetland watering or increase flow variability.

4. Provide a reserve of water for water quality management purposes:
• Reserve 20 000 ML of water in Wyangala Dam each water year.
• Release this water for purposes to reduce salinity levels or mitigate blue-green algae outbreaks.

The development and management of environmental flows for the Lachlan River are discussed in Section 3.2.2.

1.3 This report

The major aims of this report are to review the current environmental impacts of Wyangala Dam and explore environmental improvement options which may be incorporated into the dam safety upgrade project. State Water Corporation (State Water) provided the following brief for this report:

• Review all available literature on the current knowledge and status of the impact of Wyangala Dam on the surrounding environment.
• Describe how these issues relate back to the Wyangala Dam Upgrade Project.
• Outline any further investigations/works/operational changes required that would improve the current environmental situation and benefit the Wyangala Dam Upgrade Project (based on assessment of current environmental condition and consultant’s expert opinion).

All aspects of the above brief are addressed in this report entitled A Review of the Existing Literature on the Environmental Effects of Wyangala Dam. The major proportion of the report consists of the review of literature — an overall perspective on the environmental effects of Wyangala Dam — and environmental improvement options are then developed in the synthesis (Section 4).
2  METHODOLOGY

The literature review formed the basis for the evaluation of current environmental condition which, in turn, provided the basis for the recommendation of environmental improvement options. Therefore, the literature review is a substantial and integral component of this report: over 110 documents are cited in the bibliography and many other documents were read but deemed irrelevant to the project. Published and peer reviewed literature specific to Wyangala Dam, Lake Wyangala and the Lachlan River, and relevant to the major issues identified, were located by searches (ISI Web of Science, Google Scholar and Streamline). The amount of published and peer reviewed literature was relatively small; therefore, most relevant information was contained in ‘grey’ literature such as agency reports and unpublished data. Grey literature were obtained directly from agency staff (State Water, DIPNR, NSW Fisheries, Department of Environment and Conservation (DEC)). Other grey literature were obtained from searches of agency websites.

Unpublished data were obtained from State Water (water quality and storage levels), NSW Fisheries (fish surveys and competitions) and DEC (macroinvertebrate) — the data from State Water and NSW Fisheries are presented in this report. These sources of information were vital because of a general lack of published literature and agency reports on many issues of environmental concern. Unpublished data aided the development of an assessment of current condition and identification of environmental trends.

The literature review was organised into major sections developed by State Water and the Murray–Darling Freshwater Research Centre (MDFRC). Each section combines information from a number of sources, some specific to Wyangala Dam and the Lachlan River and some general to dams and rivers, so that current condition can be explained in an accessible style. The major sections are river regulation, stratification and cold water pollution, catchment condition, sedimentation, water quality, fish, macroinvertebrates and vegetation. At the end of each of these sections, the literature is briefly evaluated. The synthesis section was developed once the literature review was completed and an assessment of current environmental condition could be made. The synthesis drew upon expertise from the MDFRC and includes a conceptual model of how Lake Wyangala functions, ascertains the key drivers of environmental condition, and identifies critical knowledge gaps.

For the most part, this report examines the impacts of Wyangala Dam on the downstream environment within approximately 200 km. Impacts from the operational procedures of the dam, however, are experienced along the entire length of the Lachlan River, in effluent streams and on the Lachlan Valley floodplain: this fact is only really mentioned in regard to river regulation (Section 3.2). Upstream catchment influences on water quality in Lake Wyangala are also discussed (Section 3.4).
3 LITERATURE REVIEW

3.1 Regional Overview

In 1815, when George Evans and his party came upon the Lachlan River at Cowra, it was, at the time, the most important discovery in inland Australia. It was the explorer’s second foray into the abyss west of the Blue Mountains and the discovery revealed ‘…a great stretch of valuable territory’ (Scott 1929). Evans was instructed by Governor Lachlan Macquarie to head west from Bathurst until he met with the western ocean, or found some country fit for cultivation ‘…that would support settlement in the drought-parched and grass-deficient colony’ (Marriott 1988, p. 9). But in the Lachlan Valley around Cowra, within 75 miles (120 km) of Bathurst, Evans found fine grazing country, rich and fertile soils, extensive woodlands and a large river: ‘An handsomer and finer Country I never saw..’ he remarked (Scott 1929).

3.1.1 The Lachlan Valley

The Lachlan Valley is located in the central west of New South Wales (NSW: Figure 1). It is surrounded by the Macquarie and Darling valleys to the north and west, respectively, and the Murrumbidgee Valley to the south. In total catchment area, the Lachlan Valley is some 84 700 km$^2$, approximately 10% of the total land area of New South Wales (DLWC 1998; Water Resources and Irrigation Commission (WCIC) 1972). The Lachlan catchment is bordered to the east by the Great Dividing Range and runs westerly onto the Riverine Plains.

Based on physical geography, the Lachlan Valley can be separated into three distinct sections (Harris 1987). The upper section includes all of the catchment upstream of Cowra, is characterised by undulating to rugged mountainous terrain, and average annual rainfall is 760–900 mm — up to 1200 mm near the Great Dividing Range (DLWC 1998). The middle section extends from Cowra downstream to Forbes: the valley broadens, here, and the alluvial plain is enclosed by undulating to steep hills. Average annual rainfall is 800–900 mm at Forbes (DLWC 1998). The lower section of the catchment downstream of Forbes is mostly flat and annual rainfall averages 300–500 mm (DLWC 1998; WCIC 1972). Approximately 75% of the Lachlan Valley is flat (slope < 10 degrees: Travers 1996).

The estimated population of the Lachlan Valley was around 106 000 in 1996 (Australian Bureau of Statistics [ABS], cited in DLWC 1998). According to the 2001 census, the largest population centres in the Valley are (largest first) Parkes, Cowra, Forbes, Young, West Wyalong, Condobolin, Blayney, Grenfell, Crookwell, Canowindra, Hillston and Lake Cargelligo (ABS 2001). All of these towns had populations below 10 000 and Cowra and Hillston were the only towns to experience population growth between 1996 and 2001 (ABS 2001). The major industry in the Lachlan Valley is agriculture: worth an estimated $821 million in 1993 (DLWC 1998). Other important industries and contributors to employment in the region include forestry, mining, tourism, fishing and hunting, community services, wholesale and retail trade and meat and agricultural processing (DLWC 1998; Harris 1987).
Since the advent of agriculture in the region in the 1800s, large areas of the slopes and plains have been cleared and, consequently, very little native vegetation remains upstream of Condobolin (DLWC 1996). In the central Lachlan region — Cowra to Condobolin — large proportions of all vegetation communities have been cleared. Austin et al. (2000) found only vegetation communities associated with rocky hills retained more than 30% of their original coverage, whilst nine vegetation alliances had less than 10% of their original coverage remaining. Less than 4% of the Lachlan Valley is contained within NSW National Parks and just over 1% is controlled by State Forests (Harris 1987).

Agriculture in the Lachlan Valley accounts for approximately 14% of total agricultural production in NSW (Lachlan Catchment Management Board [LCMB] 2001). Agricultural activities in the valley include wool production, horticulture, feedlots and piggeries, cereals, lucerne and other irrigated crops (DLWC 1998). Irrigation agriculture increased rapidly after World War II. The amount of crop area authorised for irrigation increased from 32 700 acres (13 233 ha) in 1944 to 170 000 acres (68 796 ha) in 1971 (WCIC 1972). It was predicted in 1972, that if the trend in development continued, total irrigated area in the Lachlan Valley would reach 200 000 acres (80 937 ha) within 50 years (WCIC 1972). There was over 77 000 ha of irrigated crop area in 1991/92 (Department of Water Resources [DWR] 1992a), 80 782 ha in 1993/94 (DWR 1994a), 83 718 ha in 1995/96 (DLWC 1996) and 88 000 ha in 2000/01 (LRMC c. 2002). In 1995/96, almost 50% of the irrigated crop area was located upstream of Lake Cargelligo, 28% downstream of Lake Cargelligo, 16% in the Jemalong Irrigation District and the remainder in the Belubula River region (DLWC 1996). In order of total area, irrigated crops included winter cereals, lucerne, winter pasture, summer pasture, summer cereals, oilseeds, forage crops, grain.
legumes, vegetables, fruit and grapes. Thirty-five percent of irrigated land in the Lower Lachlan is supporting cotton crops, which is fast becoming the major irrigated crop in the region (LRMC c. 2002; State Water 2001).

There are two major sources of water in the Lachlan Valley, the Lachlan River and groundwater. Groundwater has been utilised in the Lachlan catchment since the 1800s (Marriott 1988) and now there are an estimated 12 000 groundwater bores in the region — 3000 of which are licensed (DLWC 1998). The estimated sustainable yield of groundwater within the Lachlan region is about 283 000 ML year$^{-1}$ (DLWC 1998). Approximately 62 000 ML of groundwater (22% of the estimated sustainable yield) was used in 1993/94 of which 47% was for irrigation agriculture, 37% for stock and domestic and 16% for town water supply (DLWC 1998). Much of the harvested groundwater is of good quality and is the major source for town water supplies in Forbes, Parkes, Canowindra, Grenfell and West Wyalong (DWR 1989). Most of the water utilised for agriculture, stock and domestic, and town needs, is surface water. On average 250 000 to 300 000 ML of surface water is used annually, most of which comes from the Lachlan River (Travers 1996).

3.1.2 The Lachlan River

The Lachlan River is the major stream in the catchment and runs virtually the full length of the valley (Figure 1). From its headwaters on the Breadalbane Plain east of Gunning, the Lachlan River has an overall length of about 1450 km (DLWC 1998; WCIC 1972). All of the major tributaries to the Lachlan River are located upstream of Forbes: the Abercrombie and Boorowa rivers join the Lachlan River upstream of Cowra, and the Belubula River and Mandagery Creek flow into the Lachlan between Cowra and Forbes. Inflows to the Lachlan River downstream of Forbes are rare. In fact, the river downstream of Condobolin is characterised by effluent streams — streams that leave the main river and don’t rejoin — including Willandara, Moolbong, Middle, Merrowie and Box creeks (Driver 1999).

A unique feature of the Lachlan River, and its distributaries, is that they terminate into wetlands: only occasionally do flows reach the Murrumbidgee River (LCMB 2001). These wetlands impeded John Oxley, the first European explorer to the lower Lachlan region, and he concluded that: ‘…the interior of this vast country is a marsh and uninhabitable’ (Scott 1929). Nowadays, many of these marshes and swamps are highly valued wetlands of national significance, and listed in A Directory of Important Wetlands in Australia (Environment Australia 2001). The wetlands listed are:

- Lake Cowal/Wilbetroy Wetlands
- Booligal Wetlands
- Cuba Dam
- Great Cumbung Swamp
- Lachlan Swamp (part of mid Lachlan wetlands)
- Lake Brewster
- Lake Merrimajeel/Murrumbidgul Swamp
- Lower Mirrool Creek Floodplain
• Merrowie Creek (Cuba Dam to Chillichil Swamp).

The furthest upstream wetland on this list is Lake Cowal/Wilbetroy Wetland. It is located approximately 30 km south of the Lachlan River south of Condobolin. All other listed wetlands are located further west in the Lachlan catchment.

The natural hydrological regime of the Lachlan River is similar to that of other rivers in the southern half of the Murray–Darling Basin (MDB) (Walker 1992). Flows are extremely variable but discharge is usually greatest during winter–spring (June though October) and least in late summer–autumn (LRMC c. 2002; Walker 1992). Although most rainfall in the Lachlan catchment occurs in winter, summer rainfall is more variable (DLWC 1998). Only streams in the headwaters of the catchment display any degree of reliable flow persistence and downstream of Forbes it is not rare for the watertable to be below the bed level (WCIC 1972). Lachlan River discharge also varies enormously among years: extremes of 4 and 550% of mean annual discharge have been recorded (Sheldon et al. 2000; Walker 1992). Historically, droughts have occurred with relative frequency in the Lachlan catchment, including the extended drought periods of 1937–38, 1940–45, 1982–83 (LRMC c. 2002), and the prolonged period of below average rainfall during the first few years of the current century. The Lachlan River also regularly experiences floods: between 1892 and 1984, there were over 170 floods recorded at Forbes including 22 major and 72 moderate floods (Harris 1987). Floods can cover large areas of the lower Lachlan floodplain (Roberts and Sainty 1996).

Regulation of the Lachlan River commenced in the 1860s when landholders constructed small weirs as insurance against regular periods of low flow (DWR
By the 1880s, water from the river was being diverted and stored in the floodplain lakes; Willandara Weir was constructed in 1892 to divert flows into Willandara Creek (Roberts and Sainty 1996). The completion of a weir and regulator at Lake Cargelligo in 1902 heralded large-scale water resource development in the region (DWR 1989; Sainty and Jacobs 1996). In 1935, construction of the largest water storage in the Lachlan Valley (Wyangala Dam) was completed about 50 km upstream of Cowra to stabilise agriculture in the region (Marriott 1988). Another floodplain wetland was converted into a permanent storage in 1950 and named Lake Brewster (DWR 1989), and Carcoar Dam was constructed on the Belubula River in the late 1960s (Driver 1999). In 1971, the capacity of Lake Wyangala was more than tripled (Oliver 1973). There are currently about 350 barriers on the Lachlan River including 298 dams/weirs and 31 gated weirs (Ball et al. 2001).

### 3.1.3 Wyangala Dam

Wyangala Dam is located at approximately 360 m above sea level at 35° 24′ latitude and 148° 57′ longitude (Tibby 2004). The dam is owned and operated by State Water Corporation and is used primarily to regulate flow for summer–autumn irrigation in the Lachlan Valley and for flood mitigation (Preece 2004; Travers 1996). Lake Wyangala was increased to its current capacity in 1971, by enlargements to the dam wall, because of projected water demands from expanded agricultural development in the valley (Harris 1987; WCIC 1972). Water stored in Lake Wyangala is also used to generate hydro-electricity.

The original Wyangala Dam was a mass concrete gravity dam with a maximum height of 190 feet (60 m) and a crest length of 1000 feet (305 m), creating a storage capacity of 304 000 acre feet of water in Lake Wyangala (375 000 ML: Tipping and Davidson n.d.). The new dam wall was constructed immediately downstream of the old wall, and is an earth and rockfill structure with a maximum structural height of about 82 m, a total crest length of 1450 m, and a capacity at full storage level (FSL) of approximately 1 220 000 ML or 1220 GL (Harris 1987; Oliver 1973; Preece 2004). At its base, the wall is over 200 m thick but just over 10 m wide at the top (Oliver 1973). At FSL, Lake Wyangala has a maximum depth of approximately 75 m and a surface area of over 53 km² (Geo-Eng 2001; Tibby 2004). The dam is equipped with two fixed-level intakes, one at 65 m below FSL and the other from 20–34 m below FSL, with a combined discharge capacity of 8000 ML day⁻¹ (Preece 2004). The new spillway consists of eight radial gates (14.63 m wide and 12.7 m high) and a maximum discharge capacity of 18 600 m³ s⁻¹ (Geo-Eng 2001).

Lake Wyangala is highly valued for the range of recreational opportunities it provides. It is considered one of NSW’s premier fisheries because it contains a mixture of warmwater and coldwater species (NSW Fisheries 2004; Richardson 1987). The lake is also used for other aquatic activities such as swimming, boating and water skiing; bushwalking and camping are also popular activities in the state recreational areas adjacent to the lake — Wyangala Waters and Grabine Lakeside (DWR 1989; NSW Department of Lands 2005). Marriott (1988) stated that Lake Wyangala attracted about 300 000 people to the district each year.
The two major tributaries of Lake Wyangala are the Abercrombie and Lachlan rivers. The flow regimes of these headwater rivers are similar to the upper catchment’s rainfall patterns, such that greatest flows generally occur between June and October and lowest flows occur in late summer and autumn (WCIC 1972). The winter–spring inflows to Lake Wyangala are captured and released down the Lachlan River during the summer irrigation season — typically November through to April (Preece 2004).

