



# Cold water pollution below dams in New South Wales

A desktop assessment







Department of  
**Infrastructure, Planning and Natural Resources**

# **Cold Water Pollution Below Dams In New South Wales**

## **A Desktop Assessment**

**Prepared by:  
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## Executive Summary

Water temperature is an important regulator of the natural ecological processes in rivers and streams. Dams have the potential to alter the natural temperature characteristics of aquatic ecosystems, creating potential for serious ecological impacts. In south-eastern Australia, the greatest cause for concern is the release of unseasonably cold water from the deeper layers of thermally stratified reservoirs during warmer months. This type of thermal disturbance is often referred to as cold water pollution and poses a serious threat to the viability and survival of fish and other aquatic fauna in many NSW rivers.

This report summarises the findings of a desktop study to identify dams in NSW with the potential to cause cold water pollution. The study was initiated by the former NSW Department of Land and Water Conservation and NSW Fisheries and funded by an Environmental Trust Grant. In accordance with the terms of the Project brief, the study used readily available information and simple indicators to rank dams based on the severity of their impact. This approach was necessary because of the large number of candidate dams and the limited availability of data from which to directly measure temperature disturbance.

From an initial shortlist of 93 dams, nine were identified as causing relatively large and pervasive cold water pollution—namely, Blowering, Hume, Copeton, Burrinjuck, Burrendong, Wyangala, Keepit, Khancoban and Pindari. All nine dams are located in the Murray–Darling basin and most are equipped with fixed intakes that draw water from the deeper colder layers of the storage during warmer months. A review of quantitative studies for this group shows that the size and scale of disturbance varied considerably between dams. The temperature of water immediately below some of these dams is more than 10 °C lower than natural during summer and cold water pollution may persist for several hundred kilometres downstream.

Three other groups of dams were delineated on the basis of size and scale of temperature disturbance. The study identified 14 dams that cause a moderate level of cold water pollution and another four dams that cause a relatively small and localised disturbance. A large number of shortlisted structures were deemed to have a negligible cold water pollution effect. Some large dams were found to have a negligible effect because they do not discharge to downstream waters, release water from the warm, upper layers of the storage or have mixing equipment which prevents thermal layering in the storage.

Many of the dams identified as causing severe cold water pollution are the subject of current or recently completed studies on cold water pollution. These range from modelling and monitoring studies to quantify the extent of cold water pollution through to feasibility studies of mitigation options. However, all studies are exploratory in nature and, with one possible exception (Keepit Dam), there are no specific plans in place to address cold water pollution below any of these dams in the short term. Mitigation works are scheduled for two of the dams identified as causing moderate disturbance (Tallowa and Jindabyne Dams).

To date, mitigation of cold water pollution at larger dams in NSW has generally been undertaken as part of works to meet other environmental or operational objectives—for example, fish passage and dam enlargement. For the dams identified in this study as causing severe cold water pollution, future dam safety upgrades provide the main opportunity in this regard. Unfortunately, the priorities of the dam safety upgrade program do not correspond to those for cold water pollution management, so improvements to downstream water temperature may not be realised for many years, if at all. Further, this arrangement does not encourage the use of feasible and lower-cost engineering and operational solutions that could be implemented in the short term to realise thermal benefits sooner.

The development of a formal strategy to actively manage cold water pollution below high priority dams in NSW has been mooted for some time, but confounded by uncertainty over institutional responsibilities for aspects of dam management—for example, environmental monitoring and regulation. Recent institutional reforms in NSW have clarified water delivery, regulation and resource management roles and a formal mechanism to address CWP is now under consideration.

# 1. Introduction

Water temperature is an important controlling factor of instream biological and chemical processes (Ward & Stanford 1979; ANZECC 2000). The natural spatial and temporal patterns of water temperature in rivers and streams are determined by many climatic, hydrologic and morphological variables. Human-driven changes to any of these will alter natural water temperature and create potential for ecological disturbance. Large changes in water temperature can exceed the thermal tolerance limits of aquatic organisms, leading to elimination of species from sections of river. Smaller temperature changes can induce a range of effects which reduce the viability of populations of native fish and other aquatic fauna. These include disturbance to ecosystem productivity, reduced rates of growth and reproduction and shifts in the competitive balance between species (Petts 1986).

Dams modify the natural temperature of running waters by direct and indirect means. Direct changes occur when the temperature of dam releases differs markedly to that which would occur naturally in the receiving water. Dams can indirectly change water temperature by influencing processes that control the delivery, distribution and retention of heat within the river channel—for example, changes to the volume of water in a river or stream affect its assimilative capacity for heat and alter the proportion of water originating from thermally contrasting sources (Petts 1986; Poole and Berman 2001). In eastern Australia, the issue of greatest concern is direct temperature change associated with release of cold water from the hypolimnion of thermally stratified storages. This phenomenon is often referred to as cold water pollution (CWP) because the temperature of rivers and streams below such dams is markedly lower than natural during spring and summer.

Within Australia, the ecological consequences of CWP were flagged several decades ago by Lake (1967) in relation to fish of the Murray–Darling basin. Since then, a number of studies on the CWP impacts of specific dams have been undertaken—for example, Hume Dam (Walker 1980), Dartmouth Dam (Koehn et al. 1995) and Burrendong Dam (Harris 1997). More recently, numerical modelling of populations dynamics under various temperature disturbance scenarios (Ryan et al. 2002) and controlled experiments by NSW Fisheries at Burrendong (Astles et al. 2003) clearly demonstrate a causal link between CWP and disturbance to growth and survival of selected native fish species. CWP is listed as a threatening process in Victoria (*Victorian Flora and Fauna Guarantee Act 1988*). In NSW, the State Water Management Outcomes Plan gazetted under the *NSW Water Management Act 2000* specifies targets to mitigate CWP below dams.

Both Victoria and Queensland have recently completed statewide reviews of large dams to identify and rank structures based on potential to cause CWP. The Victorian study (Ryan et al. 2001) ranked dams based on the depth and frequency (regular versus occasional) of release. The study identified 24 maximum priority dams for which additional monitoring and research was recommended. The Queensland review (Brennan draft) identified priority dams based on storage and release depth. Eighteen storages were identified as a priority for further assessment and continuous temperature monitoring will be undertaken in rivers below ten dams listed in the report (A. Mullens, Queensland Dept. Natural Resources and Mines, pers. comm.).

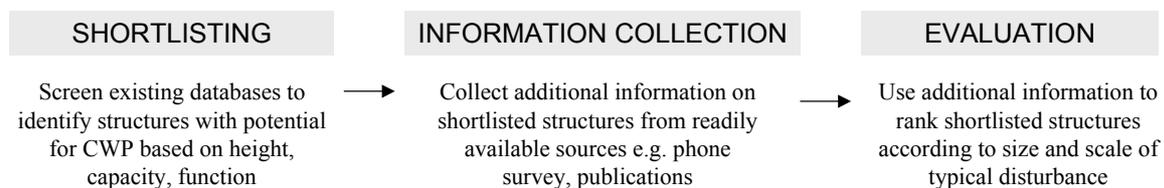
The CWP potential of instream structures across NSW has not been systematically assessed. Preliminary estimates of the extent of CWP pollution in the Murray–Darling basin have been provided by Whittington and Hillman (1998) based on expert opinion, and for specific rivers by Astles (2001). Two reviews of the CWP issue in coastal and inland river basins have been undertaken. Rish et al.(2000) summarised large dams across NSW and described the temperature management capabilities and issues associated with dams operated by State Water. NSW Fisheries (Lugg 1999) undertook a broad review of ecological, management and institutional aspects of CWP including a summary of the dams thought to cause significant CWP.

In 2002, NSW Fisheries and the former NSW Department of Land and Water Conservation (DLWC) jointly secured funding under an Environmental Trust Grant to undertake a number of projects to address CWP in NSW rivers. One of these was a preliminary desktop assessment and ranking of dams based on the severity of CWP. This report summarises the findings of the preliminary assessment.

## 2. Methods

### 2.1 APPROACH

The assessment of the CWP potential of structures in NSW was undertaken in three stages:



In accordance with the terms of the Environmental Trust Project brief, the assessment took the form of a systematic, but simple, evaluation of larger dams using available information and basic indicators of CWP potential. This approach was necessary because of the large number of structures (approximately 150 dams greater than 15 m height) and the limited availability of data from which to directly measure temperature disturbance.

### 2.2 DATA SOURCES

Several databases were considered for use in this study. The main ones were the NSW Weir Inventory Database (Bradley & Briones 1998) and later versions (e.g. NSW Fisheries 2002), NSW Dam Safety Committee (DSC) database (DSC 2002) and the national register of large dams produced by the Australian National Committee on Large Dams (ANCOLD 2002). The databases varied in the type and quality of information held. The NSW Weirs Inventory Database (Bradley & Briones 1998) is considered by some as the principal source of information on all instream structures (dams, weirs etc.) in NSW. However, the original database is outdated, and a more recent database compiled as part of a preliminary Weir Review Program (e.g. NSW Fisheries 2002) contained many errors.

The primary source of data for this report was the NSW DSC database (DSC 2003). It was the preferred database for several reasons. The DSC prescribes those dams that pose a threat to lives or a significant risk to communities (via economic loss or environmental damage) so excludes smaller structures (farm dams, levees, road and rail embankments) which were not relevant to this study. It is updated regularly and contained information of specific interest to this work, including descriptions of outlet works for many dams.

### 2.3 SHORTLISTING

There are more than 3000 licensed dams and weirs in NSW. While the DSC database already excludes many small structures, some larger dams will also not pose a significant CWP risk—for example, because they impound very small storages, they do not thermally stratify or they form part of closed, on-site pollution management systems. The aim of shortlisting was to remove from consideration all structures unlikely to cause significant impact for these types of reasons.

Dams were shortlisted for further evaluation if they met all of the following criteria:

- Create a storage > 1000 ML—to remove dams / storages too small to be of significance;
- Directly impound a river or stream, i.e. not an “off stream” structure;
- Have a relevant function, i.e. exclude dams used for on-site storage of waste, ash tailings etc.;
- Height of structure  $\geq$  10 m (see notes below).

Structure height serves as an approximate measure of maximum water depth which, in turn, is an indicator of the potential of a storage to thermally stratify. Like all indicators it represents a simplification of a complex process—the tendency of standing water to stratify will depend on numerous factors including retention time, exposure to wind and surface area. In determining a suitable cutoff value, consideration was given to 5 m as used in Victoria for shortlisting (Ryan et al. 2001). However, this was deemed too conservative because storages under 10 m depth in temperate climates are less likely to maintain stable and persistent stratification through warmer months (Petts 1986). This is supported by a recent review of thermal shock in the Murray–Darling Basin (Ryan & Preece 2003) which adopted a 5 m cutoff yet failed to find any structure under 10 m exhibiting persistent stratification. For this reason, any structure with a height of less than 10 m was excluded from further assessment<sup>1</sup>.

The final step of the shortlisting process was to cross check the DSC-based shortlist with information from other databases. In several cases, there was disagreement in the status of certain structures between databases—for example, a dam listed as off-stream in one database and on-stream in another. In such cases, the structure in question was shortlisted for further evaluation.

## 2.4 COLLECTION OF ADDITIONAL INFORMATION

Additional information on each shortlisted structure was sought to determine the severity of CWP. In most cases, quantitative information on stratification behaviour and downstream temperature impacts did not exist or was not readily available. Emphasis was therefore placed on use of indicators of CWP potential based on relevant aspects of dam infrastructure and operation—for example, the type of outlet works (intake type, number, position), release volume and pattern, artificial mixing. Two key pieces of information were readily available for most structures and formed the basis for assessment<sup>2</sup>—namely, typical summer discharge and typical release depth.

The source and type of information varied between structures but in all cases emphasis was on readily available, or published information. Principal sources of information included phone survey of owner-operators, annual environmental and compliance reports, water management licences, internet home pages, technical reports and scientific papers. In some instances, for dams known or suspected to be of high priority, raw data were sought if they were easily obtained and in a readily useable format.

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<sup>1</sup> Structure height will generally overestimate maximum water depth because most dams have a freeboard of at least several metres.

<sup>2</sup> There are a range of possible indicators of CWP potential though most will rely on information which is not readily available nor easily converted to objective or quantitative criteria. Indicators to better determine the severity of physical disturbance may include: storage residence time, downstream tributaries (no., distance, discharge) and measures of alternative operating modes. Priorities for mitigation may ultimately need to consider ecological risk i.e. the significance of a given temperature disturbance in light of biological consequences and broader ecosystem functioning. Indicators in this regard may include: presence of threatened species (which may justify increased priority); presence of other ecological stressors such as barriers to fish passage or modified flow regimes (which may reduce priority or require an integrated solution).

In some instances, available data and verbal accounts reflected recent years when much of the state was in drought. In such cases, efforts were made to obtain further information to determine CWP potential under more typical patterns of operation. This process was iterative—as structures began to emerge as high priority, more attention was given to securing further information to build a more reliable picture of typical behaviour.

## 2.5 ASSESSMENT OF SHORTLISTED STRUCTURES

The evaluation of shortlisted structures was based largely on two measures of disturbance (i) the **size** of the difference between release water and that expected to occur naturally in the river downstream (ii) the **distance** that temperatures modification persisted downstream. Simple indicators of these two measures were used as described below.

**Intake Depth:** The deeper that intakes are positioned in the storage the greater the difference between the temperature of dam releases and that expected to occur naturally downstream (assuming that the storage thermally stratifies and river releases are made). The depth of intake(s) at each dam was therefore used as an indicator of the size of temperature disturbance below the dam.

It was desirable to standardise the measurement of intake depth across structures. However, intake depth was expressed in different ways depending on the information source (e.g. verbal estimates, technical drawings, summary tables) and type of intake (e.g. single fixed, multi-level). For dams with a single or main<sup>3</sup> fixed-level intake (e.g. single pipe, intake at bottom of open tower), *depth* was specified as depth below Full Supply Level (FSL). If the position of a fixed-level intake could not be determined, *depth* was assumed to equal the height of the dam. For dams equipped with a multi-level (selective withdrawal) intake (e.g. floating trunnion, multi-level intake tower), *depth* was specified as the typical depth of the intake below the water surface. If water was normally released through multiple intakes at one time, *depth* was taken as the midpoint of the lowest and highest intake in use. If there was no specific policy governing use of a multi-level intake, *depth* was specified as the midpoint of the lowest and highest intake. If intake depth was expressed as a range over time, the midpoint of the range was used. If no information was available on the normal position of multi-level intakes or operating range, *depth* was specified as half the dam height. Structures which typically release via overtopping / spilling were assigned a *depth* of 1 m, unless this was by way of vertical lift/radial gates in which case *depth* was specified as the depth of the spillway sill below FSL. For the purpose of data analysis, dams equipped with artificial mixing equipment (e.g. aeration destratification or surface impellers) were assigned a *depth* of 5 m on the basis that releases from such storages would be of a similar temperature to the upper mixed layer of a stratified storage.

