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Native Fish Strategy

Scoping options for the ecological assessment of cold water pollution downstream of Keepit Dam, Namoi River

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C.A. Boys, N. Miles and T. Rayner

NSW Department of Primary Industries

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CONTENTS

List of tables v

List of figures vi

Acronyms used in this report viii

Acknowledgements ix

Non-technical summary x

1. Background 1

1.1 The nature and extent of cold water pollution in the Murray-Darling Basin 1

1.2 Impact of CWP on native fish of the MDB 3

1.2.1 Redistribution of species 3

1.2.2 Timing and success of reproduction 4

1.2.3 Growth and metabolism 5

1.2.4 Recruitment 6

1.3 Keepit Dam and the nature of CWP in the Namoi River 6

1.4 Anticipated outcomes of the construction of a multi-level offtake at Keepit Dam 8

1.5 Impact assessment into the mitigation of CWP in the Murray-Darling Basin 10

1.6 Objective of this scoping report 11

2. Scoping process 12

3. Sensitive assemblage components and development of hypotheses 14

3.1 Redistribution of species 15

3.2 Spawning and larval production 17

3.3 Recruitment 17

3.4 Growth 17

4. Project design considerations 19

4.1 Impact assessment framework 19

4.2 Spatial stratification 20

4.2.1 Impact location 20

4.2.2 Control locations 21

4.2.3 Reference locations 24

4.2.4 Spatial extent of impact and control locations 26

4.3 Sampling frequency and season 28

4.3.1 Annual sampling 28

4.3.2 Seasonal sampling 28

5. Analytical aspects of the sampling design 29

6. Sampling and experimental protocol 32
6.1 Electrofishing 32
6.2 Unbaited traps 32
6.3 Egg and larval sampling 33
6.4 Cage experiments 34
6.5 Water quality monitoring 34
6.6 Possibility for ongoing condition monitoring 34
6.7 Data management and quality assurance 35
6.8 Study timeline 35

7. Feasibility of design and indicative budget 36

8. Risk assessment and management 39
8.1 MLO construction 39
8.2 Ability to detect an effect under current climatic conditions and likelihood of a CWP event 39

9. Final recommendations 44
9.1 Recommendation 1: More extensive CWP mitigation research is needed in the MDB 44
9.2 Recommendation 2: MBACI study design 44
9.3 Recommendation 3: Budget 44
9.4 Recommendation 4: Likelihood of detecting an impact at Keepit Dam 45
9.5 Recommendation 5: Current climatic conditions are not conducive to doing the proposed research in the foreseeable future 45

10. References 46

LIST OF TABLES

Table 1: Key characteristics of of 11 large storages in the MDB. 2

Table 2: Summary of thermal preferences for fish species commonly or historically found in the upper MDB 5

Table 3: Key components of fish assemblage structure and function expected to be sensitive to thermal changes brought about by MLO operation, their hypothesised response, the indictors that can be used to measure them and practical examples of their measurement. 15

Table 4: The Key elements of rigorous impact monitoring designs 19

Table 5: Proposed sampling design options for investigating the impact of MLO operation on the fish assemblage downstream of Keepit Dam 21

Table 6: ANOSIM testing for differences between a-priori groups of sites downstream of Copeton, Burrendong and Keepit Dams based on having a high-potential CWP, low-potential CWP zone and those sites further downstream that are beyond the extent of CWP (no potential). 28

Table 7: Estimates of spatial (between sites) and temporal (within sites) variance for six MDB species obtained from electrofishing CPUE data collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007). MACPEE Murray cod; RETSEM Australian smelt; CYPCAR carp; TANTAN freshwater catfish; MACAMB golden perch; and MELFLU crimson-spotted rainbowfish 30

Table 8: Approximate budget per annum of proposed project design (Example 2, Figure 21) 38

Table 9: Current program for dam safety upgrades within SWC for the period 2009-2014 (dependent on portfolio and funding constraints) 43

LIST OF FIGURES

Figure 1: Location of major storages within NSW that have been identified as potential sources of CWP in Preece (2004). Source: www.dnr.nsw.gov.au 4

Figure 2: Lake Keepit and Keepit Dam on the Namoi River (photo: State Water Corporation) 6

Figure 3: Fitted curves for Tmax (annual maximum temperature) downstream of Keepit Dam (●) and for the pre-dam reference condition. Broken lines are 95% confidence intervals. The fitted curve for pre-dam Tmax is a function of elevation and adjusted to the median time of day of summer temperature measurement across the basin (12:00 hours). Source: Preece and Jones (2002) 7

Figure 4: Water temperature of the Namoi River recorded from stations upstream (○) and downstream (●) of Keepit Dam. Lines are fitted LOESS (locally weighted scatterplot smothing) curves. Source: Preece and Jones (2002) 7

Figure 5: Namoi River Catchment showing reaches that have a high and low potential for CWP based on findings of Preece and Jones (2002) 8

Figure 6: Potential improvement in the temperature of release from current deep FLO and surface withdrawals possible with a MLO at Keepit Dam (based on 100 years of modelled flow data). Adapted from MHL (in prep). Note that these are estimates of release temperatures only and may not reflect actual water temperature downstream of dam after mixing has occurred 9

Figure 7: Withdrawal temperatures from Keepit Dam expected at 2000ML.day-1 for surface and deep offtakes. Bold line shows median value, box shows upper and lower quartiles and whiskers show upper and lower extremes. Source: MHL in prep 10

Figure 8: Scoping process and components contributing to the final experimental design options 13

Figure 9: Scatter plots of ambient water temperature (°C) against length (mm) for six abundant fish species caught in main channel sites in the Namoi, Gwydir and Macquarie Rivers. Source: NSW DPI 2007 16

Figure 10: The 'window' of effective spawning for a number of MDB fish species in relation to the potential improvement in the temperature of release from current deep FLO and surface withdrawals possible with a MLO at Keepit Dam (based on 100 years of modelled flow data). Adapted from MLO (in prep). Note that these are estimates of release temperatures only and may not reflect actual water temperature downstream of dam after mixing has occurred 18

Figure 11: Minimum spawning thresholds for four native species in relation to fitted curves for Tmax (annual maximum temperature) downstream of Keepit Dam (-●-) and for the pre-dam reference (—) condition. Broken lines are 95% confidence intervals. The fitted curve for pre-dam Tmax is a function of elevation and adjusted to the median time of day of summer temperature measurement across the basin (12:00 hours). Adapted from Preece and Jones (2002) 18

Figure 12: Existing NSW DPI sampling sites in the Namoi Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Keepit Dam were used in the multivariate analysis of fish assemblage composition 23

Figure 13: Existing NSW DPI sampling sites in the Gwydir Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Copeton Dam were used in the multivariate analysis of fish assemblage composition 23

Figure 14: Existing NSW DPI sampling sites in the Macquarie Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Burrendong Dam were used in the multivariate analysis of fish assemblage composition 24

Figure 15: The distribution of Namoi, Gwydir and Macquarie River channel sites in three-dimensional ordination space (presented as two separate two-dimensional plots: XY and XZ) based on similarity in fish assemblage composition, as defined by SSHMDS of electrofishing CPUE (number of individuals caught per hour 'power-on' time; $\log_{10}(x+1)$ transformed, Bray-Curtis metric, stress = 0.1391). PCC vector lines are shown below their respective plots and illustrate species contributions to the spatial arrangement of sites. MCAO r-squared values: *** = 0%, ** = 1%, * = 2-5%. Note: vector length is indicative of the orientation in three dimensions, not the relative importance in determining the distribution of sites in ordination space. See page vii for full species names. CARAUR: Goldfish, *Carassius auratus*; CYPCAR: Carp, *Cyprinus carpio*; GAMHOL: Gambusia (mosquito fish), *Gambusia holbrooki*; MACAMB: Golden perch, *Macquaria ambigua*; MACPEE: Murray cod, *Maccullochella peelii peeli*; MELFLU: Crimson-spotted rainbowfish, *Melanotaenia fluviatilis*; NEMERE: Bony herring, *Nematalosa erebi*; PHIGRA: Flathead gudgeon, *Philipnodon grandiceps*; RETSEM: Australian smelt, *Retropinna semoni* 25

Figure 16: The distribution of high, low and unaffected CWP sites in the Namoi, Gwydir and Macquarie Rivers in three-dimensional ordination space (presented as two separate two-dimensional plots: XY and XZ) based on similarity in fish assemblage composition, as defined by SSHMDS of electrofishing CPUE (number of individuals caught per hour 'power-on' time; $\log_{10}(x+1)$ transformed, Bray-Curtis metric, stress = 0.1391). PCC vector lines are shown below their respective plots and illustrate species contributions to the spatial arrangement of sites. MCAO r-squared values: *** = 0%, ** = 1%, * = 2-5%. Note: vector length is indicative of the orientation in three dimensions, not the relative importance in determining the distribution of sites in ordination space. See page vii for full species names. CARAUR: Goldfish, *Carassius auratus*; CYPCAR: Carp, *Cyprinus carpio*; GAMHOL: Gambusia (mosquito fish), *Gambusia holbrooki*; MACAMB: Golden perch, *Macquaria ambigua*; MACPEE: Murray cod, *Maccullochella peelii peeli*; MELFLU: Crimson-spotted rainbowfish, *Melanotaenia fluviatilis*; NEMERE: Bony herring, *Nematalosa erebi*; PHIGRA: Flathead gudgeon, *Philipnodon grandiceps*; RETSEM: Australian smelt, *Retropinna semoni* 27

Figure 17: Relationship between number of sampling sites and standard error of the mean based on CPUE abundance data for Murray cod collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007) 30

Figure 18: Relationship between number of sampling sites and standard error of the mean based on CPUE abundance data collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007). MACPEE Murray cod; RETSEM Australian smelt; CYPCAR carp; TANTAN freshwater catfish; MACAMB golden perch; and MELFLU crimson-spotted rainbowfish 31

Figure 19: Performance of different gear types in sampling run and pool habitats in the Barwon-Darling River and other lowland rivers in New South Wales during the New South Wales Rivers Survey. Numbers of fish caught represent data collected only from Barwon-Darling River, whereas numbers of species data were collected from unregulated lowland rivers throughout New South Wales (i.e. Barwon-Darling, Murray, North and South Coast). Data source: Faragher and Rogers (1997) 33

Figure 20: Proposed experimental design before optimisation 36

Figure 21: Ghannt diagram showing two possible fieldwork scenarios to achieve the design shown in Figure 20. Both scenarios will cost approximately the same as illustrated by the Full Time Equivalent (FTE) figures shown. N.B. 6 staff per week = 6 FTE. This translates to a total of 60 FTE per year to conduct the fieldwork component of the project 37

Figure 22: Flow diagram of the draft approval process for MLO construction at Keepit Dam. Provided by SWC on behalf of the CWP Inter-Agency Group 40

Figure 23: Murray River system inflows with extended drought periods highlighted (Source: MDBC 2006a) 41

Figure 24: The volume of water in storage in NSW dams between February 2005 and February 2007. (Source: NSW DNR Water Information website) 41

Figure 25: Storage levels of eight large storages in the MDB between February 2005 and February 2007 (Source: NSW DNR Water Information website) 42

ACRONYMS USED IN THIS REPORT

CWP	Cold water pollution
DECC	Department of Environment and Climate Change
FLO	Fixed-level offtake
IMEFR	Integrated Monitoring of Environmental Flows - Rivers
MDB	Murray-Darling Basin
MDBC	Murray-Darling Basin Commission
MLO	Multi-level offtake
NSW DNR	New South Wales Department of Natural Resources
NSW DPI	New South Wales Department of Primary Industries
NSWRS	New South Wales Rivers Survey
SRA	Sustainable Rivers Audit

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NON-TECHNICAL SUMMARY

MD798 Scoping options for the ecological assessment of cold water pollution mitigation downstream of Keepit Dam, Namoi River

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OBJECTIVE:

This report was commissioned by the Murray-Darling Basin Commission (MDBC) to scope the feasibility of a four year impact assessment investigating the response of the fish assemblage in cold water pollution (CWP) affected reaches of the Namoi River to a proposed multi-level offtake (MLO) at Keepit Dam. The objective of this report is to outline a scientifically robust and cost effective impact assessment, should such a study be commissioned at Keepit Dam. This report provides background information and analysis to inform the design of a full impact study and reports on the feasibility of its implementation.

NON TECHNICAL SUMMARY:

Cold water pollution (CWP) remains a significant problem hindering the recovery of native fish populations in the Murray-Darling Basin (MDB). Despite this, of all the factors impacting on native fish, CWP is among the easiest to recognise and quantify in magnitude and extent. There are several pragmatic solutions available to alleviate its impact, however, faced with the large capital outlay required to build mitigating infrastructure, the decision whether to address CWP at large storages continues to be made largely based on financial considerations rather than the potential ecological benefits. When and where CWP has the potential to be addressed as part of dam safety upgrade projects, researchers need to be ready to measure the ecological response to such works. Whilst there is sufficient knowledge demonstrating the negative impact of CWP on the MDB fish assemblage, further research is needed to gauge the degree of ecological improvement from CWP mitigation. It is recommended that research into CWP mitigation within the MDB be considered of high priority and be supported through the Murray-Darling Basin Commission's Native Fish Strategy.

This report details how monitoring fish assemblage response to CWP mitigation in the MDB can be achieved based on a well-established impact assessment design framework, appropriate sampling equipment and fish assemblage indicators. Whilst scoping the Keepit Dam case study, however, it became apparent that this type of monitoring study is not without its problems. A four year study determining fish assemblage response to the operation of a MLO at Keepit Dam would cost about $1.2 million, almost half of the proposed works budget. Whilst the maximum 5ºC improvement in temperature expected downstream of Keepit Dam, may have positive effects on the fish assemblage, the response may not be large enough to be cost-effectively measured using the indicators available. Based on this, other suitable locations for a CWP mitigation monitoring and evaluation study need to be explored as possible alternatives to Keepit Dam. The current magnitude of CWP downstream of many storages in the MDB is much larger than what is experienced downstream of Keepit Dam. These other storages may provide better case studies to assess CWP mitigation because the potential for thermal improvement is greater. This is based on the assumption that greater improvements in temperature will result in larger changes in fish assemblage indicators and will therefore be easier to detect in a study with a given level of statistical power. Alternative storages will have to be localities where CWP mitigation works are already being planned (e.g. Burrendong Dam). The design proposed in this scoping report can be equally applied to other large storages throughout the MDB, with only a small amount of additional work required to apply the design to the site-specific characters of habitat, thermal regime and the fish assemblage.

The 2007–08 irrigation season was not a suitable time to study CWP in the MDB. The extended drought, record low inflows and very low storage levels meant that the probability of experiencing the required CWP event in the first year of the study was highly unlikely. This problem was not unique to Keepit Dam and was experienced at all large storages in the Basin. It was therefore recommended that this project not be undertaken in the 2007-08 financial year. However, other storages can fill quickly. For example, in 2005 Lake Hume's storage levels rose from 20% to 90% in five months and levels at Blowering Dam rose from less than 10% to 65% over the same period. These rapid filling events were due to flow releases from upstream storages, not from natural inflows. With the recent breakdown of El Nino in south eastern Australia, there is promise of improved inflows into MDB storages. Given the high priority of research into CWP mitigation in the MDB, it is recommended the opportunity to support such research be re-addressed annually using up-to-date predictions of storage levels and the likelihood of CWP events.

KEYWORDS:

Cold water pollution, thermal pollution, Murray-Darling Basin, Namoi River, native fish, multi-level offtake.

1. BACKGROUND

1.1 The nature and extent of cold water pollution in the Murray-Darling Basin

Cold water pollution (CWP) refers to an artificial lowering in the temperature of a water body and usually occurs downstream of large storages. A pre-requisite for CWP is the establishment of a substantial temperature differential between the warmer surface (epilimnetic) layer and deeper (hypolimnetic) layer in impounded waters (Lugg and Astles in press). Thermal stratification can result in a difference between epilimnetic and hypolimnetic layers that exceeds 13°C in most large storages in the MDB (Table 1), with these extreme differences typically occurring during the months of December to February (Lugg and Astles in press). These dams are fitted with fixed-level offtakes (FLO) that typically draw water from the cooler hypolimnion, resulting in a suppression of water temperatures downstream of the dam compared to what would naturally occur in the absence of the dam. In a recent review, Lugg and Astles (in press) have summarised the main impacts of cold water pollution as:

- **summer suppression** – the reduction in temperature compared to natural conditions that typically occurs from mid spring to late summer and reaches a maximum in summer;
- **winter elevation** – the increase in temperature compared to natural conditions that typically occurs from mid autumn to mid spring and reaches a maximum in winter;
- **seasonal displacement** – the timing delay of natural temperature peaks, troughs, rises and falls; and
- **annual amplitude reduction** – the reduction in the natural difference between annual maximum and minimum temperatures.

The release of CWP from thermally stratified storages for irrigation and town water supply is widespread throughout the MDB (Phillips 2001, Lugg and Astles in press). In the NSW and ACT sections of the MDB alone, there are 73 large dams and 146 smaller dams or weirs with some capacity to cause CWP due to the height and type of structure (initially short-listed by Rish *et al*. (2000) and refined by Lugg and Astles (in press)). In their recent review into the scope of CWP throughout the MDB, Lugg and Astles (in press) identify at least 19 major locations in NSW and Victoria where some form of CWP has been documented:

- Macintyre Brook downstream of Coolmunda Dam (Whittington and Hillman 1999).
- Dumaresq River downstream of Glenlyon Dam (Lugg 1999, Whittington and Hillman 1999).
- Gwydir River downstream of Copeton Dam (MDBC 1987, Lugg 1999, Whittington and Hillman 1999).
- Namoi River downstream of Keepit Dam (Lugg 1999, Whittington and Hillman 1999, Preece and Jones 2002).
- Cudgegong River downstream of Windamere Dam (Lugg 1999, Acaba *et al*. 2000).
- Macquarie River downstream of Burrendong Dam (MDBC 1987, Lugg 1999, Whittington and Hillman 1999, Acaba *et al*. 2000).
- Lachlan River downstream of Wyangala Dam (Lugg 1999, Whittington and Hillman 1999, Burton 2000).
- Belubula River downstream of Carcoar Dam (Lugg 1999).
- Murrumbidgee River downstream of Burrinjuck Dam (MDBC 1987, Lugg 1999, Whittington and Hillman 1999).
- Tumut River downstream of Talbingo Dam (Whittington and Hillman 1999) and downstream of Blowering Dam (Lugg 1999, Whittington and Hillman 1999).
- Yanco Creek downstream of its offtake from the Murrumbidgee River (Whittington and Hillman 1999).
- Upper Murray River from Snowy scheme (MDBC 1987, Lugg 1999) and Murray River downstream of Hume Dam (Walker 1979, Lugg 1999, Whittington and Hillman 1999, Ryan *et al*. 2001).
- Mitta Mitta River downstream of Dartmouth Dam (Blyth *et al*. 1984, Koehn *et al*. 1997, Whittington and Hillman 1999, Ryan and Koehn 2001, Ryan *et al*. 2001).
- Kiewa River downstream of Rocky Valley Dam (MDBC 1987, Whittington and Hillman 1999).
- Buffalo River downstream of Buffalo Dam (Ryan and Koehn 2001).
- King River downstream of William Hovell Dam (Ryan and Koehn 2001).

Table 1: Key characteristics of 11 large storages in the MDB.

Dam	Catchment	Capacity (ML)	Fixed level intake depth estimate (m)	Dam height (m)	Period	Temperature (°C) range of deep layer (observed minimum – observed maximum)	Temperature (oC) range of surface layer (observed minimum – observed maximum)	Maximum observed difference between surface and deep layer (°C)
Pindari*	Border Rivers	312 000	11	85	7/97–5/99	2.9 (11.2–14.1)	14.0 (13.5–27.5)	14.2
Copeton*	Gwydir R.	1 364 000	69	113	10/97–6/99	3.8 (10.1–13.9)	14.3 (12.6–26.9)	14.0
Split Rock	Namoi R.	397 370	7	66	7/97–5/99	1.8 (12.1–13.9)	13.2 (13.7–26.9)	14.0
Keepit*	Namoi R.	423 000	24	55	10/97–4/99	13.0 (11.0–24.0)	14.9 (11.7–26.6)	8.8
Chaffey	Namoi R.	61 800	6	54	7/97–6/99	4.1 (9.3–13.4)	16.5 (11.2–27.7)	14.8
Burrendong*	Macquarie R.	1 190 000	37	76	11/98–11/99	2.8 (11.1–13.9)	13.1 (12.0–25.1)	13.6
Windamere	Macquarie R.	368 000	7	67	11/97–11/99	9.5 (10.0–19.5)	17.9 (10.1–28.0)	15.9
Wyangala*	Lachlan R.	1 220 000	50	85	2/96–5/97	10.3 (10.8–21.1)	15.2 (12.5–27.7)	16.1
Burrinjuck*	Murrumbidgee R.	1 026 000	42	93	11/90–3/99	11.0 (8.1–19.1)	20.0 (9.9–29.9)	16.2
Blowering*	Murrumbidgee R.	1 628 000	74	112	2/92–4/99	5.5 (8.5–14.0)	15.9 (11.2–27.1)	16.7
Hume*	Murray R.	3 038 000	29	51	-	-	-	-
Khancoban*	Murray R.	21 500	12	18	-	5.5 (11–12)	15.9 (12–15)	4

Source: Lugg and Astles (in press) and Preece (2004) based on data supplied by NSW Department of Infrastructure, Planning and Natural Resources.
* Represents those dams short-listed as likely to cause severe CWP (Preece 2004).

- Broken River downstream of Nillahcootie Dam (Ryan and Koehn 2001).
- Goulburn River downstream of Eildon Dam (MDBC 1987, Gippel and Finlayson 1993, Whittington and Hillman 1999, Ryan *et al*. 2001).
- Campaspe River downstream of Eppalock Dam (Growns 1998, Whittington and Hillman 1999, Ryan *et al*. 2001).
- Loddon River downstream of Cairn Curran Dam (Ryan *et al*. 2001).
- Fyans Creek (Wimmera River tributary) downstream of Bellfield Dam (Ryan *et al*. 2001).

Although preliminary assessments indicate that as many as 14 dams within Queensland undergo thermal stratification during warmer months, there has been no formal investigation into potential CWP downstream of these structures (Blanch 2001).