Between January 1975 and December 2004, the amount of water in Lake Wyangala ranged from 3 to 100% of capacity (Table 1). The lake is generally at its greatest capacity prior to the commencement of the irrigation season, and lowest levels generally occur in April–June. Also, lake capacity is most likely to fall below 75% of capacity from March–July, and most likely to reach 90% of capacity from September–March.

In recent years, there have been two sustained periods of low storage levels at Lake Wyangala. The first occurred between March 1980 and March 1984 during which maximum levels remained below 50% of capacity — the average minimum and maximum levels for 1983 were nine and 13% of capacity, respectively (Figure 4). The maximum level of Lake Wyangala dropped below 50% of capacity again in April 2002 and has remained low ever since (Figure 4) — below 20% since January 2003, below 15% since January 2004, and expected to drop to 5.5% in June 2005 (State Water 2005).

A number of proposals for extra water storages on the Lachlan River have been investigated in the last 30 years. The main motivation for these investigations has been that existing storages were considered ‘grossly inadequate’ and would not meet
expected expansion of agricultural production in the Lachlan Valley (Saudi n.d. – a). Three prospective sites upstream of Lake Wyangala have been considered — Hillandale, Abercrombie and Narrawa (Saudi n.d. – b) — and one site downstream of Wyangala Dam — Badgery (Sinclair Knight & Partners 1983). Diverting water from the Shoalhaven River, a coastal stream, to increase the volume of water available for development in the Lachlan Valley has also been considered (Saudi n.d. – a).

**Table 1.** Storage levels of Lake Wyangala from January 1975 to December 2004. Minimum, maximum, mean minimum, mean maximum, number of years at > 75% capacity and number of years at > 90% of capacity — all numbers are percentages of dam capacity. Raw data supplied by Neil Boyton (State Water Wyangala Dam).

<table>
<thead>
<tr>
<th>Month</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Minimum (mean ± SD)</th>
<th>Maximum (mean ± SD)</th>
<th>No. of years min. &gt; 75%</th>
<th>No. of years max. &gt; 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5</td>
<td>100</td>
<td>71 ± 30</td>
<td>76 ± 30</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>February</td>
<td>3</td>
<td>99</td>
<td>69 ± 30</td>
<td>73 ± 30</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>March</td>
<td>3</td>
<td>100</td>
<td>66 ± 30</td>
<td>70 ± 30</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>April</td>
<td>3</td>
<td>100</td>
<td>63 ± 30</td>
<td>67 ± 31</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>May</td>
<td>3</td>
<td>100</td>
<td>62 ± 30</td>
<td>64 ± 30</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>June</td>
<td>5</td>
<td>100</td>
<td>62 ± 30</td>
<td>65 ± 30</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>July</td>
<td>6</td>
<td>100</td>
<td>64 ± 30</td>
<td>70 ± 30</td>
<td>9</td>
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<tr>
<td>August</td>
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<td>69 ± 29</td>
<td>75 ± 31</td>
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<td>100</td>
<td>74 ± 31</td>
<td>78 ± 31</td>
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<tr>
<td>October</td>
<td>11</td>
<td>100</td>
<td>75 ± 32</td>
<td>78 ± 32</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>November</td>
<td>8</td>
<td>100</td>
<td>75 ± 32</td>
<td>77 ± 32</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>December</td>
<td>6</td>
<td>100</td>
<td>72 ± 32</td>
<td>76 ± 32</td>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

**Figure 4** Mean annual storage levels of Lake Wyangala between 1975 and 2004, based on minimum and maximum monthly levels. Raw data supplied by Neil Boyton (State Water, Wyangala Dam).
3.1.4 Impacts of large dams on the surrounding environment

The potential environmental impacts of large dams are many and varied. There are initial and on-going impacts created purely by the existence of a dam and reservoir, and there are impacts caused by the subsequent dam operations. The most obvious impacts, both physical and biological, occur in the reservoir itself and directly downstream of the dam wall (McCully 1996; Ward and Stanford 1983). A dam can also impact on the upstream environment, as the properties of longitudinal hydrologic connectivity — the transfer of matter, energy and organisms up and downstream — are altered (Pringle 2001). The environmental effects of dams are by no means restricted to the aquatic environment (Petts 1984). For example, changes to the fish community downstream of a dam will most likely have repercussions for waterbirds that rely on them as a food source.

Three orders of impacts have been suggested for the effects of dams on the downstream environment (Petts 1984, pp. 24–25). The first refers to longitudinal hydrologic connectivity and occurs at the moment of dam closure — commonly effected by this process are plankton, water quality, flow regime and sediment load. Second-order impacts depend on first-order impacts, catchment condition and riverine characteristics prior to dam closure; all of which may cause changes to channel morphology, substrate composition, macrophyte communities and periphyton. Third-order impacts reflect changes created by first- and second-order impacts and may be evident in changes to fish and macroinvertebrate communities. The impacts to ecological communities downstream and upstream of dams are caused by alterations, usually reductions, to aquatic habitat diversity (Finlayson et al. 1994; McCully 1996).

State Water is taking this opportunity, as part of the current dam safety upgrade project, to investigate options to ameliorate some of the impacts of Wyangala Dam on the surrounding environment (see environmental improvement options in Section 5).

3.2 River regulation and flow regime

Rivers in the MDB are among the most hydrologically variable in the world (Puckridge et al. 1998). To counter this variability, namely the marked seasonality of flow and the severity of droughts, large dams are often constructed in the headwaters of rivers (Ball et al. 2001). In NSW, the majority of rivers are regulated by headwater dams, with the aim of ensuring a reliable supply of water for human usage downstream (Ball et al. 2001; Thoms and Sheldon 2000). The consequence for many regulated rivers in the MDB is that their natural hydrological regimes are modified substantially.

In most rivers of the MDB, a number of ecosystem components are impacted by changes to the physical environment created by altered flow regimes. Regulating rivers for irrigation purposes tends to reduce seasonal flow variability and annual volumes of flow (Finlayson et al. 1994; Maheshwari et al. 1995). Reducing natural variability acts to stabilise water levels, allowing plants such as cumbungi (Typha spp.) and Phragmites australis to invade river channels (Maheshwari et al. 1995). This stabilisation of water levels can also alter the composition of algal communities and is linked to the local extinction of snails (Sheldon and Walker 1997). The diversity, extent and availability of aquatic habitats is effected by river regulation
(Bowen et al. 2003), which, in turn, has implications for a variety of aquatic fauna such as fish (Gehrke et al. 1995; Humphries et al. 2002), shrimps (Richardson et al. 2004), other macroinvertebrates (Humphries and Cook 2004), and waterbirds (Kingsford and Thomas 1995). Fauna that have evolved in the context of natural flow patterns are the ones most threatened by conditions created by altered hydrology (Bunn and Arthington 2002).

### 3.2.1 Regulation of the Lachlan River at Wyangala Dam

The major characteristics of the natural flow patterns of the Lachlan River were described earlier (Section 3.1.2). Regulation of the Lachlan River has been substantial since the construction of Wyangala Dam, such that the river’s hydrological regime has been altered along its entire length. Many of the distributaries and effluents in the lower Lachlan River also experience dramatically modified flow conditions, as do some of the ‘nationally significant’ wetlands. Tributaries upstream of Lake Wyangala, including the upper Lachlan River, are not subject to regulation and maintain their natural flow patterns.

The effects of river regulation on the Lachlan River downstream of Wyangala Dam can be summarised as follows (Sheldon et al. 2000):

- Decrease in median monthly flow.
- Shift in flow seasonality.
- Decrease in frequency of large floods.
- Decrease in frequency of moderate winter flooding.
- Increase in frequency of moderate summer flooding.
- Increase in frequency of low summer flooding.
- Decrease in frequency of zero flow.

Summer and winter are the seasons during which regulation of the Lachlan River is most pronounced (DLWC 1998). Naturally low flows during summer are augmented by releases from the dam because of irrigation demands: average summer flows at Forbes are twice those of natural conditions (DLWC 1998). Naturally higher winter flows are captured by Wyangala Dam and held for the following irrigation season; consequently, flows in the Lachlan River downstream of the dam are considerably less, on average, than those which would have naturally occurred. The flow patterns described above occur, under regulated conditions, at Cowra (Figure 5b) and further downstream at Forbes (DLWC 1998).

The impact of river regulation is slightly different towards the lower end of the Lachlan River. At Booligal, the river used to cease to flow 25% of the time, but under current regulated conditions the river rarely ceases to flow (McMahon and Finlayson 2003). Similar flow patterns occur near the terminus of the Lachlan River at Oxley. Proportionately, the monthly distribution of flows is similar between regulated and unregulated conditions (the hydrograph is a similar shape), however current average annual flow is about half that of pre-regulation (DLWC 1998). The combination of river regulation and water abstraction has contributed to the relatively constant low flows now experienced at the terminus of the Lachlan River (Sheldon et al. 2000).
Periods of no flow punctuated by widespread flooding were part of the natural flow regime of the lower Lachlan River, prior to construction of Wyangala Dam (Roberts and Sainty 1996).

The major environmental impacts of river regulation in the Lachlan River are seasonal flow changes, loss of flow variability, increased frequency of algal blooms, reduction in wetland extent and a reduction in the abundance of native fish species (Hillman et al. 2003).

**The Lachlan River distributaries**

Several of the distributaries or effluents of the Lachlan River depart the main river between Lake Brewster and Hillston. These distributaries run west and then
southwest over flat and treeless plains before terminating (Driver 1999; MurrayDarling Basin Commission (MDBC) 2004). The hydrological regimes of some of these distributaries have been dramatically altered by regulation.

Willandra Creek flows away from the Lachlan River downstream of Lake Brewster (at Willandra Weir) and terminates at Gunnaramby Swamp near Ivanhoe (Driver 1999). Prior to regulation, Willandra Creek was an ephemeral stream with extensive periods of zero flow broken by infrequent high flow events (Love 1999). Flows were most likely to occur in winter–spring with dry periods most common in summer–autumn (Driver 1999). Willandra Creek operates as a different system under regulated conditions, and is now characterised by unseasonal flows and a much more permanent presence of water (Love 1999). Flow changes have caused some remnant pools along Willandra Creek to fill with silt and changes in the density of aquatic plants such as cumbungi and ribbon weed (Vallisneria gigantea) have been noted (Driver 1999; Love 1999; Roberts and Sainty 1996).

Distributaries downstream of Willandra Weir, such as Moolbong, Middle, Merrowie and Box creeks, have also had their flow regimes altered. Alterations to the mouths of the channels have lowered the commence-to-flow, and the regulated Lachlan River ensures a much more permanent flow pattern. Riparian vegetation along these tributaries generally consists of a narrow band of black box (Eucalyptus largiflorens), cooba (Acacia salicina) and lignum (Muehlenbeckia florulenta), but, with the advent of almost perennial flows, some stands of red gum (E. camaldulensis) have developed (Driver 1999).

The Great Cumbung Swamp

This wetland, and other nationally significant wetlands along the Lachlan River, is subject to a highly regulated hydrological regime. The frequency of flooding in the Great Cumbung Swamp has been reduced and replaced by more constant low flows (Maher 1990; Sheldon et al. 2000). As a direct consequence, some of the vegetation in the swamp has changed: inundation-tolerant cumbungi has invaded the central, permanently wet part of the swamp; some red gums have died from long periods of inundation and other red gums on the perimeter of the swamp are stressed from too little water (Sheldon et al. 2000). In turn, this has impacted on habitat and conditions for breeding waterbirds (Maher 1990).

3.2.2 Environmental flow management

Environmental flow policies in NSW developed out of recognition of widespread declines in riverine health. In the Lachlan River, declines in water quality, native fish stocks, channel structure and the diversity of riverine flora had been noted over a period of time, but were more pronounced after the upgrade to Wyangala Dam in 1972 (Roberts and Sainty 1996). River regulation and water extraction were identified as two of the major contributors to these declines and the environmental flows introduced to the Lachlan River in 1992/93 were amongst the first in the state (Hillman et al. 2003; Jayasuriya 2003). The major aims of environmental flows are to improve water quality, aquatic biodiversity and general ecosystem health (Jayasuriya 2003), which, in turn, should make use of the river as a water resource more sustainable. The economic benefits of environmental flows are difficult to quantify in
monetary terms; this is unfortunate given that water for the environment is often portrayed as being at the expense of other major water users, such as irrigators (Jayasuriya 2003).

The environmental flows introduced to the Lachlan Valley in 1992/93 were in the form of an environmental contingency allocation (ECA). The main aims of the ECA were to reintroduce important features of natural flow variability in the Lachlan River and to address specific environmental problems as they arose (DWR 1992b). The natural flow variability was protected by minimum flow targets and the sharing of unregulated freshes and floods (DWR 1994b). The ECA of 100 000 ML — an amount only achieved in a year of 100% water user allocation — was held in Lake Wyangala (LRMC c. 2002). The ECA was used nine times from 1992 to 1997, ranging from 650 ML in 1993/94 to 14 525 in 1992/93, for purposes such as the dilution of blue-green algal blooms and riverine salinity, and flooding of the Booligal rookery (LRMC c. 2002; Travers 1996).

In 1998/99, a new set of environmental flow rules were introduced based on the recommendations of the LRMC (Hillman et al. 2003). The general objectives of these new rules were to provide a healthy river environment that supported sustainable and prosperous communities, find a better balance of water sharing between users and the environment, encourage community involvement in water management decisions and to adopt an adaptive management approach (LRMC 1998). Key features of the 1998/99 environmental flow rules were:

- Translucent releases from Wyangala Dam of up to 350 000 ML annually.
- A 20 GL high security ECA for management of critical environmental events — eliminated when water allocations are below 50%.
- A limit of 30 000 ML on off-allocation diversions annually.
- Minimum flow of 100 ML day⁻¹.

The extremely low levels in Lake Wyangala since 2002 have meant very low ECAs: only 3% of entitlement in 2002/03 (MDBC 2004). This has placed added pressure on water for environmental purposes, such that the dates and inflow thresholds for translucent releases from Wyangala Dam were recently changed (DIPNR 2004b). Lower water allocations to users may have also increased pressure on water for the environment as diversions were over the annual ‘Cap’ target by 1 GL in the Lachlan Valley (MDBC 2004). Cumulatively, diversions in the Lachlan Valley were 80 GL above the Cap between 1997 and 2003 (MDBC 2004).

Hillman and Brierley (2002, p. 623) indicated that the LRMC operates within a fairly strict legislative and policy framework, such that ‘…the reduction in irrigation diversions cannot exceed an average of 10% in NSW.’ According to the LRMC, the environmental flow rules for the Lachlan Valley have provided environmental outcomes better than possible under the previous arrangements (LRMC c. 2002). Despite this claim from the LRMC, environmental groups indicated that the current flow arrangement — the WSP gazetted in February 2003 for the Lachlan River — was ‘bad’ and should be substantially rewritten in terms of its environmental provisions (Inland Rivers Network [IRN] 2003). The prioritisation of storage levels and irrigation requirements over the ecological requirements of the river was viewed
as unsatisfactory (IRN 2003). Chessman and Jones (2001, pp. 10–11) acknowledged this and other limitations of current environmental flow policies such as:

- The objectives of flow rules are based on hydrological and not ecological outcomes.
- The implementation of environmental flows is not a controlled experiment, making it difficult to accurately assess the outcomes.
- For many parameters there is very little pre-environmental flow data.
- Changes in flow regime bought about by flow rules are small in relation to total water use.

An amended WSP (see Section 1.2) was released in 2004 (DIPNR 2004a).

### 3.2.3 Evaluation of literature

Information on river regulation in the Lachlan River is well represented in a range of literature types. Historical and current flow regimes in the Lachlan River have been the subject of peer reviewed scientific papers, agency reports and were also included in a collection of anecdotes. The development of environmental flow rules for the Lachlan River has also been well documented in peer reviewed publications and agency management plans. Consequently, the specific effects of Wyangala Dam on the hydrological regime of the Lachlan River are well understood, as are the constraints under which regulation of the dam occurs.