**Discharge:** The thermal characteristics of hypolimnetic releases will extend further downstream under high discharge because larger volumes of water are less responsive to heat flux and move at a higher velocity (Ward 1985). An estimate of summer discharge from the dam's intakes was therefore sought as a relative measure of the length of river affected by CWP.

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<sup>3</sup> Many dams have a bypass or scour intake which is rarely, if ever, used.

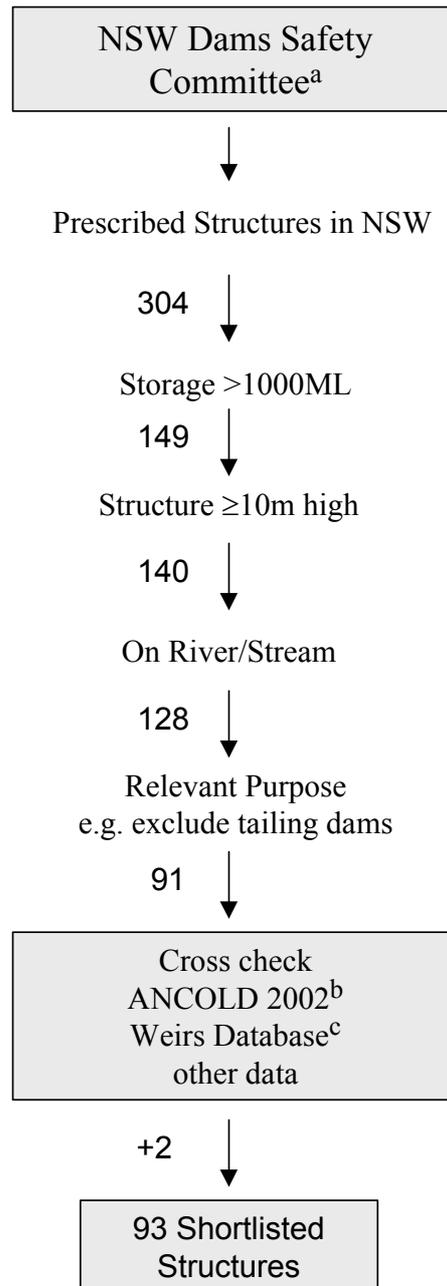
Determining typical summer discharge is problematic as dam releases vary significantly within seasons, between years and under different modes of operation—for example, regular small riparian releases versus occasional bulk water transfers. Again, information on discharge came from a variety of sources (verbal estimates, hardcopy and electronic records) and was expressed in different ways (daily time series data, monthly and annual summaries, short and long terms records, licence conditions). Determining typical summer discharge was difficult for recent and short records which may reflect extreme conditions associated with the drought that has occurred over much of NSW for the last few years. Good long-term records were available for many larger dams. In such cases, discharge was measured as median January discharge. Where data was not readily available, owner / operators were asked for a verbal estimate of typical summer discharge. Other sources of discharge information included environmental and riparian flow targets specified in water management licences, summary data in annual reports, published technical reports and scientific papers. Seepage was ignored.

This report focuses on ongoing CWP that is expected to occur under normal operating conditions (and for which most information is available). It has not considered less frequent, but ecologically significant, thermal disruptions that may arise as a result of variations to normal operating procedures. Example of this include CWP from an otherwise warm-release dam caused by occasional use of a low-level intake; bulk water transfers from a dam which normally releases a small riparian flow.

### 3. Findings

#### 3.1 SCREENING AND SHORTLISTING

Screening of the DSC database and subsequent cross-checks with other data sources yielded a shortlist of 93 structures (Figure 1). Each of the shortlisted structures is summarised in Appendix A.



**Figure 1. Shortlisting of structures.**

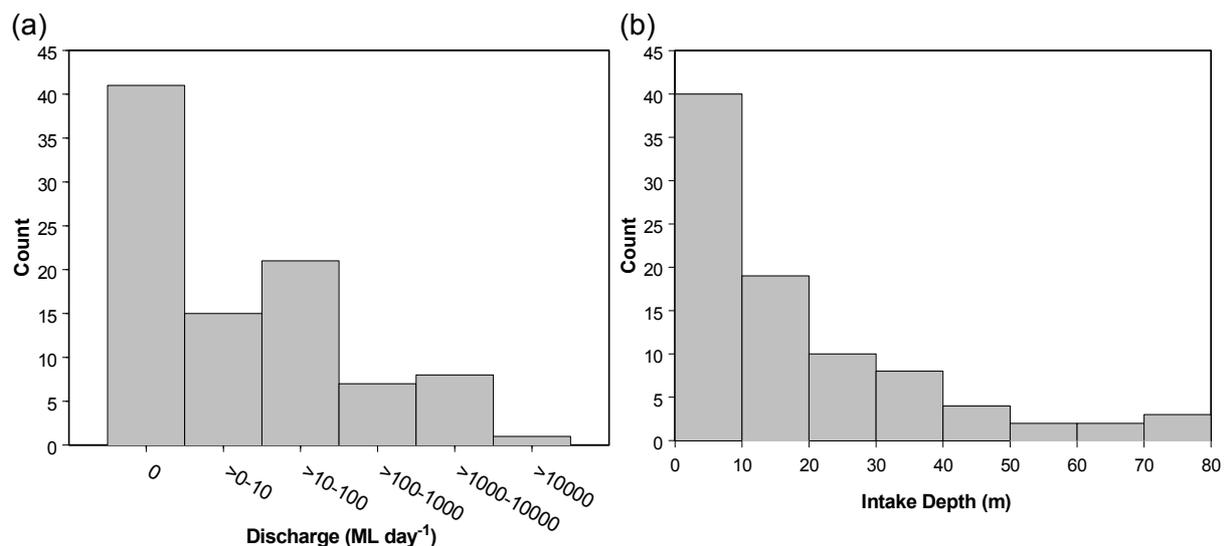
a. DSC 2003; b. ANCOLD 2002; c. Bradley & Briones 1998. Shortlist excludes two prescribed dams not yet built (Shannon Creek Dam, Chain of Ponds 13B)

### 3.2 OVERVIEW OF SHORTLISTED STRUCTURES

Additional information on each of the 93 shortlisted structures was obtained from various sources as summarised in Appendix A.

Discharge data for all shortlisted structures are summarised in Figure 2a. Forty one dams did not discharge to downstream watercourses under normal operating conditions. Water is diverted from these dams for range of purposes including supply for town water, industrial processes and hydro-electric power generation. They include several dams that did not have river outlet works or had their outlet works decommissioned. The principal mechanism of thermal disturbance below diversion dams is that associated with modified hydrology i.e. lower than natural flow reducing water's assimilative capacity for heat leading to greater temperature fluctuations. In such cases, thermal effects are likely to be of secondary importance to the fundamental ecological disturbance associated with reduced flow.

Figure 2b summarises intake depth data for all shortlisted structures with river outlet works, irrespective of whether or not they normally release downstream. Forty dams released water from an equivalent depth of 10 m or less under normal operating conditions. Just over half of these were dams equipped with artificial mixers—these were assigned an intake depth of 5 m to reflect the fact that the temperature of releases from such dams would be similar to that of the surface mixed layer of stratified storages. The other half of structures released from shallower depths via spillways or shallow intakes—for example, multi-level intake towers, floating trunnions. These structures are noteworthy because the surface mixed layer of most storages extends between 5 and 10 m below the water surface. It is therefore likely that a significant proportion of water released from such dams during warmer months will be drawn from the surface mixed layer, resulting in markedly smaller thermal disturbance compared to structures drawing from greater than 10 m depth.



**Figure 2. Typical summer discharge (a) and intake depth (b) for shortlisted structures in NSW.**  
Plot (b) excludes structures without river outlet works.



The arrangement of structures in Figure 3 provides a basis for their separation into categories according to the potential severity of CWP. Towards the top of Figure 3 there are a group of 10 dams which are distinct from the rest in that they all had a discharge equal to or greater than 1000 ML day<sup>-1</sup> **and** released water from greater than 10 m depth. These structures are likely to cause relatively large and pervasive disturbance compared to all others and therefore form a group on their own.

Amongst the remaining structures (those that discharge less than a 1000 ML day<sup>-1</sup>), a second group of structures can be delineated—namely, those with a depth greater than or equal to 10 m. These dams are still likely to cause severe localised disturbance because they normally draw from below the thermocline. However, because discharge from these dams is an order of magnitude lower than the first group, CWP will persist over a markedly shorter distance downstream. This group of structures will therefore cause a moderate level of disturbance relative to the first group.

There is little objective basis for separating out remaining structures in Figure 3. However, there is a third (small) group of structures which draw from between 5 m and 10 m depth and have a discharge of similar magnitude to the second (moderate disturbance) group. These structures will generally draw water from the vicinity of the thermocline rather than the hypolimnion, resulting in a smaller temperature differential between releases and that occurring naturally downstream. This, in combination with only moderate discharge, should cause relatively localised disturbance.

The process just described formed the basis for grouping of structures according to the severity of disturbance as follows:

1. *Severe CWP*: deep intake ( $\geq 10$  m) and large discharge ( $\geq 1000$  ML day<sup>-1</sup>);
2. *Moderate CWP*: deep intake ( $\geq 10$  m) and smaller discharge ( $> 5$  and  $< 1000$  ML day<sup>-1</sup>);
3. *Minor CWP*: shallower intake ( $> 5$  and  $< 10$  m) and smaller discharge ( $> 5$  and  $< 1000$  ML day<sup>-1</sup>);
4. *Negligible CWP*: very shallow intake ( $\leq 5$  m) and very small discharge ( $\leq 5$  ML day<sup>-1</sup>).

The relative importance of structures within each of the first three groups was determined by multiplying intake depth and discharge for each structure and using the product to rank structures. i.e. higher ranked structures will have colder and larger releases and lower ranked structures will have warmer and smaller releases.

The location of all structures causing severe, moderate and minor CWP is shown in [Figure 4](#). Each of the four groups is summarised below, together with some selected examples of individual structures to indicate the actual magnitude and scale of CWP for each group.

### **Group 1—Structures Likely to Cause Severe Cold Water Pollution**

Nine dams in NSW have been identified as causing severe thermal disturbance (Table 1, Figure 4). A tenth structure, Jounama Dam, was ranked within this group based on discharge and depth of release (Appendix A). However, the dam is located immediately below Talbingo Dam and immediately upstream from the headwaters of Blowering Dam. This negates its direct influence (and the significance of any mitigation works) on the temperature regime of the Tumut River.

All structures in this group are located within the Murray–Darling basin. The group is characterised by dams that impound deep storages and release large volumes of cold hypolimnetic water during spring and summer. On this basis they are expected to cause large changes to the natural water temperature regime over long sections of river.

Each of the structures in Table 1 is described below together with available data on the size and extent of temperature modification.

**Table 1. Structures Likely to Cause Severe Cold Water Pollution.**

| Rank | Name       | Owner <sup>a</sup> | Height (m) | Surface Area (km <sup>2</sup> ) | Capacity (ML) | Mean Depth <sup>b</sup> (m) | Intake Depth (m) | Discharge (ML day <sup>-1</sup> ) |
|------|------------|--------------------|------------|---------------------------------|---------------|-----------------------------|------------------|-----------------------------------|
| 1    | Blowering  | SW                 | 112        | 44.6                            | 1 628 000     | 36.5                        | 74               | 8 200                             |
| 2    | Hume       | MDBC               | 51         | 202.0                           | 3 038 000     | 15.0                        | 29               | 20 000                            |
| 3    | Copeton    | SW                 | 113        | 42.6                            | 1 364 000     | 32.0                        | 69               | 3 600                             |
| 4    | Burrinjuck | SW                 | 93         | 55.0                            | 1 026 000     | 18.7                        | 42               | 5 200                             |
| 5    | Burrendong | SW                 | 76         | 72.0                            | 1 190 000     | 16.5                        | 37               | 4 000                             |
| 6    | Wyangala   | SW                 | 85         | 53.0                            | 1 220 000     | 23.0                        | 50               | 1 700                             |
| 7    | Keepit     | SW                 | 55         | 44.0                            | 423 000       | 9.6                         | 24               | 2 000                             |
| 7    | Khancoban  | SH                 | 18         | 4.7                             | 21 500        | 4.6                         | 12               | 4 000                             |
| 9    | Pindari    | SW                 | 85         | 10.5                            | 312 000       | 29.7                        | 11               | 1 000                             |

a. SW = State Water; MDBC=Murray Darling Basin Commission; SH = Snowy Hydro Ltd.