1.2 Impact of CWP on native fish of the MDB

The modification of thermal regimes by CWP threatens the condition of riverine fish assemblages in the MDB (Koehn 2001, Ryan and Koehn 2001, Preece and Jones 2002, Lugg and Astles in press) and the amelioration of its impacts is a key component of the MDBC's Native Fish Strategy (MDBC 2003). The impacts of CWP on the biology and life-cycles of fish in the MDB can be summarised into four key components:

- Redistribution of species
- Timing and success of reproduction
- Growth and metabolism
- Recruitment

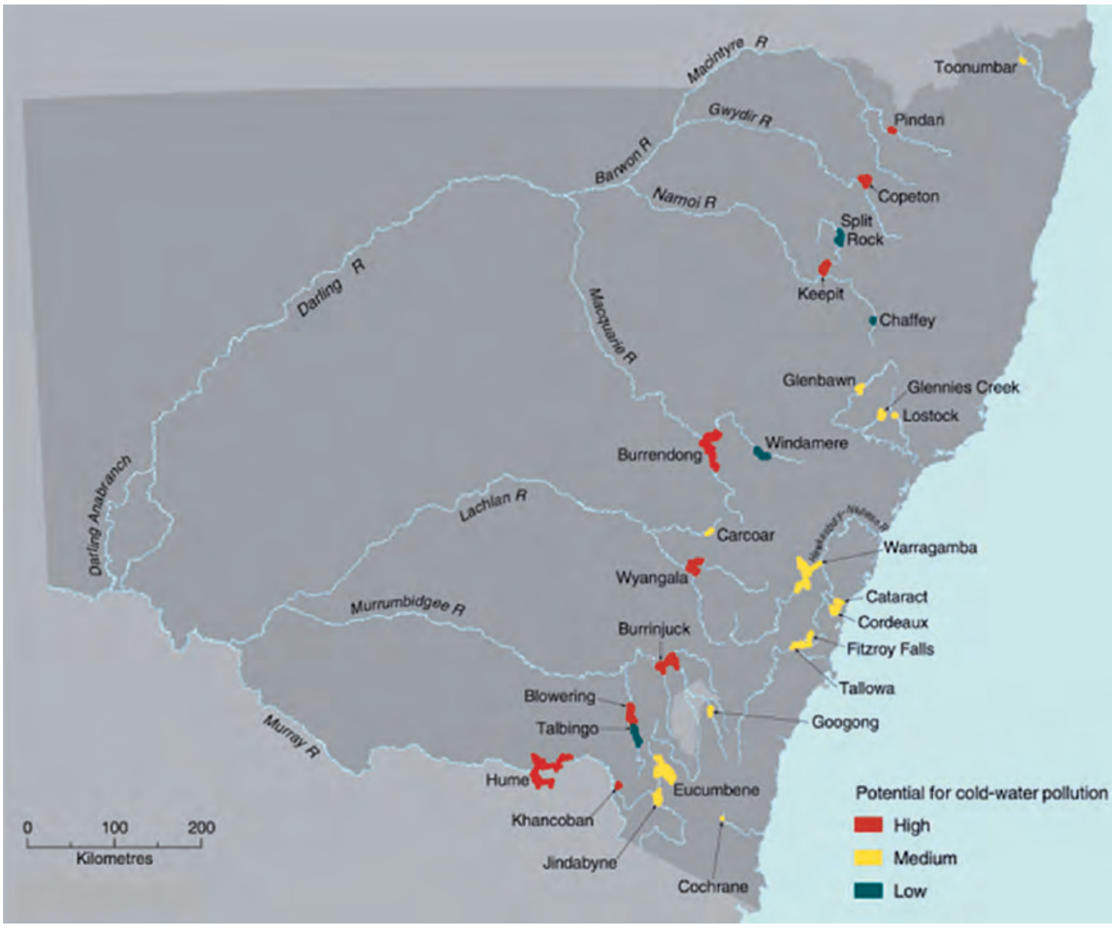
1.2.1 Redistribution of species

Fish are ectothermic and their physiology and behaviour are responsive to changes in the ambient temperature of their environment (Beitinger and Fitzpatrick 1979, Fuiman and Batty 1997). Fish can only tolerate specific temperature ranges (Table 2) and this, coupled with the fact that many species are highly vagile and can disperse large distances to find suitable habitats (Reynolds 1983, Koehn and Nicol 1997), means that daily and seasonal fluctuations in temperature can cause a change in assemblage composition over a relatively short time frame. Manipulative experiments on silver perch (*Bidyanus bidyanus*) and Murray cod (*Maccullochella peelii peeli*) by Astles *et al.* (2003) illustrate this rapid redistribution in response to temperature. It was shown that a temperature difference of 6.8°C is enough to induce both silver perch and Murray cod to select warmer water habitats when presented with a thermal gradient of 22.5 to 15.7°C (Astles *et al*. 2003).

If temperature suppression persists for an extended period, species redistribution coupled with increased mortality and spawning and recruitment failure can lead to a replacement of warm-water species with those more tolerant of colder water, effectively causing a shift in assemblage structure. A prime example of this has occurred in the Mitta Mitta following the construction of Dartmouth Dam (Koehn *et al*. 1995). Twelve years after the construction a loss of Murray cod, trout cod (*Maccullochella macquariensis*) and Macquarie perch (*Macquaria australasica*)was reported from the Mitta Mitta, with these species being replaced by a cold water tolerant species, brown trout (*Salmo trutta*) (Koehn *et al*. 1995). Other cold water species such as redfin perch (*Perca fluviatilis*) may also be advantaged by a reduction in temperature. Catch records obtained from the Freshwater Fish Research database (NSW DPI 2007) reveal that redfin perch have been recorded below Burrendong Dam, well outside their expected latitudinal and altitudinal range.

Mortality due to an inability to tolerate reduced temperatures can result in the loss of species from CWP affected areas. Manipulative experiments downstream of Burrendong Dam have clearly demonstrated that juvenile silver perch undergo significantly higher rates of mortality when water temperature is reduced by 11°C, a temperature change that is representative of the summer suppression observed at other sites in the Basin (Astles *et al*. 2003).

Figure 1: Location of major storages within NSW that have been identified as potential sources of CWP in Preece (2004). Source: www.dnr.nsw.gov.au



1.2.2 Timing and success of reproduction

Reproduction in fish is often linked to annual cycles of day length (photoperiod) and temperature variations (Jobling 1995). This is indeed the case for species in the MDB, which can have clearly defined spawning tolerances and breeding seasons (Table 2), closely triggered by subtle rises in temperature and river flows (Lake 1967b, d, Koehn and O'Connor 1990, McDowall 1996, Humphries *et al*. 2002b, King *et al*. 2003, Pusey *et al*. 2004, Treadwell and Hardwick 2004).

The chance of spawning failure increases if CWP suppresses temperature below critical spawning thresholds throughout the potential spawning window (Koehn 2001). In these cases, fish will often re-absorb their gonads rather than spawn (Lugg and Astles in press). Species with 'narrower' spawning windows are at greater risk than protracted (i.e. can potentially spawn over a long period) or opportunistic spawners (Humphries *et al*. 2002b). Furthermore, alien species such as trout, redfin perch and carp typically have lower spawning temperature thresholds than native species (McDowall 1996, Table 2) and therefore may experience greater reproductive success in CWP affected areas.

The development and eventual hatching of fish eggs is sensitive to temperature (Jobling 1995). Most native species in the MDB have eggs capable of normal development and hatching within a temperature range of 5°C (Table 1). Therefore, CWP of the magnitude experienced below a number of structures in the MDB (Preece 2004, Lugg and Astles in press) can create unsuitable conditions for development in a number of species. Manipulative experiments on freshwater catfish (*Tandanus tandanus*) have illustrated this, with hatching success falling from 100% to just 40% when temperature was reduced from 28°C to 16°C (Koehn 2001). Within the range of tolerance, thermal changes can delay the development of eggs, leaving them vulnerable to higher mortality due to predation, infections and environmental changes (e.g. sedimentation) (Lugg and Astles 2004, in press). For example, eggs of crimson spotted rainbowfish (*Melanotaenia fluviatilis*) can hatch in as little as 4.5 days at 27°C, but hatching takes 9 days at 20°C (Koehn and O'Connor 1990).

Table 2. Summary of thermal preferences for fish species commonly or historically found in the upper MDB

Common name	Species name	Breeding season	Spawning temp.	Optimal egg development	Approximate range of thermal tolerance (all life stages)
Native species					
Australian smelt	*Retropinna semoni*	Aug-Apr[24]	>15°C[1]	15-18°C[1]	
Bony herring	*Nematalosa erebi*	Oct-Dec[9]	18-20°C[25]		9-38°C[11]
Crimson-spotted rainbowfish	*Melanotaenia fluviatilis*	Oct-Feb[24]	20°C[7]	24-27°C[7,14]	>7°C[18]
Flyspecked hardyhead	*Craterocephalus stercusmuscarum*	Oct-Feb[21]	>23.6°C[6]		9.3-36°C[11,12]
Freshwater catfish	*Tandanus tandanus*	Oct-Mar[16]	>24°C[1]	19-25°C[1]	1.4-38°C[1]
Golden perch	*Macquaria ambigua*	Nov-Mar[1]	23.6°C[1]	27-31°C[1]	4-37°C[8]
Carp gudgeons*	*Hypseleotris spp.*	Oct-Dec[1]	22.5°C[1]	18-23°C[2]	
Murray cod	*Maccullochella peelii peeli*	Sept-Nov[10]	20°C[1]	20-27°C[20]	10-37°C[11]
Silver perch	*Bidyanus bidyanus*	Sept-Jan[9]	>23.3°C[1]	24-27°C[12]	2-32°C[3]
Trout cod	*Maccullochella macquariensis*	Sep-Nov[16]		25°[2]	
Olive perchlet	*Ambassis agasizii*	Nov-Dec[9]	>23°C[17]		
Spangled perch	*Leiopotherapon unicolor*	Nov-Feb[4]	>20°C[4]	24-27°C[5]	5-44°C[4]
Purple spotted gudegon	*Mogurnda adspersa*	Dec-Feb[22]	20-34°C[22]	20-29°C[22]	19-34°C[15]
Introduced species					
Carp	*Cyprinus carpio*	Sept-Dec[19]	17-25°C[19]		
Redfin	*Perca fluviatilis*	Oct-Nov[24]			
Gambusia	*Gambusia holbrooki*	Oct-Apr[23]			
Goldfish	*Carassius auratus*	Dec-Feb[19]			

Lake 1967a[1]; Lake 1967b[2]; Lake 1967c[3]; Llewellyn 1973[4]; Beumer 1979[5]; Llewellyn 1979[6]; Backhouse and Frusher 1980[7]; Pollard *et al.* 1980[8]; Llewellyn 1983[9]; Rowland 1983[10]; Merrick and Schmida 1984[11]; Rowland 1984[12]; Semple 1985[13]; Crowley *et al.* 1986[14]; Hansen 1988[15]; Koehn and O'Connor 1990[16]; Allen 1996a[17]; Allen 1996b[18]; Brumley 1996[19]; Harris and Rowland 1996[20]; Ivantsoff and Crowley 1996[21]; Larson and Hoese 1996[22]; McDowall 1996a[23]; Humphries *et al.* 2002[24]; Pusey *et al.* 2004[25].

1.2.3 Growth and metabolism

Fish metabolism is highly responsive to fluctuations in the ambient temperature (Beitinger and Fitzpatrick 1979, Jensen *et al.* 1993, Jobling 1993, Clarke and Johnston 1999). Metabolic rate in fish decreases with decreasing ambient temperature (Clarke and Johnston 1999), and as such, fish inhabiting CWP affected areas can experience reduced growth rates, increased stress and increased susceptibility to disease (Koehn 2001). Conversely, increases in ambient temperature (within the preferred temperature range of the fish) and increasing metabolic rate can increase food intake, hence promoting faster growth (Jobling 1981, 1993). For example, spangled perch (*Leiopotherapon unicolor*) have been observed to stop feeding when temperatures fall below 16°C and also lose weight until temperatures increase above this point (Gehrke 1988). Astles *et al.* (2003) manipulated the temperature of water released from Burrendong Dam and showed that silver perch (ranging in length from 50–65mm) reared in warmer channels (24° to 18°C) grew an average of 25% in length and 112% in weight over a 31 day period, whereas the fish reared in the cooler channels (12° to 14°C) grew an average of only 2% in length and 16% in weight. Similarly, freshwater catfish kept at 29°C over a 10 week period grew three times faster than those kept at 12°C (Koehn 2001).

1.2.4 Recruitment

Irrespective of spawning, the recruitment of individuals into a population is reliant on whether conditions exist to promote the survival and development of eggs and larvae (Humphries *et al*. 2002b). Eggs and larvae are more susceptible than adults to sub-optimal environmental conditions (Jobling 1995, Fuiman 2002) and the level of mortality during these early life history stages will determine the strength of year classes in subsequent years (Chambers and Trippel 1997). In some MDB fish species the optimal conditions for their recruitment may be associated with low-flow conditions during the warmer months (Humphries *et al.* 1999) and these species, in particular, may be vulnerable to river regulation and CWP. If conditions remain sub-optimal for several years, poor recruitment over a number of years is likely to lead to population decreases (e.g. Henderson and Brown 1985).

1.3 Keepit Dam and the nature of CWP in the Namoi River

Keepit Dam has a capacity of 423 000 ML, a maximum depth of 40 m, a mean depth of 9.6 m and covers an area of 44 km^2 (Preece and Jones 2002, Preece 2004) (Figure 2). Completed in 1960, the dam was built to regulate flow for irrigated crop production (principally cotton) in the Namoi River. Regulated discharges are made via a FLO structure positioned approximately 24 m below full supply level (Preece 2004). The largest discharges from the dam coincide with peak irrigator demand and occur from December to February (Preece and Jones 2002). Smaller releases also occur in September to allow downstream irrigators to water fields in preparation for planting. Median January discharge during the peak irrigation period is approximately 2000 ML.day^{-1} and outside the irrigation period, minimum flows approximate 10 ML.day^{-1}.

Early estimates of the extent of CWP below Keepit Dam by NSW Fisheries (cited in Preece and Jones 2002) range from 180 to over 300 river kilometres. Recent modelling by Preece and Jones (2002) suggests that early estimates based on extrapolation from other large storages in the MDB over-estimate the extent of the problem. The current belief is that during the peak irrigation season a 5°C depression in river temperature occurs 2 km downstream of Keepit Dam, with the impact being largely eliminated by 40 km downstream (Preece and Jones 2002) (Figure 3). A minor reduction in temperature of less than 0.5°C for up to 100km downstream of Keepit Dam is indicated, although this reduction was not statistically significantly different from the expected norm (Preece and Jones 2002). The smaller extent of CWP than once thought has been attributed

Figure 2: Lake Keepit and Keepit Dam on the Namoi River (photo: State Water Corporation).

to the shallower depth of the FLO when compared to other large storages in the MDB (Table 1), coupled with the relatively shallow nature of the impoundment which promotes the heating of deeper waters (Preece and Jones 2002). Furthermore, the bathymetry of Lake Keepit is such that in a typical irrigation season most of the cold hypolimnion can be removed, effectively unstratifying the water column earlier in the year than expected from normal surface cooling (MHL in prep).

Temperature suppression downstream of Keepit Dam is observed from September to March and the largest differences between upstream and downstream temperatures are observed between October and January (Figure 4, Preece and Jones 2002). The maximum annual temperature immediately downstream of Keepit Dam occurs in February, which is several weeks later than expected naturally (Preece and Jones 2002). At Gunnedah (46 km downstream) the peak temperature is four days later on average than the natural background temperatures for this point in the river (Preece and Jones 2002).

Figure 3: Fitted curves for Tmax (annual maximum temperature) downstream of Keepit Dam (●) and for the pre-dam reference condition. Broken lines are 95% confidence intervals. The fitted curve for pre-dam Tmax is a function of elevation and adjusted to the median time of day of summer temperature measurement across the basin (12:00 hours). Source: Preece and Jones (2002).

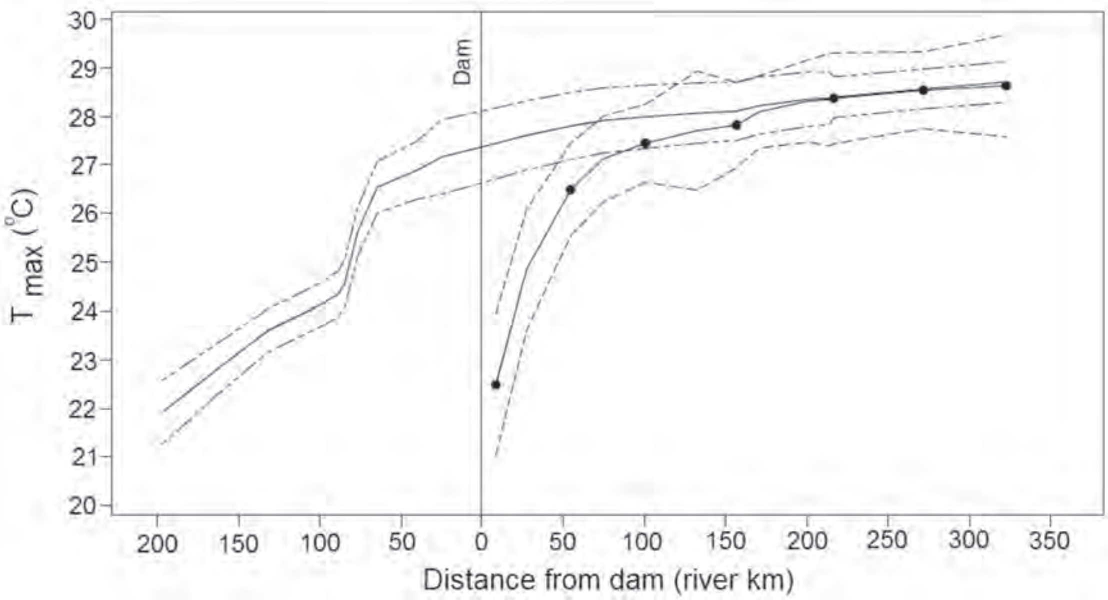
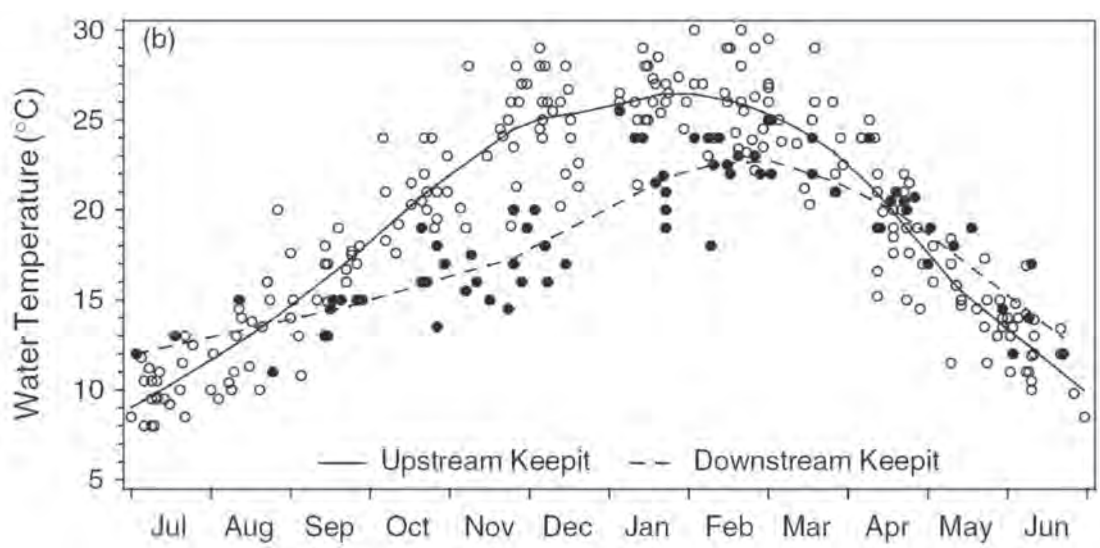
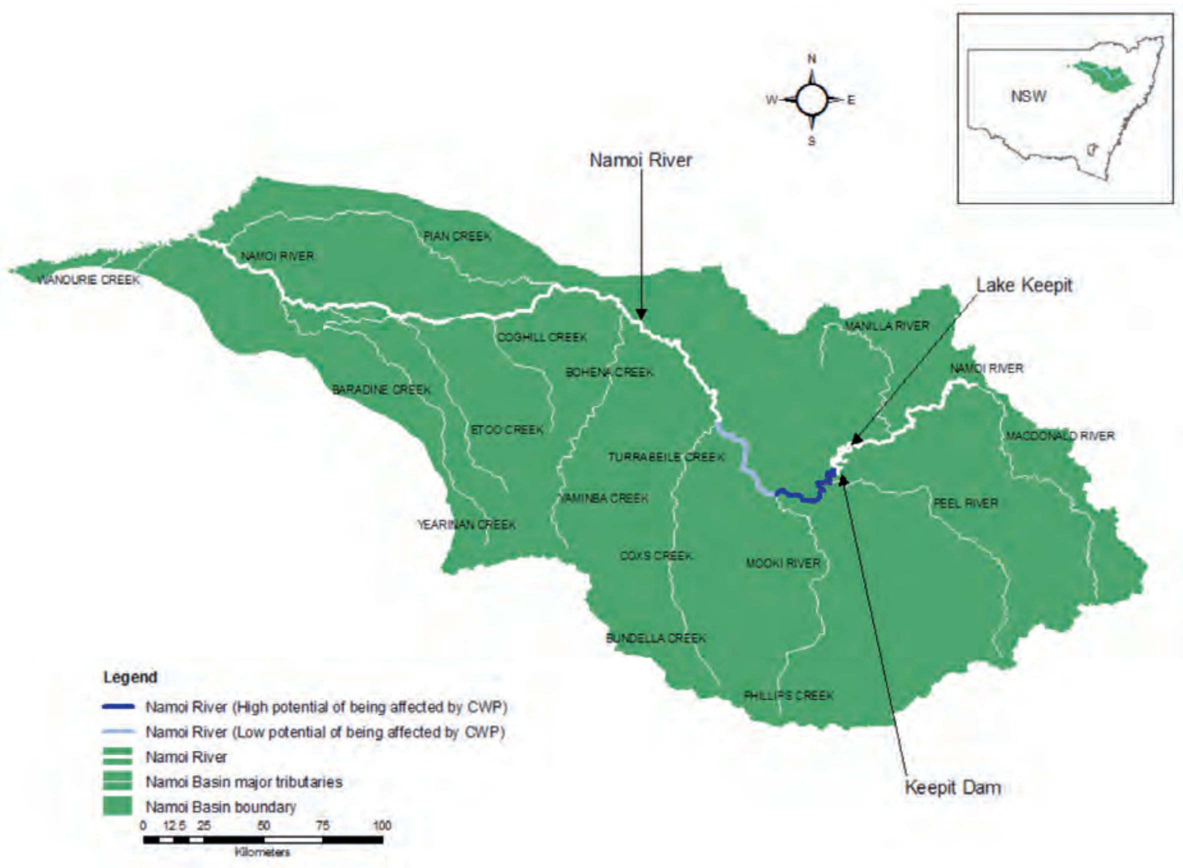


Figure 4: Water temperature of the Namoi River recorded from stations upstream (○) and downstream (●) of Keepit Dam. Lines are fitted LOESS (locally weighted scatterplot smothing) curves. Source: Preece and Jones (2002).