Despite recent modifications to the WSP, environmental/ecological considerations remain secondary to social and rural water needs. This will continue to make it difficult to achieve substantial environmental improvements.

### 3.3 Stratification and cold water pollution

One common environmental effect of large water storages is an altered temperature regime. Cold water pollution (CWP) is one such thermal impact and is driven by processes occurring within the lake: consequently, water temperature downstream of a dam is substantially colder than would occur naturally. CWP is most prevalent below dams that discharge water from low levels within a reservoir, primarily during the warmer months (Boulton and Brock 1999; Preece 2004; Sherman 2001).

Thermal stratification within reservoirs is the key driver of CWP. Most large reservoirs in southern Australia mix once a year (winter) and stratify in summer (Boulton and Brock 1999). When these reservoirs stratify in summer, water temperatures at the bottom (hypolimnion) can be more than 12 °C below water temperature at the surface, or epilimnion (Sherman 2001). The greatest change in water temperature occurs in the thermocline, which is situated in the metalimnion (Figure 6). CWP is exacerbated when the only outlet for discharge from the dam is located in the hypolimnion.
Figure 6 The three regions of a stratified lake. The thermocline, or greatest change in water temperature, occurs in the metalimnion.

As water temperature is one of the most important regulators of natural ecological processes (Preece 2004), the repercussions of CWP on the natural environment can be quite severe. Unnaturally low water temperatures can impact on a wide range of chemical and biological processes within the reservoir and in the river downstream (Sherman 2001). For example, it can slow metabolic processes in a range of organisms such as phytoplankton and invertebrates, and is known to interfere with the feeding, growth, survival and reproduction of native fish (Koehn et al. 1995). In turn, CWP can influence the distribution of fish and other aquatic fauna below dams (Humphries and Cook 2004; Richardson et al. 2004). The impacts of CWP can extend significant distances downstream: cold water releases from large dams can reduce water temperature by over 10 °C for more than 300 km downstream (Ball et al. 2001).

3.3.1 Wyangala Dam and the Lachlan River

In terms of water temperature, Lake Wyangala functions like many other large headwater storages in the MDB. The reservoir is relatively well mixed during winter and early spring (June–September), and during this period inflows to the lake are greatest and water temperatures range from 10 to 15 °C (Geo-Eng 2001). Lake Wyangala begins to stratify in spring and is strongly stratified by mid spring (November). Although the strength of stratification varies each year, Lake Wyangala is usually strongly stratified until autumn (Geo-Eng 2001; Preece 2004). Bowling et al. (1995) cited in Preece (2004) found that stratification was strongest in January when surface waters reached 23 °C and bottom waters reached only 11 °C. According to Geo-Eng (2001), minimum water temperatures in Lake Wyangala did not vary greatly during the year (8–12 °C), but average temperature and maximum surface water temperature increased rapidly after September and reached 25–28 °C by January.

The depth of stratification in Lake Wyangala varies throughout the year, but during the spring months, when the irrigation season commences, the depth to which mixing occurs may be as narrow as seven metres (Geo-Eng 2001). The mixing depth deepens from summer onwards until thorough mixing of the lake occurs in winter. Lake Wyangala is currently fitted with two fixed-level intakes, one at 65 m below FSL and the other from 20–34 m below FSL (Preece 2004). Typically, releases from the lake are drawn from the lower intake located in the hypolimnion and, subsequently, cold
water enters the Lachlan River, particularly during the irrigation season (Preece 2004). Burton (2000) found that water temperature directly below Wyangala Dam was depressed by up to 7 °C between November and March.

Based on extrapolation of CWP from other storages, it has been suggested that CWP from Wyangala Dam reduces water temperature as far downstream as 400 km (Lugg 1999). Preece (2004), however, doubted the effects would be experienced quite that far downstream because of the comparatively low levels of discharge. Natural summer water temperatures at Cowra (45 river kilometres from Wyangala Dam) can be reduced by up to 10 °C (DLWC 1998). Burton (2000) found that water temperature below Wyangala Dam recovered to within 1–2 °C by Forbes — about 170 river kilometres. Other reports suggest that summer water temperatures are effected downstream of Forbes (Fisheries Scientific Committee 2005).

Warm water releases from Wyangala Dam occur during June and July (Burton 2000). The magnitude of temperature change is small (4°C) in comparison to cold water releases (10°C) and is thought to recover between Cowra and Forbes. The impact on native fauna is likely to be minimal.

There is evidence that oxygen levels in Lake Wyangala are lower in the hypolimnion than in the surface waters (Geo-Eng 2001). Even during destratification (winter–spring), dissolved oxygen in the hypolimnion only increases to about 50% saturation. Dissolved oxygen levels in the Lachlan River are expected to recover directly below the dam wall.

3.3.2 Cold water pollution mitigation options

A number of options for improving the temperature of irrigation releases from Wyangala Dam have been investigated (Geo-Eng 2001). Only two options were recommended (other options were deemed inappropriate because of existing contractual obligations to run water through the power station, the strength of stratification in Lake Wyangala, cost and/or other practical constraints [Geo-Eng 2001]):

- Local destratification of Lake Wyangala.
- A multilevel offtake.

Local destratification involves pumping a plume of water, of sufficient volume and momentum, down to the offtake levels. This type of system has been successfully fitted and operated in reservoirs in the United States and South Australia. The estimated cost of such a system at Lake Wyangala is in the order of $250 000 in capital cost and $50 000 to operate annually (Geo-Eng 2001).

A multilevel offtake could be installed in Lake Wyangala by constructing a new tower or modifying the existing one. The preferred option is a ‘high level offtake’ as data from the late 1990s indicated that intakes within the top 15 m of the storage range would have met temperature requirements 85% of the time (Geo-Eng 2001). The works would involve excavating two 2.5 × 3 m openings towards the top of the existing tower at an estimated cost of $2 500 000 (Geo-Eng 2001). Sherman (2001) indicated that retrofitting Wyangala Dam would cost up to $10 000 000.
3.3.3 Evaluation of literature

The process of stratification in reservoirs and the effects of cold water releases downstream have been the subject of much scientific literature. It is evident that stratification occurs in Lake Wyangala, although the data on which reports are based are not extensive. The report by Burton (2000) into the altered temperature regime of the Lachlan River below Wyangala Dam was based on a solid data set and provided an excellent level of information. Information on dissolved oxygen levels in Lake Wyangala is limited to an incomplete data set included in Geo-Eng (2001).

3.4 Catchment condition upstream of Lake Wyangala

The quality of inflows from the headwater streams, the upper Lachlan and Abercrombie rivers, is a major determinant of water quality in Lake Wyangala. The long term annual discharges of the upper Lachlan and Abercrombie rivers are 370 000 ML and 300 000 ML, respectively (Travers 1996). Water quality in these headwater streams is dependent on catchment condition; that is, a broad range of factors including underlying geology, past and present land use, and vegetation cover. Collectively, these factors, and others, combine to describe overall catchment condition. The upper Lachlan catchment (including the Crookwell subcatchment) covers 562 040 ha, or just over 6% of the total Lachlan Valley catchment, whilst the Abercrombie subcatchment occupies 264 708 ha (LCMC 1998). Widespread changes to catchment condition can lead to a significant deterioration in water quality (DLWC 1998).

3.4.1 Geology and mineral resources

The geology of the catchment above Lake Wyangala is related to three tectonic zones that are also associated with mineral deposits in the region (Sinclair Knight & Partners 1983). The first tectonic unit, The Molong, occupies most of the catchment and contains flysch sandstones and shale, quartzite, slate and phyllite which are intruded by granite batholiths. Mineralisation in this zone is mostly sparse, but some gold deposits have ‘sweated out’ (Sinclair Knight & Partners 1983). The other two tectonic zones are characterised by developed volcanics and fossil sediments deposited during marine conditions. The Goulburn Synclinorial Zone occupies parts of the eastern and south-eastern extremities of the catchment and contains stratiform deposits of metals such as copper, lead and zinc, and some veins of gold. The Hill End Synclinorial Zone, located around the lower reaches of the Abercrombie River, has similar metal deposits to the Goulburn Zone but vein gold is abundant (Sinclair Knight & Partners 1983).

The catchment above Lake Wyangala is rich in metal deposits, mostly gold, copper, lead, zinc and tungsten, and there are lesser amounts of antimony, tin and iron (Sinclair Knight & Partners 1983). Other mineral deposits also present include sapphire, diamond plus quarry materials such as quartz gravel, marble and barite. Interest in gold deposits in parts of the Abercrombie catchment date back to 1851: the mining of gold and other materials continues (Sinclair Knight & Partners 1983). There are also reports of tin, iron, tungsten, copper, silver and lead mining in the region (Daniel n.d.). Prior to the construction of Wyangala Dam, the area known as Wyangala was used for gold mining — and rabbit trapping (Marriott 1988).
Figure 7 Abercrombie River (Photo by Frances Marston [www.rivers.gov.au/model/images.htm]).

Figure 8 Lachlan River at Reid’s Flat above Lake Wyangala (Photo by G. Rees).
3.4.2 Land use

The influence of catchment land use on water quality is significant and is most easily categorised in terms of pollutants. Point source pollution is normally associated with towns and industry, where pollutants such as salts, nutrients, heavy metals, petroleum products and sediments can enter waterways (DLWC 1998). The widespread clearing of naturally forested land, associated dryland salinity, and the liberal application of fertilisers and pesticides can cause sediments, nutrients and salt to enter waterways via diffuse source pollution.

Much of the land upstream of Lake Wyangala has been cleared for agriculture, particularly parts of the upper Lachlan and Crookwell subcatchments (Table 2). The cleared portions of land are used predominantly for sheep and cattle grazing (Sinclair Knight & Partners 1983). Apart from 13% of the Abercrombie subcatchment, very few densely forested areas remain. Daniel (n.d.) divided the region into 17 sections and found that sheet and gully erosion was prevalent in all of them and, in most sections, sheet erosion was described as moderate and gully erosion as deep.

<table>
<thead>
<tr>
<th>Land use</th>
<th>Abercrombie</th>
<th>Upper Lachlan</th>
<th>Crookwell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grazing — vegetation cleared</td>
<td>33</td>
<td>61</td>
<td>64</td>
</tr>
<tr>
<td>Grazing — vegetation thinned</td>
<td>29</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Grazing — vegetation virgin timber</td>
<td>13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Grazing — sown pasture</td>
<td>12</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Park or reserve area</td>
<td>10</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Irrigated broadacre crops</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Rural residential or urban</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Note: more than one land use can occur at any one site

Heavily forested areas are generally restricted to parts of the Abercrombie subcatchment. Some pine plantations exist in the upper part of that catchment, but there is little potential for significant expansion of this industry (Sinclair Knight & Partners 1983).

The banks of Lake Wyangala are a concern in regard to catchment condition, as was evident during a site visit in March 2005 when the dam was at around 10% of capacity (Figure 10). In some areas there was little vegetation on the banks beyond occasional grass patches and erosion of banks was evident and extensive. In other areas, weeds were prolific and when the lake refills a pulse of carbon and nitrogen is likely to enter the reservoir. This is an extremely difficult situation to manage — removal of weeds will probably increases erosion potential — and may be purely a consequence of low storage levels in the lake over a long period.
3.4.3 Dryland salinity

The widespread clearing of land for European-style agriculture is generally considered the cause for the spread of dryland salinity throughout the MDB (Vaze et al. 2004). Subsequently, river salinity is influenced by the amount of land salinisation within a catchment (DLWC 1998). One process by which this occurs is when the water table rises, as a response to the removal of deep-rooted vegetation, and salts from groundwater are concentrated at the soil surface. Here, the salts are easily mobilised during rainfall and transported into streams (Thurtell and Burton 2003).

Widespread land-use change is the driving force behind increased dryland salinity in the Lachlan catchment (DLWC 1998). According to Moore and Joyce (1998), the upper Lachlan subcatchment is showing visible signs of dryland salinity. The upper Lachlan is thought to contribute large amounts of salt into Lake Wyangala (Moore and Joyce 1998; Thurtell and Burton 2003). The catchment of the Boorowa River, which enters the Lachlan River between Wyangala Dam and Cowra, has visible signs of dryland salinity throughout (Moore and Joyce 1998). Extensive remedial works have been undertaken to arrest the spread of dryland salinity in the Boorowa catchment (Freudenberger et al. 2004; Vaze et al. 2004).

3.4.4 Nutrient sources

Although the nutrients phosphorus and nitrogen are essential for plant growth, excessive amounts of either can cause significant problems in waterways (DLWC 1998). Phosphorus, in particular, is poorly represented in the soils and geology of the Lachlan catchment (LCMC 1998). Nutrients are widely applied to increase agricultural production and, generally, can find their way into waterways attached to...
sediments during rainfall events — diffuse source pollution. Point sources of nutrients include sewage treatment plants and saleyards. The relative contributions of point and diffuse sources by land use type are given in Table 3.

Table 3: Contributors of point source pollution upstream of Lake Wyangala and estimated annual loads. Taken from LCMC (1998).

<table>
<thead>
<tr>
<th>Point source</th>
<th>Phosphorus (kg yr⁻¹)</th>
<th>Nitrogen (kg yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boorowa sewage treatment plant</td>
<td>1002.0</td>
<td>3607.0</td>
</tr>
<tr>
<td>Crookwell sewage treatment plant</td>
<td>263.0</td>
<td>946.8</td>
</tr>
<tr>
<td>Gunning sewage treatment plant</td>
<td>180.0</td>
<td>648.0</td>
</tr>
<tr>
<td>Wyangala Dam sewage treatment plant</td>
<td>75.0</td>
<td>270.0</td>
</tr>
<tr>
<td>Wyangala Waters sewage treatment plant</td>
<td>75.0</td>
<td>270.0</td>
</tr>
<tr>
<td>Boorowa Saleyards</td>
<td>6.3</td>
<td>23.5</td>
</tr>
<tr>
<td>Crookwell Saleyards</td>
<td>23.5</td>
<td>76.6</td>
</tr>
</tbody>
</table>

Streambank and gully erosion, unsealed roads, salt outbreaks and horticulture contribute significant amounts of phosphorus and nitrogen in the Lachlan catchment (Table 4). However, mixed farming and grazing contribute most to predicted nutrient loads in the Lachlan catchment, despite the generation rates of these land use types being relatively low. Mixed farming and grazing are the most extensive land use types in the catchment and, combined, contribute 84% of the total phosphorus load and 89% of the total nitrogen load (LCMC 1998).

There are marked differences in the average nutrient generation rates and loads of each of the subcatchments upstream of Lake Wyangala. The LCMC report separated the area into five subcatchments: Lachlan headwaters, Lachlan River above Crookwell River, Lachlan River below Crookwell River, Abercrombie River and Wyangala Dam (LCMC 1998). The highest phosphorus and nitrogen generation rates occurred in the Lachlan headwaters and the lowest in the Abercrombie River and Wyangala Dam and surrounds (Table 5).

It should be noted that whilst most nutrients are generated from diffuse sources, nutrients entering waterways from point sources play a critical role in water quality problems such as blue-green algal bloom (see Section 3.6.5).
Table 4  Nutrient generation rates in the Lachlan Valley (kg ha\(^{-1}\) yr\(^{-1}\)). Taken from LCMC (1998).