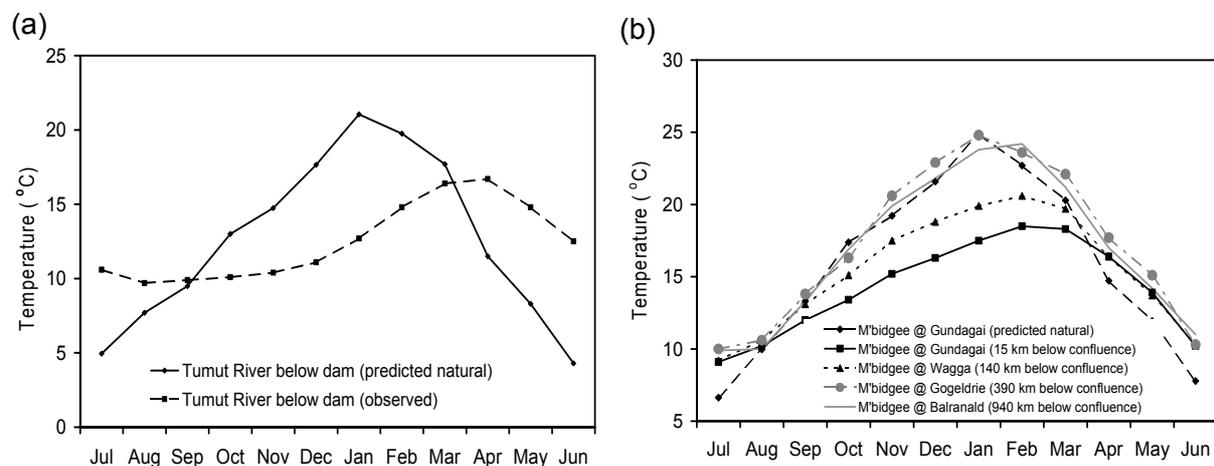
b. Storage capacity divided by surface area at FSL

### **Blowering Dam (Murrumbidgee River Basin – 410)**

*Description:* Blowering Dam on the Tumut River provides regulated flow for summer irrigation in the Murrumbidgee valley. Irrigation releases typically start in October and run through to Easter and are relatively constant through this period. Based on historical discharge data (DIPNR, unpub.), median January discharge below the dam is approximately 8200 ML day<sup>-1</sup>. Releases can only be made via a single fixed-level intake and an ungated spillway (the dam spills infrequently). The intake structure comprises a 41 m high open intake tower with trashrack covered inlets from 33 to 74 m below FSL. The dam is equipped with a hydro-electric power station (HEPS) that is serviced by the open tower and operates at discharge above 1500 ML day<sup>-1</sup> (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* Blowering thermally stratifies from November to May and large temperature differences between surface and bottom waters have been recorded (e.g. 28 and 11 °C respectively in January 1993; Bowling et al. 1994). The intake draws water from below the thermocline leading to marked temperature disturbance below the dam (Figure 5a). Reductions in natural summer temperature of the Tumut River immediately below the dam of 13 to 16 °C have been reported (Keenan and Buchan, unpub.). Thermal modifications persist along the length of Tumut River and into the Murrumbidgee River below the Tumut–Murrumbidgee confluence, approximately 80 km downstream. Blowering's contribution to CWP in the Murrumbidgee River below the confluence is confounded by the potential influence of Burrinjuck Dam. However, based on the difference in discharge between the two dams (Table 1) Blowering is likely to be the main contributor. Irrespective

of the main contributing source, available information (Keenan and Buchan unpub.; Astles 2001; Figure 5b) indicates CWP in the Murrumbidgee River persists for between 200 and 300 river km below the confluence.



**Figure 5. Water temperature of the Tumut River at Blowering Dam (a) and Murrumbidgee River downstream of the Tumut - Murrumbidgee confluence. Adapted from Lugg (1999).**

### Hume Dam (Upper Murray River Basin – 401)

*Description:* Hume Dam on the Murray River provides regulated supply for irrigation, urban use and hydro-electric power generation. The storage undergoes an annual filling and draining cycle characterised by a full / near full storage in December and dropping to 25% capacity in May (Dreverman 2001). Based on historical discharge data (DIPNR unpub.), median discharge below the dam is approximately 15 000 ML day<sup>-1</sup> in spring and 20 000 ML day<sup>-1</sup> in summer. Minimum releases from the storage occur in winter and are in the order 600 ML day<sup>-1</sup> at Heywoods gauging station (Ryan et al. 2001). The dam's outlet works comprise two sets of intakes—one at 30 to 34 m below FSL servicing irrigation release valves and the other at 23 to 30 m below FSL servicing the HEPS (Sherman 2003).

*CWP Potential:* The high ranking of this dam in Table 1 reflects the extremely large summer discharges from Lake Hume in summer. While the storage undergoes annual thermal stratification, it has large exposed surface area which encourages wind mixing (Croome 1980). The surface mixed layer is often quite deep e.g. 9 m (Sherman 2003), 15 m (Croome 1980), and seasonal drawdown may lead to entrainment of warmer surface layers into withdrawal currents. As a consequence of all these factors, the size of temperature disturbance below Hume Dam is not as great as other dams in this group. Maximum average temperatures below Hume Dam are between 5 and 7 °C lower than the surface of the storage (Dreverman 2001) and approximately 3 °C lower than the Murray River upstream from the storage (Walker 1980). Because of the extremely large discharges from the dam, thermal modification will generally persist along the 200 km section of Murray River between Hume Dam and the headwaters of Lake Mulwala (Walker 1980).

### **Copeton Dam (Gwydir River Basin – 418)**

*Description:* Copeton Dam on the Gwydir River provides regulated flow for irrigation in the Gwydir valley. Irrigation releases typically commence in September and run through until March. Based on historical discharge data (DIPNR, unpub.), median January discharge below the dam is approximately 3600 ML day<sup>-1</sup> although there is considerable year to year variation in irrigation releases, depending on the amount of spring / summer rainfall received. Outside of the irrigation season, a riparian flow of 30 to 40 ML day<sup>-1</sup> is maintained. The intake structure comprises a 37 m high open intake tower with trashracks covered inlets from 57 to 69 m below FSL. A separate bypass line exists with a centreline positioned 86 m below FSL. The outlet works are equipped with a HEPS that has a maximum discharge of approximately 2000 ML day<sup>-1</sup> and the dam has a gated spillway (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* Copeton impounds a deep storage which exhibits strong and persistent thermal stratification on an annual basis from early spring through to late autumn. During summer, the thermocline is typically positioned between 5 and 10 m below the water surface. The temperature of bottom waters remains relatively constant through summer (13 °C) while surface temperatures are approximately 24 to 26 °C (Bowling et al. 1994, 1995). The magnitude and extent of CWP below the dam has not been quantified. Based on extrapolation from other storages, NSW Fisheries (Lugg 1999) estimated that serious CWP<sup>4</sup> persists for 300 km below the dam.

### **Burrinjuck Dam (Murrumbidgee River Basin – 410)**

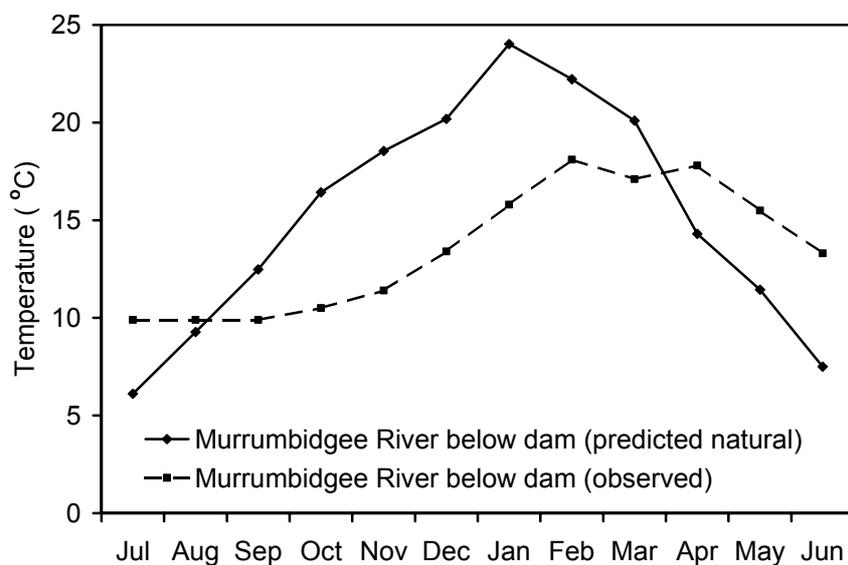
*Description:* Burrinjuck Dam on the Murrumbidgee River supplies regulated flows for irrigation in the Murrumbidgee valley. Irrigation releases commence in September and cease in March. Based on historical discharge data (DIPNR, unpub.), median January discharge below the dam is approximately 5200 ML day<sup>-1</sup>. Outside of the irrigation season, Burrinjuck provides a riparian flow of 615 ML day<sup>-1</sup>. The dam is equipped with a gated spillway and fixed-level intakes at three different depths. A low-level intake (50 m below FSL) is used regularly to avoid silting. Two mid-level intakes (sill 42 m below FSL) service the dam's HEPS and typically take all flow between 600 and 5500 ML day<sup>-1</sup>. The dam has two upper-level intakes at approximately 14 m below FSL (one recently installed to service the HEPS) which can only be used when storage is above 45 % capacity (Rish et al. 2000; R. Leggot, State Water, pers. comm.).

*CWP Potential:* The storage stratifies through the warmer months with temperature differences between surface and bottom waters exceeding 10 °C when the storage is near to full supply (e.g. 25 and 13 °C respectively in January 1994; Bowling 1994). The magnitude (and extent) of thermal modification below the dam depends on the specific intake(s) in use. Even with recent commissioning of an upper level intake to the HEPS, the mid-level intake is expected to be used frequently in summer (R. Leggot, State Water, pers. comm.). Keenan and Buchan (unpub.) report the maximum temperature depression immediately downstream is 7 to 8 °C (Figure 6). Estimates of the length of Murrumbidgee River affected by Burrinjuck are confounded by the influence of Blowering Dam on the Tumut River, which joins the Murrumbidgee approximately 100 km below Burrinjuck Dam. Keenan and Buchan

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<sup>4</sup> Defined as >5°C peak depression

(unpub.) state the CWP effect of Burrinjuck cease prior to the Tumut River confluence. Irrespective of the relative CWP contributions from the two dams, available information (Keenan & Buchan, unpub.; Astles 2001; Figure 5b) indicates CWP in the Murrumbidgee River persists for between 200 and 300 river km below the confluence.



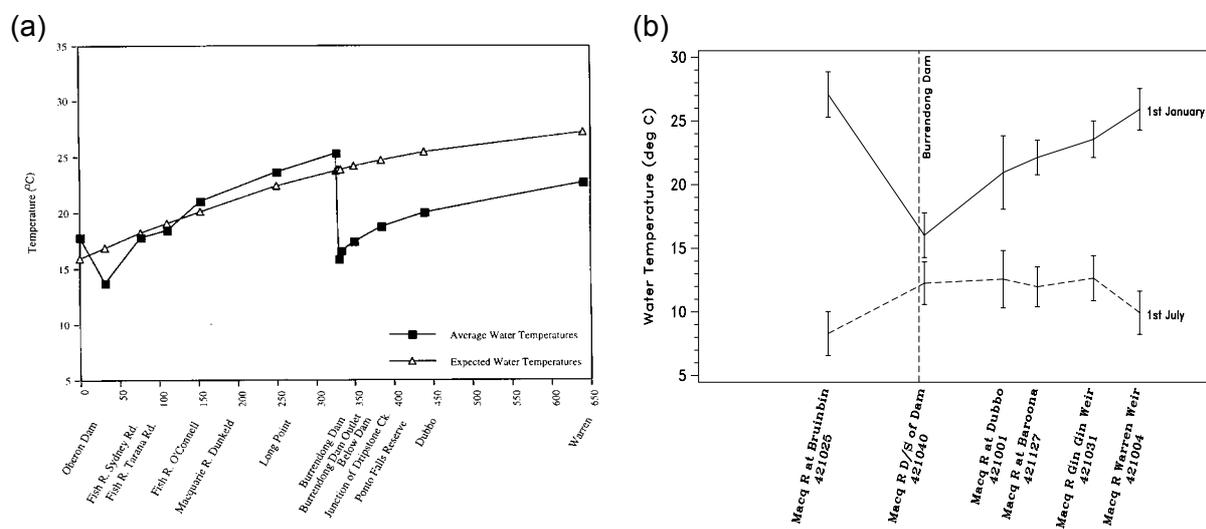
**Figure 6. Water temperature of the Murrumbidgee River at Burrinjuck Dam.**  
Adapted from Lugg (1999).

### **Burrendong Dam (Macquarie River Basin – 421)**

*Description:* Burrendong Dam on the Macquarie River provides regulated supply for irrigation (mainly cotton). Irrigation releases are usually made between September and April / May. The discharge capacity of outlet valves is 8200 ML day<sup>-1</sup> at FSL. Based on historical discharge data (DIPNR, unpub.), median January discharge below the dam is approximately 4000 ML day<sup>-1</sup>. Outside the irrigation season, the minimum (riparian) flow released from the dam is typically between 80 to 150 ML day<sup>-1</sup>. The intake structure comprises a 57 m high open intake tower with trashrack covered inlets from 0 to 37 m below FSL. Water drawn through the intake structure may be directed via penstock valves or a HEPS which has a maximum discharge of 5700 ML day<sup>-1</sup> (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* The storage thermally stratifies from spring to autumn. Available data for a full / near-full storage in January show differences between surface and bottom water temperatures of approximately 12 °C (25 and 13 °C respectively) (Bowling et al. 1994, 1995; Sherman 2000). As summer releases are typically drawn from the hypolimnion, marked alterations to the natural thermal regime of the Macquarie River occur. Burrendong Dam has been the subject of a number of studies to determine the size and persistence of thermal disturbance below the dam (Harris 1997; Acaba et al. 2000; Burton and Raisin 2001a). Estimates of the scale of CWP vary because different data, statistical

methods and reference conditions were used in each study. It appears however that temperature disturbance may persist for 300 to 400 km downstream (Figure 7).



**Figure 7. Water temperature of the Macquarie River above and below Burrendong Dam from Harris 1997 (a) and Acaba et al. 2000 (b).**

### Wyangala Dam (Lachlan River Basin – 412)

*Description:* Wyangala Dam on the Lachlan River regulates flow for summer irrigation in the Lachlan valley. Irrigation releases typically commence in November and run through to Easter. Based on historical discharge data (DIPNR, unpub.), median January discharge below the dam is 1700 ML day<sup>-1</sup>. Outside of the irrigation season, minimum discharge is approximately 200 ML day<sup>-1</sup>. The dam is equipped with two fixed-level intakes at different heights with a combined discharge capacity of approximately 8000 ML day<sup>-1</sup> at FSL. The lower intake is a trashrack covered pipe with a centreline 65 m below FSL. The higher level intake extends from 20 to 34 m below FSL. Releases from both the high and low level can be directed via a HEPS, which operates at a minimum and maximum discharge of 600 and 2400 ML day<sup>-1</sup> respectively. A separate bypass intake is positioned directly below the bottom trashrack of the high level intake and is used at times of maintenance. The dam also has a gated spillway (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* Wyangala storage thermally stratifies from spring to autumn. Temperature differentials between surface and bottom waters of 12 °C have been recorded in January (23 and 11 °C respectively; Bowling et al. 1995). Releases from the dam are typically drawn from the hypolimnion via the fixed-level intakes. In a preliminary assessment of Wyangala Dam's thermal impact, Burton and Raisin (2001b) determined that water temperature immediately below the dam was lower than natural from November to March with a maximum depression of 7 °C. CWP effects were estimated to persist for approximately 170 km. However, based on extrapolation from other storages, NSW Fisheries (Lugg 1999) estimated that serious CWP<sup>5</sup> extends approximately 400 km downstream.