Based on these recent findings, it has been decided to split the extent of CWP potential in the Namoi River into a high potential area, which extends from the base of Keepit Dam to its confluence with Mooki River (approximately 40 km downstream) and a low potential area from the confluence of the Mooki River and the confluence with Coxs Creek approximately 100 km downstream (Figure 5).

Figure 5: Namoi River Catchment showing reaches that have a high and low potential for CWP based on the findings of Preece and Jones (2002)



1.4 Anticipated outcomes of the construction of a multi-level offtake at Keepit Dam

The State Water Corporation (SWC) is currently exploring the feasibility of constructing a multi-level off-take (MLO) on Keepit Dam as part of a current dam safety upgrade. SWC, in conjunction with a Community Reference Panel, agreed on four project objectives for the upgrade: dam safety, improved environmental outcomes, flood mitigation and sustainable regional development. MLO construction was one of the options investigated under the improved environmental outcomes objective. The MLO will allow water to be released from above the thermocline (Sherman 2000). This will be the first substantial attempt to mitigate CWP in the MDB and the intention is to restore a more-natural thermal regime to approximately 100 km of river downstream of the dam. Works are scheduled for completion in late 2009.

State Water recently commissioned Manly Hydraulic Lab (MHL) to model the anticipated change in release temperature from Keepit Dam after installation of a MLO. Whilst the findings are yet to be formally released, some key conclusions from the report have been provided by SWC for use in this scoping report (MHL in prep):

- Improvements in CWP can only be achieved with surface withdrawal during December and January, with potential improvements also possible in February during times of high stratification and irrigation demand (Figure 6).
- At 2000 $ML.day^{-1}$ (median discharge required to meet irrigation demand downstream) a surface offtake can achieve a 2-5˚C improvement in the temperature of release when compared to the present deep offtake (Figure 7).

- Larger discharges result in the entrainment of a thicker water layer and reduce the benefit of releasing water from the surface.
- Although MHL has confidence in the likely improvement in the release temperature from surface withdrawal, such improvement is highly reliant on a number of factors, namely the degree of stratification and the thickness of the withdrawal layer, which is in turn a function of discharge. This variability is reflected in the minimum and maximum intervals shown in Figure 6.

Figure 6: Potential improvement in the temperature of release from current deep FLO and surface withdrawals possible with a MLO at Keepit Dam (based on 100 years of modelled flow data). Adapted from MHL (in prep). Note that these are estimates of release temperatures only and may not reflect actual water temperature downstream of dam after mixing has occurred.

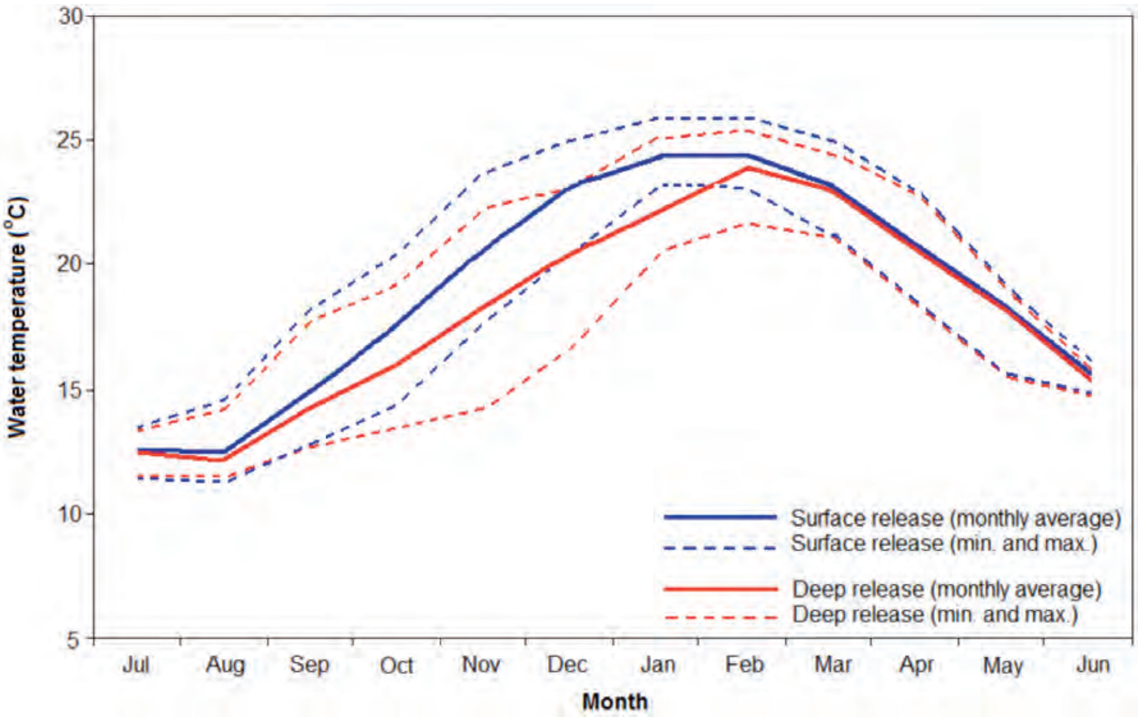
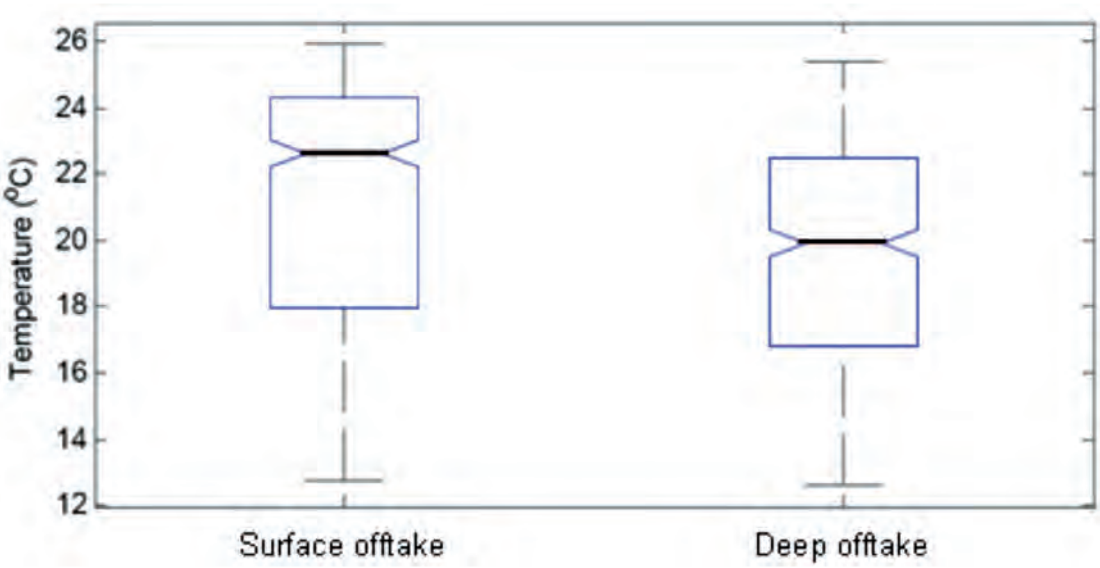


Figure 7: Withdrawal temperatures from Keepit Dam expected at 2000ML.day-1 for surface and deep offtakes. Bold line shows median value, box shows upper and lower quartiles and whiskers show upper and lower extremes. Source: MHL in prep.



1.5 Impact assessment into the mitigation of CWP in the Murray-Darling Basin

Concerns over the impact of CWP in the MDB have been around for almost three decades (Walker 1980). A 2001 workshop into the distribution and ecological effects of CWP in the MDB (Phillips 2001) instigated a renewed call for action among researchers and managers to address the problem of CWP. This challenge was taken up as part of the MDBC's Native Fish Strategy, which lists CWP amelioration as one of its six key driving actions (MDBC 2003). Further to this, a scoping of potential mitigation techniques has been completed (Sherman 2000), providing managers with cost effective alternatives for CWP remediation. In 2005, a CWP Inter-Agency Group involving key government agencies (NSW DNR, NSW DPI, DECC, SWC) in partnership with dam owners, community groups and environmental scientists, established a CWP Strategy to identify the areas most seriously affected, and to progress infrastructure projects to mitigate or prevent CWP. It is clear, however, that until baseline data are collected showing positive environmental responses to CWP mitigation, short-term economic considerations will always win out over longer-term environmental goals when deciding on whether to invest in the infrastructure required to address the CWP problem.

Resource managers and the broader community must be presented with scientifically-rigorous and defensible evidence of the effectiveness of any management options to reduce CWP. The construction of a MLO at Keepit Dam would appear to provide an excellent opportunity to test a number of hypotheses regarding the affect of CWP in a lowland river of the MDB and the ecological response to its mitigation.

The question may be asked as to whether there are existing monitoring programs that could provide data to answer these hypotheses. Rivers in the MDB are currently being monitored under a number of large-scale projects, including:

- Sustainable Rivers Audit (SRA: MDBC and State Agencies), which provides benchmark and ongoing assessment of the condition of river health, reporting at the catchment scale;
- Integrated Monitoring of Environmental Flows (IMEF: DIPNR), which investigates the relationship between flow regimes, biodiversity and ecosystem processes in regulated rivers and wetlands, as well as the unregulated Barwon-Darling River, in NSW. IMEF also reports at the catchment scale.

These and other smaller projects have specific objectives and hence assess ecological condition at scales that are appropriate for the questions they are designed to answer. It is well recognised that spatial scaling needs to be carefully considered when studying how biota respond to environmental heterogeneity and human induced impacts (Wiens 1989, Menge and Olson 1990, Levin 1992, Horne and Schneider 1995, Poizat and Pont 1996, Inoue *et al*. 1997, Bult *et al*. 1998, Mason and Brandt 1999, Crook *et al*. 2001, Boys *et al*. 2005, Boys and Thoms 2006). In ecological studies the chosen scale of measurement dictates how the ecosystem is viewed (Levin 1992), as well as the perceived distribution of an organism and its apparent response to perturbations (Allen *et al*. 1993, Bult *et al*. 1998, Boys and Thoms 2006). Therefore, conducting assessments of the fish assemblage over inappropriate spatial scales increases the risk of either failing to detect or drawing inaccurate conclusions regarding fish-habitat associations or changes in population dynamics (Wiens 1995, Holbrook *et al*. 2000).

Although the SRA, IMEF and other smaller projects may provide data on components of the fish assemblage in reaches of river affected by CWP, the frequency of sampling (e.g. once every three years in any particular catchment as part of the SRA) as well as the list of indicators used, are largely unsuitable for the robust testing of some of the key hypotheses associated with detecting an assemblage response to MLO operation at Keepit Dam (see Chapter 3). As a result, a specific design and sampling framework needs to be tailor-made with the objective of detecting a change in the fish assemblage at the spatial and temporal scales relevant to the change that will be expected from the operation of the MLO. This does not negate the integration of some of the data from other projects in a full impact assessment of MLO operation at Keepit Dam, and if possible the design should try to take advantage on the long-term data that will come from the SRA and avoid duplicating any effort. For example, as part of this scoping report, data from the SRA, the Pilot SRA and IMEF have been used in analyses of sampling power, to establish methodologies and to help identify potential control and reference sites, thus negating the need for a lengthy and costly pilot study.

1.6 Objective of this scoping report

Given the high profile and widespread nature of CWP, as well as the typically high cost of its mitigation, the Murray-Darling Basin Commission (MDBC) has commissioned this report to scope the feasibility of a four year impact assessment investigating the response of the fish assemblage in CWP affected reaches of the Namoi River to the operation of a MLO at Keepit Dam. A further goal of a full impact study would be to use the resulting knowledge to estimate the likely long-term recovery of the fish assemblage and provide information to assist in the remediation of other riverine habitats affected by CWP throughout the MDB.

It is the objective of this scoping report to ensure if a full impact assessment was commissioned at Keepit Dam, that it would provide a scientifically-robust and cost effective assessment of changes in the native fish assemblage associated with the operation of a MLO. Specifically, the key objective of this report is to provide background information and analysis to inform the design of a full impact study.

2. SCOPING PROCESS

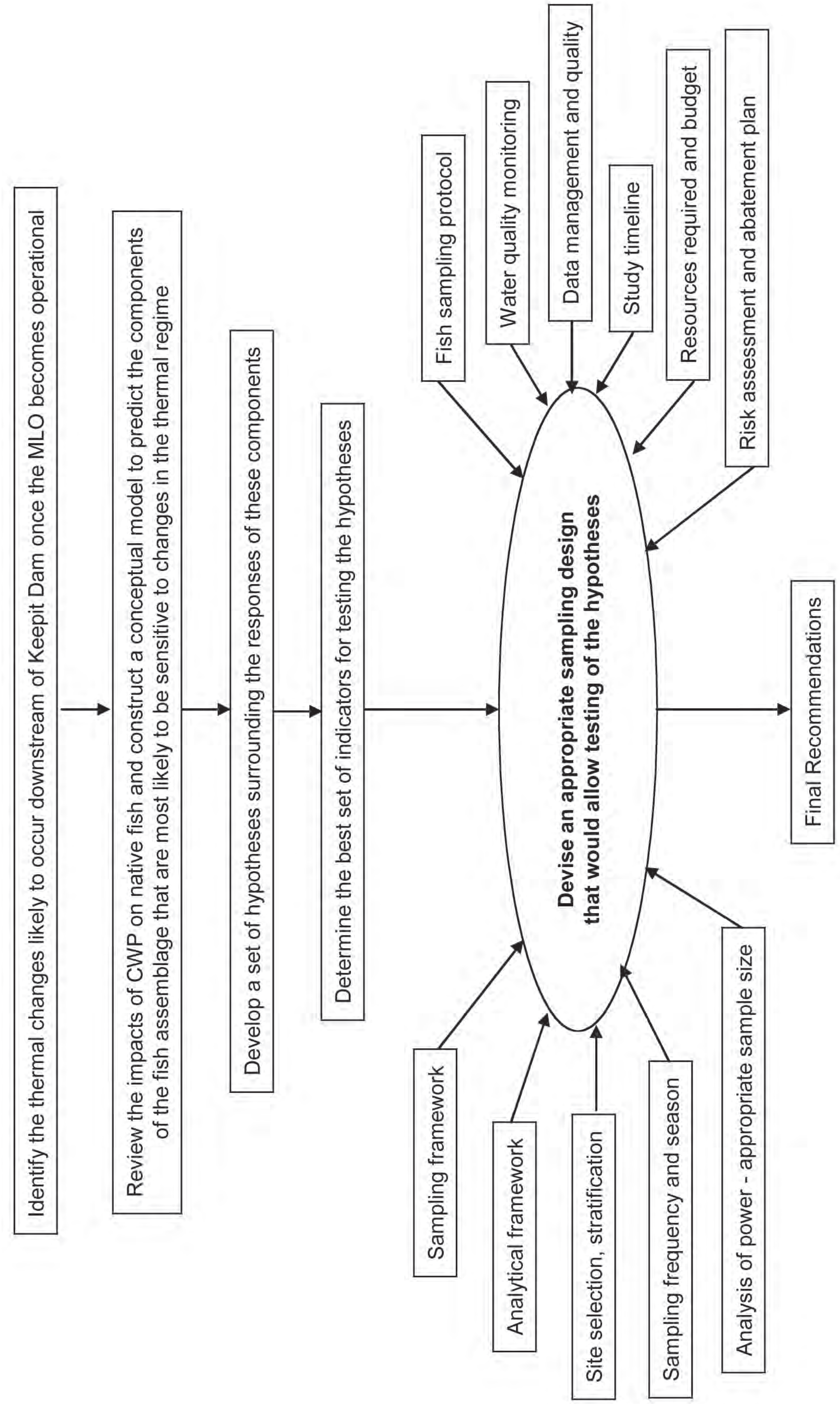
A multi-step process was used to devise a number of experimental design options and develop methods for a full impact assessment (Figure 8). Initially it was necessary to consult State Water to identify the extent of the current problem of CWP downstream of Keepit Dam, and predict what thermal changes are likely to occur once the MLO becomes operational. Should inadequate data exist, it would be necessary to conduct further modelling into the potential impact. It was necessary to review the literature to ascertain what problems CWP pose to the survival, growth and reproduction of native fish in the MDB, and this information is reported in the introduction of this report. This information has been used to identify the components of the fish assemblage likely to respond to amelioration of the thermal regime. From this, a number of hypotheses have been devised that will allow the responses of these components to be directly tested. Further, a list of potential indicators has been compiled according to their relevance for detecting the desired response.

An inevitable part of designing an impact assessment in complex ecological systems is that there needs to be compromises made between different design criteria. Ultimately this makes no monitoring program perfect, however, if legitimate and conclusive inferences are sought, it is essential that careful design choices are made and their likely impact on meeting the objectives of the monitoring project documented. This report outlines the logic behind the sampling design options formulated to assess the response of the fish assemblage to MLO operation at Keepit Dam. Appropriate study design options have been devised to enable testing of key hypotheses and validation or refinement of the conceptual response model. Various components of the experimental design were scoped:

1. The sampling framework suited to this type of impact assessment;
2. The analytical framework suited for testing the hypotheses and model;
3. The criteria for the selection, stratification and location of sampling sites;
4. The appropriate level of temporal replication and timing of sampling;
5. An appropriate level of precision and therefore sample size required to detect a response to MLO operation;
6. Appropriate method, including sampling gear types, water quality monitoring, resources required, as well as the trade-offs that must be made in establishing an optimised sampling program
7. Data management, storage and quality assurance practices;
8. An appropriate timeline for the project has been devised in accordance with State Water Corporation (SWC) work schedules;
9. The anticipated budget;
10. The anticipated risks to project failure and appropriate measures to minimise these.

A steering committee was established to both review the scoping process and to review the draft scoping report and final recommendations. This committee consisted of Craig Boys (principal investigator, NSW DPI), Jim Barrett (chair, MDBC), John Harris (independent ecologist, Harris Consulting), Wayne Robinson (independent biometrician, University of Sunshine Coast) and Jocelyn Karsten (SWC). A further independent review of this document was undertaken by Simon Nicol (ecologist, Arthur Rylah Institute) and Peter Jackson (ecologist, private consultant). Additionally, the final draft was reviewed by scientists and managers of the MDBC's Native Fish Strategy Implementation Working Group.

Figure 8: Scoping process and components contributing to the final experimental design options



3. SENSITIVE ASSEMBLAGE COMPONENTS AND DEVELOPMENT OF HYPOTHESES

To infer a response in the state of the fish assemblage following CWP mitigation requires that components of the structure and function of the fish assemblage be investigated with a set of formal hypotheses testable using direct or derived indicators. For example, spawning is a key component of fish assemblage function, and the presence of fish eggs and larvae are indicators that infer spawning. Similarly, species diversity is an indicator of changes in assemblage structure. As not all components of the fish assemblage are sensitive to changes in thermal regime, it is not necessary, nor is it financially viable, to collect data on an exhaustive set of indicators. Instead, indicators need to be identified that are likely to respond to MLO operation and the anticipated improvements in thermal regime, over the appropriate time scales.

To detect an ecological change from MLO operation at Keepit Dam it is essential we be realistic about what assemblage response is expected. There are two unknowns that make this task especially hard. First, it is impossible to predict the level of thermal amelioration anticipated with any great certainty. Although a MLO will enable selective withdrawal from Lake Keepit, the exact temperature of releases will not be under the direct control of the researcher. This is because release temperatures both before and after MLO construction is highly dependent on factors outside the control of the researcher or dam operator, such as discharge from the dam and the degree of thermal stratification in the storage. These two variables are a function of downstream irrigator demand, dam capacity, predicted inflows and policy regarding water allocations (see section 1.4). In the worst case scenario for researchers, CWP will not be experienced during the 'before impact' phase of the study (see chapter 10), negating the possibility of studying thermal amelioration through MLO operation.

The second unknown is being able to predict what level of improvement may be detectable within the constrained timeframe afforded by an impact assessment study. The response of the fish assemblage to CWP amelioration would be expected to continue for decades and is also under the influence of other stressors, such as barriers to migration, habitat destruction, alien species and river regulation. Being able to anticipate the likely trajectory and strength of ecological change will be difficult because we do not have an in-depth understanding of which stressors are key limiting factors to assemblage recovery.

Table 3 summarises the key components of fish assemblage structure and function likely to be sensitive to amelioration in CWP, and the hypotheses and indicators that can be used to investigate them. The hypotheses were selected because they could be considered for use in detecting a response to CWP amelioration at any structure throughout the MDB. In this section, each hypothesis and indicator will be considered for appropriateness for use in a Keepit Dam study, based on the anticipated level of thermal change expected. Because of the two constraints mentioned above, it is not possible, nor necessary to attempt to quantify the level of indicator response expected. Whilst some of the hypotheses will test a directional response (e.g. increase in abundance), others are non-directional in response (e.g. assemblage change). This is important to note as it is the aim of this impact assessment to detect differences in the fish assemblage through time as a consequence of CWP amelioration. The direction, magnitude of these responses, as well as whether the response is of biological or ecological significance is a separate issue that can be addressed following the assessment.

The hypotheses listed for consideration satisfy most of the following requirements:

- are supported by best available information on the likely ecological response to CWP mitigation in the Namoi River fish assemblage;
- rely on indicators that can be measured using techniques that are both practical and cost effective to implement during routine monitoring across large spatial scales;
- are largely insensitive to confounding factors, or still retain strong inferential power in light of these external factors;
- can be generically applied to other areas in the MDB;
- are testable over the temporal scales relevant to the life of the monitoring program; and
- are testable within the bounds of a feasible sampling and analytical framework.

Table 3: Key components of fish assemblage structure and function expected to be sensitive to thermal changes brought about by MLO operation, their hypothesised response, the indictors that can be used to measure them and practical examples of their measurement.