<table>
<thead>
<tr>
<th>Land use type</th>
<th>Phosphorus (kg ha(^{-1}) yr(^{-1}))</th>
<th>Nitrogen (kg ha(^{-1}) yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Urban, established</td>
<td>1.00</td>
<td>7.5</td>
</tr>
<tr>
<td>Village, unsewered, &lt;600 mm</td>
<td>1.10</td>
<td>6.5</td>
</tr>
<tr>
<td>Village, unsewered, &gt;600 mm</td>
<td>1.60</td>
<td>9.0</td>
</tr>
<tr>
<td>Rural residential, &lt;600 mm</td>
<td>0.50</td>
<td>3.0</td>
</tr>
<tr>
<td>Rural residential, &gt;600 mm</td>
<td>0.60</td>
<td>4.00</td>
</tr>
<tr>
<td>Horticulture, Annual, Irrigated</td>
<td>2.70</td>
<td>20.0</td>
</tr>
<tr>
<td>Horticulture, Perennial</td>
<td>1.40</td>
<td>14.0</td>
</tr>
<tr>
<td>Cropping, Annual, Irrigated</td>
<td>1.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Cropping, perennial, irrigated</td>
<td>0.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Cropping, dryland, &gt;550 mm</td>
<td>0.7</td>
<td>6.0</td>
</tr>
<tr>
<td>Mixed farming, &gt;550 mm</td>
<td>0.8</td>
<td>14.0</td>
</tr>
<tr>
<td>Grazing, improved pastures, 500–700 mm</td>
<td>0.35</td>
<td>6.0</td>
</tr>
<tr>
<td>Grazing, improved pastures, &gt;700 mm</td>
<td>0.55</td>
<td>8.0</td>
</tr>
<tr>
<td>Grazing, unimproved pastures, 500–700 mm</td>
<td>0.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Grazing, unimproved pastures, &gt;700 mm</td>
<td>0.27</td>
<td>6.4</td>
</tr>
<tr>
<td>Dairy grazing</td>
<td>1.1</td>
<td>6.8</td>
</tr>
<tr>
<td>National Parks/Nature Reserves</td>
<td>0.04</td>
<td>2.0</td>
</tr>
<tr>
<td>Native forestry, grazed</td>
<td>0.08</td>
<td>2.20</td>
</tr>
<tr>
<td>Plantation forestry</td>
<td>0.06</td>
<td>1.0</td>
</tr>
<tr>
<td>Streambank/gully erosion (Class 71–104)</td>
<td>6.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Roads, unsealed (only &gt; 550 mm)</td>
<td>5.00</td>
<td>25.0</td>
</tr>
<tr>
<td>Salt outbreak</td>
<td>5.00</td>
<td>25.0</td>
</tr>
</tbody>
</table>

Table 5  Average nutrient generation rates in subcatchments of the upper Lachlan Valley. Taken from LCMC (1998).

<table>
<thead>
<tr>
<th>Land use</th>
<th>Phosphorus: Rate and Load</th>
<th>Nitrogen: rate and Load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg ha(^{-1}) yr(^{-1})</td>
<td>kg yr(^{-1})</td>
</tr>
<tr>
<td>Lachlan headwaters</td>
<td>0.41</td>
<td>24 493</td>
</tr>
<tr>
<td>Lachlan River above Crookwell R.</td>
<td>0.38</td>
<td>51 427</td>
</tr>
<tr>
<td>Lachlan River below Crookwell R.</td>
<td>0.36</td>
<td>23 727</td>
</tr>
<tr>
<td>Abercrombie River</td>
<td>0.32</td>
<td>85 404</td>
</tr>
<tr>
<td>Wyangala Dam and surrounds</td>
<td>0.28</td>
<td>48 996</td>
</tr>
</tbody>
</table>
3.4.5 River condition and water quality

Two reports have assessed river condition in the upper Lachlan and Abercrombie catchments, and the Crookwell subcatchment. Each report has adopted slightly different techniques. *An Assessment of Riverine Corridor Health in the Lachlan Catchment* (Massey 1998) used the following parameters:

- Reach environment condition
- Bank stability
- Bed and bar stability
- Aquatic habitat conditions
- Riparian vegetation condition
- Aquatic vegetation condition
- Conservation value
- Scenic and recreation value.

Overall riverine environment condition was assessed by collecting data from numerous waterways in the two major catchments and one subcatchment. This included a total of 48 sites across the Abercrombie catchment, 67 sites in the upper Lachlan and 15 sites in the Crookwell. Although the Abercrombie catchment was in relatively better condition, than the other two catchments, 46% of the Abercrombie catchment was considered to be in poor condition (Table 6).

<table>
<thead>
<tr>
<th>Riverine environment condition</th>
<th>Abercrombie</th>
<th>Upper Lachlan</th>
<th>Crookwell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>26</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>22</td>
<td>31</td>
<td>45</td>
</tr>
<tr>
<td>Poor</td>
<td>46</td>
<td>64</td>
<td>55</td>
</tr>
</tbody>
</table>

A different classification system was used in the *Stressed Rivers Assessment Report* for the Lachlan catchment (Love *et al.* 1999). In this report, there were nine categories based on levels of hydrologic and environmental stress. Hydrologic stress related to a hydrologic index (water usage/streamflow) and the assessment of environmental stress was based on parameters similar to those used by Massey (1998). They were:

- River bank stability
- Bed and bar stability
- Riparian vegetation
- Aquatic vegetation
- Presence of structures (such as weirs) in the stream channel.
Love et al. (1999) concluded that the Abercrombie River was under low hydrologic stress and medium environmental stress, and was of high conservation value. The conservation value of the Abercrombie River had been identified by the National Parks and Wildlife Service (NPWS) and NSW Fisheries. The Lachlan River above Reid’s Flat had high hydrologic stress and high environmental stress, but was also of high conservation value — previously recognised by NSW Fisheries. The Crookwell River had low hydrologic stress and medium environmental stress, but was not of high conservation value. Most of the environmental stress across all catchments was due to very poor riparian vegetation condition and the high number of instream structures.

**Salinity**

At least two studies have investigated stream salinity levels upstream of Lake Wyangala. Moore and Joyce (1998) sampled at sixteen sites above the lake during 1993 and 1994 and found that the Abercrombie River had lower salinity levels than the Crookwell and upper Lachlan rivers. The Abercrombie River consistently recorded levels of below 500 µS cm⁻¹, the Crookwell River was usually between 400 and 600 µS cm⁻¹, but the upper Lachlan River was usually between 1000 and 1200 µS cm⁻¹ (Moore and Joyce 1998). The upper limit for drinking water is 800 µS cm⁻¹ (or EC) — discernible taste at this level — and major biological effects can be measured at 1500 EC (MDBMC 1999; Neilsen et al. 2003). Although discharges into Lake Wyangala from the Abercrombie and upper Lachlan rivers are similar, the upper Lachlan contributes twice as much of the salt load into the dam (Moore and Joyce 1998). Similar results were found when salinity levels were measured fortnightly between July 2000 and June 2001 (Thurtell and Burton 2003). The upper Lachlan River averaged 600–700 µS cm⁻¹ — and often exceeded 800 µS cm⁻¹ — whereas the Crookwell and Abercrombie rivers averaged 385 and 279 µS cm⁻¹, respectively.

**Nutrients**

Two separate studies include nutrient data upstream of Lake Wyangala: the DLWC Key Sites Water Quality Monitoring Program (1992–1996), as reported in LCMC (1998b); and the water quality study by Thurtell (2003) collected data fortnightly between April 1999 and November 2000. Both studies obtained nutrient samples from the upper Lachlan River at Numby and the Abercrombie River at Abercrombie. The study by Thurtell (2003) also included nutrient data from three other sites upstream of the lake: the Lachlan River at Narrawa, the Crookwell River at Narrawa North, and Rocky Bridge Creek in the Abercrombie catchment. Phosphorus levels in streams above Lake Wyangala were heavily influenced by flow, with peak concentrations occurring just prior to peak inflows (Thurtell 2003).

| Table 7. Water quality ratings used for DLWC reporting (LCMC 1998). |
|---------------------------------|-----------------|-----------------|-----------------|
| Indicator                      | Good            | Fair            | Poor            |
| Total phosphorus (µg P/L)      | <20             | 20–50           | 50              |
| Salinity — EC (µS/cm)          | <280            | 280–800         | >800            |
| Turbidity (NTU)                | <5              | 5–50            | >50             |
| Blue-green algae (cells/mL)    | <2000           | 2000–15000      | >15000          |

27
In the DLWC report, total phosphorus (TP) levels in the upper Lachlan River (1992–1996) averaged 49 µg L⁻¹ with a range of 1–77 µg L⁻¹. According to DLWC ratings, average TP in the upper Lachlan River was ‘fair’ and the maximum recorded was ‘poor’ (Table 7). TP in the Abercrombie River averaged 32 µg L⁻¹ (fair) and ranged between 10 and 50 µg L⁻¹ for the same period (LCMC 1998). Thurtell (2003) assessed TP, and other nutrients, against default trigger values recommended for upland rivers by the Australian and New Zealand Environment and Conservation Council (ANZECC) — the trigger value for TP of 20 µg L⁻¹ equates to ‘good’ water according to DLWC reporting (ANZECC 2000; LCMC 1998). All median TP levels were below the trigger values for upland rivers; however, mean values for both sites in the upper Lachlan (Narrawa and Numby) and at Crookwell were above the trigger value of 20 µg L⁻¹. The two sites in the Abercrombie catchment exceeded the trigger value for TP on fewer occasions than all other sites (Thurtell 2003).

The mean and median values for total nitrogen (TN) were above the default trigger level for upland rivers (250 µg L⁻¹) at all sites (Thurtell 2003). Average and maximum TN levels, as with TP, were lower at the Abercrombie sites compared to all sites in the upper Lachlan and Crookwell rivers. TN exceeded the default trigger level 75% of the time at Rocky Bridge Creek compared with 96% in the Crookwell River (Thurtell 2003). TN values above 1000 µg L⁻¹ frequently occurred at Narrawa and Numby and on fewer occasions at Crookwell.

**Turbidity**

Turbidity levels in the upper Lachlan River were generally higher than in the Crookwell and Abercrombie rivers (Thurtell 2003). However, all sites sampled had generally low turbidity levels and were below the default trigger level 80% of the time — the default trigger level for upland rivers is 2–25 NTU. The trigger level was usually only exceeded during periods of major run-off (local rainfall). Widespread erosion in the upper Lachlan catchment was considered the likely cause of the high turbidity rates recorded in the upper Lachlan River (300–400 NTU). High turbidity usually corresponded with higher levels of nutrients, particularly phosphorus (Thurtell 2003).

**Aquatic fauna**

Despite a paucity of published (and unpublished) studies or reports, the rivers upstream of Lake Wyangala are regarded highly for their stocks of native fish. Notably, the rivers upstream of Lake Wyangala are absent from the recommendation that the Lachlan River be declared an endangered ecological community (Fisheries Scientific Committee 2005). Limited populations of Macquarie perch (*Macquaria australasica*) occur in the Abercrombie catchment, according to Richardson (1987) — this species is vulnerable and totally protected in these waters (NSW Fisheries 2002, 2004). Other native fish thought to occur upstream of Wyangala Dam include river blackfish (*Gadopsis marmoratus*), silver perch (*Bidyanus bidyanus*), flathead gudgeon (*Philypnodon grandiceps*), Murray cod (*Maccullochella peeli*), golden perch (*M. ambigua*) and catfish (*Tandanus tandanus*). The Abercrombie and upper Lachlan Rivers are also considered ‘notified’ streams for trout — brown trout (*Salmo trutta*) and rainbow trout (*S. gairdnerii*) (NSW Fisheries 2004). Common carp (*Cyprinus carpio*) are also present in these streams (DLWC 1998).
A study of the macroinvertebrate communities in the Lachlan River and its tributaries found greatest species richness above Wyangala Dam (Suter 1997). The Abercrombie and upper Lachlan Rivers recorded over 70 macroinvertebrate taxa and the Crookwell River recorded over 100 taxa. The diversity of taxa found upstream of Wyangala Dam was similar to that in the upper catchment of the River Murray (Suter 1997).

### 3.4.6 Catchment management

High water quality in headwater streams is essential for (at the least) reasonable quality water in Lake Wyangala and the Lachlan River further downstream. Therefore, comprehensive management of the Abercrombie and upper Lachlan catchments is critical. Some of the current and potential threats, posed by the catchment upstream of Lake Wyangala on the downstream environment, have been identified in reports and studies. Several catchment management actions to ameliorate environmental impacts have also been suggested.

![Figure 10](www.rivers.gov.au/model/images.htm) The upper Lachlan River (Photo by Nicki Daws)

The Soil Conservation Service (SCC) reported the community’s perspective on catchment management issues (SCC c. 1991). In the headwaters of the Lachlan catchment, a number of major and minor issues were identified and included:

- The decline of native vegetation (trees and pastures).
- Noxious and nuisance weeds around Lake Wyangala and the upper Abercrombie River.
- Soil erosion, particularly gully erosion.
- Nutrients entering water storages and exacerbating algal blooms.
- Dryland salinity.
Some of the suggested actions overlap and would assist in the management of several issues simultaneously. For example, ‘accelerated revegetation’ and ‘stock exclusion’ would help combat native vegetation decline, erosion and dryland salinity. Similarly, excluding stock from gullies and riparian zones would reduce erosion and nutrient input to waterways.

Nutrients occurred in high enough concentrations to impact on aquatic communities in Lake Wyangala (Thurtell 2003). Effective nutrient management should operate at the catchment scale given the scope of nutrient sources; management should target those areas and sources that make the greatest nutrient contribution (LCMC 1998). The upper Lachlan catchment requires erosion controls and could specifically target first and second order streams, unsealed roads and salt-affected areas (LCMC 1998; Thurtell 2003). Agricultural practices, namely frequent tillage and fertiliser application, contribute significant concentrations of nutrients to waterways, and should be managed appropriately (LCMC 1998). Concentrations of phosphorus entering Lake Wyangala should be minimised in the future because of the lake’s low buffering capacity (Joyce 1998).

The upper Lachlan River was identified as a priority area for stream salinity management because of the large amounts of salt being exported downstream (Moore and Joyce 1998). Recommended management actions included the removal of noxious weeds and extensive tree planting to lower groundwater and reduce erosion. Although other rivers upstream of Lake Wyangala are less salt-affected, in particular the Abercrombie River, they must remain so: otherwise, the capacity to dilute saline flows into Lake Wyangala from the Lachlan River will be diminished (Thurtell 2003). Proactive catchment management should prevent land management practices that promote dryland salinity in these subcatchments.

3.4.7 Evaluation of literature

The literature on catchment condition demonstrates a good general understanding of many of the potentially threatening processes to water quality in Lake Wyangala. Furthermore, strategies and actions to ameliorate the effects of identified threatening catchment processes have been detailed in reports such as the Lachlan Catchment Blueprint 2002–2012 (LCMB 2001). There are, however, other potential catchment influences that haven’t been studied in sufficient detail. For example, there is a history of mining in the catchment yet there are no reports of investigations into potential pollutants — such as acid, mercury and cyanide — from abandoned mine sites. The wetting and drying cycles of other aquatic ecosystems are known to influence nutrient concentrations (Baldwin and Mitchell 2000). Lake storage levels above dams used primarily for summer irrigation tend to fluctuate substantially and, subsequently, considerable areas of land are wetted and dried annually.

3.5 Sedimentation

Dams act as traps for river sediments, allowing the deposition and accumulation of the river’s suspended load in the reservoirs upstream of them (Boulton and Brock 1999; McCully 1996). This build up of sediments is a major concern for dam managers as it can reduce storage capacity and impact on dam function (Poff and Hart 2002).
Sediments entering a reservoir may be sourced from surface soils in the catchment, stream banks and beds and from the dam banks. Sedimentation rates are governed by factors such as geology, slope, land use and vegetation cover, and can vary greatly among catchments (Poff and Hart 2002).

Sedimentation has a number of functions in the movement and transformation of pollutants, such as nutrients and heavy metals, and can, therefore, significantly affect water quality. Sediment particles can readily adsorb pollutants, such that sediment deposition may be an important pathway for the removal of pollutants from the water column. The re-suspension of sediments may allow pollutants to re-enter the water column, facilitating their transport through an aquatic ecosystem. The chemical composition of pollutants can be transformed by the various biotic and abiotic processes associated with sediments.