<sup>5</sup> Defined as >5°C peak depression

### **Keepit Dam (Namoi River Basin – 419)**

*Description:* Keepit Dam on the Namoi River regulates flow for irrigated crop production. The largest discharges from the dam occur from September to February. Based on historical discharge data (DIPNR, unpub.), median January discharge is approximately 2000 ML day<sup>-1</sup>. Outside of the irrigation period, minimum flows are approximately 10 ML day<sup>-1</sup>. Regulated discharge from the reservoir is made via two fixed-level pipes through the dam, with the intake centreline of both approximately 24 m below FSL. One intake serves a HEPS while the other serves irrigation valves. The dam is equipped with a gated spillway (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* Keepit thermally stratifies from spring to autumn. However the storage has a relatively shallow mean depth (<10 m, Table 1) so deeper waters heat relatively early and broad thermal gradients develop through summer (Preece & Jones 2002). Historical estimates of the magnitude and extent of thermal modification below the dam range from 180 river km (Whittington and Hillman 1998) to a 5 °C peak depression over 300 river km (Lugg 1999). However, a recent analysis of Keepit's impacts suggests the natural temperature regime of the Namoi River recovers within 100 km of the dam (Preece & Jones 2002).

### **Khancoban Dam (Upper Murray River Basin – 401)**

*Description:* Khancoban Dam on the Swampy Plain River is a re-regulation dam and its principal function is to collect water from Murray 2 Power Station for releases to Swampy Plain River at uniform discharge (DLWC 1998). Mean annual flow in the Swampy Plain River immediately below Khancoban dam has increased by 400 % compared to pre-scheme flows. The 50<sup>th</sup> percentile exceedance flow immediately below the dam is approximately 4000 ML day<sup>-1</sup> (DLWC 1998). This value has been used for the purpose of ranking (Table 1) but may overestimate summer flows which are typically the smallest on a seasonal basis. The outlet works comprise a regulating gate within the spillway structure with a crest approximately 12 m below FSL. The spillway is equipped with two radial gates (SMHEA 1993; Ryan and Preece 2003).

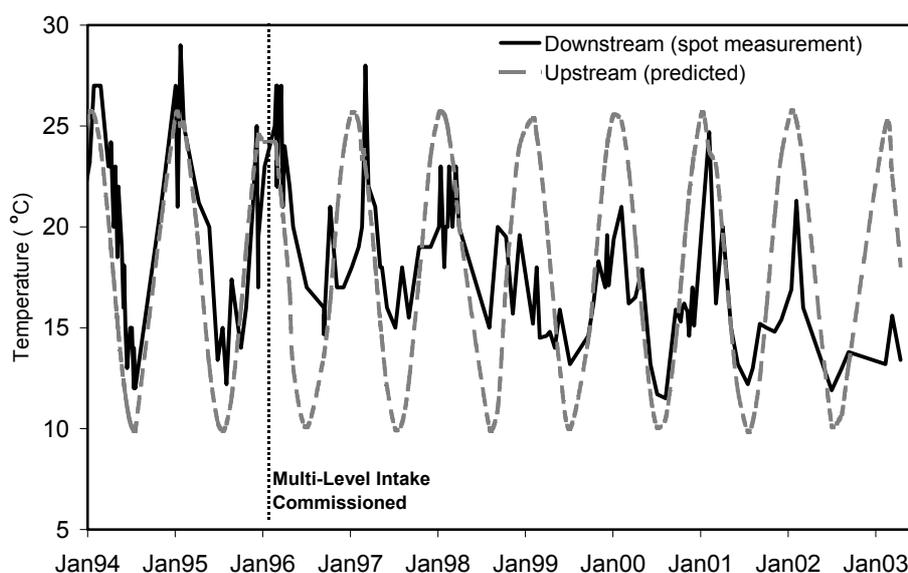
*CWP Potential:* Despite being very shallow (mean depth 4.6 m, Table 1), available profile data indicate the entire storage is often relatively cold during summer—for example, 12 to 15 °C in the surface layers and 11 to 12 °C near the bottom (Bowling 1993). Most inflow to the storage is cold water transferred from Island Bend Pondage, Lake Eucumbene and Jindabyne via a series of power stations and small storages (SMHEA 1993; Bowling 1993). The 50<sup>th</sup> percentile exceedance flow immediately below the dam (DLWC 1998) is approximately 20% of storage volume. This suggests the storage has a very short retention time with limited opportunity for atmospheric heating. The combination of cold inflows and short retention times will result in releases which are markedly colder than natural, and colder than that which would otherwise occur from such a shallow storage.

### **Pindari (Border Rivers Basin – 416)**

*Description:* Pindari Dam on the Severn River provides regulated supply for irrigators along the Borders rivers. Irrigation releases are made between September and March. Based on historical operational data for the years since enlargement (DIPNR, unpub.), median January discharge from the

dam is approximately 1000 ML day<sup>-1</sup>. Outside of the irrigation season, a minimum flow of 13 ML day<sup>-1</sup> is released from the dam. Pindari Dam's outlet works consists of two separate intake structures. The original (low level) intake tower has a fixed inlet approximately 70 m below FSL. A multi-level intake tower was installed as part of the dam enlargement in the mid 1990's and consists of a single column of 12 inlets from 0 to 37 m below FSL. Under normal operating conditions, three vertically adjacent inlets are used at one time (DIPNR 2003a).

*CWP Potential:* Profile data collected between July 1997 and May 1999 (DIPNR, unpub.) indicate the storage undergoes strong thermal stratification which commences in early spring and persists well into winter with only a brief (1 to 2 month) period of mixing. Data for January (DIPNR, 2003a) show a relatively shallow thermocline (5 m below water surface) and temperature differentials between surface and bottom waters of 13 °C (e.g. 26 and 13 °C respectively). Releases are generally made via the multi-level intake tower. Intakes are typically set moderately deep (6 m to 15 m below the water surface) to minimise release of potentially toxic cyanobacteria from the storage (DIPNR 2003a) which, in combination with the shallow thermocline, results in a considerable proportion of water being drawn from the hypolimnion during summer. Available, but limited, data suggest a marked disturbance to water temperature immediately below the dam since enlargement (Figure 8)—average January water temperature below the dam is approximately 6 °C lower than natural (DIPNR 2003a).



**Figure 8. Water temperature of the Severn River above and below Pindari Dam (DIPNR 2003a).**

### **Group 2—Structures Likely to Cause Moderate Thermal Disturbance**

This group contains 14 structures (Table 2, Figure 4). With the exception of Carcoar and Googong Dams, all are located in coastal river basins. A 15<sup>th</sup> structure, Oaky River Dam, was ranked in this group based on discharge and depth of release (Appendix A). However, it is a small hydro-power dam (2780 ML) with relatively large inflows—long term historical flow records (DIPNR, unpub.) indicate annual inflows are 10 times the storage capacity. The dam maintains a high throughput to maximise

power generation so retention times are likely to be sufficiently short to minimise stratification. This structure is therefore likely to have a negligible CWP effect.

Most structures in this group will thermally stratify through warmer months and release water from the hypolimnion or lower reaches of the thermocline to cause significant thermal disturbance immediately below the dam. However, the scale of effect below the structures will not be as great as that of the first group (Table 1) because discharges in warmer months are generally an order of magnitude lower.

The order of structures in Table 2 is indicative at best. This is because discharge figures for Sydney Catchment Authority (SCA) dams were based on short and recent data records and may be unreliable in light of considerable variability in operation of these dams and the recent prolonged drought. Also, at the time of writing, environmental flow provisions from SCA dams in the Hawkesbury-Nepean system were the subject of a review and the Government is expected to specify new environmental flow regimes for these dams (SKM 2003).

**Table 2. Structures Likely to Cause Moderate Cold Water Pollution.**

| Rank | Name                       | Owner <sup>b</sup> | Height (m) | Surface Area (km <sup>2</sup> ) | Capacity (ML) | Mean Depth <sup>c</sup> (m) | Intake Depth (m) | Discharge (ML day <sup>-1</sup> ) |
|------|----------------------------|--------------------|------------|---------------------------------|---------------|-----------------------------|------------------|-----------------------------------|
| 1    | Glenbawn                   | SW                 | 100        | 26.1                            | 750 000       | 28.7                        | 14               | 340                               |
| 2    | Tallowa                    | SCA                | 43         | 9.3                             | 85 500        | 9.2                         | 13               | 180                               |
| 3    | Cataract                   | SCA                | 56         | 9.0                             | 94 300        | 10.5                        | 15               | 130                               |
| 4    | Warragamba                 | SCA                | 113        | 75.0                            | 2 057 000     | 27.4                        | 35               | 45                                |
| 5    | Lostock                    | SW                 | 38         | 2.2                             | 20 000        | 9.1                         | 21               | 70                                |
| 6    | Glennies Ck                | SW                 | 67         | 15.4                            | 283 000       | 18.7                        | 14               | 100                               |
| 7    | Carcoar                    | SW                 | 46         | 3.9                             | 35 800        | 9.2                         | 31               | 45                                |
| 8    | Cordeaux                   | SCA                | 57         | 8.3                             | 93 600        | 11.3                        | 10               | 100                               |
| 8    | Jindabyne                  | SH                 | 72         | 30.3                            | 690 000       | 22.8                        | 20               | 50                                |
| 10   | Toonumbar                  | SW                 | 44         | 1.3                             | 11 000        | 8.5                         | 24               | 32                                |
| 11   | Cochrane <sup>a</sup>      | EE                 | 29         | 0.3                             | 3085          | 10.3                        | 15               | 45                                |
| 12   | Eucumbene                  | SH                 | 116        | 145.0                           | 4 798 400     | 33.1                        | 55               | 6                                 |
| 13   | Googong                    | AA                 | 67         | 7.0                             | 124 000       | 17.7                        | 13               | 16                                |
| 14   | Fitzroy Falls <sup>a</sup> | SCA                | 14         | 5.0                             | 23 500        | 4.7                         | 10               | 18                                |

a. Limited CWP potential because less prone to thermal stratification

b. SW = State Water; SCA=Sydney Catchment Authority; SH = Snowy Hydro Ltd.; EE=Eraring Energy; AA=ActewAGL

c. Storage capacity divided by surface area at FSL

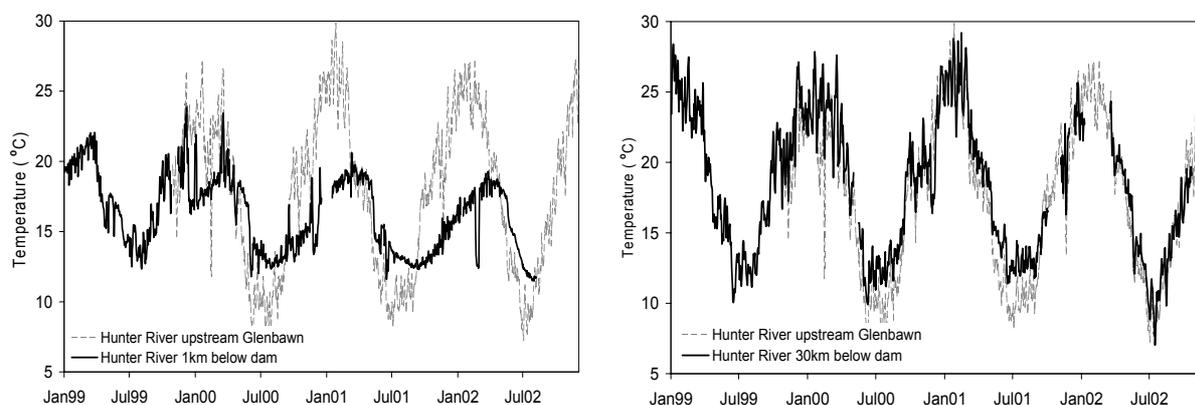
Summaries for selected structures in Table 2 are provided below. Due to the large size of this group and the relatively minor nature of disturbance associated with many of the lower ranked structures, detailed summaries are restricted to the seven dams in the top half of the group.

### **Glenbawn (Hunter River Basin – 210)**

*Description:* Glenbawn Dam on the Hunter River provides regulated river releases for town water supply and industrial uses (principally Bayswater and Liddell power stations). Based on historical discharge data for the period since enlargement, median January discharge below the dam is approximately 340 ML day<sup>-1</sup>. Releases are made via a multi-level intake tower and a separate fixed-level intake structure. The multi-level intake tower operates consists of 14 inlet ports from 0 to 37 m below FSL with three vertically adjacent intakes use at one time. The fixed-level intake draws water

from near the bottom of the storage. It is used only at low discharges, during maintenance or when the height of intakes are being changed (DLWC 2003a).

*CWP Potential:* The storage thermally stratifies with large differences between surface and bottom water temperatures (e.g. 25 and 12 °C respectively (DLWC 2003a)). Intakes are typically positioned quite deep (10 to 19 m depth) as a precaution against the release of potentially toxic cyanobacteria. This depth coincides with the mid to lower reaches of the thermocline (DLWC 2003a). Under normal operating conditions marked temperature disturbances occurs immediately below the dam (Figure 9). A report on the impacts of Glenbawn Dam (Acaba et al. 2000) estimated maximum summer temperatures immediately below the dam to be approximately 7 °C lower than upstream. Recent data (DLWC 2003a) indicate the temperature regime of the Hunter River has largely recovered 30 km below the dam (Figure 9) although a small effect (approximately 1 °C depression in January) has previously been detected 70 km downstream (Acaba et al. 2000). More severe CWP may occur below Glenbawn in response to water orders from the thermal power stations<sup>6</sup>.



**Figure 9. Water temperature of the Hunter River above and below Glenbawn Dam (DLWC 2003a).**

### **Tallowa Dam (Shoalhaven River Basin – 215)**

*Description:* Tallowa Dam on the Shoalhaven River is part of the SCA's Shoalhaven scheme. It provides water to the Shoalhaven district via releases to the Shoalhaven River and provides water to Sydney during drought via inter-basin transfers (SCA 2002a). The storage often remains at, or close to, FSL and spills frequently. SCA's Water Management Licence for Tallowa (DLWC 2003b) specifies an environmental release of 90 ML day<sup>-1</sup> and a riparian release of up to 90 ML day<sup>-1</sup>. Daily discharge data for 2001 to 2004 (SCA, unpub.) indicate releases are relatively constant at 180 ML day<sup>-1</sup>. New outlet works are proposed for Tallowa<sup>7</sup>. The dam's existing works comprise two gated conduits serviced by fixed-level intakes at 20 m below FSL (SCA, unpub.).

<sup>6</sup> The power stations fill their on-site storages from off-allocation flows when such flows are available. When river flows are insufficient to fill the on-site storages, the usual practice is to order water from Glenbawn Dam. At such times the volume of water released from Glenbawn will be greater than that under normal operating conditions (Table 2) and the effects of CWP may extend further downstream.

<sup>7</sup> High level fishway recommended by Healthy Rivers Commission Inquiry (HRC, 1999). Proposed fishway and multi-level intake structure in detailed design phase (R. Nevill, DIPNR, pers. comm.).