Assemblage component	Hypothesised response	Indicator(s), metrics and analyses suitable for testing hypothesis
Redistribution of species	**Hypothesis 1** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in assemblage composition or structure in those areas currently affected by CWP **Hypothesis 2** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in the abundance of certain species in those areas currently affected by CWP	Change in assemblage composition using multivariate dissimilarity (Bray-Curtis) and Analysis of Similarity (ANOSIM). Analyses of Variance (ANOVA) of species richness, species diversity, proportion of native species to alien species ANOVA on abundance of selected species
Spawning and larval production	**Hypothesis 3** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to an increase in the successful spawning of fish in those areas currently affected by CWP **Hypothesis 4** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in the chronology or timing of spawning of fish in those areas currently affected by CWP	ANOVA on abundance of egg or larval life stages, determine gonad somatic index (GSI) to establish reproductive status Timing of appearance of egg and larval life stages, determine GSI to establish chronology or timing of spawning
Recruitment	**Hypothesis 5** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to an increased success of recruitment in those areas currently affected by CWP	ANOVA on abundance of recent recuits
Growth	**Hypothesis 6** Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to increased growth rates of fish in those areas currently affected by CWP	ANOVA on changes in fish weight from cage experiments

3.1 Redistribution of species

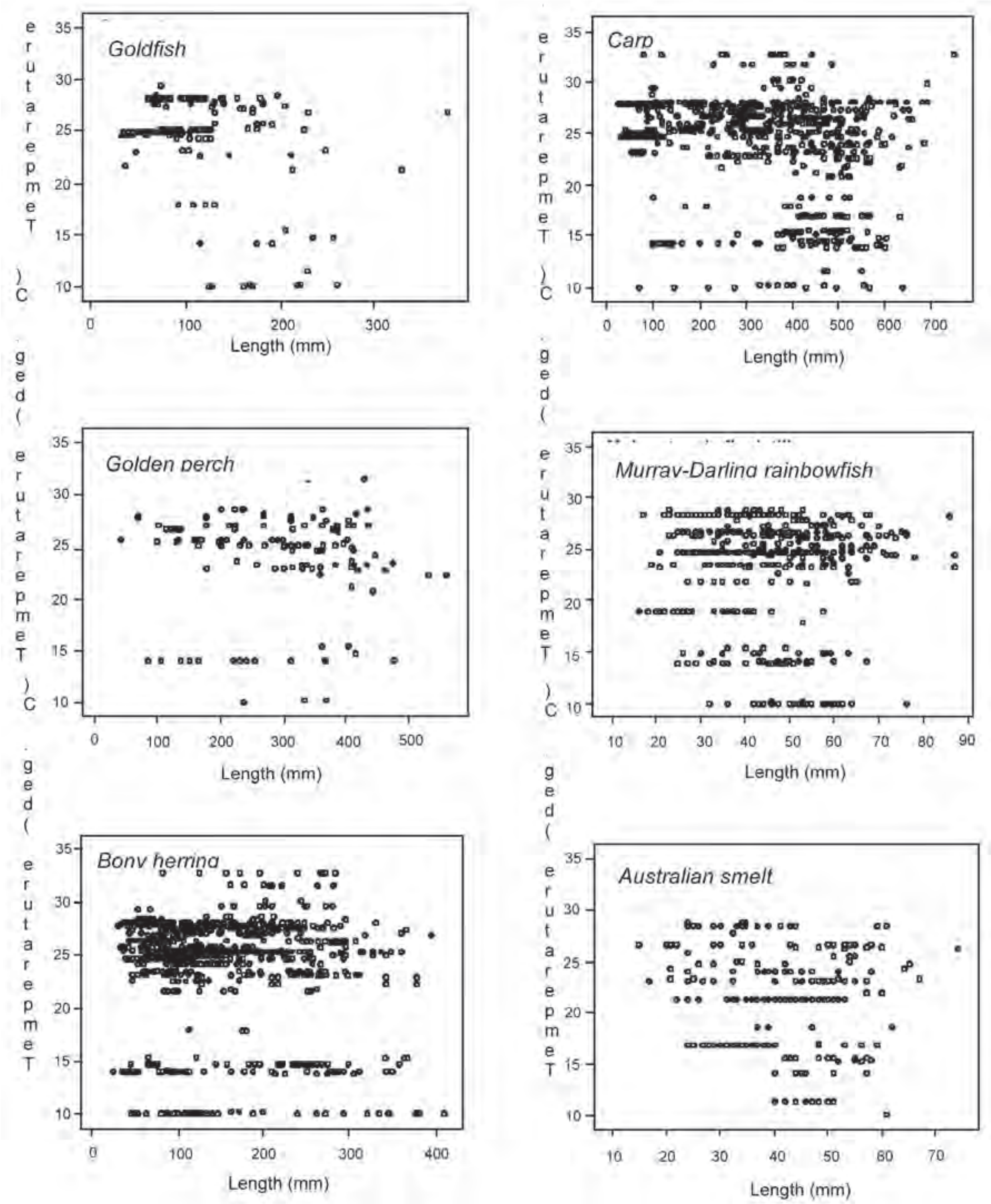
Hypothesis 1: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in assemblage composition or structure in those areas currently affected by CWP; and

Hypothesis 2: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in the abundance of certain species in those areas currently affected by CWP.

Both these hypotheses are concerned with a change in the large-scale distribution of species that may be expected when CWP is ameliorated (see section 1.2.1). The 5°C depression in temperature that can currently occur due to CWP downstream of Keepit Dam does not push temperature beyond the tolerable range of any of the fish species inhabiting the Namoi River (Table 2). Despite this, there is evidence to suggest that CWP downstream of Keepit Dam may be altering the composition of the fish assemblage, that is the relative abundances of species in the assemblage (see analysis in section 4.2.4). It is likely, however, that even under the largest change in temperature expected from MLO operation at Keepit Dam (a 5°C increase), there will be only a subtle change in assemblage composition, reflecting short-term responses such as a redistribution of individuals into more preferential habitats, rather than species replacement due to changes in survivorship of juveniles and adults.

Assemblage composition in addition to metrics such as species richness, species diversity and proportion of natives to aliens are indicators which can be readily applied to test these first two hypotheses. It is unlikely that size class analyses using juvenile and adult life stages will show any differences due to CWP amelioration, as a quick interrogation of the Freshwater Fish Research Database (NSW DPI 2007) reveals that most size classes have been sampled over a larger temperatures range than will be expected during the proposed study (Figure 9).

Figure 9: Scatter plots of ambient water temperature (°C) against length (mm) for six abundant fish species caught in main channel sites in the Namoi, Gwydir and Macquarie Rivers. Source: NSW DPI 2007. See Table 2 for a full list of scientific names.



3.2 Spawning and larval production

Hypothesis 3: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to an increase in the successful spawning of fish in those areas currently affected by CWP; and

Hypothesis 4: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to change in the chronology or timing of spawning of fish in those areas currently affected by CWP.

Hypotheses 3 and 4 relate to the postulated impacts of CWP on spawning. CWP can cause summer suppression and seasonal displacement of temperature in the Namoi River from what is expected under normal conditions (see section 1.3). Superimposing the spawning thresholds of native fish species over plots of the possible range of thermal improvement suggests that improvements in spawning success may be experienced immediately as a result of MLO operation (Figure 10 and Figure 11). MLO operation has the potential to increase the window of potential spawning for all species (Figure 10), allowing spawning to occur earlier in the breeding season. Murray cod, silver perch and freshwater catfish could benefit the most since these species typically fail to spawn in the average year (Figure 10). Even when CWP is evident, however, minimum spawning thresholds may be restored in the river within 25 km downstream of Keepit Dam (Figure 11). Therefore any improvements may only be noticeable immediately downstream of the dam. Larval abundance is a suitable indicator of spawning in those species that undergo a drifting phase (e.g. golden perch and carp). However, for other species (e.g. rainbowfish, Australian smelt (*Retropinna semoni*) and gudgeons (*Hypseleotris spp.*)) spawning and reproductive status may need to be inferred from calculations of the gonad somatic index (GSI).

3.3 Recruitment

Hypothesis 5: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to an increased success of recruitment in those areas currently affected by CWP.

Because fish are more susceptible to mortality from disturbances during egg and larval stages than as adults (Harvey 1987, Merigoux and Ponton 1999), it is hypothesised that recruitment success among native species can be enhanced by mitigating CWP at Keepit Dam. The presence of recent recruits would provide a sensitive indicator of improvements in recruitment and this can be determined by analysing fish's otoliths. In comparison, estimates of population size would be less useful during a short impact assessment, since it is sequential recruitment over long time periods that leads to improved population sizes (Humphries *et al*. 2002b).

3.4 Growth

Hypothesis 6: Restoring a natural thermal regime in the Namoi River, through MLO operation, will lead to increased growth rates of fish in those areas currently affected by CWP.

At best, a 10–24% improvement in temperature can be achieved thorough MLO operation at Keepit Dam during December and January (Figure 6). This level of improvement appears minor when compared to the 62% and 142% increases in temperature previously reported to induce faster growth rates in silver perch and catfish, respectively (Koehn 2001, Astles *et al*. 2003). Therefore whilst it bears consideration, Hypothesis 6 involves the least sensitive of all the anticipated responses and is the most difficult to study due to the logistical difficulties associated with cage experiments (see section 6.4). These difficulties need to be kept in mind and before any full-scale experiment is attempted, it is advised that pilot trials be conducted in the first year to further determine feasibility.

Figure 10: The 'window' of effective spawning for a number of MDB fish species in relation to the potential improvement in the temperature of release from current deep FLO and surface withdrawals possible with a MLO at Keepit Dam (based on 100 years of modelled flow data). Adapted from MLO (in prep). Note that these are estimates of release temperatures only and may not reflect actual water temperature downstream of dam after mixing has occurred.

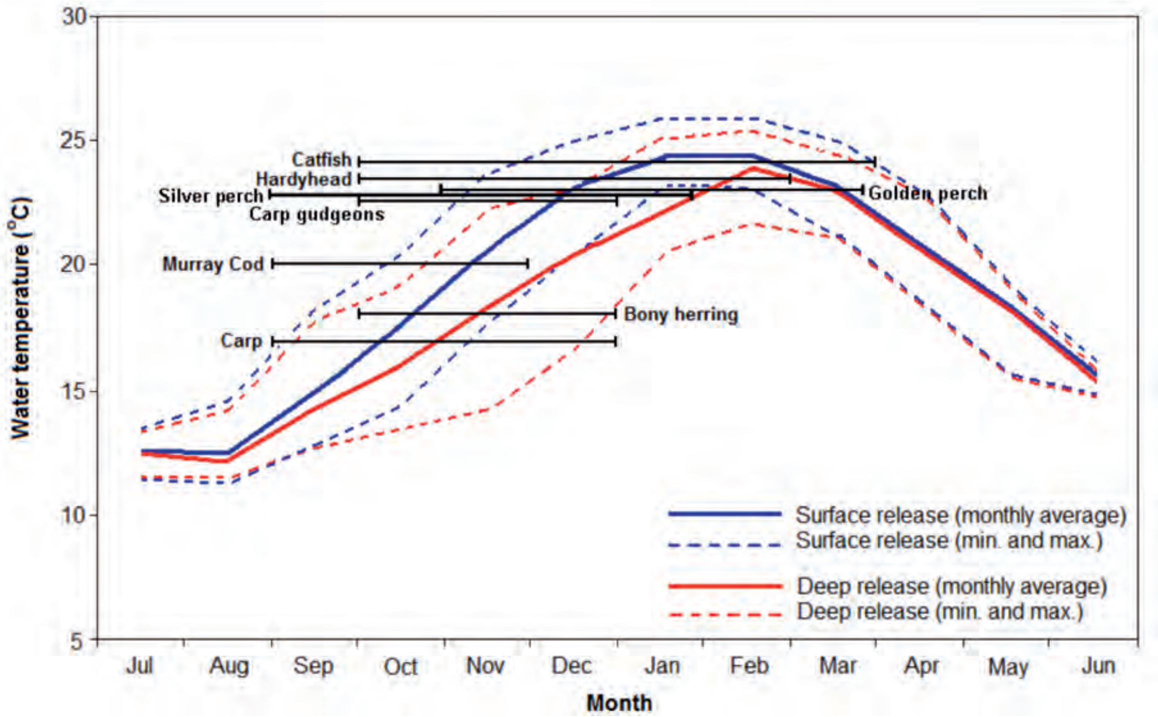
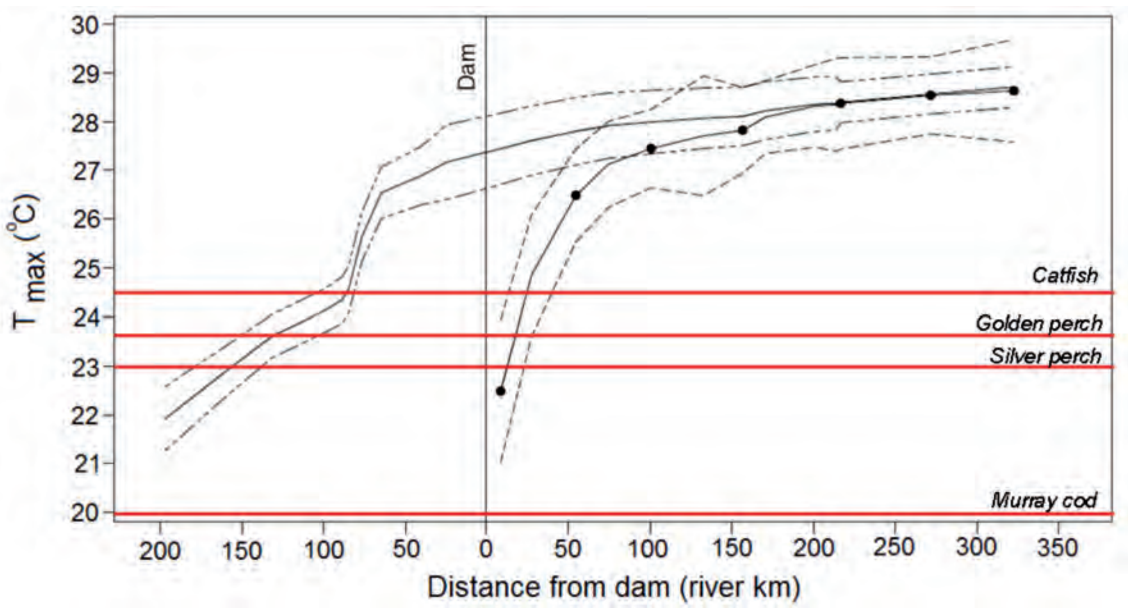


Figure 11: Minimum spawning thresholds for four native species in relation to fitted curves for Tmax (annual maximum temperature) downstream of Keepit Dam (-●-) and for the pre-dam reference (—) condition. Broken lines are 95% confidence intervals. The fitted curve for pre-dam Tmax is a function of elevation and adjusted to the median time of day of summer temperature measurement across the Basin (12:00 hours). Adapted from Preece and Jones (2002).



4. PROJECT DESIGN CONSIDERATIONS

4.1 Impact assessment framework

Impact monitoring aims to discriminate change resulting from an activity of interest (the 'impact') from change arising from other processes independent of the activity. To do this, a variable's state prior to the start of a particular activity (i.e. the '*before*' condition) is compared to a state consistent with the hypothesis that the activity has affected the variable (referred to as the '*after*' condition). The first criterion of a suitable design for impact assessment is sampling at the impact location (area where the impact is most likely) before and after the impact has occurred. In this case, the activity is defined as the commencement of MLO operation, the 'impact' is the change in the thermal regime downstream of Keepit Dam and the 'impact location' is the reach currently affected by CWP and where the ameliorated thermal regime is expected (Table 4).

Comparing an impact site before and after an activity, however, does not allow changes caused by the impact to be distinguished from those changes caused by unrelated external factors that may have occurred in coincidence with the activity of interest. To do this, ideally, you would need data from the impact location before and after the impact, both in the presence and absence of the impact. This is not possible, and a separate location must be chosen which lies beyond the influence of the activity (i.e. '*control location*'). A number of criteria must be met by control locations (see section 4.2.1), most important being that they are as similar as possible in all respects to the impact location, except for the presence of the impact (Downes *et al*. 2002). The assumption being made is that the impact location would have behaved in the same way as the control location in the absence of the impact (Underwood 1991). Control locations therefore act as the best available surrogate for the impossible scenario of collecting data at the impact location both before and after the activity, in absence of the activity (Downes *et al*. 2002). If a departure in state between impact and control locations takes place post-activity, it can be inferred that the activity has had a measurable impact.

Table 4: The key elements of rigorous impact monitoring designs

Element	Definition	Definition in proposed study
Activity	A change in state (human-induced or otherwise) that triggers the impact response	The commencement of MLO operation at Keepit Dam
Impact	The resultant change triggered by an impacting activity	Change in the thermal regime downstream of Keepit Dam
Impact location	An area under the influence of the impact	Reach of the Namoi River within the current influence of CWP and likely to undergo thermal amelioration as a result of MLO operation
Control location	An area beyond the influence of the impact, but as similar as possible to the impact location in other respects	Reach of the Namoi River or nearby regulated river that is similar to the impact location in most respects but outside of the influence of MLO operation at Keepit Dam.
Reference location	An area deemed as close as possible to the desired state of the impact location after the hypothesised response has occurred	Reach of the Namoi River or nearby river without CWP but still under the influence of a large dam (regulated)
Site	Replicate areas of sampling nested within the larger spatial scale of impact, control and reference locations	Area of sampling
Before condition	A state prior to the start of a particular activity	The state of the fish assemblage before MLO operation begins
After condition	A state after the start of a particular activity. This state may indicate no change or a change consistent with the hypothesis that the activity has affected the state	The state of the fish assemblage before MLO operation begins

The assessment of impact and control locations, both before and after an impact, are the fundamental elements of a family of rigorous impact monitoring designs generically termed BACI (Before versus After, Control versus Impact) (Green 1979). Statistical inference remains weak, however, when only a single impact and control location are assessed. This is because both locations can undergo different trajectories independent of the putative impact due to natural phenomenon or unanticipated changes coinciding with the impacting activity (Eberhardt 1976, Underwood 1992). To overcome the spatial and temporal variation inherent to most natural systems, the basic BACI design needs to be extended to include multiple times during the before and after periods, and multiple control and (ideally) impact locations. Such MBACI (Multiple BACI) designs are more robust because there is less likelihood that an impact will be attributed to changes that may occur simply by chance.

In most impact assessments, however, there is only one legitimate impact location for a given activity (Downes *et al*. 2002). This is indeed the case at Keepit Dam where there is only one continuous section of river where MLO operation will result in CWP amelioration. What could be done with the Keepit Dam project, as with most impact monitoring (Underwood 1991), is an asymmetrical design with multiple control locations being compared to a single impact location. This makes the replication of control locations even more important because they become the only data source from which to extract 'normal' behaviour from the dynamics of a single impact location (Downes *et al*. 2002).

The use of impact and control locations both before and after the commencement of MLO operation is a defensible way of attributing a response to CWP amelioration. However, it may also be possible to test whether any changes that are detected are towards some reference or target state (Chapman and Underwood 2000). Unlike in many published studies (see Norris *et al*. 2004), the reference state will not be defined as one which is least impacted, natural or pristine, since this state is not realistically attainable on the Namoi River which will remain highly regulated and modified in other ways irrespective of CWP. In this case, the reference condition provides an indication of what the Namoi River may be like in the absence of CWP, whilst retaining the other stressors that are unlikely to be affected by MLO operation (e.g. altered hydrological regime).

To test such a full rehabilitation model, data are required from three different treatments (Table 4): (a) the CWP affected area that will be influenced by MLO operation, '*impact location*'; (b) a CWP affected area beyond the influence of MLO operation, '*control location*'; and (c) an area representing a CWP unaffected condition that MLO operation will be targeting, '*reference location*'. With such a design, the control condition will inform whether a change has resulted from the impact and the reference condition will inform whether the change is in the desirable direction. The design therefore becomes more complicated than a traditional BACI design because there is a need to make two simultaneous comparisons: impact versus reference versus control. What is being tested for is 'bioequivalence' between impact and reference states and different analytical approaches must be used compared to the traditional falsification approaches applied to BACI designs (chapter 5).

Five different sampling design options are proposed for monitoring the response of the fish assemblage to MLO operation at Keepit Dam (Table 5). These designs lie along a gradient of inferential certainty (Downes *et al*. 2002) and the options listed are listed in order from weaker BACI to relatively stronger full rehabilitation models (Table 5). Option 5 is among the most rigorous designs available for impact assessments, however, as inferential certainty increases so does the cost associated with monitoring. Eventually, tradeoffs will have to be made between the complexity of design and the degree of spatial and temporal replication. These tradeoffs are explored further throughout this report and final recommendations will be made on a reduced set of options based on optimisation of the monitoring program after acknowledgment of the likely funding budget.

4.2 Spatial stratification

The choice of impact, control and reference locations involves a range of spatial and temporal considerations related to both the extent and size of the impact and the anticipated response in biological indicators. This section outlines the logic behind the choice of appropriate treatment groups necessary to implement the design options listed in Table 5.

4.2.1 Impact location

The impact location itself is conceptually easy to define, and is the reach of the Namoi River within the current influence of CWP and likely to undergo thermal amelioration as a result of MLO operation (Table 4). Defining the extent of the impact location at the time of study, however, is a much harder task and is addressed in section 4.2.3. Multiple sites nested within the impact location will be influenced by a common source of impact and will

Table 5: Proposed sampling design options for investigating the impact of MLO operation on the fish assemblage downstream of Keepit Dam

Power of inference	Proposed Option	Spatial design	Temporal design	Cost/ benefit
Increased ability to attribute a given change to MLO operation ↓	Option 1 (BACI)	• 1 impact location • 1 control location • Multiple replicate sites within each location	• Multiple years before and after • Multiple seasons, months or weeks (see section 0)	Increased project cost or reduced 'within location' and 'tempora'l replication (see chapter 9) ↓
	Option 2 (MBACI)	• 1 impact location • Multiple control locations • Multiple replicate sites within each location	• Multiple years before and after • Multiple seasons, months or weeks (see section 0)	
	Option 3 (Full rehabilitation model)	• 1 impact location • 1 control location • 1 reference location • Multiple replicate sites within each location	• Multiple years before and after • Multiple seasons, months or weeks (see section 0)	
	Option 4 (Full rehabilitation model)	• 1 impact location • Multiple control locations • 1 reference location • Multiple replicate sites within each location	• Multiple years before and after • Multiple seasons, months or weeks (see section 0)	
	Option 5 (Full rehabilitation model)	• 1 impact location • Multiple control locations • Muliple reference locations • Multiple replicate sites within each location	• Multiple years before and after • Multiple seasons, months or weeks (see section 0)	

not be independent measures of this impact. Therefore, they can not be considered different impact locations and instead these multiple sampling sites are merely sub-samples of the larger impact location. Furthermore, locations that are close together relative to the migratory capabilities of fish species are unlikely to be independent when assemblage composition is analysed.