Sediments derived from surface soils are of particular concern to dam managers, especially in catchments where significant parcels of native vegetation have been cleared for agriculture. After rainfall events, erosion in these areas can be extensive and hazardous to aquatic ecosystems (Poff and Hart 2002). In agricultural areas, surface soils are likely to carry enhanced concentrations of phosphorus from fertilisers or biological cycling (Norrish and Rosser 1983; Richardson 1994). Sediments derived from stream bank and bed erosion consist mostly of subsoils and will only contain phosphorus derived from rock weathering.

### 3.5.1 Lake Wyangala

Sediment deposits in Lake Wyangala differ in comparison to deposits behind other large dams. According to Outhet (1984), the large variation in water levels — a combination of irrigation demand and catchment rainfall (10–100% in a year) — produces a very different set of sediment deposits than would naturally occur. There were three main types of deposit in Lake Wyangala: main basin deposit, tributary arm deposit and channel deposit (Outhet 1984). Main basin deposit was faintly coloured laminate of uniform medium clay texture with an average thickness of 150 mm; it is formed by fine particles settling slowly out of still water (Outhet 1984). The tributary arm deposit runs in an upstream direction away from the main basin deposit. Sediment is coarser, lighter in colour and colour laminations become more distinct the further upstream. Tributary arm deposit is formed by particles settling out from running water with less velocity and turbulence downstream (Outhet 1984). The channel deposit thins near the dam wall and near the upstream backwater limit, and is composed of ‘…many layers of contrasting texture which are interbedded clays, silts and sands’ (Outhet 1984, p. 80). The laminated channel deposit is the consequence of a highly variable depositional environment, moving and still water and a variable sediment load. One of the causes of this variation is inflows moving along the exposed original channel when water level in the lake is low, and another is occasional density or turbidity currents moving along submerged original channels when the lake is closer to capacity (Outhet 1984).
3.5.2 Evaluation of literature

Only the one study has investigated sediment deposition in Lake Wyangala and, consequently, understanding of this subject is poor. Sediment deposition is generally a key driver of water chemistry processes in large water storages and, given that the suite of deposits in Lake Wyangala are different than other lakes, it is a process that warrants further study. Future studies should investigate aspects of sedimentation such as rates, sediment quality (e.g. nutrient levels) and sources.

3.6 Water quality

This section is primarily concerned with water quality in Lake Wyangala, but water quality downstream of the dam is also discussed (Section 3.6.7). The quality of water in large storages is usually influenced by a number of factors. In the case of Lake Hume on the River Murray, sediment deposition, prolonged anoxia through stratification, and repeated wetting and drying cycles in the upper reaches of the reservoir were considered the key drivers of water quality (Howitt et al. 2005). Existing knowledge of some of the likely drivers of water quality in Lake Wyangala — catchment condition, sedimentation and stratification, for example — is detailed in previous sections. Predictions of some of the internal chemical processes occurring in Lake Wyangala have been based primarily on differences between inflows to the reservoir and downstream discharge (Thurtell 2003; Thurtell and Burton 2003).

In this section, data collected irregularly between 1986 and 2005, from various locations within Lake Wyangala and directly downstream, were analysed and used to generate a more informed understanding of water chemistry processes in the lake — this data was collected and supplied by State Water. Although the data contained many parameters that had been examined during the period 1986–2005, for many parameters the data coverage was sketchy and insufficient to properly describe either the range of the variable or the long-term trends. Analysis of the data set was limited, therefore, to pH, electrical conductivity, total nitrogen and total phosphorus at the Lachlan River Station (directly downstream of the dam wall), Station 1 (dam wall), Station 2 (Grabine State Recreation Area), Station 3 (Lachlan Arm) and Station 5 (Abercrombie Arm).

3.6.1 pH

pH was measured intermittently over the 1986–2005 period, with about 50 separate sampling dates at Station 1 (dam wall) — usually at more than one depth — and somewhat fewer measurements at the other stations. There was no noticeable difference between samples taken at the surface and at depth for Stations 1–5, so for data analysis, surface and depth samples were combined for each station.

The range of pH at the four stations within Lake Wyangala and the station directly downstream of the dam wall are illustrated by box and whisker plots (Figure 11). The pH results indicate that the water in Lake Wyangala is slightly alkaline. In fact, many of the pH measurements taken at the dam wall (Station 1) and the Lachlan River downstream were outside the range recommended for lowland rivers, freshwater lakes and reservoirs (6.5–8.0: ANZECC 2000).
When all the pH data for Lake Wyangala were combined — all stations and all depths — and plotted against time, there is evidence that pH in the reservoir is increasing (Figure 12). Although the data are highly variable, there is a positive correlation between time and pH ($r^2 = 0.32$). This trend to more alkaline conditions contradicts other studies that suggest some inland waters are becoming more acidic (Hart et al. 1997; Howitt et al. 2005).

[Figure 11: Box and whisker plot showing the range of pH measured in Lake Wyangala and downstream. The box borders the 25th and 75th percentiles, the median is represented by the solid line within the box, the mean by the dotted line, the whisker caps encompass the 10th and 90th percentiles and outliers are marked as symbols. Raw data supplied by B. Hindmarsh (State Water).]
Figure 12 pH data from all stations at Lake Wyangala combined and plotted against time. Correlation between time and pH ($r^2 = 0.32$). Raw data supplied by B. Hindmarsh (State Water).

Figure 13 Box and whisker plot showing the range of EC levels in Lake Wyangala and downstream. The box borders the 25th and 75th percentiles, the median is represented by the solid line within the box, the mean by the dotted line, the whisker caps encompass the 10th and 90th percentiles and outliers are marked as symbols. Raw data supplied by B. Hindmarsh (State Water).
3.6.2 Salinity

A twelve-month study (2000–2001) concluded that Lake Wyangala may be diluting salt concentrations in the Lachlan River downstream. This process was facilitated by the storage of floodwaters and the relatively low salt level inflows from the Abercrombie River (Thurtell and Burton 2003). However, that study did not sample salinity levels in Lake Wyangala and, instead, based its findings on differences between inflows to the lake (Section 3.4.5) and outflows. Here we describe salinity concentrations in Lake Wyangala based on raw data supplied by State Water.

Electrical conductivity (EC) was measured at the same time as pH at the same five sites (Figure 13). Lake Wyangala consistently exceeded the ANZECC default trigger levels for EC in lakes and reservoirs (20–30 µScm⁻¹: ANZECC 2000). The EC levels recorded in Lake Wyangala were, however, well below the 1500 EC threshold at which salt is thought to impact on aquatic biota (Nielsen et al. 2003). The data also showed that salinity levels in the Lachlan Arm of Lake Wyangala (Station 3) were statistically higher (t-test: p<0.001) than levels in the Abercrombie Arm (Station 5).

![Figure 14](image)

**Figure 14** Electrical conductivity (EC) levels — surrogate for salinity — at all stations in Lake Wyangala as a function of time. Raw data supplied by B. Hindmarsh (State Water).
When all of the EC data for Lake Wyangala were combined — all stations and all depths — and plotted against time, there was evidence that salinity in the reservoir is increasing (Figure 14). After reaching a maximum in the mid-1990s, EC levels in Lake Wyangala declined towards the end of the century, but since then there has been an almost linear increase in salinity. This increase has also been observed in the Lachlan River directly downstream of the dam. Whether this increase simply reflects the decline in water levels in the reservoir during the same period or an increase in saline inflows to the reservoir cannot be unequivocally determined from the data. However, there is strong evidence that salinity in the Lachlan Arm (Station 3) of Lake Wyangala has increased over time (Figure 15: $r^2=0.56$).

![Figure 15](image)

**Figure 15** Electrical conductivity (EC) levels — surrogate for salinity — at Station 3 (Lachlan Arm). Correlation between time and EC ($r^2=0.56$). Raw data supplied by B. Hindmarsh (State Water).

### 3.6.3 Nutrients: phosphorus and nitrogen

There has been a relatively good sampling regime for total phosphorus (TP) and total nitrogen (TN) in Lake Wyangala, with over 100 sampling occasions at Station 1 (dam wall) at, usually, more than one depth. Samples at multiple depths were also taken at Station 2 (Grabine State Recreation Area), Station 3 (Lachlan Arm) and Station 5 (Abercrombie Arm) on most sampling occasions.

Levels of TP consistently exceeded the ANZECC default trigger levels for lakes and reservoirs (0.01 mg L$^{-1}$), but were often below the trigger level for lowland rivers (0.05 mg L$^{-1}$) (ANZECC 2000). There is some evidence for the accumulation of TP
in the deeper waters (hypolimnion) of Lake Wyangala; demonstrated by the greater mean and median of TP in deep water samples compared to surface samples collected at Station 1 (dam wall). Similar phenomena were observed at other stations (Figure 16).

There was insufficient data to explore reactive or organic phosphorus in Lake Wyangala.

Figures 16 Box and whisker plots showing the range of total phosphorus in surface waters (0.25m) and deep waters (>10m) in Lake Wyangala and downstream. The box borders the 25th and 75th percentiles, the median is represented by the solid line within the box, the mean by the dotted line, the whisker caps encompass the 10th and 90th percentiles and outliers are marked as symbols. Raw data supplied by B. Hindmarsh (State Water).

Concentrations of total nitrogen (TN) in Lake Wyangala, particularly in the deeper waters of the hypolimnion, consistently exceeded the ANZECC trigger levels for total Kjeldahl N in lakes and reservoirs (0.35 mg L^{-1}) and lowland rivers (0.50 mg L^{-1}: ANZECC 2000). There were clear differences between the concentrations of TN in the surface waters compared to deeper waters, suggesting nitrogen accumulation in the hypolimnion (Figure 17).

As noted previously, on most sampling occasions, samples were taken at more than one depth — usually at the surface and near the bottom of each station within the lake. When the difference between the concentration of TN in the surface water and
TN concentrations in the deeper waters (hypolimnion) were plotted at Station 1 (dam wall), it was apparent that on most occasions water in the hypolimnion contained more TN than the surface water (Figure 18). Greater concentrations of TN in the hypolimnion were also observed at the other three stations within Lake Wyangala. Indeed, of the 89 occasions where both surface and deep waters were sampled for TN, the deep waters (hypolimnion) were enriched relative to the surface water on 68 of those occasions; on 16 occasions the surface waters were TN enriched, and on only five occasions was there no difference. Similar patterns were observed at the other three stations in Lake Wyangala.

There were insufficient data to explore ammonia and nitrate distributions in the lake.

![Box and whisker plots showing the range of total nitrogen in surface waters (0.25m) and deep waters (>10m) in Lake Wyangala and downstream.](image)

**Figure 17** Box and whisker plots showing the range of total nitrogen in surface waters (0.25m) and deep waters (>10m) in Lake Wyangala and downstream. The box borders the 25th and 75th percentiles, the median is represented by the solid line within the box, the mean by the dotted line, the whisker caps encompass the 10th and 90th percentiles and outliers are marked as symbols. Raw data supplied by B. Hindmarsh (State Water).
3.6.4 Turbidity

The following turbidity characteristics of waters in Lake Wyangala were reported in the *Lachlan Catchment: State of the Rivers Report*. For the seasons 1993/94, 1994/95 and 1995/96, turbidity levels in Lake Wyangala were considered ‘low–moderate’, ‘low’ and ‘moderate’, respectively (DLWC 1998).

Turbidity levels in the Lachlan River and its tributaries above Forbes are generally low and within the ANZECC guidelines for upland streams (<25 NTU for upland streams: ANZECC 2000). However, Thurtell (2003) found that Lake Wyangala suppressed turbidity levels in the Lachlan River by trapping suspended solids and other material following rainfall in the catchment upstream.

3.6.5 Blue-green algae

Blue-green algae are not in fact algae, but cyanobacteria. And, as with other small, free floating photosynthetic organisms, they are an important component of aquatic ecosystems and respond rapidly to altered environmental conditions (Hötzel and Croome 1999). Environmental conditions that can encourage or exacerbate algal blooms — an event of excessive growth — include stratification, high nutrient concentrations, high water temperatures, abundant sunlight, calm waters, low turbidity and high pH (DLWC 1998). Blue-green algal blooms have a wide range of
social, economic and environmental impacts as they threaten human and animal health (LCMC 1998). Large blooms can create major problems for town, stock and domestic users when they occur in water supplies (Central West Regional Algal Coordinating Committee (CWRACC) c.2004). During HIGH alert conditions (see below), water is presumed unsafe for human contact or stock and domestic supply (LCMC 1998).

A number of agencies have responsibilities in regard to the monitoring, management and reporting of blue-green algae in Lake Wyangala (CWRACC c.2004). DIPNR is responsible for coordinating monitoring of surface waters, preparing weekly status reports, developing catchment management strategies and issuing press release warnings. State Water Corporation is responsible for the monitoring of storages, the implementation of control measures and preparation of weekly reports during major blooms (other agencies with responsibilities include NSW Agriculture, Department of Health, DEC and local governments).

The first recorded major blue-green algal bloom in Lake Wyangala was in 1993/94; previous to that event, algal blooms in the reservoir had been rated as low-moderate only (LCMC 1998). The 1993/94 event at Lake Wyangala was followed by another major bloom in 1995/96 and since then they have become an annual event. Although algal blooms in Lake Wyangala may be exacerbated during dry periods, as suggested by the LCMC (LCMC 1998), they occur, seemingly, regardless of storage level. The CWRACC uses the following blue-green algal alert levels: LOW alert (500–2000 cells mL⁻¹), MEDIUM alert (2000–15 000 cells mL⁻¹) and HIGH alert (>15 000 cells mL⁻¹; CWRACC c.2004). The period during which HIGH alert levels are reached tends to be October–May: the 1993/94 bloom extended from October to May and the 1995/96 bloom extended from November to May, but it is unclear whether a HIGH alert was maintained throughout these periods (LCMC 1998). During the 2004/05 water season, blue-green algae levels were HIGH from 7 December to 27 January, and again from 7 March through to 30 March (DIPNR 2004c, 2005). On a site visit in March 2005, blue-green algae were evident in the Abercrombie Arm of Lake Wyangala (personal observation).

Most of the major causes of blue-green algal blooms are apparent at Lake Wyangala, and the timing of blooms is consistent with those major causes (e.g. stratification, nutrient levels, low turbidity, high water temperature). However, better knowledge of blue-green algae in the reservoir may be of benefit to managers. For example, there may be some regions within the lake more prone to algal blooms than other areas, and the movement of algae through the water column may be important when considering offtake options. There is already a significant body of knowledge, and data, of many of the contributing factors to algal blooms in Lake Wyangala such as temperature profiles, stratification, nutrients and turbidity, and State Water Corporation currently regularly samples at four locations within the reservoir. This data/knowledge could be used to generate a model of the movement of blue-greens in the storage. Additional information, such as Chlorophyll a and algal types (genera), may also be useful.
3.6.6 Faecal coliform

Water quality can be significantly reduced by bacteria entering via waste discharges from farms and towns and recreation areas. Human contact with disease-producing organisms poses a significant health risk and can result in the contraction of respiratory and gastro-intestinal infections, viruses, skin, eye and ear infections (Martin 1991).

DLWC (1998) summarised a study of bacteria levels in the Lachlan River and indicated that levels of faecal coliform in Lake Wyangala were generally acceptable. An earlier study of bacteriological conditions in Lake Wyangala found that the Department of Health guidelines for ocean bathing waters were exceeded on only one occasion (Martin 1991).

3.6.7 Water quality downstream of Wyangala Dam

Wyangala Dam directly impacts on water quality downstream. The effects of cold water pollution on water temperatures in the Lachlan River downstream of the dam were discussed in Section 3.3.1. Wyangala Dam also impacts on a range of other water quality parameters (Thurtell 2003; Thurtell and Burton 2003).