*CWP Potential:* The storage thermally stratifies on an annual basis. Because intakes are fixed, release depth is determined by storage level and ranges between 5 and 20 m (SCA, unpub.). However, the storage is often at full supply so intakes are expected to usually draw from the hypolimnion and lower thermocline. The temperature of water in the storage adjacent to outlet is 12 °C (SCA 2002b) and the temperature of water within the first few hundred metres below the dam in summer is approximately 17 °C (Gehrke et al. 2001; SCA 2002b). There are limited data available from which to assess the downstream persistence of thermal modifications. Based on annual time series data for 2001/02 at stations above and below the dam (SCA 2002b), the water temperature of the Shoalhaven River 30 km below the dam was comparable to inflow temperatures, suggesting near complete recovery. However, CWP is regarded as a serious issue below Tallowa because of the dam's position in the catchment<sup>8</sup>.

### **Cataract Dam (Hawkesbury River Basin – 212)**

*Description:* Cataract Dam on the Cataract River is operated by the SCA. The dam is not equipped with diversion works (DLWC 2003b) and its principal function is to transfer water via Cataract River for diversion at Broughtons Pass Weir, approximately 10 km downstream. The Water Management Licence for Cataract (DLWC 2003b) specifies an interim environmental release of 1.3 ML day<sup>-1</sup>. Total river releases for 2001/02 and 2002/03 were 60 902 (SCA 2001b) and 42 340 ML (SCA unpub.) respectively. Daily discharge data (SCA unpub.) for the summers of 2001/02 and 2002/03 indicate releases range from 30 to 460 ML day<sup>-1</sup> with an average of approximately 130 ML day<sup>-1</sup>. River outlet works comprise a scour outlet and main supply outlet which is serviced by two intakes at different levels (SCA, unpub.).

*CWP Potential:* Cataract Dam thermally stratifies from spring to autumn. The main and scour outlets (the latter used for riparian flow) both draw from between 9 and 20 m depth (SCA, unpub.) so for much of the time water will be drawn from below the thermocline leading to marked temperature disturbance immediately below the dam. The dam periodically releases relatively large volumes of water during summer. However, the direct effects of Cataract Dam on the thermal regime of the Cataract River will generally persist only to Broughtons Pass Weir (10 km downstream) where water is then diverted to water filtration plants.

### **Warragamba Dam (Hawkesbury River Basin – 212)**

*Description:* Warragamba Dam on the Warragamba River is the largest dam of the Sydney Water Supply scheme, supplying up to 80% of Sydney's water supply. The majority of stored water is diverted by the Warragamba Pipeline to three water filtration plants (SCA 2002a). The SCA's Water Management Licence (DWLC 2003b) specifies an environmental release matched to inflow up to 33.3 ML day<sup>-1</sup> and a minimum riparian release of 10 ML day<sup>-1</sup>. Total river releases for 2001/02 (12 941 ML, SCA (2001a)) equalled the combined environmental and riparian flow requirement specified in the licence. River releases are not usually made from the dam itself but from a riparian valve on the Warragamba Pipeline. The intake to the pipeline has intakes at three depths from 15 to 55m below FSL (SCA unpub.). The dam is also equipped a separate deeper intake and river outlet for a HEPS

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<sup>8</sup> Unlike many other dams in this study, Tallowa Dam is located towards the bottom end of the Shoalhaven River catchment and obstructs fish passage to some 80% of the catchment. It is also serves as a thermal barrier (CWP would discourage fish from entering a fishway) and failure to address CWP below this dam would undermine potential benefits of improved fish passage.

however available data (SCA unpub.) indicates this is used infrequently (last major HEPS release was in 1998).

*CWP Potential:* The storage has a maximum depth of 105 m and thermally stratifies each year with only a short (1 to 2 month) period of mixing. Water temperatures at the surface and the deepest measured point over a 20 year period averaged 24 and 13 °C respectively (Ferris and Tyler, 1992). All intakes servicing the riparian line are below the surface mixed layer. River temperature data for 2000/01 (SCA 2001) and 2001/02 (SCA 2002b) indicate that river releases remain constant at about 13 °C throughout the year. Despite a very large local CWP effect, river releases are restricted to a small riparian flow. Available data (SCA 2001; 2002b) indicate the temperature regime of the Warragamba River has largely recovered 20 km downstream from the dam.

### **Lostock Dam (Hunter River Basin – 210)**

*Description:* Lostock Dam on the Patterson River provides regulated releases for pasture irrigation (dairy and beef), town water supply and riparian users. Irrigation releases typically commence in September. Based on historical discharge data (DIPNR, unpub.) median January discharge below the dam is approximately 70 ML day<sup>-1</sup>. A riparian release of 40 ML day<sup>-1</sup> is generally maintained to ensure a flow of 25 ML day<sup>-1</sup> occurs at the bottom of the Patterson River. The outlet works include a intake tower with trashrack covered inlets 10 to 21 m below FSL (Rish et al. 2000). The dam does not have a separate scour intake / outlet. Downstream releases from Lostock are typically made via the intake structure although the dam spills on a yearly basis and more often in January through to March (M. Sharkey, State Water, pers. comm.).

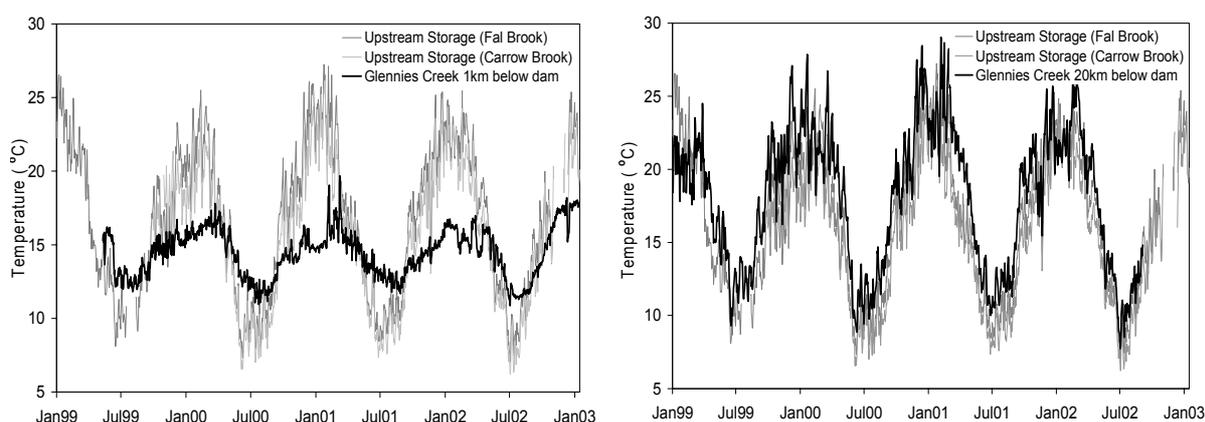
*CWP Potential:* The dam thermally stratifies each year and large temperature differential between surface and bottom waters reportedly occur (M. Sharkey, State Water, pers. comm.). Time series temperature data from a stream gauging station below the dam (DIPNR, unpub.) show a mean daily temperature in January of approximately 20 °C. This is likely to be several degrees lower than that expected naturally, based on extrapolation of inflow temperatures for other dams in the Hunter Basin (Figure 9, 10).

### **Glennies Creek Dam (Hunter River Basin – 210)**

*Description:* Glennies Creek Dam on Glennies Creek provides stored water for diversion to town water supply (Singleton) as well as regulated river releases for irrigation and industrial use on Glennies Creek and the Lower Hunter. Based on historical data (DIPNR, unpub.) median January discharge below the dam is approximately 100 ML day<sup>-1</sup>. The multi-level intake tower has two columns of 14 inlet ports. The tower operates with four intakes in use at one time (two per column) with a combined height of approximately 4.5 m. Water is piped directly from the dam's penstock to Singleton town water supply (DLWC 2003b).

*CWP Potential:* The storage thermally stratifies each year and large differences between surface and bottom water temperatures have been recorded (e.g. 27 and 13 °C respectively, DLWC (2003c)). Because Singleton town water supply is connected directly to the penstock, regular blooms of potentially toxic blue-green algae pose a significant constraint to operation of intake tower for

management of downstream water temperature. The top of the shallowest intake in both columns is typically maintained 13 m below the water surface (DLWC 2003c). However, despite large temperature disturbance immediately below the dam (Figure 10), impacts remain relatively localised due to the small discharges. Available data indicate downstream water temperatures are restored to natural within 20 km of the dam (Figure 10).



**Figure 10. Water temperature above and below Glennies Creek Dam. (DLWC 2003b).**

### **Carcoar Dam (Lachlan River Basin – 412)**

*Description:* Carcoar Dam on the Belubula River provides water for irrigation supply along the length of the Belubula River. Irrigation releases are typically made between October and Easter and range from 20 to 100 ML day<sup>-1</sup>. Based on historical operational data (DIPNR, unpub.), median January discharge from the dam is approximately 45 ML day<sup>-1</sup>. Outside of the irrigation season, a minimum flow of 2 ML day<sup>-1</sup> is maintained downstream. The outlet works include a single fixed-level intake with trashrack covered inlets between 20 and 31 m below FSL. Downstream releases from Carcoar are normally made via the intake structure although the dam spills on a yearly basis, typically in winter/early spring (Rish et al. 2000; Ryan and Preece 2003).

*CWP Potential:* Reports on the stratification behaviour of Carcoar storage coincided with use of artificial aeration destratification at the storage. No studies or reports are available for the period since the mixing equipment was decommissioned. Unaudited profile data for January 2001 (DSNR unpub.), when the storage was within 1 m of FSL, indicates a temperature difference between surface and bottom waters of 12.5 °C (22.5 and 10 °C respectively). Based on examination of intake depth and discharge data from similarly ranked dams in Table 2, the nature of impacts may be similar to that of Glennies Creek, i.e. a potentially large but localised disturbance.

### **Overview of Remaining Structures in Group 2**

The severity of thermal disturbance below most of the remaining structures in Table 2 can be gauged by their position relative to the top and mid-ranked structures just described. Two notable exceptions to the general pattern of behaviour are Cochrane and Fitzroy Falls Dams. Both have limited potential

to thermally stratify—Fitzroy Falls has a mean depth of just 4.7 m and only exhibits limited stratification (SCA 2002a)<sup>9</sup>. Cochrane Dam has a short retention time due to hydropower operations<sup>10</sup>. Both will have a markedly smaller CWP effect compared to other dams in this group.

The remainder of dams in the bottom half of Table 2 are of sufficient depth to develop marked thermal gradients and have intakes that draw from the thermocline or hypolimnion. However, all but one have small summer discharges (<50 ML day<sup>-1</sup>) and are expected to recover within 50 km. Cordeaux Dam makes larger releases than that indicated in Table 2 (up to 400 ML day<sup>-1</sup>, SCA (unpub.)). However, water is diverted at Pheasants Nest Weir, approximately 20 km downstream, thereby limiting the distance that CWP will persist.

Two remaining noteworthy structures in Group 2 are Jindabyne Dam and Eucumbene Dam, both of which are located within the Snowy Mountains Scheme. Jindabyne Dam on the Snowy River is equipped with a river outlet pipe serviced by an intake approximately 20 m below FSL. The dam releases a riparian flow of up to 50 ML day<sup>-1</sup> which equates to 1% of average natural flow (Webster, 1998). However, increased environmental flows and new outlet works are scheduled for this dam<sup>11</sup>. Eucumbene Dam on the Eucumbene River is the central storage of the Snowy Mountains Scheme and receives the headwaters of five rivers. The dam's river outlet comprises two conduits with fixed intakes 55 m below FSL which can provide a riparian release of up to 6 ML day<sup>-1</sup> (Bevitt et al. 1998).

### Group 3—Structures Likely to Cause Minor Cold Water Pollution

This group contains just four structures (Table 3, Figure 4) which are expected to cause a relatively small and localised CWP effect under normal operating conditions due to shallow releases and small discharges.

**Table 3. Structures Likely to Cause Minor Cold Water Pollution.**

| Rank | Name       | Owner <sup>a</sup> | Height (m) | Surface Area (km <sup>2</sup> ) | Capacity (ML) | Mean Depth <sup>b</sup> (m) | Intake Depth (m) | Discharge (ML day <sup>-1</sup> ) |
|------|------------|--------------------|------------|---------------------------------|---------------|-----------------------------|------------------|-----------------------------------|
| 1    | Talbingo   | SH                 | 162        | 19.4                            | 921 400       | 47.4                        | 6                | 250                               |
| 2    | Windamere  | SW                 | 67         | 20.3                            | 368 000       | 18.1                        | 7                | 150                               |
| 3    | Split Rock | SW                 | 66         | 21.5                            | 397 370       | 18.5                        | 7                | 120                               |
| 4    | Chaffey    | SW                 | 54         | 5.4                             | 61 800        | 11.4                        | 6                | 75                                |

a. SH = Snowy Hydro Ltd.; SW = State Water

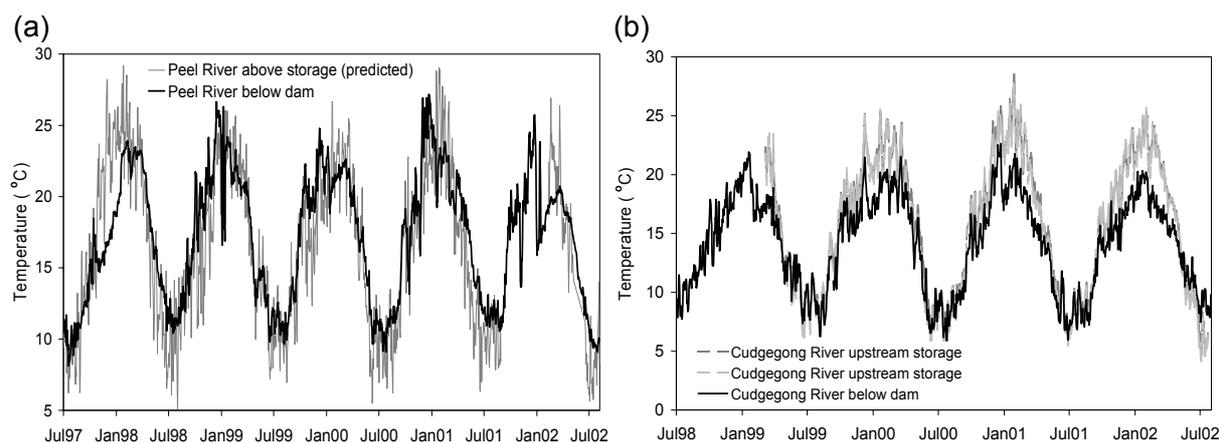
b. Storage capacity divided by surface area at FSL

Three of the dams (Windamere, Split Rock and Chaffey) are selective withdrawal dams located in the central and north west region of the Murray–Darling basin. The principal means of release from all

<sup>9</sup> The HRC (1999) has noted that due to its position in the (upper) catchment, Fitzroy Falls will only have a small impact on riverine ecology.  
<sup>10</sup> Cochrane Dam is a small storage in terms of volume (3085 ML) and relative to inflows which are 9 times the storage capacity (HRC 2000). Retention times are likely to be sufficiently short to minimise stratification. Temperature at the discharge point is reportedly within 1 to 2 °C of natural (I. Forster, Connell Wagner, W. Wilton Eraring Energy, pers. comm.).