4.2.2 Control locations

The control location(s) should act to isolate the effect of interest, namely the response in the fish assemblage to MLO operation and CWP amelioration. To do this, control location(s) that satisfy the following criteria will need to be chosen:

- As similar to the impact location as possible so that the potential differences can be attributed to the commencement of MLO operation at Keepit Dam;
- Beyond the influence of MLO operation at Keepit Dam;
- Independent from each other and from impact and reference locations in their response to MLO operation at Keepit Dam.

If control locations are chosen that are substantially different physically, hydrologically and biologically from the impact location, it is likely that there will be greater baseline variation and different temporal dynamics that could result in the design having lower power to detect an impact (Downes *et al*. 2002). Based on the above criteria, suitable controls to the Namoi River impact location must be other large lowland rivers, regulated by a large storage and impacted by CWP during summer irrigation releases. According to Preece (2004), there are a number of regulated rivers in the MDB that can be grouped with Keepit Dam as having a similarly high potential for CWP (Table 1 and Figure 1):

- Severn River in the Border Rivers Catchment (downstream of Pindari Dam);
- Gwydir River (downstream of Copeton Dam);
- Macquarie River (downstream of Burrendong Dam);
- Lachlan River (downstream of Wyangala Dam);
- Murrumbidgee River (downstream of Burrinjuck Dam);
- Tumut River (downstream of Blowering Dam); and
- Murray River (downstream of Hume Dam).

Although there are no published accounts of in-channel habitat comparisons between these rivers, similarities between habitats in different rivers can often be inferred by analysing the structure of the resident fish assemblages (Boys and Thoms 2006) . This is because the spatial distribution of fish in a river is non-random (Schlosser 1991) and often reliant on the availability of suitable habitat (Ims 1995, Kramer *et al*. 1997, Crook *et al*. 2001, Fausch *et al*. 2002). It has been hypothesised that fish view rivers in a hierarchical way: selecting a suitable reach of river, followed by suitable mesohabitats within that reach, and finally suitable microhabitats (Kramer *et al.* 1997). This hierarchical form of decision making is best described as a process whereby physical habitat at different scales act as a series of landscape filters controlling the distribution of fish (Poff 1997).

Fish assemblages in lowland rivers of the MDB show substantial differences in species composition among different regions. A distinct regional identity exists that differs between the northern MDB (including the Darling, Gwydir, Namoi and Macquarie Catchments) and the southern MDB (including the Murray, Murrumbidgee and Lachlan Catchments) (Gehrke 1997, Gehrke and Harris 2001). Based on these regional identities, the above list of possible control locations can be further narrowed down to the Gwydir River (downstream of Copeton Dam) and the Macquarie River (downstream of Burrendong Dam). Both Copeton and Burrendong dams supply regulated flows for downstream irrigators from late spring through to late summer (Preece 2004).

To further test the suitability of the Gwydir and Macquarie Rivers as potential controls for the Namoi River, a multivariate analysis of fish assemblages was conducted using three-dimensional semi-strong hybrid multidimensional scaling (SSHMDS: Belbin 1991). Catch per unit effort (number of individuals per hour of electrofishing 'power-on' time) was calculated for each fish species (total of 17 species) caught at main channel sites on the Gwydir, Namoi and Macquarie Rivers during previous NSW DPI surveys (Figures 13, 14 and 15). The dataset was limited to sites downstream of Keepit, Copeton and Burrendong Dams and projects which incorporated electrofishing pursuant to similar sampling frameworks (i.e., New South Wales Rivers Survey, Integrated Monitoring of Environmental Flows – Rivers, and the Sustainable Rivers Audit). CPUE data were log-transformed prior to ordination using PATN v3.03 (Belbin 1994). Pair-wise analysis of similarity testing (ANOSIM; PRIMER v5.2.7) was used to test for differences between a-priori groups of sites based on rivers (Gwydir, Namoi and Macquarie Rivers).

To identify the species that were most important in determining spatial and temporal variation in assemblage composition, Principal Component Correlation (PCC; PATN v3.03) was applied to fish abundance data and habitat variables (including water quality and productivity measures) and tested using the Monte-Carlo Attributes in Ordination (MCAO) permutation test (seed value = 1235, 1000 iterations). PCC vectors were plotted on ordination figures if the percentage of MCAO permutation r-squared values that exceeded the real r-squared (the r-squared value from the real groups) was less than or equal to 5%, and coded as follows: *** = 0%, ** = 1%, * = 2-5%. These percentages approximate p-values of <0.001, <0.01 and <0.05, respectively (Lee Belbin, *pers. comm.* 2005). However, because actual 'p-values' are not produced by MCAO testing, we describe PCC vectors with 'significant' results as 'strongly' correlated with the distribution of sites in ordination space.

No difference was found in the assemblage composition between the Namoi, Gwydir and Macquarie Rivers downstream of their respective dams (ANOSIM: Global R=0.02, p>0.05). The ordination also reveals that Namoi River sites are more closely matched to Gwydir River sites than Macquarie River sites (Figure 15). Based on these findings it is recommended that the Gwydir River downstream of Copeton Dam be the first choice for a control location, with the Macquarie River downstream of Burrendong Dam providing a suitable alternative if a second control is required. The selection of controls on rivers with similar hydrological and biotic conditions but in different catchments is ideal because it maximises the chance that the controls will be independent of the impact.

Figure 12: Existing NSW DPI sampling sites in the Namoi Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Keepit Dam were used in the multivariate analysis of fish assemblage composition.

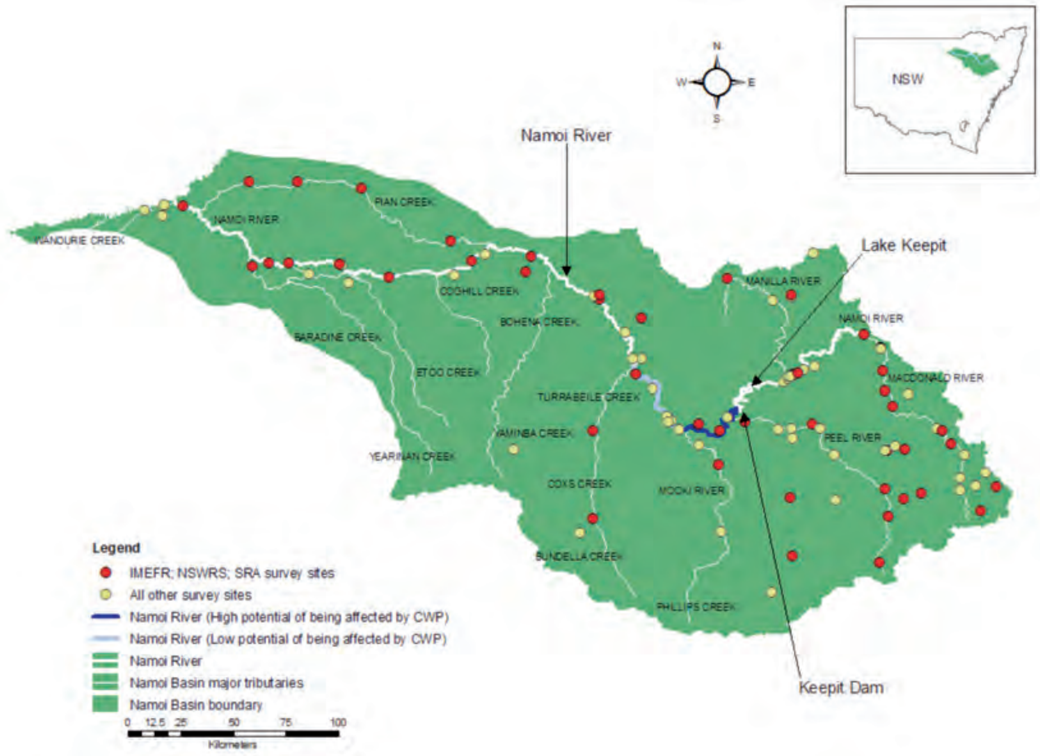


Figure 13: Existing NSW DPI sampling sites in the Gwydir Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Copeton Dam were used in the multivariate analysis of fish assemblage composition.

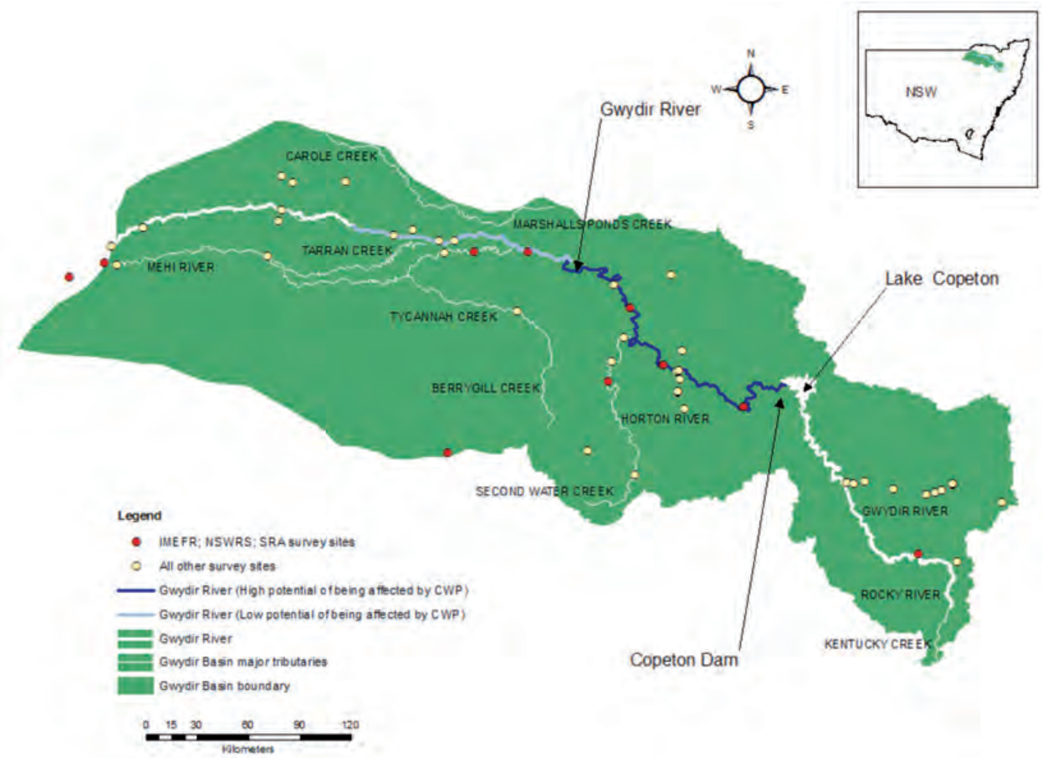
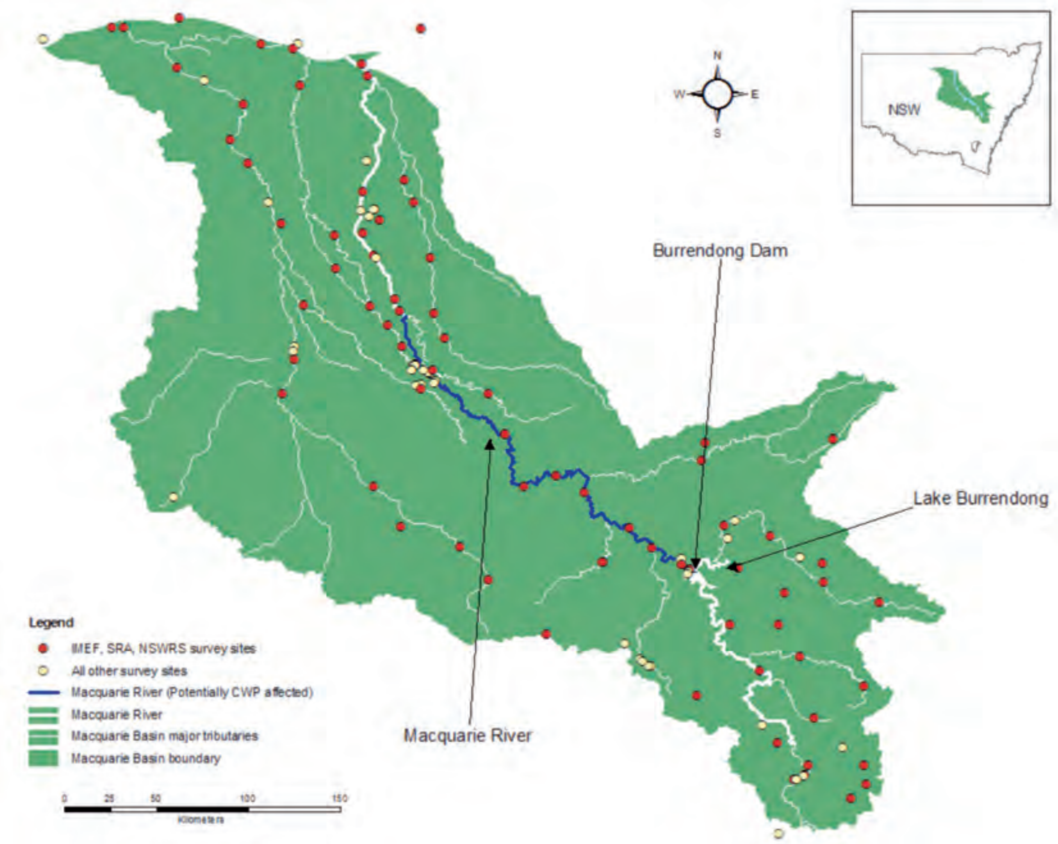


Figure 14: Existing NSW DPI sampling sites in the Macquarie Catchment. Electrofishing data from Integrated Monitoring of Environmental Flows – Rivers (IMEFR), New South Wales Rivers Survey (NSWRS) and Sustainable Rivers Audit (SRA) sites downstream of Burrendong Dam were used in the multivariate analysis of fish assemblage composition.

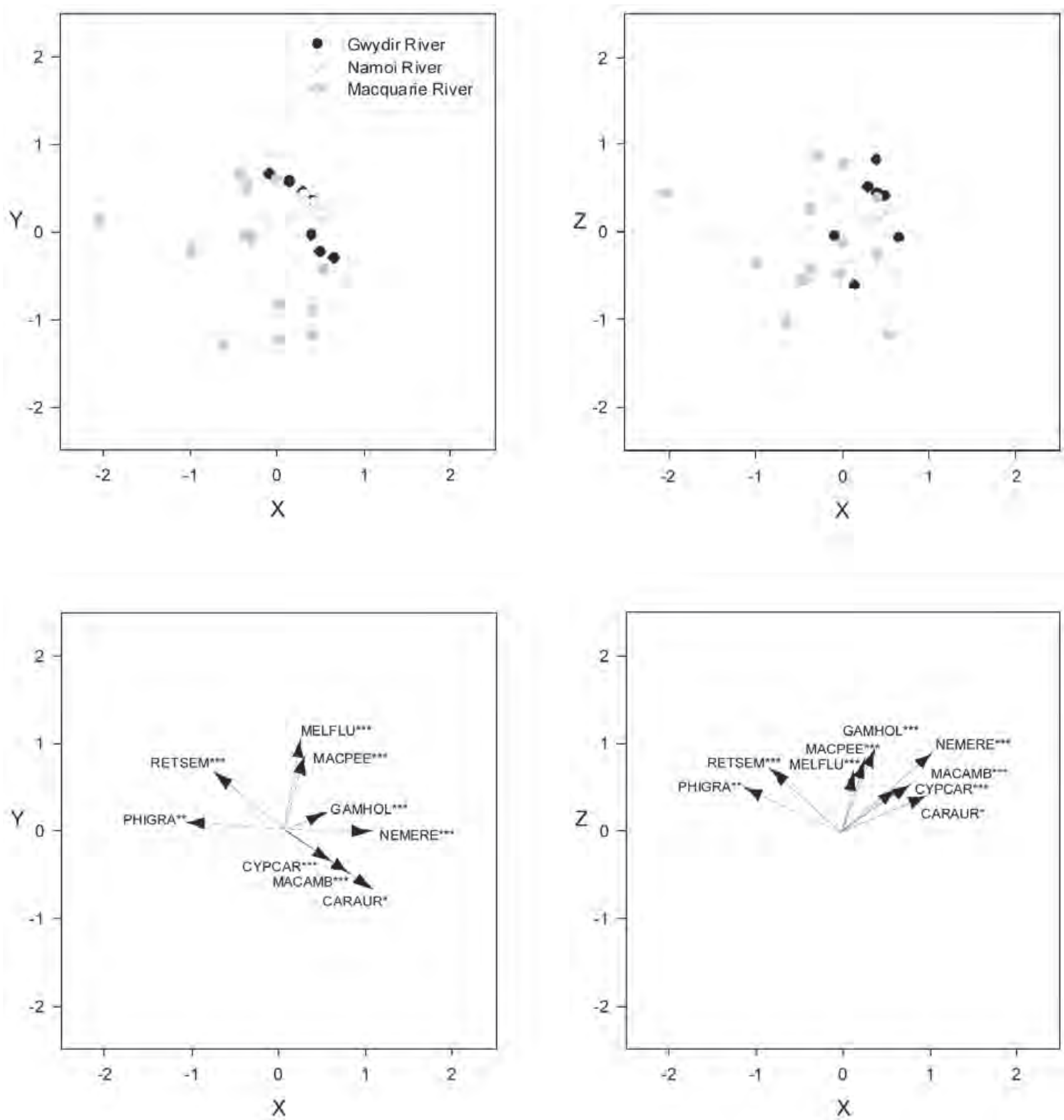


4.2.3 Reference locations

A suitable reference location to gauge the status of change downstream of Keepit Dam will need to be beyond the influence of MLO operation at Keepit Dam, be without CWP, but still be regulated by a large dam and under the influence of spring-summer irrigation flows. A problem with situating these reference locations on the same river as the impact location is that the mobility of many fish species is such that they can easily move throughout a river system and redistribute themselves. This creates the problem of spatial autocorrelation and a lack of independence between impact and reference locations (Legendre 1993), thus violating an important assumption of statistical procedures such as ANOVA. Secondly, species composition often changes naturally as one moves upstream or downstream (Matthews 1986, Ibarra and Stewart 1989, Vila-Gispert *et al.* 2002, Boys and Thoms 2006). As a result, studies such as this one, which will rely on assemblage composition to detect an impact, may be confounded by natural longitudinal differences in assemblages if reference sites are all located upstream or downstream of the impact. It would, therefore, not be suitable to locate references downstream of the CWP affected area in the Namoi. It is also not suitable to locate sites upstream of Keepit Dam due to confounding factors such as hydrological differences and fish stocking.

Ideally, a reference location would be situated on a different river from the impact location since this maximises the likelihood that the reference will be beyond the influence of MLO operation at Keepit Dam. Because large dams can have a wide range of impacts on river systems in addition to CWP (such as reduced flow variability, reversal of seasonal flow patterns, barriers to fish passage and alteration of geomorphic and sediment transport processes), the selection of a reference location not under the influence of a large dam is likely to provide a condition that will never be attainable, no matter how well CWP is mitigated. This problem is evident in a study of Astles *et al.* (2003), which examined the effects of CWP on native fish downstream of Burrendong Dam. Because the unregulated Bogan River was used as a reference river, it remains unclear whether CWP or other factors associated with river regulation were responsible for differences in the assemblage composition found between the Macquarie and Bogan Rivers.

Figure 15: The distribution of Namoi, Gwydir and Macquarie River channel sites in three-dimensional ordination space (presented as two separate two-dimensional plots: XY and XZ) based on similarity in fish assemblage composition, as defined by SSHMDS of electrofishing CPUE (number of individuals caught per hour 'power-on' time; $\log_{10}(x+1)$ transformed, Bray-Curtis metric, stress = 0.1391). PCC vector lines are shown below their respective plots and illustrate species contributions to the spatial arrangement of sites. MCAO r-squared values: * = 0%, ** = 1%, * = 2-5%. Note: vector length is indicative of the orientation in three dimensions, not the relative importance in determining the distribution of sites in ordination space. See page vii for full species names. CARAUR: Goldfish, *Carassius auratus*; CYPCAR: Carp, *Cyprinus carpio*; GAMHOL: Gambusia (mosquito fish), *Gambusia holbrooki*; MACAMB: Golden perch, *Macquaria ambigua*; MACPEE: Murray cod, *Maccullochella peelii peeli*; MELFLU: Crimson-spotted rainbowfish, *Melanotaenia fluviatilis*; NEMERE: Bony herring, *Nematalosa erebi*; PHIGRA: Flathead gudgeon, *Philipnodon grandiceps*; RETSEM: Australian smelt, *Retropinna semoni*.**



One solution may be to select reference locations on nearby regulated river systems (e.g. Gwydir and Macquarie Rivers), but ensure they are far enough downstream to be beyond the extent of CWP in these rivers. Again, however, this may be problematic because the storages on these rivers need to be without CWP, whilst retaining other impacts associated with large dams. This is unlikely to be the case in the Gwydir or Macquarie Rivers and these rivers are therefore not suitable as reference locations.

A practical solution to the selection of reference locations could not be found in this scoping study. An alternative may be to create a '*reference condition*', based on some pre-conceived idea of what the expected assemblage attributes should be. Such an approach is currently being applied to define the Pre European Reference Condition for fisH (PERCH) scores in the SRA (MDBC 2004). Defining a reference condition in this way requires a lot of time workshopping and refining the scores based on extensive literature reviews and expert panel involvement.

4.2.4 Spatial extent of impact and control locations

Defining the bounds of the impact location depends on a variety of considerations related to the downstream extent (or scale) of CWP in the Namoi River, the extent of the perceived impact from MLO operation and the spatial scales at which the fish assemblage indicators are expected to respond. The most recent analysis of CWP in the Namoi River reported a 5°C depression in river temperatures 2 km downstream of Keepit Dam, with the impact being largely eliminated by 40 km downstream. Although temperature depression was found to extend up to 100 km downstream, this suppression was not significantly different from the expected norm. Beyond 100 km there was no evidence of any suppression (Preece and Jones 2002). These findings provide the basis for splitting the extent of CWP potential in the Namoi River into a high-potential zone which extends from the base of Keepit Dam to its confluence with Mooki River (approximately 40 km downstream) and a low-potential zone from the confluence of the Mooki River and the confluence with Coxs Creek approximately 100 km (Figure 12).