Sediments with attached phosphorus appear to settle in Lake Wyangala (Thurtell 2003). Total phosphorus (TP) concentrations immediately downstream of Wyangala Dam were lower than TP concentrations entering the lake from the Abercrombie and upper Lachlan rivers (see Section 3.4.5). TP concentrations directly downstream of Wyangala Dam only exceeded the upland river trigger level 6% of the time (Thurtell 2003). TP concentrations generally increased further downstream in the Lachlan River and are influenced by catchment land use and inflows from the Boorowa and Belubula rivers (Thurtell 2003). Approximately 80 km downstream of Wyangala Dam, TP concentrations in the Lachlan River exceeded the upland trigger level 81% of the time. TP concentrations continue to increase below Forbes, such that the default trigger level for lowland rivers (50 µg L⁻¹) is exceeded at Corrong (lower Lachlan River) 90% of the time (Thurtell 2003).

Higher concentrations of total nitrogen (TN) occurred immediately downstream of Wyangala Dam compared to TN concentrations of lake inflows (Section 3.4.5). According to Thurtell (2003), Wyangala Dam contributed to higher concentrations of nitrogen to the Lachlan River downstream. Whereas TN in the Abercrombie and upper Lachlan rivers exceeded the trigger level for upland rivers 48 and 68% of the time respectively, TN concentrations directly below Wyangala exceeded the same trigger level at least 98% of the time. All sites along the Lachlan River between Wyangala and Forbes had average (mean and median) TN above the default trigger level for upland rivers (250 µg L⁻¹), and all sites in the lower Lachlan had average TN concentrations well above the trigger level for lowland rivers (500 µg L⁻¹; Thurtell 2003).

The different relationship between TP and TN concentrations immediately downstream of Wyangala Dam, compared to all other Lachlan River sites, is likely to be influenced by the frequent large algal blooms in the lake (Thurtell 2003).
Turbidity levels and concentrations of suspended solids averaged about the same immediately above and below the dam wall. The lake did, however, dampen the influence of high flow events, as there were significantly fewer outliers — high turbidity and greater concentrations of suspended solids — directly below the dam (Thurtell 2003). Turbidity levels between Wyangala and Forbes were usually below the trigger level for upland streams (25 NTU), but the Lachlan River further downstream exceeded the trigger level for lowland streams (50 NTU) more than 20% of the time (Thurtell 2003).

A study of salinity levels in the Lachlan River found that salt concentrations were diluted in Lake Wyangala (Thurtell and Burton 2003). Consequently, riverine salinity levels were lower in the Lachlan River downstream of the dam than they were in the river upstream of the lake. The main factors contributing to this phenomenon are the storage of floodwaters in Lake Wyangala and the influence of fresh inflows from the Abercrombie River (Thurtell and Burton 2003). Salinity levels in the Lachlan River increase further downstream due largely to inflows (often above 800 EC) from the Boorowa and Belubula rivers. Below Forbes, salinity levels continue to increase with river length (Thurtell and Burton 2003).

Discharges from Lake Cargelligo and Lake Brewster contribute to the high levels of nutrients, turbidity, salinity and the incidence of algal blooms in the lower Lachlan River. These two off-river storages are shallow, eutrophic waterbodies which frequently experience water quality problems (Thurtell et al. 2003). Releases from Wyangala Dam are sometimes required to dilute poor quality water in or released from the off-river storages. Releases from Wyangala are also often required to dilute polluted inflows from the Boorowa and Belubula rivers.

3.6.8 Evaluation of literature

There is no literature on water quality in Lake Wyangala beyond the few reports summarised in the *Lachlan River: State of the Environment Report* (DLWC 1998). Fortunately, a significant body of data had been collected on a range of water quality parameters at various locations within the lake — some of this data was analysed and presented in this report. It was noted, though, that a substantial proportion of the data could not be analysed because of irregularities and inconsistencies. Given the importance of high quality water in Lake Wyangala to the Lachlan system, priority should be placed on the collation, analyses and syntheses of collected data, in line with quality assurance and quality control protocols.

3.7 Fish

3.7.1 Status of fish community

The collection of fishing anecdotes contained in *Listening to the Lachlan* (Roberts and Sainty 1996) indicates that large native fish were once abundant in the Lachlan River. Freshwater catfish, golden perch, Murray cod and silver perch were caught from the full length of the river whilst Macquarie perch occurred as far downstream as Condobolin. Populations of the introduced redfin (*Perca fluviatilis*) ‘exploded’ in the 1940s along the mid and lower reaches of the Lachlan River, as did populations of
common carp (\textit{Cyprinus carpio}) during the 1970s. Populations of large native fish noticeably declined after the enlargement of Wyangala Dam was completed in 1971.

Llewellyn (1983) generated the following list of fish fauna in the Lachlan catchment from a combination of existing reports and the author’s own studies:

- **Native**
  - Mountain galaxias (\textit{Galaxias olidus})
  - Australian smelt (\textit{Retropinna semoni})
  - Freshwater catfish
  - Hardyhead (\textit{Craterocephalus fluvialilis})
  - Chanda perch (\textit{Ambassis castelnaui}): now olive perchlet (\textit{A. agassizii})
  - Golden perch
  - Macquarie perch
  - Murray cod
  - Silver perch
  - Flathead gudgeon
  - Gudgeon (\textit{Hypseleotris} spp.).

- **Introduced**
  - Brown trout
  - Rainbow trout
  - Goldfish (\textit{Carrassius auratus})
  - European carp — common carp
  - Mosquitofish (\textit{Gambusia affinis}): now \textit{G. holbrooki}
  - Redfin perch.

The above list was not, unfortunately, accompanied by descriptions of sampling locations, nor did it separate which species occurred from records and which occurred in the author’s survey (Llewellyn 1983).

The \textit{NSW Rivers Survey} in 1996 included fish sampling in the Lachlan River and some of its tributaries. Three sites above Lake Wyangala were sampled: two in the Abercrombie catchment and one on the upper Lachlan River near Rugby. The only site sampled on the Lachlan River downstream of Wyangala Dam was near Hillston in the lower reaches of the river; samples were also collected from the two major tributaries to the Lachlan below Wyangala, the Boorowa and Belubula rivers (Harris and Gehrke 1997). Despite an increased sampling effort, the \textit{NSW Rivers Survey} collected only 14 species, three less than in the previous study (Llewellyn 1983). One species, bony bream (\textit{Nematalosa erebi}) was not collected in the previous study (Schiller \textit{et al.} 1997). More native fish occurred at sites above Lake Wyangala than in downstream sites and tributaries (Table 8). It is also worth noting that the golden perch native to the Lachlan system is genetically distinct from the rest of the species common throughout the MDB (Roberts and Sainty 1996).
Table 8 Native fish caught in the Lachlan Catchment during the NSW Rivers Survey (based on Harris and Gehrke 1997).

<table>
<thead>
<tr>
<th>Species</th>
<th>Wyangala u/s</th>
<th>Abercrombie</th>
<th>Lachlan</th>
<th>Lachlan</th>
<th>Boorowa R.</th>
<th>Belubula R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bony bream</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mountain galaxias</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australian smelt</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golden perch</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macquarie perch</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silver perch</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flathead gudgeon</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gudgeon spp.</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The MDB is dominated by alien fish species and the Lachlan catchment is no exception. In the *NSW Rivers Survey*, brown trout, rainbow trout, goldfish, common carp and mosquitofish were collected from sites above Lake Wyangala (Faragher and Lintermans 1997). In the Abercrombie and upper Lachlan rivers, carp densities were greater than 90 kg site\(^1\) (Driver *et al.* 1997). Goldfish, common carp and redfin were collected from the Lachlan River further downstream near Hillston (Faragher and Lintermans 1997); carp numerically dominated the river between Forbes and Hillston in an earlier survey (Richardson 1987). Rainbow trout, goldfish and redfin also occurred in the Boorowa River (Faragher and Lintermans 1997).

Recent surveys have included sites on the Lachlan River between Wyangala Dam and the confluence of the Belubula River (R. Pethebridge, DPI, unpublished data). However, this data set from annual surveys conducted between 1998 and 2002 also included fish collected from the Belubula River (Table 9). In the 1998–2002 surveys, common carp was easily the most abundant species and non-native fish accounted for about 75% of all fish captured/observed. Native fish numbers were extremely low, freshwater catfish and Macquarie perch were not recorded at all, and golden perch and Murray cod were only observed, not captured. River blackfish were first captured in 2001 and in reasonable abundance in 2002, but the occurrence of this species in the Lachlan River below Wyangala Dam had not been reported previously — there was an anecdotal reference to blackfish below Hillston in Roberts and Sainty (1996). It is unclear, from this study, whether river blackfish were captured/observed in the Lachlan or Belubula rivers (R. Pethebridge, DPI, unpublished data).

There is very limited data on past and present fish populations in Lake Wyangala. Burchmore (1987) conducted one survey in the lake, but the only subsequent data comes from annual angling tournaments (R. Pethebridge DPI, unpublished data). The fish captured in the 1987 survey were 346 freshwater catfish, two Macquarie perch, 13 silver perch, four brown trout, 85 rainbow trout, six goldfish and five carp. The
Burchmore (1987) report concluded that catfish populations were high and stable, rainbow trout abundance was increasing, but carp and Macquarie perch numbers were remaining low. Fishing tournament data from 2001–2004 indicated a decline in the number of native fish captured (R. Pethebridge DPI, unpublished data). Of particular note was the decline in capture of freshwater catfish, golden perch and Murray cod, and the extremely low abundance of Macquarie perch (Table 9). The number of carp captured also declined between 2001 and 2004.

Table 9 Results of fish surveys from sites between Wyangala and Goolongong on the Lachlan River and the Belubula River below Carcoar Dam. Numbers of fish ‘observed’ in parentheses (Data supplied by R. Pethebridge DPI).

<table>
<thead>
<tr>
<th>Species</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain galaxias</td>
<td>7(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Australian smelt</td>
<td></td>
<td>11(15)</td>
<td></td>
<td></td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>Golden perch</td>
<td>0(1)</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Murray cod</td>
<td>0(2)</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Flathead gudgeon</td>
<td></td>
<td></td>
<td>2(1)</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Gudgeon spp.</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>River blackfish</td>
<td>3(1)</td>
<td>10(9)</td>
<td></td>
<td></td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>*Brown trout</td>
<td>18(10)</td>
<td>15(2)</td>
<td>3(2)</td>
<td>4(4)</td>
<td>1</td>
<td>59</td>
</tr>
<tr>
<td>*Rainbow trout</td>
<td>8(8)</td>
<td>1</td>
<td>1(1)</td>
<td></td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>*Goldfish</td>
<td>4(6)</td>
<td>2(1)</td>
<td></td>
<td></td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>*Common carp</td>
<td>16(32)</td>
<td>11(15)</td>
<td></td>
<td>33(28)</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>*Gambusia</td>
<td></td>
<td>3(12)</td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>*Redfin</td>
<td>4(2)</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>

Native and introduced species are stocked in Lake Wyangala for the specific benefit of recreational anglers. For the two stocking seasons 2001/02 and 2002/03, Lake Wyangala was stocked with the following total numbers of fish (NSW Fisheries 2005a, 2005b, 2005c):

- 142 000 rainbow trout
- 157 500 golden perch
- 170 000 silver perch
- 49 060 Murray cod.

Over 50 000 golden perch and 13 000 Murray cod were stocked in the Lachlan catchment downstream of Wyangala Dam (NSW Fisheries 2005d, 2005e, 2005f, 2005g).

Whilst Lake Wyangala may be valued highly as a fishery, the amount of fish stocking that occurs there indicates it is not a self-sustaining resource. In fact, fish stocking is a ‘…stop-gap measure which satisfies angling needs…’ and ‘…tends to reduce
genetic diversity in the remnant natural populations which, in turn, can lead to a long-
term decline in vigour’ (Roberts and Sainty 1996, pp. 22–23). On a site visit to Lake
Wyangala in March 2005, common carp were clearly abundant in at least the
Abercrombie Arm (personal observation).

Table 10  Fish captured from fishing tournaments in Lake Wyangala 2001–2004 (Data supplied by R.
Pethebridge, DPI).

<table>
<thead>
<tr>
<th>Species</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater catfish</td>
<td>58</td>
<td>34</td>
<td>17</td>
<td>5</td>
<td>114</td>
</tr>
<tr>
<td>Golden perch</td>
<td>100</td>
<td>108</td>
<td>157</td>
<td>73</td>
<td>438</td>
</tr>
<tr>
<td>Macquarie perch</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Murray cod</td>
<td>14</td>
<td>9</td>
<td>1</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Silver perch</td>
<td>5</td>
<td>12</td>
<td>9</td>
<td>39</td>
<td>65</td>
</tr>
<tr>
<td>Brown trout</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Rainbow trout</td>
<td>93</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>93</td>
</tr>
<tr>
<td>Trout (unspecified)</td>
<td>38</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Carp</td>
<td>57</td>
<td>31</td>
<td>34</td>
<td>12</td>
<td>134</td>
</tr>
</tbody>
</table>

In the *NSW Rivers Survey*, significant proportions of fish had diseases or
abnormalities, including 18.8% of fish at the upper Abercrombie River site, 0.7% at
the lower Abercrombie site, 8% of fish in the Lachlan River near Hillston and 6.5% of
stated that the *NSW Rivers Survey* showed the ‘…site sampled on the Belubula River
had the highest number of native species with abnormalities in NSW…’. The *NSW
Rivers Survey* states that no fish sampled in the Belubula River had abnormalities
(Harris and Gehrke 1997). The proportion of fish with abnormalities varied largely
among sampling occasions. For example, on one survey, all fish (100%) collected
from the upper Abercrombie site were abnormal — a large departure from the overall
proportion of fish at that site with abnormalities (18.8%; Harris and Gehrke 1997).

Despite a number of shortcomings of existing reports and data, it can be presumed
that native fish populations, in Lake Wyangala and downstream of the dam, are in a
severely impoverished state. Of the 13 species included in reports/surveys since
1983, several are threatened or of concern because of declines in abundance.
Macquarie perch and silver perch are currently considered ‘vulnerable’ and freshwater
catfish, Murray cod and flathead gudgeon are scarce (Kennelly and McVea 2003).
Fish surveys conducted recently in the Condamine, lower Murray, Lachlan and Ovens
rivers, as part of the *Sustainable Rivers Pilot Audit* (MDBC 2004c), found that the
Lachlan River had the lowest proportion of expected native species; meaning that
native species which were once widespread are now rare and patchy.

3.7.2 Threatening processes
The decline in abundance of native fish throughout the MDB is most likely a
symptom of dwindling natural ecological function and overall ecosystem health.
Most of the threats to native fish populations are attributable to the dramatic changes that have occurred in river systems over the last century. The key threats, as identified by the MDBC (2003, p. 5), are:

- **Flow regulation** — changes to flow volume and seasonality, modification of high and low flows.
- **Habitat degradation** — removal of instream habitats (snags), sedimentation, loss of riparian vegetation, altered flow and affect on food sources.
- **Lowered water quality** — increased nutrients, sedimentation, turbidity, salinity, altered temperature regime, pollutants.
- **Barriers** — dams and weirs that impede fish movements/migrations upstream and downstream.
- **Alien species** — competition and/or predation.
- **Exploitation** — depletion of native fish stocks by commercial and recreational fishing.
- **Diseases** — viruses, diseases and parasites.
- **Translocation and stocking** — loss of genetic integrity and fitness by inappropriate translocation and stocking of native species, predation by stocked alien species.

Many of these threatening processes have occurred, or continue to occur, in the Lachlan River; some are a direct result of the existence and operation of Wyangala Dam. For example, regulation of Wyangala Dam has dramatically altered the hydrological regime of the Lachlan River (Section 3.2.1), cold water releases occur from November to March each year (Section 3.3.1), the dam is a substantial barrier to fish movements, and alien species are abundant and stocked regularly (Section 3.7.1). The consequence for native fish is that the natural environment, the context in which their life history strategies have evolved (Bunn and Arthington 2002), is dramatically altered.