<sup>11</sup> A Heads of Agreement (anon, 2000) outlines the arrangements for implementation of the outcomes from the Snowy Water Inquiry (Webster, 1998). This includes requirement for Snowy Hydro Limited (Snowy Hydro) to increase environmental flows into the Snowy River by June 2005. As part of this, Jindabyne will be fitted with a new auxiliary spillway, hydropower station and outlet works. Environmental releases will be drawn from near the reservoir surface to avoid adverse temperature problems.

dams is via a multi-level intake tower. Available data (DSNR 2003; DIPNR 2003b,c) indicate that intakes for all three dams are typically positioned within the thermocline. However, the use of multiple intakes at each dam may result in a proportion of hypolimnetic water being released. Under normal operating conditions<sup>12</sup> discharge are typically small (Table 3). The small discharge and shallow withdrawal depth (relative to dams in other groups) limit the size and scale of impact below these dams (Figure 11).



**Figure 11. Water temperature above and below Chaffey (DIPNR 2003c) (a) and Windamere (DSNR 2003) (b) Dams.**

The remaining structure in Group 3 is Talbingo Dam which discharges to Tumut River via a headrace channel and Tumut 3 Power station (DLWC 1998). Discharge from Tumut 3 Power Station re-enters the Tumut River approximately 3 km below the dam. The dam's river outlet is rarely, if ever, used. While flows immediately below the dam are negligible, the stretch of Tumut River below Tumut 3 Power Station receives higher than natural flows because water is transferred to the power station from other basins (DLWC 1998). Talbingo Dam is deep and undergoes strong thermal stratification (Ryan and Preece 2003). However, the main mode of release is via a headrace channel, the sill of which is approximately 12 m below FSL (SMHEA 1993). The direct effects of Talbingo will be further limited by its location immediately upstream of Jounama and Blowering storages. However, Talbingo may exert an indirect effect on the Tumut River by providing colder than natural inflows to Blowering to influence stratification behaviour in that storage.

#### Group 4—Structures with a Negligible Effect

A total of 66 shortlisted structures are unlikely to cause significant CWP under normal operating conditions for one (or more) of the following reasons:

- they do not discharge to natural waters or release less than 5 ML day<sup>-1</sup>;
- they are equipped with artificial destratification equipment e.g. impellers, aerator;

<sup>12</sup> Split Rock and Windamere dams have two distinct operating regimes. They are upstream from Keepit and Burrendong dams respectively and high volume transfers of water to the downstream storages occur every few years. Higher discharges and deeper intakes may be used at such times leading to more severe and extensive CWP.

- they release via overtopping or from intakes positioned at a depth of 5 m or less;
- other reasons such as unique location (Jounama) or manner of operation (Oakly River).

As noted previously (Figure 2a), forty one structures do not discharge under normal operating conditions. Another 13 have typically discharge 5 ML day<sup>-1</sup> or less. These are all diversionary structures and reductions in natural flow below these dams will be the dominant mechanism of thermal disturbance i.e. reducing the assimilative capacity for heat leading to greater temperature fluctuations.

Twenty three structures were equipped with artificial mixers which will prevent or minimise thermal stratification. Discharge from these dams were therefore expected to have water temperatures close to that occurring naturally in downstream water. Similarly, all structures drawing water through intakes set at less than 5 m below the surface were assumed to release water with a temperature close to that expected to occur naturally.

A noteworthy feature of this group is that it contains five storages with a capacity greater than 100 000 ML—namely, Avon, Liddell, Mangrove Creek, Wetherell and Tantangara Dams. A brief description of each of these dams is provided below.

Avon Dam (Height: 72 m; Capacity: 214 360 ML) on the Avon River is one of four SCA dams of the upper Nepean Water Supply scheme. The dam supplies water to the Illawarra region via diversion to the Illawarra water filtration plant (SCA 2002a). The storage is equipped with artificial destratification equipment and the dam's river outlets comprise a scour outlet with a fixed intake 60 m below FSL and main outlet serviced by a two-level intake (SCA, unpub.). The main outlet is not used. A riparian/environmental release of up to 1.8 ML day<sup>-1</sup> is specified in the Water Management Licence (DLWC 2003b), however the scour outlet cannot release less than 25 ML day<sup>-1</sup>. Consequently there is currently no environmental flow from the dam<sup>13</sup> and thermal disruption is limited to the indirect effects associated with flow diversion rather than direct effects of cold water releases.

Liddell Cooling Water Dam (44 m; 148 000 ML) on Bayswater Creek provides cooling water for Bayswater and Liddell Power Stations. The cooling water intake, pipeline and pumping station are located further up the storage and away from the dam. River outlets comprise a main line and separate scour line both serviced by a submerged intake tower with an intake positioned approximately 24 m below FSL. Water can be discharged to Bayswater Creek within the provisions of the Hunter Salinity Trading Scheme. In any case, river releases are extremely rare due to the need to conserve water for cooling (B. Cullen and E. Burton, Macquarie Generation, pers. comm.).

Mangrove Creek Dam (80 m; 190 000 ML) is used as back-up supply dam for Wyong and Gosford when run of river flows are insufficient to meet demand. The storage is artificially destratified. Raw water from Mangrove Creek Dam is distributed by two means (i) releases to Mangrove Creek are made via selective withdrawal intake tower which typically draws from 3 m below surface (ii) inter-valley transfer to Wyong Creek via a separate, rudimentary selective withdrawal structure consisting of a vertical pipe which typically draws from 1 m depth. (A McLeod, Wyong Council, pers. comm.;

<sup>13</sup> Modifications to outlet works have been flagged but not in works schedule for the 2003/04 financial year (Richard Nevill, DIPNR, pers. comm.).

M. Redrup GWCWC, pers. comm.). The combination of infrequent releases, surface withdrawal and artificial mixing limit direct thermal effects of this dam on receiving waters.

Tantangara Dam (45 m, 254 100 ML) on the Murrumbidgee River diverts the headwaters of the Murrumbidgee River to Lake Eucumbene in the Snowy River drainage basin (SMHEA 1993). All inflows are diverted with the exception of large floods (DLWC 1998). The dam's river outlet consists of one conduit through the dam with an intake 34 m below FSL. Minimum flows must be maintained downstream but this is normally achieved by downstream catchment inflows. Consequently no water is released from the dam under normal operating conditions, and mean annual flow volume below the dam is approximately 2 % of the pre-dam flow (DLWC 1998). Under current operation, thermal disturbance below this dam will normally be limited to the indirect effects associated with flow diversion rather than the direct effects of cold water releases. However, under a current Heads of Agreement between State and Federal Governments, environmental flows will be increased and outlet works upgraded<sup>14</sup>. These actions should minimise both the indirect and direct impacts of this dam on downstream water temperature.

Lake Wetherell (12 m, 267 000 ML) forms part of the Menindee Lake system and provides regulated supply for town water and irrigation along the lower Darling, as well as occasional releases to supplement flow in the Murray River (Harriss et al. 1998). Lake Wetherell releases water via a gated main weir and a separate outlet regulator. Releases from the weir are restricted to flood operations and river releases are typically made via the outlet regulator. The sill level of the regulator is approximately 9 m below FSL. However, the lake water level is drawn down several metres in spring to minimise evaporative losses associated with shallow overbank areas (Harriss et al. 1998) so the outlet is just 7 m below the water surface. In a typical year, releases from the outlet regulator cease in November (M. Arandt, State Water, pers. comm). Lake Wetherell stratifies during warmer months with temperature differentials between surface and bottom waters of up to 8 °C (Harriss et al. 1998) However, bottom waters sometimes exhibit significant increases in temperature relatively early in the heating period (e.g. bottom water temperature of 17 °C recorded in November 1992; Bowling 1994). Thermal stratification may also be disrupted in response to hydrometeorological events such as large inflows (Bowling 1994). The relative warm temperature of deeper strata in Lake Wetherell in combination with a shallow withdrawal depth will therefore reduce the severity of thermal disturbance associated with use of the outlet regulator.

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<sup>14</sup> A Heads of Agreement (anon. 2000) outlines the arrangements for implementation of the outcomes from the Snowy Water Inquiry (Webster, 1998). This includes a requirement for environmental flows from Tantangara to improve river health by June 2005. Snowy Hydro will construct outlet works to meet the new volumetric requirements that will include the ability to draw water from the surface mixed layer.

## 4. Discussion and Conclusions

Of the 27 dams found to have significant CWP potential, nine have been identified as causing severe disturbance while another 14 have been identified as causing moderate disturbance. These findings are generally consistent with the earlier review undertaken by NSW Fisheries (Lugg 1999). Table 4 shows that eight of the nine dams identified in this study as causing severe CWP were also flagged by NSW Fisheries as the major contributors to CWP in NSW.

**Table 4. Status of Dams Associated with a Severe and Moderate CWP Effect**

| Dam            | This Report | NSW Fisheries <sup>a</sup> | Cold Water Pollution Status   |
|----------------|-------------|----------------------------|---|
| Blowering      | High        | ✓ (60 <sup>b</sup> )       | CWP mitigation may be considered at time of scheduled dam safety upgrade  |
| Hume           | High        | ✓ (300)                    | MDBC study of CWP impacts and mitigation options underway   |
| Copeton        | High        | ✓ (300)                    | CWP mitigation may be considered at time of scheduled dam safety upgrade  |
| Burrinjuck     | High        | ✓ (400 <sup>b</sup> )      | Assessment / thermal modelling of CWP impacts underway  |
| Burrendong     | High        | ✓ (400)                    | Feasibility study of draft tube mixer (MHL 2003) and thermal curtain (MHL 2004) completed. Further development of thermal curtain and selective withdrawal options underway. CWP mitigation may be considered at time of scheduled dam safety upgrade |
| Wyangala       | High        | ✓ (400)                    | CWP mitigation may be considered at time of scheduled dam safety upgrade  |
| Keepit         | High        | ✓ (300)                    | Multi-level intake design options being considered as part of options development for current dam safety upgrade (due 2006). Decision on whether or not to proceed with CWP mitigation not yet made   |
| Khancoban      | High        | ✓ (120)                    |   |
| Pindari        | High        | ✗                          | Actions for improved management of selective withdrawal intake identified (DIPNR2003a)<br>Study of options for structural modifications to intake tower complete (GHD 2003)   |
| Glenbawn       | Medium      | ✓                          | Actions for improved management of selective withdrawal intake identified (DLWC 2003a)<br>Study of options for structural modifications to intake tower complete (GHD 2003)   |
| Tallowa        | Medium      | ✓ (30)                     | Proposed fishway and multi-level intake structure in detailed design phase  |
| Cataract       | Medium      | ✗                          | Impacts limited by downstream diversion weir. Subject of review of environmental flows by Hawkesbury-Nepean River Management Forum  |
| Warragamba     | Medium      | ✓ (50)                     | Subject of review of environmental flows by Hawkesbury-Nepean River Management Forum  |
| Lostock        | Medium      | ✓ (45)                     |   |
| Glennies Creek | Medium      | ✓                          | Actions for improved management of selective withdrawal intake identified (DLWC 2003c)<br>Study of options for structural modifications to intake tower complete (GHD 2003)   |
| Carcoar        | Medium      | ✓ (50)                     |   |
| Cordeaux       | Medium      | ✗                          | Subject of review of environmental flows by Hawkesbury-Nepean River Management Forum  |
| Jindabyne      | Medium      | ✗                          | Outlet works to be upgraded to meet new environmental flow targets—works to include provision for surface release   |
| Toonumbar      | Medium      | ✗                          |   |
| Cochrane       | Medium      | ✗                          | Limited CWP potential because less prone to thermal stratification  |
| Eucumbene      | Medium      | ✗                          |   |
| Googong        | Medium      | ✗                          | Negligible CWP (Blanch 2000)  |
| Fitzroy Falls  | Medium      | ✗                          | Limited CWP potential because less prone to thermal stratification  |

a. Lugg (1999). Tick indicates dam was noted as a significant contributor; number in brackets is estimate of the length of river (km) subject to severe (>5°C peak depression) CWP.

b. The combined effects of Burrinjuck and Blowering Dams estimated to persist for 400 km downstream.

Pindari Dam was not listed by Lugg (1999) as a significant source of CWP but was identified as a severe-disturbance dam in this assessment. Despite the installation of a selective withdrawal intake tower in 1995, the use of multiple and deeper intakes at Pindari leads to a large proportion of water being drawn from the base of the thermocline and hypolimnion. Available but limited data show marked temperature depression immediately below the dam (typically 6 °C lower than natural in January). On the basis of typical discharge, the direct effects of this dam may extend 100+ km downstream.

Several other findings from this preliminary assessment are worthy of note. Earlier reports on Keepit Dam have flagged it is a major CWP contributor, with effects estimated to persist for at least 200 to 300 km downstream. This study has also identified Keepit as one of the dams likely to cause severe CWP. However, it was one of the lower ranked dams in this category, consistent with recent findings that the natural temperature regime of the Namoi River is normally restored within 100 km of the dam. Similarly, the length of river affected by CWP from Wyangala Dam has traditionally been considered comparable to that below the most severe CWP dams in NSW (i.e. 400 km, Table 4). However, discharge from Wyangala is typically less than half of that of the most severe dams so the natural temperature regime of the Lachlan River below this dam may recover over a much shorter distance than originally thought. Brogo Dam (not shown in Table 4) was also flagged by NSW Fisheries as a significant contributor to CWP. However, it is unlikely to be significant because of small discharges and a shallow release depth, the latter aided by a simple but effective sliding gate mechanism retrofitted to the dam in 1996.