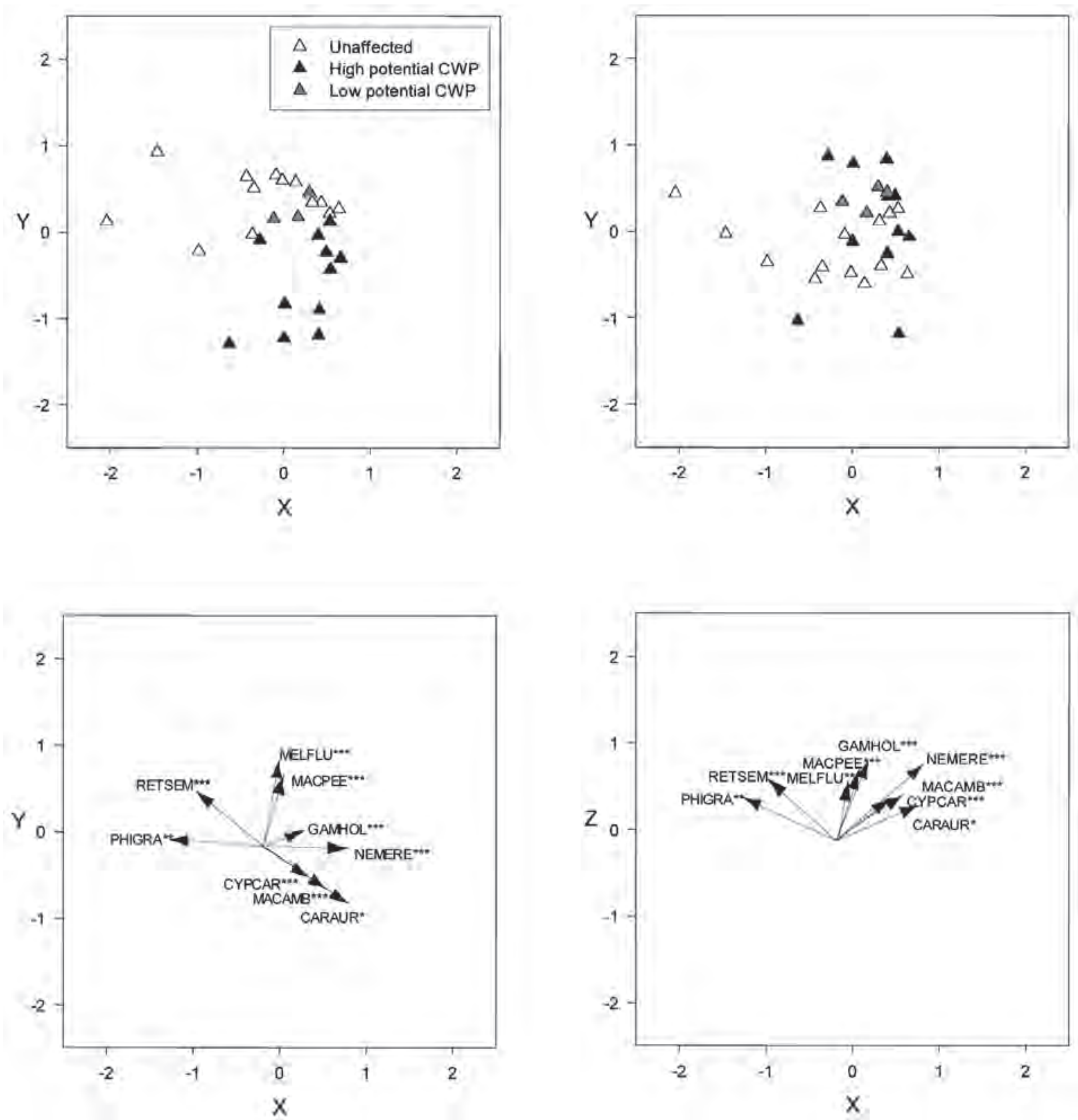
The extent of CWP downstream of Copeton Dam on the Gwydir River has not been quantified. Based on extrapolation from other large storages in the MDB, it has been estimated that a depression greater than 5ºC may persist as far as 300 km downstream of the dam (Lugg 1999). On closer consideration of the specific hydrological nature of the Gwydir, it appears unlikely that CWP would extend much father than Pallamallawa Weir (upstream of Moree) based on the retention of water in the weir pool. Based on this and the initial extrapolation outlined in Lugg (1999), the extent of CWP in the Gwydir River has been split into a high-potential zone between Copeton dam and Pallamallawa Weir and a low-potential zone from Pallamallawa Weir to 300 km downstream of Copeton Dam (Figure 13).

A number of studies have tried to determine the extent of CWP downstream of Burrendong Dam on the Macquarie River and estimates have varied based on differences in data, statistical tests and the reference conditions used (Harris 1997, Acaba *et al*. 2000, Burton and Raisin 2001 cited in Preece 2004). It is believed that CWP may persist for 300 to 400 km downstream of Burrendong Dam (Preece 2004). Based on this estimate, the current scoping report has designated the zone up to 300 km downstream of Burrendong Dam as being potentially affected by CWP (Figure 14).

To further test the suitability of these estimates in describing the extent of CWP in the Namoi, Gwydir and Macquarie Rivers, multivariate analysis of fish assemblages caught during NSW DPI surveys was conducted using three-dimensional semi-strong hybrid multidimensional scaling as per the methods described in section 4.2.2 (see Figures 12–14 for the location of IMEF, NSWRS and SRA sites that were used). The same ordination technique as in section 4.2.2 was used, but this time pair-wise ANOSIM was used to test for differences between a-priori groups of sites based on river treatment groups (high-potential CWP zone, those sites within the low-potential CWP zone and those sites further downstream that are beyond the extent of CWP).

Based on the multivariate analysis, those sites located within the high potential CWP zones had a significantly different fish assemblage composition than those sites beyond the extent of CWP (Figure 16 and Table 6). No significant difference was found between high and low-potential and low and no potential zones (Figure 16 and Table 6). These results alone do not suggest that CWP is responsible for the difference in assemblage composition observed between high and no-potential CWP zones, as zonation in fish assemblages have been reported over similar spatial scales in the Barwon-Darling River, possibly in response to habitat differences, barriers to fish passage and localised recruitment events (Boys *et al*. 2005, Boys and Thoms 2006). The results do provide further information as to the likely scale of the impact, suggesting that in order to maximise the likelihood of elucidating the potential improvements in CWP, earlier estimates of potential extent of CWP need

Figure 16: The distribution of high, low and unaffected CWP sites in the Namoi, Gwydir and Macquarie Rivers in three-dimensional ordination space (presented as two separate two-dimensional plots: XY and XZ) based on similarity in fish assemblage composition, as defined by SSHMDS of electrofishing CPUE (number of individuals caught per hour 'power-on' time; $\log_{10}(x+1)$ transformed, Bray-Curtis metric, stress = 0.1391). PCC vector lines are shown below their respective plots and illustrate species contributions to the spatial arrangement of sites. MCAO r-squared values: * = 0%, ** = 1%, * = 2-5%. Note: vector length is indicative of the orientation in three dimensions, not the relative importance in determining the distribution of sites in ordination space. See page vii for full species names. CARAUR: Goldfish, *Carassius auratus*; CYPCAR: Carp, *Cyprinus carpio*; GAMHOL: Gambusia (mosquito fish), *Gambusia holbrooki*; MACAMB: Golden perch, *Macquaria ambigua*; MACPEE: Murray cod, *Maccullochella peelii peeli*; MELFLU: Crimson-spotted rainbowfish, *Melanotaenia fluviatilis*; NEMERE: Bony herring, *Nematalosa erebi*; PHIGRA: Flathead gudgeon, *Philipnodon grandiceps*; RETSEM: Australian smelt, *Retropinna semoni*.**



to be more conservative and concentrate on those zones identified in this report as having the highest potential for CWP. The selection of sites within those high-potential zones makes sense since the effects of CWP will be most apparent immediately downstream of a dam and diminish with increasing distance downstream as there is more opportunity for heat exchange. Since the extent of CWP may very well fluctuate throughout the period of any study, it would not be sensible to locate sites that are close to the currently perceived extent of CWP. The placement of a series of sampling sites over the longitudinal gradient of potential impact (that is distance from CWP source and potential for CWP) can help resolve the nature of any improvements when conducted in association with gradient analysis and the collection of water temperature data. Such analysis is well-suited to multivariate studies in assemblage structure.

Table 6: ANOSIM testing for differences between a-priori groups of sites downstream of Copeton, Burrendong and Keepit Dams based on having a high-potential CWP, low-potential CWP zone and those sites further downstream that are beyond the extent of CWP (no potential).

Groups	R statistic	Significance level
Global	**0.177**	**0.02**
Pairwise comparisons		
High-potential CWP versus low-potential CWP	-0.08	0.61
High-potential CWP versus no-potential CWP	0.319	0.001
Low-potential CWP versus no-potential CWP	-0.034	0.52

4.3 Sampling frequency and season

4.3.1 Annual sampling

Rivers are typically dynamic over most time scales and large dryland rivers of the MDB are among the most variable in the world (Horwitz 1978, Walker *et al.* 1995, Puckridge *et al.* 1998). If this variability is not acknowledged and accounted for in the survey design, there is a risk that natural variability may be interpreted incorrectly as an impact, or conversely, baseline variability can mask a real impact (Underwood 1991, Keough and Mapstone 1995). Whether because of inadequate funding or insufficient prior knowledge of an impact, the majority of studies published to date have only been undertaken after an impact has started (reviewed by Downes *et al*. 2002). Collecting baseline or 'before' data for more than one annual cycle of the potential impact of interest greatly improves the ability to account for baseline variability (Underwood 1991).

An assumption of BACI designs is that impact, control and reference locations are being monitored in parallel. Whilst exactly concurrent sampling is rarely possible, the researchers should try to complete sampling at all locations and sites within as small a timeframe as possible. The order in which locations (i.e. impact control and reference) are sampled should be changed from year to year to reduce the possibility that confounding and unexpected biases related to sampling order will affect inferences about impact. This is the easiest way of ensuring that any (often unknown) biases are spread equally among all locations throughout the life of the monitoring program. Whilst it is feasible to randomise the sampling order among locations, it is acknowledged that randomising the order in which sites are sampled within locations is rarely practical, as this will drastically escalate the costs associated with travelling between sites. Again, minimising the window of time over which the sampling is carried out will minimise the possibility of temporal biases. Alternatively, the sites can be sampled in the same order, with only the starting position randomly selected (Downes *et al*. 2002).

4.3.2 Seasonal sampling

Since the objective of the proposed study design is to detect an ecological response to MLO operation, it is preferable to sample regularly throughout the period when the impact of CWP is presumed to be the largest. In this case, monitoring would have to span at least two irrigation seasons as these coincide with the most likely time of CWP in downstream reaches (section 1.3). In the average year this peak irrigation season extends from December to February. To effectively test Hypotheses 1 and 2, it would be adequate therefore to sample juveniles and adults once during this period. Since Hypothesis 5 requires that recent recruits be caught, sampling would also need to be conducted in autumn. Testing of Hypotheses 3 and 4 involves both the sampling of larval drift as well as obtaining calculations of GSI for those species without a drifting larval stage. Ideally, this sampling should be conducted monthly or bi-monthly between late October and March. Final recommendations regarding the frequency of sampling will be made as part of the design optimisation process (Chapter 9).

5. ANALYTICAL ASPECTS OF THE SAMPLING DESIGN

This section addresses the question of how to best allocate sampling effort within the study area. That is, what level of effort (number of replicate sites) is required to give the greatest level of precision (smallest standard error) and therefore greatest level of power to detect change. Precision and power will continue to increase as effort increases. This improvement in precision eventually diminishes with increased effort, however, and at some point in time increases in precision only serve to provide power to detect what may be ecologically insignificant differences. An important part of optimising a cost-effective design is therefore to determine at what level of sampling effort much of the potential gain in precision is achieved.

The approach taken in this scoping report was not to anticipate an effect size, but merely to show at what level of sampling, further increases in effort lead to diminishing improvements in power. This gives some guidance as to the appropriate level of sampling effort required, without the need to quantify what level of response is likely. For the purpose of comparing precision obtained by different degrees of sampling effort, juvenile and adult fish abundance has been used. Abundance is an important indicator for testing Hypotheses 1, 2 and 5 (Chapter 3) and adequate information was available on this indicator from the Freshwater Fish Research Database (NSW DPI 2007). Larval abundance data from the IMEF project was also initially explored, but was later judged to be inadequate for the current process. Standard error was used as a measure of precision and a formal calculation of "power" was avoided due to the uncertainty of the magnitude of thermal and ecological response that may be expected from MLO operation.

A linear model appropriate to represent the catch per unit effort (CPUE) of a fish species Y, from river *i*, site *j*, time *k* is:

Y_{ijk} = baseline + River_i +Site_{ij} +Error_{ijk}

The "Site" and "Error" terms are classed as random effects with mean zero and variances σ^2_s and σ^2 respectively. Based on this model, the variance of the mean CPUE for a species from a river, averaged over sites and times can be written as:

$(T\sigma^2_s + \sigma^2)/TS$

Where T is the number of observation times and S is the number of sampling locations.

Thus change in the precision of CPUE due to changing the number of sampling locations can be examined by obtaining estimates of the variance components σ^2_s and σ^2. These estimates were obtained from electrofishing catch data collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007). Each river had approximately ten sampling sites (see Figures 13, 14 and 15) and each site was visited from one to five times over five years (1999, 2000, 2001, 2005, 2006) during spring and summer. CPUE values for a range of species were recorded. Murray cod (MACPEE) will be used to illustrate the process.

Firstly, data on Murray cod CPUE were log(count+1) transformed, which stabilised variance and imposed a reasonable degree of symmetry in order to meet the assumptions of the linear model.

Estimates of the variance components were:

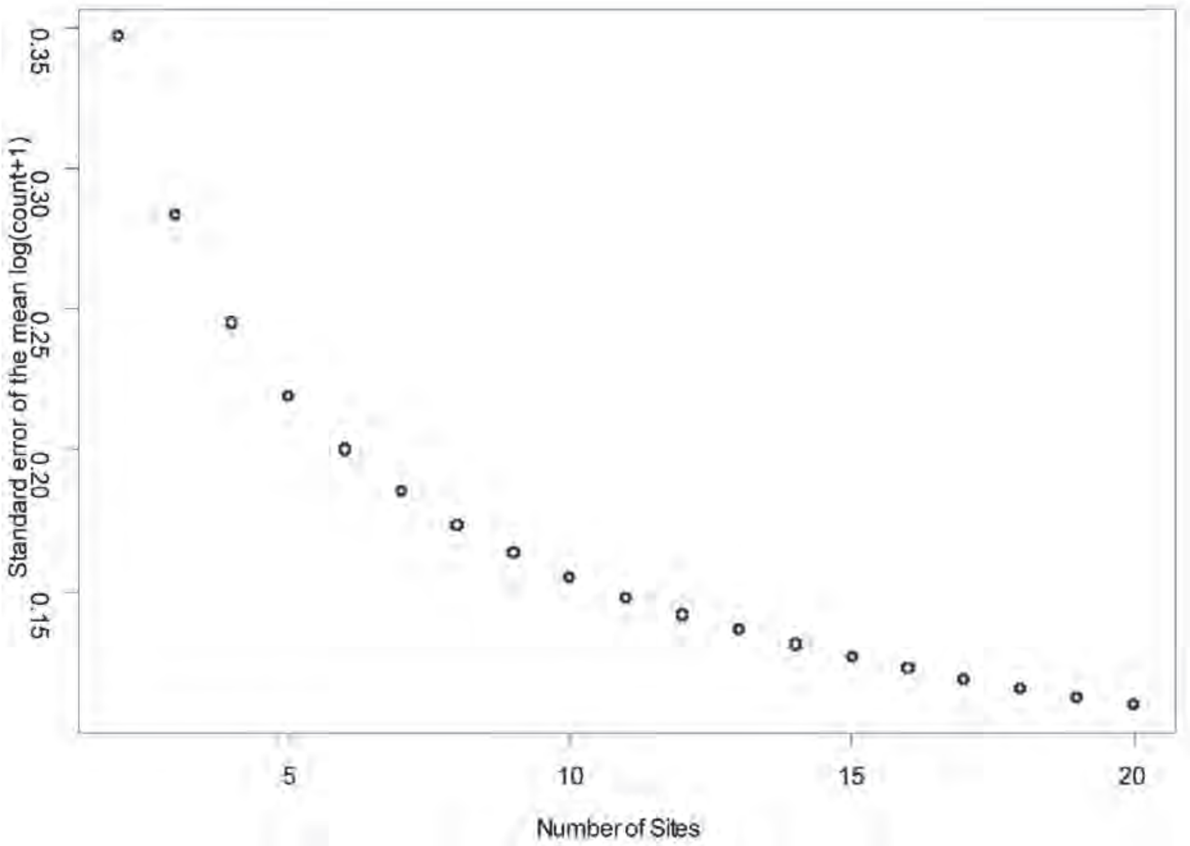
σ^2_s (variance between sites) = 0.08

σ^2 (variance within sites) = 0.79

These numbers indicate that variation within sites (due to time) is tenfold the variance between sites, implying accurate representation of average Murray cod CPUE in the Namoi, Macquarie and Gwydir Rivers is dependent on sufficient repetition of the number of sampling efforts.

A sampling program's power to detect change is strongly driven by the size of the standard error associated with the mean measurements taken. That is, the smaller the standard error associated with the mean, the greater the precision and ability to detect a difference between means, in this case an "impact" from MLO operation. Applying the formula for the standard error of mean CPUE for Murray cod in a river, fixing "T" at five occasions (maximum level of replication that was present in the pilot data) and varying S from 2 to 20 locations, it appears much of the potential gain in precision would be obtained by about ten sites (Figure 17).

Figure 17: Relationship between number of sampling sites and standard error of the mean based on CPUE abundance data for Murray cod collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007).

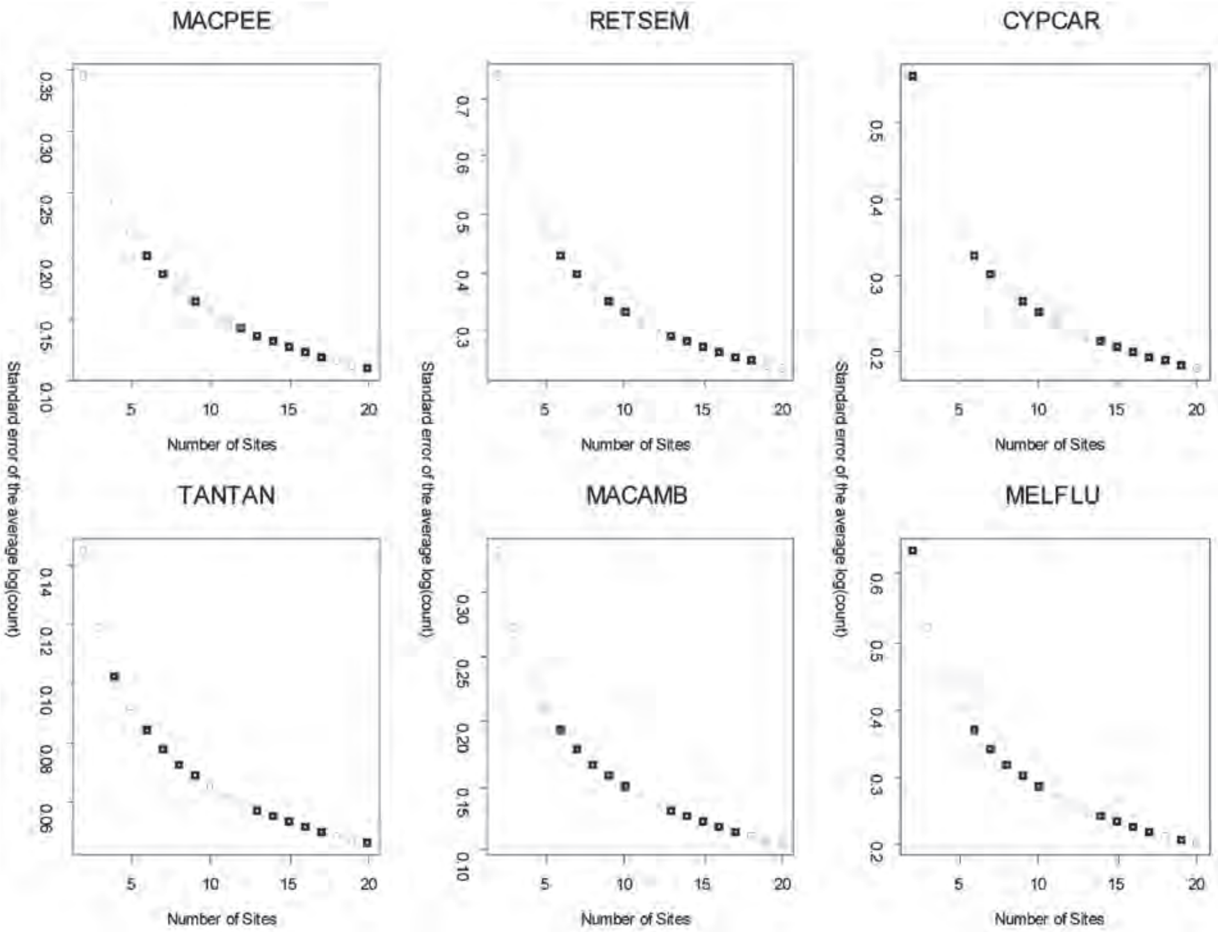


Repeating the above process on another five species of interest yielded different estimates of the variance components (Table 7). The larger variability due to time relative to that due to sites was reasonably consistent. Table 7 also shows that CPUE values for Australian smelt (RETSEM) were the most variable, while counts of freshwater catfish (TANTAN) were the most uniform. Again, applying the formula for the standard error of mean CPUE, fixing "T" at five occasions and varying S from 2 to 20 locations, it appears that much of the potential gain in precision would be obtained by about 10 sites (Figure 18). It is therefore recommended that a minimum of 10 sites be sampled from the impact location (Namoi River) and each of the two control locations (Macquarie and Gwydir Rivers), with the inclusion of extra sites considered to build some redundancy into the design and allow for potential loss of replicates.

Table 7: Estimates of spatial (between sites) and temporal (within sites) variance for six MDB species obtained from electrofishing CPUE data collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007). MACPEE Murray cod; RETSEM Australian smelt; CYPCAR carp; TANTAN freshwater catfish; MACAMB golden perch; and MELFLU crimson-spotted rainbowfish.

	MACPEE	RETSEM	CYPCAR	TANTAN	MACAMB	MELFLU
σ2s (variance between sites)	0.08	0.74	0.52	0.02	0.11	0.57
σ2 (variance within sites)	0.79	1.74	0.54	0.11	0.56	1.18

Figure 18: Relationship between number of sampling sites and standard error of the mean based on CPUE abundance data collected from the Namoi, Macquarie and Gwydir Rivers during the NSWRS, IMEF and SRA (NSW DPI 2007). MACPEE Murray cod; RETSEM Australian smelt; CYPCAR carp; TANTAN freshwater catfish; MACAMB golden perch; and MELFLU crimson-spotted rainbowfish.