Cold water pollution (CWP) in the Lachlan River is likely to impact on various aspects of native fish ecology including activity, feeding, digestion, growth, survival and reproduction (Koehn et al. 1995). The impacts experienced during the reproductive phases are possibly the most damaging. Burton (2000) compared the temperature requirements for native fishes to spawn and water temperatures below Wyangala Dam during their respective spawning periods (Table 11). The cumulative effect of modified breeding events (year after year), combined with other threatening processes, could be responsible for the depauperate native fish populations that currently occur in the Lachlan River. The most serious effects of CWP may be experienced as far downstream as Forbes (Section 3.3.2).

All native fish located between Wyangala Dam and Cowra have less opportunity to spawn than native fish above the dam because of cold water releases during the irrigation season (Table 11). Freshwater catfish and silver perch are not triggered to spawn and bony bream and golden perch are rarely triggered to spawn between the dam and Cowra (45 km downstream). In the rivers above Lake Wyangala, trigger temperatures for spawning are reached 20% of the time for silver perch and 98% of the time for Murray cod: this compares with 0% and 42% for silver perch and Murray
cod, respectively, at Cowra. Noticeably, carp spawning appears least disadvantaged by cold water releases from Wyangala Dam. The above impacts of reduced water temperature on native fish breeding are also likely to be experienced in Lake Wyangala during stratification (Section 3.3).

Table 11 Percentage of time spawning trigger temperatures are currently reached during native fish breeding periods (Modified from Burton 2000).

<table>
<thead>
<tr>
<th></th>
<th>Numby</th>
<th>Cowra</th>
<th>Forbes</th>
<th>Condobolin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bony bream</td>
<td>60</td>
<td>5</td>
<td>92</td>
<td>73</td>
</tr>
<tr>
<td>Carp</td>
<td>98</td>
<td>34</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Freshwater catfish</td>
<td>21</td>
<td>0</td>
<td>29</td>
<td>44</td>
</tr>
<tr>
<td>Golden perch</td>
<td>78</td>
<td>13</td>
<td>92</td>
<td>89</td>
</tr>
<tr>
<td>Murray cod</td>
<td>98</td>
<td>42</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Silver perch</td>
<td>20</td>
<td>0</td>
<td>40</td>
<td>46</td>
</tr>
</tbody>
</table>

Two species of native fish, golden perch and silver perch, are believed to be induced to spawn by a combination of a flood pulse and water temperature rising above a minimal threshold (Koehn and O’Conner 1990). The breeding periods for these two species are substantially modified by CWP alone (Table 11), and their chances of experiencing a spawning cue are even further reduced given that the rise in water temperature must be accompanied by a flood pulse.

3.7.3 Evaluation of literature

It is not possible to accurately determine the status of native fish populations in any part of the Lachlan River from the available published literature. Data from recent surveys and fishing competitions provide qualitative, presence/absence-type information only. In general, scientific knowledge of native fish in Lake Wyangala and the Lachlan River is poor. Previous studies are sporadic in terms of frequency and location. Some studies/reports do not include a description of methodology and/or sampling effort and there is no indication of whether sampled fish were stocked or not. There are no reports and/or data on population dynamics, therefore information on fish breeding and/or recruiting does not exist. There are also discrepancies between the cited conclusions of surveys and the actual findings of surveys. Another problem involves the casual reporting of the status of native fish in reports and plans. For example, in LRMC (c. 2002, p. 5) it is stated that 15 native species occur in the Lachlan of which ‘…7 are threatened and 4 are not known since 1996’, yet no actual species are listed. The 1983, 1997 and 1998–2002 surveys of fish in the Lachlan River, described in this report, report a total of only 13 species of native fish (Harris and Gehrke 1997; Llewellyn 1983).

3.8 Macroinvertebrates

Dams can have profound effects on macroinvertebrate communities, upstream and downstream. In the case of Wyangala Dam, the macroinvertebrate community
upstream of the dam — in the lake — is likely to have changed from a typically diverse upland stream community, to a less diverse one comprised of only species that can survive in permanent slow-flowing or still waters. There are no reports or data to support this, but it is an expected outcome. The impacts of a dam on macroinvertebrates downstream can be equally dramatic. In other rivers, large impoundments have altered downstream macroinvertebrate community structure and reduced species richness (Humphries and Cook 2004; Koehn et al. 1995). The main factors behind changes to macroinvertebrate communities are similar to those listed as the main causes of native fish decline: loss of habitat, changes to natural flow patterns and altered temperature regime. As with native fish, macroinvertebrates are likely to have evolved in the context of natural flow patterns (Bunn and Arthington 2002). Modifications to aspects of macroinvertebrate ecology are likely to have implications for native fish, given that fish reproduction and patterns of macroinvertebrate abundance may be synchronised.

3.8.1 Status of macroinvertebrate community

There have been macroinvertebrates samples collected upstream and downstream of Lake Wyangala, but none in Lake Wyangala itself. Unfortunately, only one of these assessments has been compiled into a report (Suter 1997); the rest remain in databases awaiting analysis and interpretation. Suter (1997) sampled macroinvertebrates at numerous sites above and below Lake Wyangala and observed a decrease in species richness immediately below the dam wall — over 100 taxa upstream of storage compared to 40 below — despite an increase in overall macroinvertebrate abundance. Suter (1997) concluded that the discontinuity of flows created by Wyangala Dam was the reason for such reduced species richness. That study also found that species richness was low along much of the Lachlan River.

Rapid assessment of macroinvertebrates at sites along the Lachlan River and tributaries was conducted irregularly between 1994 and 1999 as part of the National Rivers Health Program (E. Turak, DEC, unpublished data). In this assessment, animals were identified to family, and assessments were made of the observed taxa at each site compared to the expected taxa (a reference condition). Although sites were sampled above and below Lake Wyangala, family level identification did not provide adequate resolution to delineate differences in macroinvertebrate communities.

3.8.2 Evaluation of literature

Literature on macroinvertebrate communities along the Lachlan River is very limited (one study), but there has been a substantial amount of macroinvertebrate samples collected and processed over a significant period of time (10 years). It is important that this data is collated and analysed so that trends in the macroinvertebrate communities upstream and downstream of Lake Wyangala can be ascertained. Some previous surveys have only identified animals to family, which may not provide enough resolution for meaningful conclusions. Macroinvertebrate samples have not been previously collected from Lake Wyangala itself, so even basic assessments of changes to the macroinvertebrate community have not been made.
3.9 Riparian and instream vegetation

Vegetation is one of the most obvious and important features of aquatic ecosystems. It is an excellent indicator of ecosystem health because its relative condition impacts directly on the health of other ecosystem components. Vegetation performs a variety of roles in ecosystem function including primary production, a source of food/detritus for secondary production, habitat for terrestrial and aquatic fauna, bank and sediment stabilisation, and nutrient and water cycling. In the context of this report, riparian and instream vegetation refers to floating, submerged and emergent macrophytes in a stream/wetland and along its edges.

Assessment of vegetation condition can provide a good indication of disturbance. Riparian vegetation can be degraded by such factors as land-clearing, cultivation, over-stocking, weed infestation, excavation and river regulation (DLWC 1998). Floating, emergent and submerged instream vegetation can be degraded by stock trampling and grazing, river regulation, stream bed instability, foraging by carp, instream salinity and sedimentation (Massey 1998).

This section is concerned with riparian and instream vegetation downstream of Wyangala Dam — above and in Lake Wyangala was discussed earlier (see Section 3.4.5). Although the regulatory influence of Wyangala Dam is experienced the full length of the Lachlan River, this section focuses on the river between the dam and Jemalong Weir downstream of Forbes. Changes to vegetation in the lower Lachlan River and distributaries were also discussed earlier (Section 3.2.1)

3.9.1 Status of vegetation downstream of Wyangala Dam

A large proportion of the natural vegetation cover throughout the Lachlan catchment has been cleared, mostly for agriculture. In the central Lachlan region, roughly from Cowra to Condobolin, there has been extensive clearing of virtually every vegetation community type. Only native vegetation communities associated with rocky hills, montane environments and one particular mallee alliance have retained more than 30% of their original predicted cover (Austin et al. 2000). Floodplain and riparian forest types, such as those associated with red gum, grey box (E. macrocarpa) and yellow box (E. melliodora), have retained less than 5% of their original cover (Austin et al. 2000).

In a widespread assessment of riverine corridor health in the Lachlan catchment, riparian vegetation was in mostly poor condition and instream vegetation in mostly very poor condition (Massey 1998). Small native trees and shrubs existed only in the relatively small and few areas fenced off from stock, large trees were predominantly old and exotic species such as willows (Salix spp.) had proliferated. Between Wyangala Dam and Jemalong Weir, 67% of riparian vegetation was considered to be in very poor condition, 24% in poor condition and 8% in moderate condition (Massey 1998). For the most part, the riparian zone was either cleared for agriculture to the stream edge or, if a narrow riparian zone did exist, it was dominated by willows. The condition of instream vegetation along the same reach was even worse: 82% very poor, 15% poor and 3% moderate. Submerged instream vegetation occurred at only 23% of sampled sites and emergent instream plants occurred at only 25% of sites (Massey 1998).
Other assessments of riparian and instream vegetation along the Lachlan River between Wyangala and Jemalong Weir have yielded similar results (Love et al. 1999). In the six subcatchments in this region of the Lachlan River, riparian vegetation was considered to be under high stress in three subcatchments, under medium stress in two, and indeterminate in one. Aquatic vegetation was considered to be under high stress in one subcatchment, under medium stress in four, and indeterminate in one (Love et al. 1999).

3.9.2 Evaluation of literature

The literature on riparian and instream vegetation, particularly in the upper Lachlan catchment, is limited to two broad-scale assessments. However, they provide a relatively good understanding of the current status of these important ecosystem components. They also demonstrate a cognisance of the main threatening processes to native vegetation. Vegetation communities throughout other parts of the Lachlan catchment have been somewhat more comprehensively studied in agency reports. There is, however, a general lack of quantitative species level data in current reports and assessments; this may make it difficult to gauge the success of attempts to restore native vegetation communities.
4 SYNTHESIS

4.1 Conceptual model

The construction of a dam affects processes along the continuum of the river: the river upstream is effectively converted into a lake and characteristics of the river downstream are modified. The types of riverine responses are broadly predictable, but the overall impacts of dam construction will be determined by the individual characteristics of the dam/lake. Some of the major drivers of dam impacts include size of dam wall, reservoir depth, upstream catchment characteristics and pre-dam riverine condition.

For a dam the size of Wyangala, the following changes to riverine processes would be predicted:

*Sedimentation:* Reservoirs above dam walls are depositional zones — as water current speed slows, suspended sediment from upstream will settle out. As phosphorus is often associated with suspended materials, deposition of sediments can lead to an accumulation of phosphorus within the reservoir.

*Thermal stratification:* Thermal stratification occurs when there is not sufficient energy in the reservoir to mix warmer surface waters with cooler bottom waters. Once stratified, the cooler water below the thermocline (in the hypolimnion) can become oxygen depleted (anoxic). Periods of anoxia play an important role in the biogeochemical cycling of nutrients, and some metals, and lead directly to the build up of phosphorus, ammonia, sulfides, dissolved iron and manganese in the hypolimnion. If conditions within the reservoir change, mixing occurs and nutrient-rich water in the surface waters can give rise to high productivity — often observed as algal blooms. The quality of water released from a dam will depend on the depth at which it is taken from the reservoir. If taken from the hypolimnion, releases will be substantially colder, and they may be nutrient enriched but with less suspended sediment (than would occur under natural conditions).

*Altered flow:* Flow regimes downstream are altered following the installation of dams — in most cases it is their primary purpose. Large storage dams in southern Australia are typically used for the supply of water for irrigation and flood mitigation. This has the effect of removing extreme events — large floods and extended low-flow periods — from the downstream hydrograph. Furthermore, most releases tend to be in the period from late spring to early autumn; in the southern part of the Murray–Darling Basin, this period is characterised predominantly by low flows.

*Barriers:* Dam walls disrupt river connectivity. They represent an obstacle to the upstream and downstream movement of fish and shrimps, other riverine organisms and material.

For the most part, Lake Wyangala functions as expected. However, some of the effects of the dam on the surrounding environment are due, largely, to the specific characteristics and features of Lake Wyangala, the catchment upstream, the dam wall and the Lachlan River downstream. The following phenomena occur:
• There is some nutrient enrichment at depth in Lake Wyangala: total phosphorus levels consistently exceeded ANZECC trigger levels for lakes and frequently exceeded levels for upland rivers; total nitrogen, particularly in the deeper waters, consistently exceeded trigger levels for lakes, upland and lowland rivers. The Lachlan River downstream of the dam is the transitional region from upland to lowland river as it possesses characteristics of both river type. Downstream of the dam, phosphorus levels were similar to those in rivers directly below other large storages such as Lake Hume and Lake Mulwala (Howitt et al. 2004, 2005). For most of the time, nitrogen levels in the Lachlan River were higher than levels downstream of other storages (lakes Hume and Mulwala).

• Lake Wyangala stratifies annually, reducing water temperature and dissolved oxygen levels in the hypolimnion — during summer and autumn, water temperature in the hypolimnion can be up to 12°C colder than at the surface. About 170 km of the Lachlan River is affected by cold water releases from Wyangala Dam during the irrigation season.

• Blue-green algal blooms are frequent in Lake Wyangala and have occurred at least once a year over the past decade. Conditions are most suitable for algal blooms between October and May. Algal blooms occur in Lake Wyangala because:
  - Nutrients (phosphorus and nitrogen) attached to sediments are deposited at the bottom of the reservoir throughout the year.
  - During stratification, anoxic conditions in the hypolimnion facilitate the release of nutrients from bottom sediments.
  - Nutrients are released into the surface waters when stratification breaks down (winter).
  - By October, temperatures have risen, inflows have reduced and turbidity levels are low, creating conditions suitable for algal blooms.

• The natural flow regime of the Lachlan River downstream of Wyangala Dam has been dramatically altered.

• Although saline inflows from the upper Lachlan River are diluted in Lake Wyangala — mostly by fresh inflows from the Abercrombie River — salinity levels in the reservoir are rising. Lake Wyangala already consistently exceeds the ANZECC trigger level for salinity in lakes and reservoirs. Lake Wyangala’s ability to dilute saline inflows will be reduced if salinity levels within the reservoir continue to rise. Also, the ability of releases from Wyangala Dam to dilute saline inflows from other sources into the Lachlan River further downstream will be reduced.

• A trend of increasing pH in Lake Wyangala was detected. There are two likely causes of this: lime application (to increase pH) on pastures in the catchment upstream; and algal blooms which increase photosynthesis in the reservoir and may raise pH levels.

• A reasonable assessment suggests that the Lachlan River is a severely degraded system in terms of native vegetation, fish and macroinvertebrates. Weeds infest the immediate surrounds of Lake Wyangala, and riparian and instream vegetation communities in the Lachlan River downstream are low in diversity. Lake Wyangala is highly regarded as a native fishery; however, native fish abundance
is declining and almost totally reliant on stocking. Despite claims in various reports, there is no evidence of native fish (including Macquarie perch) breeding in Lake Wyangala, the Lachlan River upstream or downstream, or the Abercrombie River. On the contrary, European carp clearly breeds successfully in, upstream and downstream of Lake Wyangala. There has also been a demonstrable loss in macroinvertebrate diversity in the Lachlan River downstream of Wyangala Dam.