With regard to management of CWP, Table 4 shows that many of the severe and moderate-disturbance dams are the subject of current, or recently completed, studies related to CWP. All these studies are exploratory in nature and, with the possible exception of Keepit and Hume Dams, will not necessarily translate to mitigation works. Of the nine high priority dams, five State Water dams are scheduled for safety upgrades in the short to medium term (Keepit, Blowering, Burrendong, Copeton and Wyangala). Under current arrangements, State Water may consider CWP mitigation in the initial scoping of upgrade options for each of these dams, but the decision to build / implement works to mitigate CWP remains subject to cost–benefit considerations. CWP mitigation works will be constructed at two medium priority dams (Tallowa and Jindabyne) as part of upgrades to meet other environmental objectives (fish passage and environmental flows respectively). In these two cases, CWP mitigation is necessary in order to maximise ecological benefits associated with the primary environmental objective.

Table 4 highlights some problems with regard to current priorities for CWP mitigation in NSW. Apart from dams within catchments subject to independent inquiries (e.g. Snowy Water Inquiry for Jindabyne Dam), priorities and timelines for CWP mitigation are driven largely by the dam safety program. As such, dams that are of high priority in terms of CWP but of low priority in terms of safety risk (e.g. Burrinjuck and Khancoban) are not likely to be considered in the short to medium term. Moreover, for those dams of high priority in the safety upgrade program (e.g. Keepit, Burrendong, Copeton), CWP mitigation remains optional and is subject to the long timelines of safety upgrade projects, i.e. six years from option investigation to build/implement. Consequently, the earliest improvements to water temperature below high priority structures will be that associated with Keepit

Dam which is due for completion in 2006 (J Potts, State Water, pers. comm). Others, such as Copeton Dam, are not likely to be addressed until towards the end of the decade.

A considerable amount of work has been undertaken in recent years to identify and develop options to mitigate CWP below priority dams in NSW. These include operational changes to improve the performance of existing selective withdrawal infrastructure (e.g. Glenbawn Dam) through to innovative, low-cost engineering solutions for high priority fixed-intake structures (Sherman 2000). The latter are of particular interest because their performance is reportedly comparable to that of traditional engineering solutions such as multi-level intake towers but associated capital costs are an order of magnitude lower—for example, capital cost of \$1.7 M for a thermal curtain at Burrendong Dam (MHL 2004) versus \$25 M (1996 prices) for a multi-level intake tower (DPWS 1996)<sup>15</sup>. Options such as these could be implemented independently of the dam safety program to realise thermal benefits sooner.

The principal recommendation arising from studies in Queensland (Brennan, draft) and Victoria (Ryan et al. 2001) is the need for further monitoring and research to accurately determine the scale and extent of problems. In NSW, many important dams are insufficiently monitored and the continued operation of some critical monitoring networks is not assured (Preece, unpub.). However, irrespective of limitations of current instream and storage monitoring, there is already sufficient knowledge of priority dams and feasible mitigation options to form the basis for a staged plan of action. A formal and independent mechanism to address CWP below high priority dams in NSW has been mooted for some time, but has been confounded by uncertainty over institutional responsibilities for aspects of dam management. Recent institutional reforms in NSW (including the formal separation of State Water from the State's natural resource management agency) have clarified water delivery, regulator and resource management roles. A formal mechanism to address CWP is now under consideration.

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<sup>15</sup> Order of cost for a tower that could access 100% of storage.

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## Appendix A – Summary of Shortlisted Structures

| Basin | Dam             | Watercourse        | Owner                        | Height (m) | Capacity (ML) | Intake Depth Estimate (m) | Discharge Estimate (ML day <sup>-1</sup> ) | Mean Depth <sup>a</sup> (m) | CWP Status        | Comments / Notes   | Principal Information Sources / Contacts <sup>b</sup>  |
|-------|-----------------|--------------------|------------------------------|------------|---------------|---------------------------|--|-----------------------------|-------------------|--|--|
| 212   | Avon            | Avon River         | SCA                          | 72         | 214360        | 60                        | 0  | 21.4                        | <i>Negligible</i> | urban water supply - diversion plus river transfers to diversion weir 15 km downstream; river transfers rare based on available data; artificial destratification; outlet works cannot deliver specified environmental release                         | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 210   | Bayswater Main  | Ramrod Creek       | Coal Operations Aust         | 27         | 1200          | na                        | 0  | nd                          | <i>Negligible</i> | on-site water management, no outlet works  | I. Tredinnick, Coal Operations Australia, pers. comm.  |
| 410   | Blowering       | Tumut River        | State Water                  | 112        | 1628000       | 74                        | 8200                                       | 36.5                        | <i>High</i>       | see report   | Ryan and Preece 2003, DIPNR HYDSYS database  |
| 219   | Brogo           | Bega River         | State Water                  | 43         | 9800          | 3                         | 70   | 9.8                         | <i>Negligible</i> | sliding gate multi-level intake  | P. Clemson, State Water, pers. comm.; DIPNR HYDSYS database  |
| 215   | Bundanoon       | Bundanoon Ck       | Wingecarribee Shire Council  | 35         | 2000          | 35                        | 0  | 6.7                         | <i>Negligible</i> | artificial destratification (diffuser bars) set mid-depth so ignored because mixing/heating may not extend to scour; river releases via scour line but only when spilling; HRC notes sig. trib. inflows within a few km                                | M. Williams, Wingecarribee Shire Council, pers. comm.; HRC (1999)  |
| 421   | Burrendong      | Macquarie River    | State Water                  | 76         | 1190000       | 37                        | 4000                                       | 16.5                        | <i>High</i>       | see report   | Ryan and Preece 2003, DIPNR HYDSYS database  |
| 410   | Burrinjuck      | Murrumbidgee River | State Water                  | 93         | 1026000       | 42                        | 5200                                       | 18.7                        | <i>High</i>       | see report   | Ryan and Preece 2003; R Leggot, State Water, pers. comm.; DIPNR HYDSYS database  |
| 412   | Cadiangullong   | Cadiangullong Ck   | Cadia Holdings Pty Ltd       | 43         | 4200          | 43                        | 3.4  | 10                          | <i>Negligible</i> | process water supply; riparian flows only  | B. Perry and J. Seaman, Cadia Holdings, pers. comm.  |
| 412   | Carcoar         | Belubula River     | State Water                  | 46         | 35800         | 31                        | 45   | 9.2                         | <i>Medium</i>     | see report   | Ryan and Preece 2003; DIPNR HYDSYS database  |
| 212   | Cascade 3       | Cascade Ck         | SCA                          | 30         | 1704          | 30                        | 0  | 7.4                         | <i>Negligible</i> | no river outlet according to Water Management Licence  | DLWC 2003b; R. Nevill, DIPNR, pers. comm.  |
| 212   | Cataract        | Cataract River     | SCA                          | 56         | 94300         | 15                        | 135  | 10.5                        | <i>Medium</i>     | river transfers only; diversion weir 10 km downstream  | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 419   | Chaffey         | Peel River         | State Water                  | 54         | 61800         | 6                         | 75   | 11.4                        | <i>Low</i>        | see report   | Ryan and Preece 2003; DIPNR. 2003c; DIPNR HYDSYS database  |
| 210   | Chichester      | Chichester River   | Hunter Water Corporation Ltd | 37         | 22700         | 37                        | 30   | 12.6                        | <i>Negligible</i> | artificial destratification; multi-level offtake (MLO) to town water; riparian flow via scour line & HEPS  | D. Holroyde, Hunter Water, pers. comm.; WML (DLWC 2002)  |
| 421   | Chifley         | Campbells River    | Bathurst City Council        | 32         | 30000         | 3                         | 90   | 13.6                        | <i>Negligible</i> | artificial destratification; river transfers via trunnion intake to downstream diversion weir  | Ryan and Preece 2003   |
| 201   | Clarrie Hall    | Doon Doon Ck       | Tweed Shire Council          | 43         | 16000         | 20                        | 50   | 7.3                         | <i>Negligible</i> | artificial destratification; river transfers via MLO to diversion weir 10 km downstream  | D. Oxenham, Tweed Council, pers. comm  |
| 219   | Cochrane        | Georges Ck         | Eraring Energy               | 29         | 3085          | 15                        | 45   | 9.6                         | <i>Medium</i>     | small hydro-power storage, large inflows and high throughput limit retention time and stratification potential; recent change in policy to store some water for summer irrigation supply may lead to increased retention time/stratification potential | Ian Forster, Connell Wagner, pers. comm.; Warwick Wilton, Eraring Energy, pers. comm.; HRC 2000                                    |
| 419   | Coepolly Ck 2   | Werris Ck          | Parry Shire Council          | 21         | 5400          | 3                         | 3  | 3.6                         | <i>Negligible</i> | riparian releases via trunnion intake  | Ryan and Preece 2003   |
| 418   | Copeton         | Gwydir River       | State Water                  | 113        | 1364000       | 69                        | 3600                                       | 32                          | <i>High</i>       | see report   | Ryan and Preece 2003; DIPNR HYDSYS database  |
| 212   | Cordeaux        | Cordeaux River     | SCA                          | 57         | 93600         | 10                        | 100  | 11.3                        | <i>Medium</i>     | diversion works decommissioned; river transfers to diversion weir 20 km downstream   | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 207   | Cowarra         | Kings Ck           | Hastings Council             | 40         | 10000         | 22                        | 0  | 14.3                        | <i>Negligible</i> | essentially off-river; partway through initial fill, artificial destratification, MLO, limited river releases expected   | R Scott, Hastings Shire Council, pers. comm.   |
| 215   | Danjera         | Danjera Ck         | Shoalhaven City Council      | 30         | 7800          | 9                         | 0  | 8.7                         | <i>Negligible</i> | back-up urban water supply via river transfers to downstream diversion weir; two intake pipes at different levels plus scour intakes   | M. Jennings, Shoalhaven Water, pers. comm.   |
| 419   | Dungowan        | Dungowan Ck        | Tamworth City Council        | 31         | 5700          | 11                        | 10   | 11.4                        | <i>Negligible</i> | artificial destratification; riparian release via MLO  | Ryan and Preece 2003; DIPNR 2003c  |
| 421   | Dunn's Swamp    | Cudgegong River    | Australian Cement Holdings   | 16         | 1440          | 16                        | 5  | nd                          | <i>Negligible</i> | riparian releases; no information received on discharge (assume less than 5ML day <sup>-1</sup> )  | Glen Best, Aust. Cement Holdings, pers. comm.  |
| 222   | Eucumbene       | Eucumbene River    | Snowy Hydro Limited          | 116        | 4798400       | 55                        | 6  | 33.1                        | <i>Medium</i>     | see report   | SMHEA 1993; Bevitt et al 1998  |
| 215   | Fitzroy Falls   | Yarrunga Ck        | SCA                          | 14         | 23500         | 10                        | 18   | 4.7                         | <i>Medium</i>     | see report   | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 401   | Geehi           | Geehi River        | Snowy Hydro Limited          | 91         | 21100         | 70                        | 0  | 30.1                        | <i>Negligible</i> | diversion for hydro-power  | Ryan and Preece 2003   |
| 210   | Glenbawn        | Hunter River       | State Water                  | 100        | 750000        | 14                        | 330  | 9.1                         | <i>Medium</i>     | see report   | DLWC 2003a; DIPNR HYDSYS database  |
| 210   | Glennies Creek  | Glennies Ck        | State Water                  | 67         | 283000        | 14                        | 100  | 9.1                         | <i>Medium</i>     | see report   | DLWC 2003b; DIPNR HYDSYS database  |
| 410   | Googong         | Queenbeyan River   | Actew AGL                    | 67         | 124000        | 13                        | 16   | 17.8                        | <i>Medium</i>     | riparian releases from MLO; reportedly drawn from surface layers   | Ryan and Preece, Blanch 2001   |
| 222   | Guthega         | Snowy River        | Snowy Hydro Limited          | 34         | 1550          | 25                        | 0  | 9.1                         | <i>Negligible</i> | diversion for hydro-power; small storage spill regularly in spring; captures all flow in summer; flows returned to river 4km upstream from Island Bend Dam   | SMHEA 1993; Bevitt et al 1998  |
| 401   | Hume            | Murray River       | River Murray Water           | 51         | 3038000       | 25                        | 20000                                      | 15                          | <i>High</i>       | see report   | Ryan et al. 2001; Sherman 2003; DIPNR HYDSYS database  |
| 204   | Humphreys Creek | Humphreys Ck       | Virotec/Norminco Ltd         | 15         | 1100          | 15                        | 0  | nd                          | <i>Negligible</i> | process water supply   | DSC 2003   |
| 222   | Island Bend     | Snowy River        | Snowy Hydro Limited          | 49         | 3000          | 31                        | 0  | 9.1                         | <i>Negligible</i> | diversion for hydro-power  | SMHEA 1993; Bevitt et al 1998  |
| 222   | Jindabyne       | Snowy River        | Snowy Hydro Limited          | 72         | 690000        | 20                        | 50   | 22.7                        | <i>Medium</i>     | see report   | SMHEA 1993; Bevitt et al 1998; Webster 1998  |
| 410   | Jounama         | Tumut River        | Snowy Hydro Limited          | 44         | 43500         | 11                        | 2500                                       | 11.4                        | <i>Negligible</i> | ranked as a High CWP Structure based on discharge and intake depth but is  | Ryan and Preece 2003   |