6. SAMPLING AND EXPERIMENTAL PROTOCOL

Whilst there is no international or Australian standard for sampling fish assemblages, there has been a move in recent years towards a standardisation of approaches between State agencies throughout the MDB as part of the SRA (MDBC 2004). There are clear benefits to be derived from adopting standardised sampling approaches in freshwater fisheries research (Bonar and Hubert 2002), not the least of which is the ability to make comparisons among data collected by different State agencies, as well as between past, current and future monitoring programs. As part of the development of the SRA (MDBC 2004), fish sampling protocols were derived and further refined from those used in the NSWRS (Harris and Gehrke 1997). Whilst it is not possible to use the same suite of methods to answer all research questions, it is recommended that where possible, all large scale monitoring programs conducted within the MDB incorporate SRA protocol (MDBC 2006b) as a bare minimum, with additional gear types and levels of effort added to address any objectives specific to the research at hand. These protocols have been developed by all State agencies in the MDB and are considered to be best-practice in fisheries research with respect to the:

- quantitative and consistent sampling of representative habitats using electrofishing;
- recording of fish health and condition;
- collection of voucher specimens; and
- measurement and sub-sampling of individuals.

6.1 Electrofishing

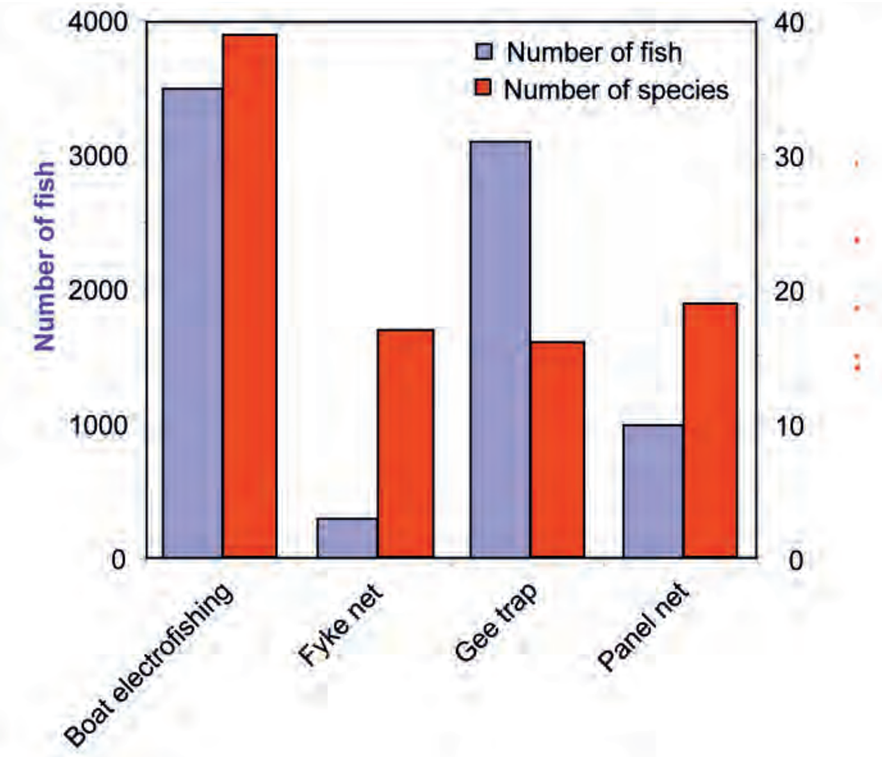
It is recommended that electrofishing be carried out in accordance with the Australian Code of Electrofishing Practice (Anon 1997). As part of the NSWRS a comprehensive assessment of the catch efficiency of several gear types (boat and backpack electrofishing, fyke nets, unbaited traps, gee traps and panel nets) showed that boat electrofishing was the most effective and least selective method for different fish species and size classes in the Barwon-Darling and other lowland rivers of the MDB (Faragher and Rodgers 1997) (Figure 19). From the SRA Pilot it was concluded that electrofishing alone provided good estimates of fish assemblage composition within a reach relative to all gear types (boat and backpack electrofishing, fyke nets and unbaited traps) (MDBC 2004).

The SRA adopts a single-pass electrofishing 'shot', carried out in an upstream direction, with no block nets. A combination of backpack-mounted and boat-mounted electrofishing is used according to the proportion of wadeable habitat that needs to be sampled (MDBC 2006b). It is likely that all habitats within the Namoi, Gwydir and Macquarie Rivers downstream of their respective large storages are assessable by boat and can be effectively sampled without the need for backpack-mounted electrofishing. The use of 12, 190-second (on-time) sub-sampling shots has been shown sufficient to achieve an asymptote in the relationship between species richness and sampling effort (MDBC 2004), with a minimum of 8 shots recommended as a minimum when attempting to describe assemblage composition. Although an attempt should be made to sample from all characteristic habitats of the reach, detailed assessments of the scale-dependent fish habitat associations in the Barwon-Darling River by Boys and Thoms (2006) indicates that partitioning sampling between shallow banks, open water and large wood habitat is sufficient to describe the entire fish assemblage at the reach scale with boat electrofishing.

6.2 Unbaited traps

There is a positive curvilinear relationship between fish size and the efficiency of capture by electrofishing (Zalewski and Cowx 1990, Kolz *et al*. 1998), meaning that small-bodied fish can often be under-represented in electrofishing samples (MDBC 2004). Because of this, fish monitoring studies have often supplemented electrofishing with passive gear types such as unbaited traps set for short periods (e.g. Harris and Gehrke 1997, MDBC 2006b). The pilot SRA found that the use of unbaited traps in combination with electrofishing, leads to some improvements in the catch of small-bodied species such as gudgeons and the young-of-year of some larger bodied natives (e.g. Macquarie Perch, when compared to electrofishing alone (MDBC 2004). Being able to access smaller bodied species is important for accurately testing Hypotheses 1 and 2, and for investigating the reproductive status (Hypotheses 3 and 4) of species that require calculation of the gonad somatic index (GSI).

Figure 19: Performance of different gear types in sampling run and pool habitats in the Barwon-Darling River and other lowland rivers in New South Wales during the New South Wales Rivers Survey. Numbers of fish caught represent data collected only from the Barwon-Darling River, whereas numbers of species data were collected from unregulated lowland rivers throughout New South Wales (i.e. Barwon-Darling, Murray, North and South Coast). Data source: Faragher and Rogers (1997)



Current SRA protocol requires the use of 10 unbaited traps set for 2 hours (MDBC 2006b), with their inclusion in future years of the SRA soon to be re-assessed. Until otherwise proven, bait traps appear to have the potential to improve species representation when set in shallow littoral habitats and they have become a minimum gear type requirement for most fish surveys done in NSW (Dean Gilligan, NSW DPI, *pers. comm.*). Their use is recommended in the proposed study for both the additional information they can bring and maintain a minimum sampling standard to allow data integration with other past, current and future projects in the MDB, such as the SRA.

6.3 Egg and larval sampling

To infer spawning (Hypothesis 3 and 4), boat-mounted electrofishing and unbaited traps will need to be supplemented with other gear types to effectively sample eggs, larvae and young-of-year fish. The dynamics of larval and juvenile fishes are complex, with changes in assemblage composition occurring spatially and temporally at a variety of scales (Turner *et al.* 1994). While many methods are available for sampling larval and juvenile fishes (e.g. light traps, baited traps, drift nets and trawl nets, electrofishing, pump samplers, sweep nets, fyke nets and seine nets), no single method can effectively capture all species (Kelso and Rutherford 1996, King and Crook 2002). Consequently, it is recommended that, if economically feasible, a variety of techniques are employed in a stratified sampling design. For example, Humphries *et al.* (2002) sampled planktonic fish from the main channel of the Campaspe and Broken rivers in northern Victoria using conical drift nets (0.5 m diameter, 1.5 m long, 500 µm mesh) positioned at the surface to capture surface drift. This was supplemented with modified quadrefoil light traps (300 mm long and 220 mm square, with 5 mm separating four side-by-side tubes) in deeper habitats, and plankton tows in pools with limited flow (nets were of the same design as drift nets, but towed behind a small boat). Flow conditions can change rapidly downstream of Keepit Dam, which may render drift nets ineffective. Larval sampling in the Namoi River as part of IMEF addresses this problem in part by supplementing the use of drift nets with active capture techniques in slackwater habitats, such as sweep net electrofishing (Ivor Growns *pers. comm.*, method described in King and Crook 2002).

Eggs and larvae are pelagic and can occur in patches of differing density (Muth and Schmulbach 1984, Humphries and Lake 2000, Gilligan and Schiller 2003, Lintermans and Phillips 2004). The amount of effort required to effectively sample eggs and larvae will therefore vary with the density, abundance and patchiness of the taxa present. There will be uncertainties regarding the degree to which net surveys provide a representative sample of the assemblage present. A single point sample from an area may not provide an accurate account of the larvae present in a reach. Greater effort may be required in deep, complex habitats (e.g., pool with abundant woody debris) than in relatively simple, shallow habitats (e.g., drying pool with no structural habitat elements). Recent larval sampling in the Namoi River using 5 nets strung across the main channel indicate that a high degree of larval patchiness may be experienced (Lee Baumgartner, *pers. comm.*). The diurnal timing, and number and length of shots will require further assessment prior to the commencement of a full-scale sampling regime. Trade-offs need to be made between trying to overcome spatial patchiness with multiple nets and the extra time it takes to sort larval samples after a sampling trip.

6.4 Cage experiments

The effect of CWP on the growth of individual fish may be investigated using in-channel or off-channel cage experiments. Juvenile silver perch, Murray cod and golden perch can be sourced from the hatchery at the Narrandera Fisheries Centre for these experiments. At the start and throughout an experiment, random sub-samples of the population can be removed, measured and weighed to determine growth rates. Astles *et al*. (2003) constructed pens adjacent to the Macquarie River, downstream of Burrendong Dam. In their study, juvenile silver perch exhibited reduced growth, survival and movement activity at lower temperatures, while both juvenile silver perch and Murray cod showed behavioural preferences for warmer water, when presented with a choice. In-channel cages would require less capital investment than off-channel pens but problems associated with securing the cages will have to be scoped. Other cage effects like mortality, changed growth rates and altered feeding behaviour may become problematic and lead to failure of the experiment. It is also questionable whether differences in growth rate would be detectable in response to a 2–5°C change in temperature that may be expected from MLO operation at Keepit Dam (see section 3.4). It is recommended that Hypotheses 6 and the use of cage experiments not be included in the full project due to logistical constraints and likely insensitivity of growth to the anticipated change in thermal regime. At best, a pilot study using a reduced number of cages may be scoped during the first year of the project to ascertain its feasibility.

6.5 Water quality monitoring

Conductivity, temperature and Secchi depth should be recorded at each site during fish sampling as per SRA protocol (MDBC 2006b). Given the focus of this study on CWP, additional continuous temperature logging equipment should be deployed. Cost effective water temperature data-loggers are available that can be deployed throughout the life of the project.

6.6 Possibility for ongoing condition monitoring

The need for ongoing monitoring after the four years may be required, to improve the statistical power with which a difference can be detected, and to detect those responses to temperature improvements that may take longer to manifest. Changes in spawning, recruitment and the occurrence of long-lived native fish species may not become apparent until many years after CWP has been mitigated. Whilst careful design should maximise being able to detect response in a timely fashion, it needs to be acknowledged by both the researchers involved and the funding agencies that an extension of monitoring may be required beyond the proposed 4 year study. It may not, however, be economically feasible to persist with the design outlined in this report. With this in mind there is potential to utilise other programs to monitor longer term trends well into the future. For instance, the SRA currently samples the Namoi catchment (and all other catchments in the MDB) once every three years. Further consideration needs to be made regarding the availability of SRA sites within the CWP impacted location downstream of Keepit Dam and the nearby controls, as SRA sampling may have to be supplemented.

6.7 Data management and quality assurance

The adoption of a standardised sampling approach for fish sampling in the SRA has lead to the development of a standardised method of data collection and management which overcomes inconsistencies among projects and research teams. It is recommended that the study adopt, as a bare minimum, SRA protocol with regard to data collection, management and quality assurance, to ensure data can be supplied to the MDBC in a usable format on request and integrated with SRA data for possible long-term monitoring.

- Field data sheets will include recording:
  - Detailed site characteristics (river name, site number, latitude and longitude).
  - Collection method.
  - Date.
  - Catch data (e.g. number of species and individuals caught and observed).
  - Biological information (length, weight, disease, reproductive condition).
  - Effort (number of shots/ traps).
  - Electrofishing settings, net types, etc.
  - Time elapsed.
  - Habitat and environmental information.
- In cases where fish identification is difficult, a small sub-sample and/or photographs of fish should be taken for later verification.

6.8 Study timeline

A common deficiency in impact monitoring is that insufficient data are gathered prior to the onset of the predicted impact (Downes *et al*. 2002). Therefore, monitoring should commence as far in advance of the impact as possible. Once a MLO becomes operational at Keepit Dam, it will not be feasible from an environmental or public relations perspective to 'switch CWP back on' and induce an unfavourable ecological response. Therefore any impact assessment must be timed so that 'before' data are collected prior to MLO operation. At best it may be possible to delay MLO commencement by a season to allow researchers to gather more data.

Cost/benefit investigations on the MLO are currently being completed by SWC in conjunction with NSW DPI, DECC and NSW DNR as part of the Keepit Dam upgrade environmental assessment process. If the upgrade and the MLO are approved and funding secured, works are scheduled for completion in late 2009. Based on this timeframe, tenders for the impact assessment would need to be sought by the MDBC in late 2007 with a view that the successful tendering agency will conduct the first year of sampling during the 2007–08 irrigation season. This will enable two years of before MLO operation data to be collected. A four year project will allow adequate time to collect two years of post MLO operation data.

7. FEASIBILITY OF DESIGN AND INDICATIVE BUDGET

Ultimately, an optimised monitoring program is one in which trade-offs are made between the desired design and the effort and resource invested so funding requirements are minimised without compromising the inferential strength of the program (Downes *et al*. 2002). Throughout the scoping process a sampling and analytical framework has been developed that will allow any change in the fish assemblage due to CWP mitigation downstream of Keepit Dam to be: 1) detected, and 2) accurately attributed to the activity of impact (Figure 20).

The suggested design consists of a minimum of 30 monitoring sites stratified equally among one impact and two control locations. The position of the 10 sites within each location should be semi-randomly chosen (to retain some reasonable spread of sites) and should be situated:

- in the Namoi River main channel between Keepit Dam and 40km downstream;
- in the Gwydir River main channel between Copeton Dam and Pallamallowa Weir; and
- in the Macquarie River main channel between Burrendong Dam and 300km downstream.

The sampling program described will need to be conducted for four consecutive years (two years before MLO operation and two after commencement of MLO operation). To obtain measures of species abundance and assemblage composition during the peak irrigation season, sampling at each site using electrofishing and unbaited traps should be conducted once during summer, with repeat sampling being conducted in autumn to sample recent recruits. Based on estimates from the SRA, approximately 5.5 sites can be completed in a week when deploying 12 electrofishing shots and 10 unbaited traps per site (Dean Gilligan, NSW DPI, pers. com.). This gives a total of six weeks in summer and six weeks in autumn (12 weeks total). Based on a recent larval drift experiment conducted by NSW DPI, it is possible to sample nine sites per week with larval drift nets, deploying four nets per site for 18 hours each (Dean Gilligan, NSW DPI, pers. com.). Four nets per site is considered a minimum based on the large degree of variability between nets, and is also considered to be the maximum that can be effectively set, retrieved and sorted in the field by two staff. This equates to 3-4 weeks worth of netting to be repeated in spring, summer and autumn, giving a total of 10-11 weeks of larval netting. Unbaited traps should also be set during the spring season, effectively providing unbaited trap data for spring, summer and autumn.

Figure 21 outlines two fieldwork scenarios: one where one crew of three technicians conducts larval drift netting independently of electrofishing, and the other involves using two separate crews in parallel. The salary costs for both scenarios will be equivalent (i.e. 60 Full-Time Equivalent (FTE) weeks/year) because, although twice the staff will be needed, the work will get done twice as fast (Figure 21).

Figure 20: Proposed experimental design before optimisation.

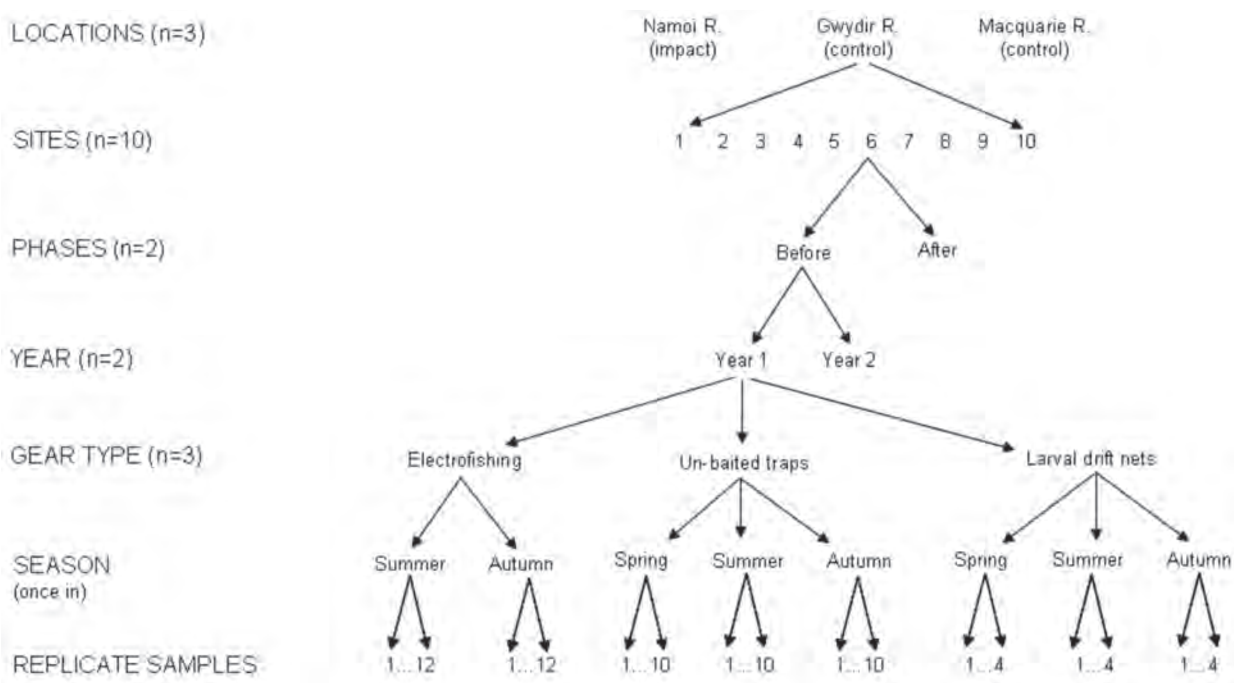


Figure 21: Ghannt diagram showing two possible fieldwork scenarios to achieve the design shown in Figure 20. Both scenarios will cost approximately the same as illustrated by the Full Time Equivalent (FTE) figures shown. N.B. 6 staff per week = 6 FTE. This translates to a total of 60 FTE per year to conduct the fieldwork component of the project.

	Spring												Summer												Autumn											
Month	September				October				November				December				January				February				March				April				May			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Example 1: 1 team of 3 staff, 24 weeks total																																				
Larval drift (12 weeks)								■	■	■	■		■	■	■	■									■	■	■	■								
Electrofishing (12 weeks)																		■	■	■	■	■	■						■	■	■	■	■	■		
Un-bait trapping (16 weeks)								■	■	■	■							■	■	■	■	■	■						■	■	■	■	■	■		
Full-time equivalent (FTE)								2	2	2	2		2	2	2	2		3	3	3	3	3	3		2	2	2	2	3	3	3	3	3	3		
Example 2: 2 teams of 3 staff, 12 weeks total																																				
Larval drift (6 weeks)								■	■				■	■											■	■										
Electrofishing (6 weeks)																		■	■	■									■	■	■					
Un-bait trapping (8 weeks)								■	■									■	■	■									■	■	■					
Full-time equivalent (FTE)								4	4				4	4				6	6	6					4	4			6	6	6					

To complete this project, two senior electrofishing operators would be required with additional casual assistance required by four staff to act as dip-netters during the six weeks of electrofishing per year. Outside field sampling, the two technical staff would complete larval sorting, data entry and assist with analysis and report writing. The indicative budget is given in Table 8, and suggests a budget of $307,966 per annum, over four years.

Table 8: Approximate budget per annum of proposed project design (Example 2, Figure 21).

Salary					
	FTE (based on 0.02 FTE/week)				
Position	**Field**	**Lab**	**Total**	**Salary[a]**	**Required per annum**
Senior Technician[b]	0.24	0.76	1	$91,700	$91,700
Junior Technician[c]	0.24	0.76	1	$86,100	$86,100
Casual assistance[d]	0.5	0	0.5	$90,000	$45,000
Total required per annum	0.98	1.52	2.5		$222,800
Operating (one-off)					
			Unit price	**Units req**	**Required**
Larval drift nets			$250	12	$3,000
Flow meters for nets			$450	12	$5,400
Unbaited traps			$4.50	10	$45
Temperature loggers			$80	30	$2,400
Report printing					1,500
				Total	$12,345
				Per annum averaged across 4 years	$3,086
Operating (on-going)					
			Unit price	**Units req**	**Required per annum**
Electrofishing boat			$400/day	60 days[e]	$24,000
Travel allowance[f]			$165/day		$39,600
Vehicle Fleet costs[g]			$0.77/km		$18,480
					$82,080
				Total required per annum	**$307,966**

[a] Includes all on-costs, leave loading and casual loading.

[b] Senior electrofisher, fieldwork manager, data entry, larval sorting, assist with data analysis and report writing.

[c] Senior electrofisher, data entry, larval sorting.

[d] 4 casual staff to act as dip-netter for 6 weeks boat electrofishing.

[e] 30 days per boat.

[f] 4 staff for 6 weeks of larval drift netting, 6 staff for 6 weeks of electrofishing.

[g] 2 vehicles for 12 weeks fieldwork at an average of 200km a day, at $0.77/km.