- The depauperate condition of aquatic fauna, particularly native fish, in Lake Wyangala and the Lachlan River downstream is probably due to a combination of impacting processes. They include:
  - Cold water pollution in the Lachlan River—caused by the combination of thermal stratification in Lake Wyangala, the fixed-level intake tower in the reservoir and the timing of irrigation releases. As a result, the suppressed water temperature between Wyangala Dam and Forbes during the fish breeding season is a likely contributor to the depauperate native fish community. Some native fish (catfish and silver perch) are denied suitable breeding conditions, whilst the duration of suitable conditions for other native species (bony bream, golden perch and Murray cod) is substantially modified.
  - Regulation of the Lachlan River at Wyangala Dam, particularly the dramatic shift from natural flow seasonality and the reduced occurrence of extreme high and low flow conditions. The effect on native fish is substantial: cues for spawning are impacted and critical nursery habitats for recruitment are reduced in size and extent.
  - Wyangala Dam represents a significant barrier for the upstream and downstream movement of aquatic fauna. The affect on native fish is likely to be significant, given that the upstream movements of some species are critical for breeding, and larvae of most species are distributed downstream by drift.

### 4.2 Assumptions — knowledge gaps

Both the conceptual model, of the environmental effects of Wyangala Dam, and the predicted environmental outcomes of CWP mitigation options and other environmental improvement options (Section 5), unavoidably include a number of assumptions. Most of these assumptions stem from the fact that many aspects of current environmental condition, of both Lake Wyangala and the Lachlan River, have not been adequately studied and currently exist as knowledge gaps. Many of these knowledge gaps were highlighted in the ‘Evaluation of literature’ sections (see Sections 3.2.3, 3.3.3, 3.4.7…etc).

Several aspects of current environmental condition are well represented in a range of literature types, such as peer reviewed publications and agency reports, and include analysis of quantitative or, at the least, qualitative data — altered flow regimes in the Lachlan River is an example. Some aspects have not been studied extensively, but conclusions as to their relative condition can be determined from the existing literature — stratification of Lake Wyangala and thermal pollution downstream are
examples. Data on several parameters of water chemistry have been collected, but not collated, analysed and presented previous to this report. One of the most poorly studied and, consequently, understood aspects of current environmental condition in Lake Wyangala and the Lachlan River is the biological component. Although macroinvertebrates have been sampled at numerous locations over a significant period of time, only one agency report on the macroinvertebrate community exists. Fish have been studied irregularly, insufficiently and qualitatively only, and any conclusion as to their current status is, at best, an assumption.
5 ENVIRONMENTAL IMPROVEMENT OPTIONS

In the previous section, we identified four major environmental effects attributable to the construction of Wyangala Dam:

- Altered flow regime in the Lachlan River downstream of the dam.
- Cold water pollution in the Lachlan River downstream of the dam.
- The dam as a barrier to both upstream and downstream fish movement.
- Degraded water quality and subsequent algal blooms within Lake Wyangala.

In this section, we examine each effect and provide management options for improved environmental outcomes. It should be noted that some of the recommendations made here currently lie outside of the scope of State Water; in those instances, it is suggested that State Water work closely with other agencies to limit the effect of Wyangala Dam on the surrounding environment.

5.1 Altered flow regime

5.1.1 Effects

The most significant environmental impact of Wyangala Dam on the Lachlan River downstream is altered hydrology: both altered flow seasonality and reduced flow variability. Evidence indicates that the natural hydrological regime of the Lachlan River has been severely disrupted whilst, at the same time, native fish and macroinvertebrate diversity has reduced, and native vegetation (instream and riparian) has become seriously degraded — this is most evident immediately downstream of the dam wall.

The effects of altered hydrology on aquatic fauna are generally well known (Section 3.2). Storing spring flood pulses in Lake Wyangala, to be released later in the irrigation season, may be denying some native fish species their cue for breeding in the Lachlan River downstream — flood pulses at the appropriate time of year are a cue for spawning for golden perch and silver perch (Humphries et al. 1999; Koehn and O’Connor 1990). In terms of native fish and macroinvertebrates, one of the major impacts of Wyangala Dam is probably the reduction in diversity, extent and availability of instream habitats. Habitats such as slackwaters — slow-flowing littoral areas — are nurseries for native fish and are critical during periods of juvenile recruitment. Slackwater areas in rivers are affected by regulation: as water is released from a dam, the size and extent of slackwaters is reduced and their arrangement is altered (Bowen et al. 2003). Native fish and macroinvertebrates have evolved in the context of natural flow patterns (Bunn and Arthington 2002) and, given that fish reproduction and patterns of macroinvertebrate abundance may be synchronised, modifications to aspects of macroinvertebrate ecology are likely to have implications for native fish. Changes to flow seasonality and reduced flow variability — the decrease in frequency of large floods and very low flows — also have significant impacts on the distribution and composition of riparian and instream native plants (Bouton and Brock 1999).
5.1.2 Management options

Options for improved environmental outcomes, in terms of hydrological regime, are heavily constrained by the current Water Sharing Plan (WSP). This is particularly the case in regard to seasonality of flows, which is probably the greatest driver of the current condition of the Lachlan River downstream of the dam. There may be, however, scope within the WSP for increasing the variability of flows — for example, small floods, short dry periods, cyclic flows — which may lead to incremental improvements in downstream ecological condition. For example, the Mitta Mitta River, in northeast Victoria, is a waterway where water release is heavily constrained by dam operations; however, cyclic release patterns during high flow periods have been trialled as a way of introducing flow variability to the river, while working within strict river operational guidelines (Sutherland et al. 2002). These water releases may be very limited in their scope, but minor improvements to in-stream productivity have been achieved.

Recommendation 1

State Water develop a modified flow regimen, that fits within the current WSP, aimed at improving in-stream production, water quality and habitat diversity based on increased variability in flows over the whole year.

The impacts of the changed flow regime should be assessed in partnership with appropriate State agencies using an adaptive management framework. Prior to establishing a modified flow plan, a baseline assessment of the river will need to be conducted and should include accurate assessments of river hydrodynamics, geomorphology and ecological condition.

5.2 Cold water pollution in the Lachlan River

5.2.1 Effects

Fish: The current impacts of cold water releases on native fish breeding are experienced at least as far downstream the Lachlan River as Cowra, and probably further — water temperature generally recovers to ‘normal’ by about Forbes. Native fish species currently most affected by CWP are those that spawn predominantly between November and March — this includes most native fish. The only exceptions, of species found in the Lachlan system, are mountain galaxias (spawning season commences mid-winter), some gudgeons (late winter to summer), Australian smelt and flathead gudgeon (both September to March) (Humphries et al. 1999; Koehn and O’Connor 1990): noticeably, all these species have been detected in the Lachlan River downstream of Wyangala Dam in recent, albeit superficial, fish surveys (R. Pethebridge DPI, unpublished data). Species with relatively short spawning periods are more vulnerable to modifications to natural temperature regimes, particularly if temperature is a cue for spawning (see DLWC 1998). Freshwater catfish and Murray cod both have short spawning periods (October–December) and have been conspicuously absent from recent surveys below Wyangala Dam (R. Pethebridge DPI, unpublished data). The duration of spawning is variable for golden perch and silver perch, but occurs between October and March (Humphries et al. 1999).
The environmental cues for spawning of native fishes are difficult to determine and undoubtedly vary among species. Species such as Murray cod spawn at the same time each year; therefore, the cue for spawning is thought to be a circannual event — moon phase or photoperiod (Humphries et al. 1999). Species such as golden perch show some variability in the timing of spawning onset each year and are thought to time their spawning event with rising water levels or floods (Humphries et al. 1999; McDowall 1996). Regardless of its importance as a cue for spawning, water temperature plays a critical role in breeding success. Recent work by Humphries (2005) determined that temperature influenced development and growth of Murray cod larvae. It is likely that other native species are affected similarly by water temperature during the breeding season.

Recent surveys of fish communities are superficial and there is no evidence to suggest that a viable native fish community actually exists downstream of Wyangala Dam. Furthermore, if works are undertaken to mitigate CWP, it is essential that a suitable monitoring program is implemented prior to carrying out any works, to gauge the success (or otherwise) of environmental improvements — determining current environmental condition is an integral phase of an adaptive management approach. Given its fundamental nature, Recommendation 2 (Section 5.2.2) is required before any other management actions are considered.

Macroinvertebrates: The current impact of cold water releases on the macroinvertebrate community is likely to be experienced as far downstream as Forbes. Closer to the dam, the impact would be greatest; from here some species are likely to have disappeared and the macroinvertebrate assemblage dominated by filter-feeding species. Any CWP mitigation measures, considered as part of the Wyangala Dam Upgrade, will probably have a similar effect on the macroinvertebrate community as they will on native fish populations: that is, the reduction in cold water releases is the only aspect likely to have an impact. Low and unseasonal water temperatures can reduce invertebrate productivity (Sherman 2000) and modify the reproductive activity of shrimps (Richardson et al. 2004).

Native vegetation throughout the Lachlan Valley below Wyangala Dam is clearly in poor condition. And, although CWP is likely to have a deleterious effect on instream vegetation diversity and distribution, it is probably a relatively minor impact compared with other dam-related impacts. Mitigating CWP only, therefore, is likely to have a negligible effect on riparian and instream vegetation along the Lachlan River downstream of Wyangala.

5.2.2 Management options

We make two recommendations here. The first (2A) places a priority on fish communities and ensures the current status of fish fauna in the Lachlan River is adequately assessed. This information is critical in determining the potential benefits of any management interventions in the operation of Wyangala Dam. The second (2B) is considerably more detailed and includes some of the survey work that would be carried out in 2A. This type of monitoring is essential in the advent of any changes to the operation of Wyangala Dam, as it will detect environmental outcomes occurring as a result of management changes. We recognise these actions are currently outside the scope of State Water, but this level of knowledge is of critical
importance before determining the cost-benefits for any in-storage remedial works. We, therefore, encourage State Water to form partnerships with other agencies to implement this recommendation.

**Recommendation 2**

- A. Determine the status of the fish community in Lake Wyangala and the Lachlan River downstream of Wyangala Dam: collect data on presence/absence, breeding and recruitment of native species. It is critical to establish whether there is, or isn’t, a viable fish community before undertaking significant works.

- B. Before the potential benefits of any management action can be determined, we recommend that a wider monitoring program is established that describes the current condition of the river: including fish, invertebrate, vegetation condition, hydrological assessment, geomorphic assessment. We also recommend that this monitoring program continue after any changes to the management of Wyangala Dam.

**5.2.3 Subsequent actions**

*If it is apparent that a viable native fish community does exist in the Lachlan River downstream of Wyangala Dam*, mitigating CWP from Lake Wyangala will be one possible management action. Two options have been short-listed for consideration (Geo-Eng 2001): local destratification of Lake Wyangala and the installation of a multilevel offtake.

The instillation of a multi-level offtake would provide a number of benefits, but localised destratification offers a potential mechanism for reducing the effects of cold water pollution and, at the same time, improving water quality within Lake Wyangala (see Section 5.4). Unfortunately, this opinion is based on a data set generated from a single water depth profile and, hence, further assessment needs to be undertaken.

**Recommendation 3**

Carry out a more detailed investigation into the suitability of localised destratification of Lake Wyangala compared to the construction of a multilevel offtake, taking into consideration not only thermal pollution but also the potential effects on water quality. Scenario testing (based on thermal dynamic models) should provide a solid basis for examining the relative merits of localised destratification compared to the construction of a multilevel offtake.

**5.3 Wyangala Dam as a barrier to fish movement**

**5.3.1 Effects**

Wyangala Dam prevents upstream and downstream movement of fish along the Lachlan and Abercrombie rivers. Fish passages have been constructed on many dams in recent years and have allowed fish to move upstream (Larinier 2000). Such fish passages are considered important in Australian waterways and substantial effort and investment has gone into constructing passages that allow fish movement past instream structures (Thorncraft and Harris 2000).
5.3.2 Management options

State Water could investigate design options for the construction of a fish passage that allows movement of fish between Lake Wyangala and the Lachlan River downstream of Wyangala Dam. Selecting an appropriate design and estimating the cost of its constructing undoubtedly requires considerable investigation and, ultimately, it may prove extremely difficult and uneconomical to do so. Fish passages (lifts or ladders) have not been installed on dams as large as Wyangala and the success of design and implementation involves a very high level of uncertainty. We doubt the value of building a passage because of the probable costs of engineering works required, and also because the poor ecological condition of the Lachlan River is probably due mostly to the effects of river regulation. It may be more efficacious and economical at this stage to improve fish passage through weirs and regulators further downstream in the Lachlan River — the cost-effectiveness and performance of fish passages is better understood in these locales and at this scale.

Recommendation 4

State Water does not undertake a feasibility study into the design and construction of a fish passage until other factors affecting downstream ecological condition have been addressed.

5.4 Nutrients and algal blooms in Lake Wyangala

The increasing incidences of nuisance blue-green algal blooms in Lake Wyangala have been noted (Section 3.6.5). One of the principle drivers of these algal blooms is the relatively elevated concentrations of nutrients (phosphorus and nitrogen) in the water storage. Any comprehensive algal bloom mitigation strategy should involve decreasing the load of nutrients, mostly associated with sediments, from entering Lake Wyangala (external loading) and also reduce the occurrence of nutrient remobilisation from sediments currently in the lake (internal loading).

5.4.1 External Loading of Nutrients

Decreasing the external loading of nutrients into Lake Wyangala involves managing catchment sources of nutrients and sediments; this currently lies outside the jurisdiction of State Water. It is suggested, however, that State Water encourage the appropriate state agencies to undertake remedial actions in the upstream catchment so that loads of sediments and nutrients entering into the lake are minimised.

Recommendation 5

State Water commissions a study to determine the historical sources of sediments currently in Lake Wyangala.

Recommendation 6

State Water encourages the relevant catchment management agency to undertake an analysis of the major current sources of sediments and nutrients in the catchment (eg. SedNet modelling) and prioritise rehabilitation of those sites.
5.4.2 Internal Loading of Nutrients

There is sufficient evidence from the water quality data that stratification of Lake Wyangala leads to the mobilisation of nutrients from sediments in the hypolimnion which, in turn, promotes algal blooms. It is possible that some of the strategies proposed for mitigating thermal pollution downstream of Wyangala Dam may also reduce the internal loading of nutrients.

Recommendation 7

In addition to thermal modelling outlined above (Recommendation 3), the study be expanded to include the impacts of internal loading of nutrients on water quality in Lake Wyangala.
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Austin, MP, Cawsey, EM, Baker, BL, Yialeloglou, MM, Grice, DJ and Briggs, SV (2000), Predicted Vegetation Cover in the Central Lachlan Region, final report of the Natural Heritage Trust Project AA 1368.97, CSIRO Wildlife & Ecology, Canberra.


Boulton, AJ and Brock, MA (1999), Australian Freshwater Ecology: Processes and Management, Gleneagles, Glen Osmond, South Australia.


Burchmore, JJ (1987), Wyangala Dam Fish Survey, internal report No. 31, June 1987, Fisheries Research Institute, Department of Agriculture New South Wales.

Burton, C (2000), A Preliminary Assessment of the Altered Water Temperature Regime of the Lachlan River, Central West, New South Wales, DLWC, Central West Region.

Central West Regional Algal Coordinating Committee (c.2004), Central West Region Blue Green Algae Contingency Plan 2004/2005, Resource Analysis Unit, DIPNR, Central West Region.


Love, D (1999), *Willandra Creek Assessment of Environmental Flow*, DLWC, Central West Region.


McDowall, RM (1996), *Freshwater Fishes of South-eastern Australia*, Reed Books, Chatswood, NSW.


Maher, P (1990), *Bird Survey of the Lachlan/Murrumbidgee Confluence Wetlands*, NPWS, Deniliquin, NSW.


Sauti (n.d. – a), *Preliminary statement on schemes for the further development of the Lachlan and Shoalhaven Valleys*, consultancy report for the WCIC of NSW, NSW Government.


Suter, P (1997), *Aquatic Macroinvertebrates of the Lachlan River, NSW*, consultancy report to DLWC.


Thurtell, L (2003), *Lachlan River Water Quality Study*, DSNR, Central West Region.