| Basin | Dam                                 | Watercourse        | Owner                        | Height (m) | Capacity (ML) | Intake Depth Estimate (m) | Discharge Estimate (ML day <sup>-1</sup> ) | Mean Depth <sup>a</sup> (m) | CWP Status | Comments / Notes  | Principal Information Sources / Contacts <sup>b</sup>   |
|-------|-------------------------------------|--------------------|------------------------------|------------|---------------|---------------------------|--|-----------------------------|------------|---|---|
| 215   | Kangaroo Pipeline Control Structure | off Yarrunga Ck    | SCA                          | 19         | 23500         | na                        | 0  | 4.4                         | Negligible | Negligible due to location (between Talbingo and Blowering Dams)<br>essentially off-river; does not release to river  | R Nevill, DIPNR, pers. comm.  |
| 419   | Keepit                              | Namoi River        | State Water                  | 55         | 423000        | 24                        | 2000                                       | 9.6                         | High       | see report  | Ryan and Preece 2003; Preece and Jones 2002; DIPNR HYDSYS database  |
| 401   | Khancoban                           | Swampy Plain River | Snowy Hydro Limited          | 18         | 21500         | 12                        | 4000                                       | 4.6                         | High       | see report  | Ryan and Preece 2003; DLWC 1998   |
| 412   | Lake Endeavour                      | Billabong Ck       | Parkes Shire Council         | 21         | 2400          | 21                        | 0  | 4                           | Negligible | diversion for town water supply   | Ryan and Preece 2003  |
| 416   | Lake Inverell                       | Macintyre River    | Inverell Shire Council       | 11         | 1500          | 5                         | 0  | 3                           | Negligible | silted  | Ryan and Preece 2003  |
| 412   | Lake Rowlands                       | Coombing Rivulet   | Central Tablelands Water     | 20         | 4500          | 20                        | 3  | 5.6                         | Negligible | artificial destratification; riparian release via scour   | Ryan and Preece 2003  |
| 418   | Lake Tullimba                       | Head Station Creek | University of New England    | 18         | 1200          | 18                        | 0  | nd                          | Negligible | water pumped to feedlot/irrigation  | DSC 2003  |
| 210   | Liddell Cooling Water               | Bayswater Ck       | Macquarie Generation         | 43         | 148000        | 24                        | 0  | 13.1                        | Negligible | releases rare and only under Hunter Salt Trading Scheme   | B. Cullen, E. Burton, Macquarie generation, pers. comm.   |
| 210   | Liddell Water Supply                | Tinkers Ck         | Macquarie Generation         | 31         | 4500          | 1                         | 0  | nd                          | Negligible | drinking water supply; releases rare (only via spill)   | B. Cullen, E. Burton, Macquarie generation, pers. comm.   |
| 210   | Lostock                             | Patterson River    | State Water                  | 38         | 20000         | 21                        | 70   | 9.1                         | Medium     | see report  | Rish et al. 2000; M Sharkey, State Water, pers. comm.; DIPNR HYDSYS database  |
| 212   | Lyell                               | Coxs River         | Delta Electricity            | 50         | 33500         | 5                         | 20   | 14.1                        | Negligible | water for power station operation; artificial destratification; riparian release via MLO  | Connell Wagner 2003a,b; DLWC 2001a  |
| 206   | Malpas                              | Gara River         | Armidale Dumaresq Council    | 31         | 13000         | 31                        | 0  | 7.2                         | Negligible | artificial destratification; riparian release only during drought either via scour or at point 20 km downstream from delivery main (serviced by MLO);                 | M. Porter, Armidale Dumaresq Council, pers. comm.   |
| 212   | Mangrove Creek                      | Mangrove Creek     | Gosford City Council         | 80         | 189200        | 3                         | 60   | 27.8                        | Negligible | back up supply, artificial destratification, river transfers (via Mangrove Ck) and diversion (to Wyong River Weir), intakes for both near surface                     | A. McLead, Wyong Council, pers. comm; M Redrup, GWCWC, pers. comm.  |
| 213   | Manly                               | Manly Dam          | Sydney Water Corporation     | 20         | 2000          | 20                        | 0  | 6.7                         | Negligible | artificial destratification; recreation; no riparian flow specified   | Richard Nevill, DIPNR, pers. comm.; DLWC (2001b)  |
| 212   | Medway                              | Medway Rivulet     | Wingecarribee Shire Council  | 25         | 1300          | 23                        | 0  | 6.5                         | Negligible | artificial destratification; diversion to town water; scour rarely used   | M. Williams, Wingecarribee Shire Council, pers. comm.   |
| 212   | Mooney Upper (1)                    | Mooney Mooney Ck   | Gosford City Council         | 27         | 4600          | 27                        | 0  | 7.7                         | Negligible | diversion for town water; artificial destratification;  | A McLead, Wyong Council, pers. comm; M Redrup, GWCWC, pers. comm.   |
| 210   | Mt Arthur Nth Env                   | off river          | Coal Operations Aust         | 17         | 1260          | 1                         | 0  | nd                          | Negligible | on-site process water supply; partway through initial fill; unlikely to release but only via spill  | I. Tredinnick, Coal Operations Australia, pers. comm.   |
| 401   | Murray 2                            | Khancoban Back Ck  | Snowy Hydro Limited          | 43         | 2310          | 28                        | 0  | 12.2                        | Negligible | diversion for hydro-power   | Ryan and Preece 2003  |
| 212   | Nepean                              | Nepean River       | SCA                          | 82         | 70170         | 15                        | 350  | 21.6                        | Negligible | artificial destratification; diversion and river transfers (available data suggest small river releases in summer); river transfers to diversion weir 20km downstream | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 206   | Oaky River                          | Oaky River         | Country Energy               | 18         | 2780          | 13                        | 70   | nd                          | Negligible | ranked as a Medium CWP structure based on discharge and intake depth but is Negligible due to limited stratification potential (high throughput for hydro-power)      | J. Charlier & K. Murphy, Country Energy, pers. comm.; DIPNR HYDSYS database   |
| 421   | Oberon                              | Fish River         | Fish River Water Supply      | 35         | 45000         | 3                         | 2.4  | 11                          | Negligible | diversion to town water; riparian release via MLO   | Ryan and Preece 2003  |
| 212   | Pejar                               | Wollondilly River  | Goulburn City Council        | 23         | 9000          | 10                        | 3  | 5.8                         | Negligible | back-up supply via occasional river transfers, usually small riparian release   | M. O'Rourke, Goulburn City Council, pers. comm.   |
| 416   | Pindari                             | Severn River       | State Water                  | 85         | 312000        | 11                        | 1000                                       | 29.7                        | High       | see report  | Ryan and Preece 2003; DIPNR 2003a; DIPNR HYDSYS database  |
| 210   | Plashett                            | Saltwater Ck       | Macquarie Generation         | 20         | 65000         | 40                        | 0  | 11.2                        | Negligible | essentially an off river storage; water pumped to storage from Hunter River, no releases  | B. Cullen, Macquarie generation, pers. comm.  |
| 216   | Porters Creek                       | Porters Ck         | Shoalhaven City Council      | 17         | 1900          | 17                        | 0  | 4.8                         | Negligible | artificial destratification; diversion; river releases rare (only to exercise scour during spill)   | M. Jennings, Shoalhaven Water, pers. comm.  |
| 213   | Prospect                            | Prospect Ck        | SCA                          | 26         | 50200         | na                        | 0  | 9.8                         | Negligible | essentially an off-river storage; no river outlet works   | DLWC 2003b  |
| 206   | Puddledock Creek                    | Puddledock Ck      | Armidale Dumaresq Council    | 19         | 1700          | 21                        | 0  | 11.3                        | Negligible | back-up town water supply (diversion); release via scour (rare)   | Mike Porter, Armidale Dumaresq Council; pers.comm.  |
| 203   | Rocky Creek                         | Rocky Creek        | Rous Water                   | 28         | 14000         | na                        | 0  | 7                           | Negligible | artificial destratification; no river outlet  | D. Patch, Rous Water, pers. comm.   |
| 421   | Rylstone                            | Cudgegong River    | Rylstone Shire Council       | 15         | 3320          | 15                        | 0  | 10.1                        | Negligible | river releases via scour (rare)   | Ryan and Preece 2003  |
| 212   | Sooley                              | Bumana Ck          | Goulburn City Council        | 13         | 3350          | 13                        | 8  | 2.8                         | Negligible | artificial destratification; town water supply - river transfers to diversion weir 2km downstream   | M. O'Rourke, Goulburn City Council, pers. comm.   |
| 419   | Split Rock                          | Manilla River      | State Water                  | 66         | 397370        | 7                         | 120  | 18.5                        | Low        | potentially severe CWP during bulk water transfers to Keepit  | Ryan and Preece 2003; DIPNR 2003b; DIPNR HYDSYS database  |
| 421   | Spring Creek                        | Spring Ck          | Orange City Council          | 16         | 4700          | 16                        | 0  | 4.3                         | Negligible | back-up town water supply - diversion   | Ryan and Preece 2003  |
| 425   | Stephens Creek                      | Stephens Ck        | Aust Inland Energy and Water | 15         | 21000         | 15                        | 0  | 2.5                         | Negligible | town water supply - diversion   | Ryan and Preece 2003  |
| 206   | Steuart McIntyre Dam                | Fattorini Ck       | Kempsey Shire Council        | 25         | 2500          | 12                        | 0  | nd                          | Negligible | artificial destratification; off-river storage; diversion to town water   | E. Ussher, Kempsey Shire Council, pers. comm.   |
| 421   | Suma Park                           | Summer Hill Ck     | Orange City Council          | 31         | 18000         | 31                        | 1  | 13.8                        | Negligible | artificial destratification; town water - diversion; riparian releases via scour line   | Ryan and Preece 2003  |
| 410   | Talbingo                            | Tumut River        | Snowy Hydro Limited          | 162        | 921400        | 6                         | 250  | 47.4                        | Low        | see report  | Ryan and Preece 2003; DLWC 1998; SMHEA 1993   |
| 215   | Tallowa                             | Shoalhaven River   | SCA                          | 43         | 85500         | 13                        | 180  | 9.2                         | Medium     | see report  | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R Nevill, DIPNR; other unpublished information supplied by R.             |

| Basin | Dam                   | Watercourse         | Owner                        | Height (m) | Capacity (ML) | Intake Depth Estimate (m) | Discharge Estimate (ML day <sup>-1</sup> ) | Mean Depth <sup>a</sup> (m) | CWP Status | Comments / Notes  | Principal Information Sources / Contacts <sup>b</sup>  |
|-------|-----------------------|---------------------|------------------------------|------------|---------------|---------------------------|--|-----------------------------|------------|---|--|
| 410   | Tantangara Dam        | Murrumbidgee River  | Snowy Hydro Limited          | 45         | 254100        | 34                        | 0  | 12                          | Negligible | diversion for hydro-power   | Charan, SCA<br>Ryan and Preece 2003  |
| 416   | Tenterfield Creek     | Tenterfield Ck      | Tenterfield Shire Council    | 13         | 1150          | 10                        | 0  | 2.9                         | Negligible | town water supply - diversion; river releases rare  | T. Larkin, Tenterfield Shire Council, pers. comm.  |
| 212   | Thompsons Creek       | Thompsons Ck        | Delta Electricity            | 54         | 27500         | 54                        | 0.9  | 16.3                        | Negligible | artificial destratification   | Connell Wagner 2003a,b; DLWC 2001a   |
| 420   | Timor                 | Castlereagh River   | Coonabarabran Shire Council  | 20         | 1140          | 10                        | 1.3  | 3.3                         | Negligible | artificial destratification; trunnion intake  | Ryan and Preece 2003   |
| 401   | Tooma                 | Tooma River         | Snowy Hydro Limited          | 67         | 28100         | 60                        | 0  | 16.5                        | Negligible | diversion for hydro-power   | Ryan and Preece 2003   |
| 203   | Toonumbar             | Iron Pot Creek      | State Water                  | 44         | 11000         | 24                        | 32   | 8.5                         | Medium     | irrigation supply; HEPS; typically releases 32 ML/day during summer   | J. Langfield, State Water, pers. comm.; DIPNR HYDSYS database  |
| 410   | Tumut 2               | Tumut River         | Snowy Hydro Limited          | 46         | 2700          | 46                        | 0  | 13.5                        | Negligible | diversion for hydro-power   | Ryan and Preece 2003   |
| 410   | Tumut Pond            | Tumut River         | Snowy Hydro Limited          | 86         | 52800         | 76                        | 0  | 26.4                        | Negligible | diversion for hydro-power   | Ryan and Preece 2003   |
| 425   | Umberumberka          | Umberumberka Ck     | Aust Inland Energy and Water | 41         | 8000          | 12                        | 0  | 5.3                         | Negligible | town water supply - diversion   | Ryan and Preece 2003   |
| 212   | Upper Cordeaux 2      | Cordeaux River      | SCA                          | 19         | 1181          | na                        | 0  | 5.1                         | Negligible | outlet decommissioned   | DLWC 2003b   |
| 412   | Upper Rodds Creek     | Rodds Ck            | Cadia Holdings Pty Ltd       | 31         | 3000          | 31                        | 0  | nd                          | Negligible | stores effluent; back-up process water supply   | B. Perry and J. Seaman, Cadia Holdings, pers. comm.  |
| 212   | Wallerawang (Wallace) | Coxs River          | Delta Electricity            | 14         | 4300          | 14                        | 0.7  | 0.3                         | Negligible | thermal power station supply; small riparian release via bottom/near bottom intake  | Connell Wagner 2003a,b; DLWC 2001a   |
| 212   | Warragamba            | Warragamba River    | SCA                          | 113        | 2057000       | 35                        | 45   | 27.4                        | Medium     | see report  | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 212   | Warragamba Weir       | Warragamba River    | SCA                          | 21         | 2954          | 1                         | 50   | nd                          | Negligible | nil storage capacity according to Water Management Licence  | DLWC 2003b   |
| 425   | Wetherell             | Darling River       | State Water                  | 12         | 267000        | 7                         | 0  | nd                          | Negligible | see report  | Ryan and Preece 2003; M Arandt, State Water, pers. comm.; Harriss et al. 1998  |
| 421   | Winburndale           | Winburndale Rivulet | Bathurst City Council        | 25         | 1850          | 2                         | 0.75                                       | 7.1                         | Negligible | mainly park watering and industrial supply; river release via siphon hose over dam or from point on service main (serviced by floating trunnion) c. 100 m downstream  | Gary Hawkins, Bathurst City Council, pers. comm.   |
| 421   | Windamere             | Cudgegong River     | State Water                  | 67         | 368000        | 7                         | 150  | 18.1                        | Low        | potentially severe CWP during bulk water transfers to Burrendong  | Ryan and Preece 2003; DSNR 2003; DIPNR HYDSYS database   |
| 212   | Wingecarribee         | Wingecarribee River | SCA                          | 19         | 34510         | 11                        | 4  | 5.5                         | Negligible | diversion to Nepean Dam and river transfers to Warragamba Dam; max. permissible discharge during summer river transfer is 400 ML/day; CWP potential exists but available flow data indicate riparian / environmental flows only during late spring and summer | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 213   | Woronora              | Woronora River      | SCA                          | 63         | 71800         | 10                        | 18   | 18                          | Negligible | artificial destratification; diversion and river transfers; river releases generally limited to specified riparian flows  | SCA 2002a; SCA 2002b; DLWC 2003b; flow data supplied by R. Nevill, DIPNR; other unpublished information supplied by R. Charan, SCA |
| 412   | Wyangala              | Lachlan River       | State Water                  | 85         | 1220000       | 50                        | 1700                                       | 23                          | High       | see report  | Ryan and Preece 2003; DIPNR HYDSYS database  |
| 220   | Yellow Pinch          | Yellow Pinch Ck     | Bega Valley Shire Council    | 40         | 3000          | 35                        | 0  | 12.5                        | Negligible | artificial destratification, rarely releases  | K McLeod & J Collins, Bega Shire Council, pers. comm.  |

a. storage capacity divided by surface area at FSL; b. refers to information other than that from Dam Safety Committee; na. not applicable; nd. no data

## References (additional to those cited in main report)

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