8. RISK ASSESSMENT AND MANAGEMENT

This report outlines the sampling and analytical framework necessary for detecting an impact from MLO operation at Keepit Dam under ideal and expected conditions. It is important to note, however, that ideal situations are rarely encountered in ecological monitoring programs. The SRA is a prime example. Severe drought in much of the MDB throughout the initial years of sampling will make it difficult to determine ecological condition representative of an 'average' year. The length of the SRA program, however, should mean that over time extreme events like this will standout against a more 'normal' background. Short-term monitoring programs, such as that proposed for the Keepit Dam project, are less robust when confronted with the realities of unexpected environmental conditions or unexpected responses of particular indicators. Therefore, a combination of realistic expectations and flexibility must be adopted when determining if a full project should be undertaken. The following section outlines some potential risks that need to be acknowledged and managed, as well as some alternative options for studying the ecological response to CWP mitigation in the MDB.

8.1 MLO construction

The decision as to whether a MLO will be constructed at Keepit Dam as part of the safety upgrade has not been finalised. Its approval involves a multi-stage process (Figure 22), currently at the cost/benefit analysis stage and still requiring Ministerial and Cabinet approval. Should government approval and funding be secured, construction should be complete by late 2009. It should be acknowledged, however, that pending the results of the cost benefit analysis, there is still a chance that MLO construction will not proceed. In spite of this, to obtain the required two years of 'before' data, sampling may need to begin before final approval has been given. Should an impact assessment be undertaken, it is recommended that the risk of the MLO not being constructed be re-assessed after the first year of sampling, with continual investment into this project contingent on construction approval being finalised before the second year (2008/2009) of sampling.

8.2 Ability to detect an effect under current climatic conditions and likelihood of a CWP event

2005–06 saw a continuation of the below-average system inflows into the MDB observed each year since 2002–03 (MDBC 2006a). An example of the severity and persistence of the drought can be seen in the Murray River system (Figure 23), where total system inflow for the five years from July 2000 to June 2006 has been the lowest on record (MDBC 2006a).

Over the past two years the volume of water in active storage (not including the Snowy system) in NSW has fallen from 6 million ML (30% capacity) to only 2.3 million ML (13% capacity) (Figure 24). This drop in capacity is reflected in all storages located in the MDB (Figure 25) and Keepit Dam was at less than 2% capacity at the time of writing this report (February 2007). The current low level of MDB storages is not conducive to the creation of CWP events because: 1) stratification of the storage is unlikely, 2) any withdrawal is likely to come from the entire range of depths, and 3) water allocations and therefore releases remain low.

Figure 22: Flow diagram of the draft approval process for MLO construction at Keepit Dam. Provided by SWC on behalf of the CWP Inter-Agency Group.

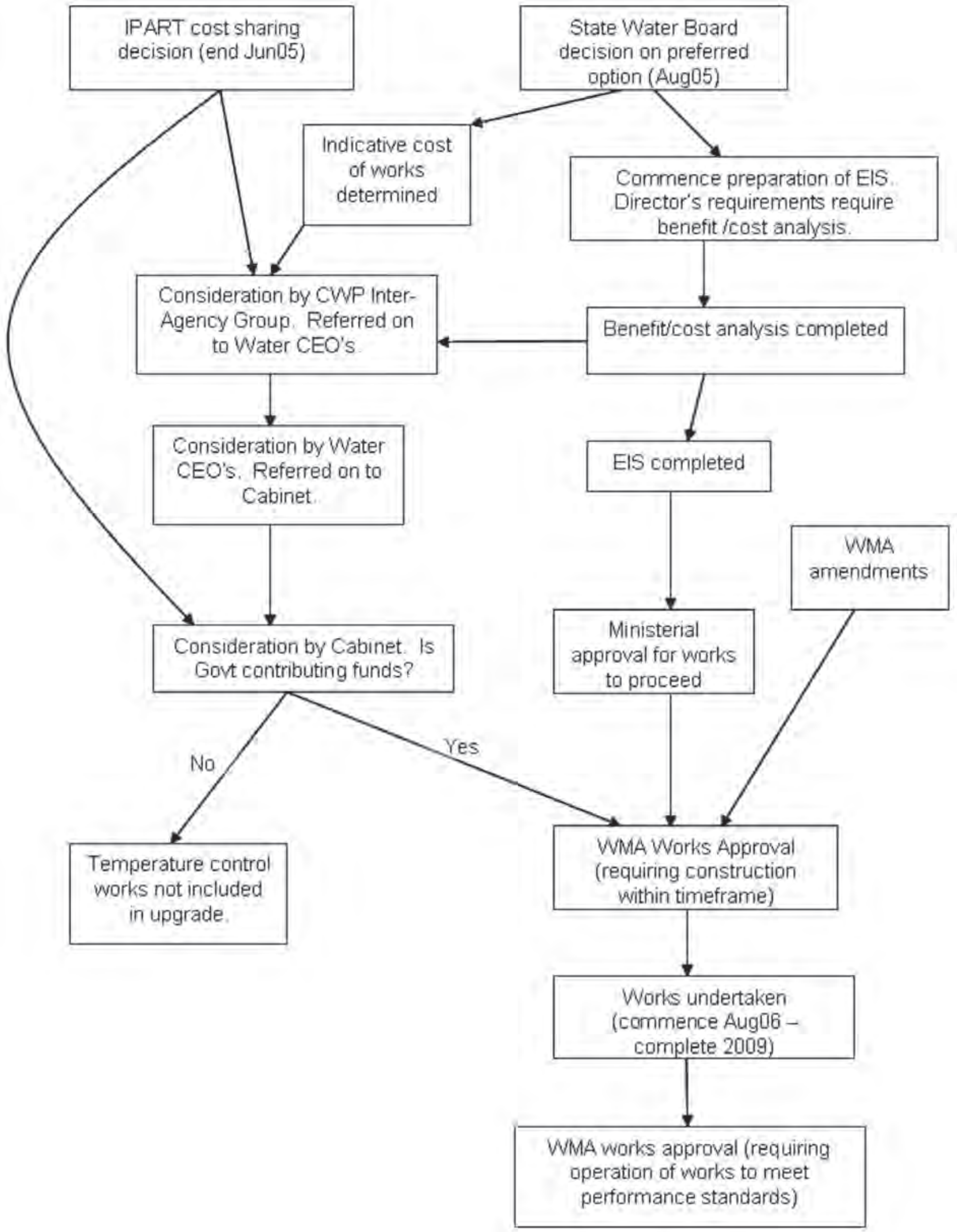


Figure 23: Murray River system inflows with extended drought periods highlighted (Source: MDBC 2006a).

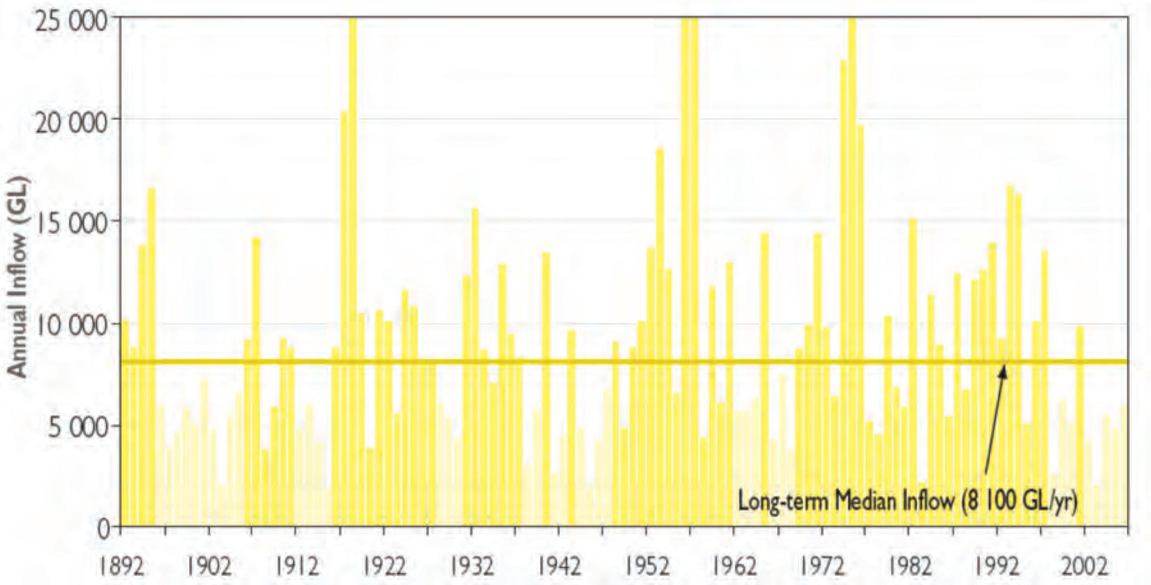


Figure 24: The volume of water in storage in NSW dams between February 2005 and February 2007. (Source: NSW DNR Water Information website).

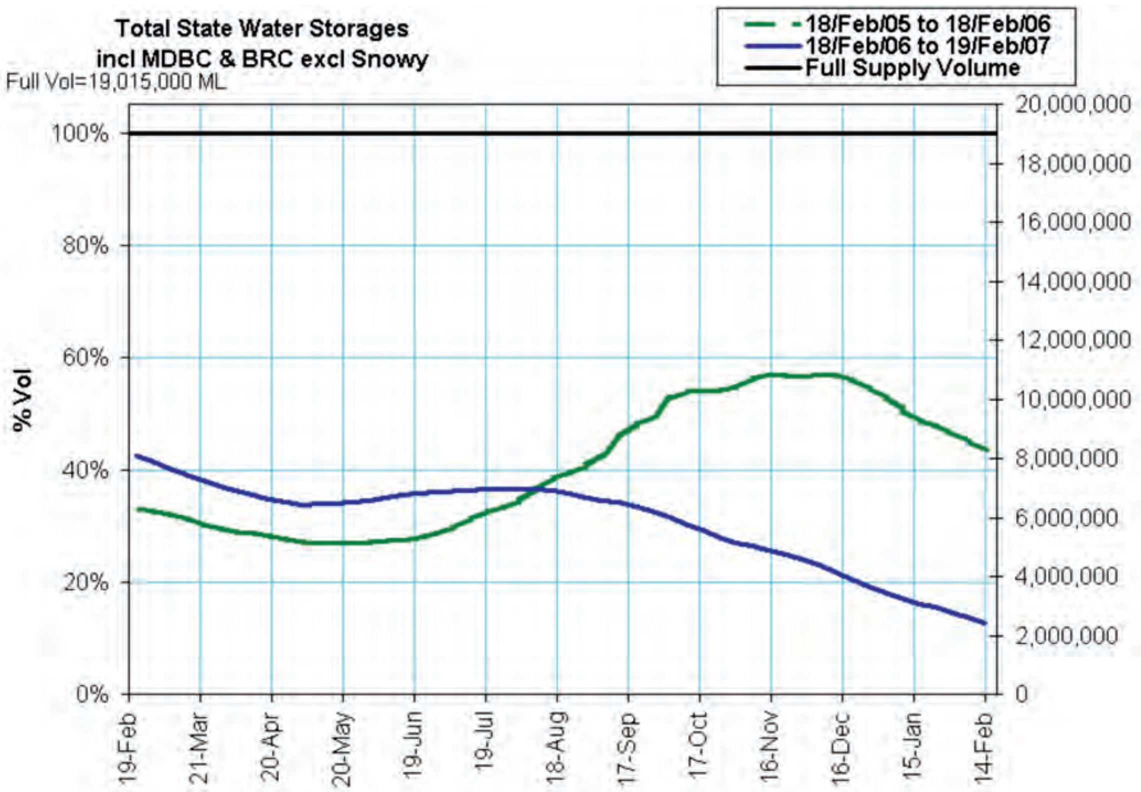
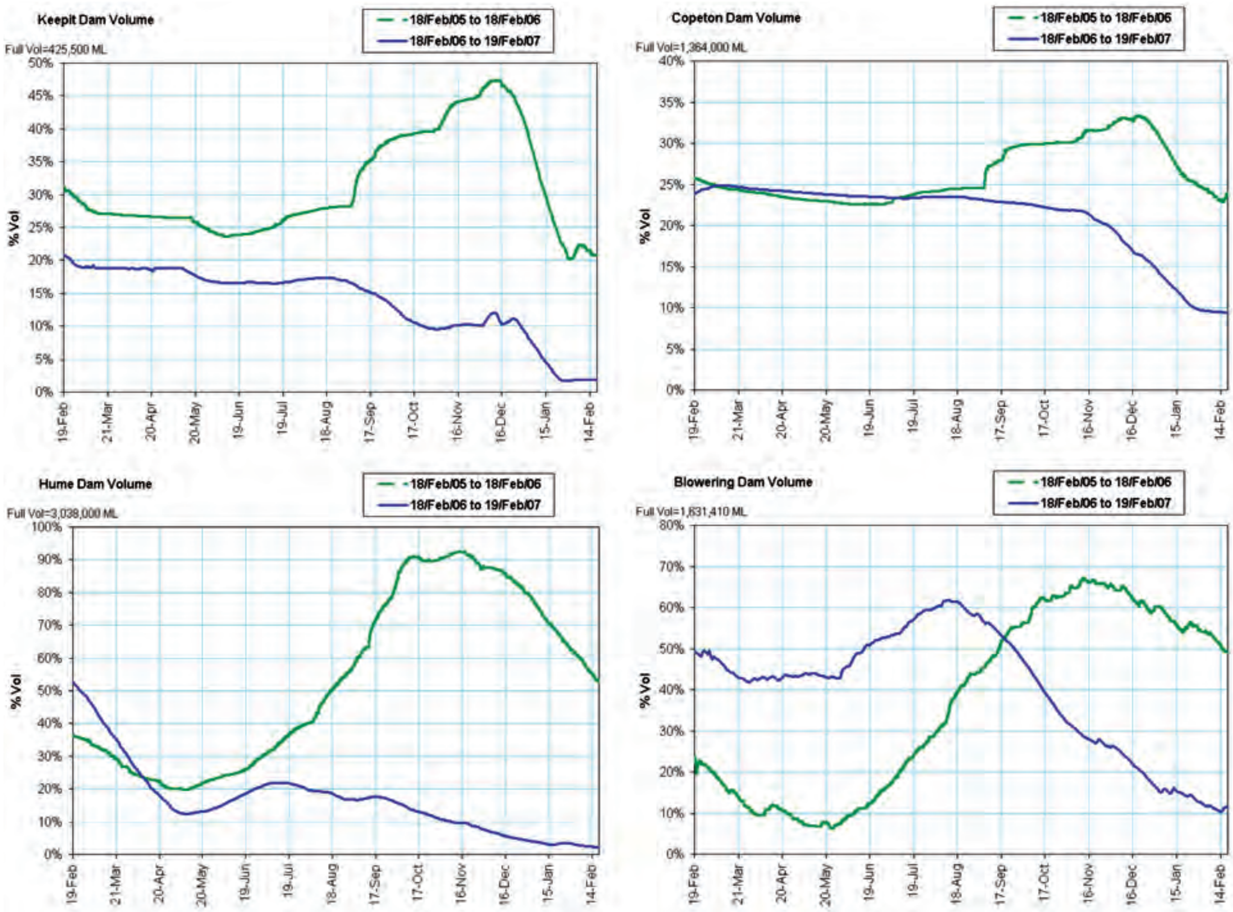


Figure 25: Storage levels of eight large storages in the MDB between February 2005 and February 2007 (Source: NSW DNR Water Information website).



The following statement was made in a Namoi Valley Water Delivery Operations Forecast - Internal Update (dated 16 January 2007):

> *"In June 2007, a resource assessment will be undertaken by the Department of Natural Resources and the allocation announcements will then be made for the 2007–08 water year. Based on the assumption of no inflows (worst case scenario), it is likely that the general security allocation announcements for both the upper and lower Namoi will be zero."*

This statement reflects the grim nature of storage levels at Keepit Dam which is unlikely to change unless significant inflows occur. The El Nino event that recently affected south eastern Australia has broken down, giving promise of higher inflows into the MDB. Not enough rain fell in MDB catchments during the 2007–08 irrigation season to fill dams for thermal stratification and CWP releases to commence. Since the current design requires the first two years of sampling prior to MLO construction be conducted during a CWP event, the current state of inflows and storage levels at Keepit Dam would not permit this study to be carried out in the 2007–08 financial year. Unfortunately the scenario is similar for all other large storages in the Basin.

Results of this scoping report identified some concern over the size of the potential thermal change achievable through MLO operation at Keepit Dam. Even under the worst case of CWP, followed by conditions most conducive to seeing an improvement from MLO operation, only a 2–5°C change is likely. This magnitude of change may not induce a response in the fish assemblage large enough to be detected using the proposed design. Based on this, other suitable options for a CWP mitigation study need to be explored.

CWP remediation measures are most likely to be undertaken during dam safety upgrades, where efficiencies can be gained by combining the necessary infrastructure with dam improvement works. Several structures have been identified by the Inter-Agency Group as being most likely to undergo safety upgrades in the foreseeable future (Table 9). The Group has set a two stage program of investigation and prioritisation of capital works programs to mitigate CWP. Stage one involves CWP mitigation works already scheduled on the capital works programs and include Keepit Dam along with Burrendong, Tallowa and Jindabyne Dams. In addition to this, Blowering, Copeton and Wyangala Dams have been endorsed by the Water CEOs for priority action in stage two. Improved operational practices of storages with existing MLO capabilities, such as Pindari, Glenbawn, Windamere, Split Rock and Chaffey Dams, may provide further options in which to conduct a CWP mitigation study. Many of the forementioned storages experience worse CWP then Keepit Dam (Table 1 page 13), and as such the potential for thermal improvement may be of a more suitable magnitude for detecting a biological response to CWP mitigation.

Table 9: Current program for dam safety upgrades within SWC for the period 2009-2014 (dependent on portfolio and funding constraints).

Dam	2008	2009	2010	2011	2012	2013	2014
Keepit		√	√	√			
Chaffey						√	√
Blowering	√	√	√				√
Burrendong				√	√		
Wyangala	√	√					
Copeton			√	√	√	√	
Spilt Rock			√	√	√		

9. FINAL RECOMMENDATIONS

9.1 Recommendation 1: More extensive CWP mitigation research is needed in the MDB

CWP remains a significant problem constraining the recovery of native fish populations in the MDB. Despite this, of all the factors impacting on native fish, CWP is the easiest to recognise, quantify in magnitude and extent, and most importantly, it is the easiest to mitigate. Unfortunately, faced with the large capital outlay required to build mitigating infrastructure, the decision whether to address CWP at large storages will continue to be made on financial merits rather than considering the potential for ecological rehabilitation. When and where CWP has the potential to be addressed as part of larger dam safety upgrade projects, researchers need to be ready to measure the ecological response to such works. It is only with solid scientific information that support for further remediation works can be galvanised. Whilst there is sufficient knowledge demonstrating the negative impact of CWP on the MDB fish assemblage, further research is needed to gauge the response of the assemblage to CWP mitigation. It is recommended that research into CWP mitigation within the MDB be considered of high priority and supported through the MDBC's Native Fish Strategy.

9.2 Recommendation 2: MBACI study design

When committing funding to a research project of this size, it is essential that all care be taken to maximise the chance of being able to detect an impact when present. This report has proposed a design that will maximise this likelihood at Keepit Dam, based on a well-established impact assessment framework, sampling equipment and fish assemblage indicators. The main components of this design are:

1. Monitoring two years before the commencement MLO operation and two years after;
2. One impact location in the Namoi River main channel between Keepit Dam and 40 km downstream;
3. Two control locations in the Gwydir River main channel between Copeton Dam and Pallamallowa Weir and in the Macquarie River main channel between Burrendong Dam and 300 km downstream;
4. A minimum of 10 replicate sites within each location;
5. Electrofishing (12 replicates) and unbaited trapping (10 replicates) (as per SRA protocol) conducted at all sites once in summer and once in autumn, with unbaited traps also set in spring;
6. Four larval drift net deployed once in spring, summer and autumn at all sites;
7. Temperature monitoring (continuous logging) and other water quality (discreet measurements on site visits) to be recorded at all sites.

9.3 Recommendation 3: Budget

A four year study determining fish assemblage response to the operation of a MLO at Keepit Dam will cost about $300,000 a year. Over four years this equates to $1.2 million. This investment in research may not seem large when viewed alongside the proposed works budgets of other structures in the Basin, or the budgets required for ongoing maintenance. A similar MLO at Burrendong Dam will potentially cost $25 million, whereas a submerged curtain at the same dam will potentially cost $3 million, with $30,000 a year required in maintenance costs (Sherman 2000). Even cheaper options such as destratification (approximately $1.5 million) have ongoing maintenance costs of $75,000-$300,000. It is the view of the authors that the benefits to be gained through improved CWP mitigation are such that funding bodies should endeavour to support this type of research given the budget outlined.

9.4 Recommendation 4: Likelihood of detecting an impact at Keepit Dam

It must be acknowledged, that at best a 5°C improvement in temperature may be experienced downstream of Keepit Dam, with this improvement diminishing with increasing distance downstream of the storage. Whilst such a change may still be extremely beneficial for the health of the fish assemblage in the Namoi River, the size of any response may be difficult to detect in a cost effective manner using the design outlined here. Based on this, other suitable locations for a CWP mitigation monitoring and evaluation study need to be explored as possible alternatives to Keepit Dam. The current magnitude of thermal depression downstream of many storages in the MDB is much larger than what is experienced downstream of Keepit Dam. These other storages may therefore provide better case studies with which to assess CWP mitigation as the potential for thermal improvement is greater. Since the proposed project is unlikely to be a viable option within the 2007-2008 financial year due to climatic conditions (see section 11.5 below), there is adequate time to scope other potential localities where CWP mitigation works are being planned (e.g. Burrendong Dam). The design proposed in this scoping report can be equally applied to other large storages throughout the MDB, with only a small amount of additional work being required to apply the design to the site- specific characters of habitat, thermal regime and fish assemblage.

9.5 Recommendation 5: Current climatic conditions are not conducive to doing the proposed research in the foreseeable future

The 2007–08 irrigation season was not a suitable time to study CWP in the MDB. The extended drought, record low inflows and very low storage levels meant the probability of experiencing the required CWP event in the first year of the study was highly unlikely. This problem was not unique to Keepit Dam and was experienced at all large storages in the Basin. It was therefore recommended this project not be undertaken in the 2007–08 financial year. However, storages can fill quickly. For instance, in 2005 Lake Hume's storage levels rose from 20% to 90% in five months and levels at Blowering Dam rose from less than 10% to 65% over the same time period (Figure 25). The recent breakdown of the El Nino event affecting south eastern Australia, gives promise of improved inflows into MDB storages. Given the high priority of research into CWP mitigation in the MDB, it is recommended the opportunity to support such research be re-addressed annually using up-to-date predictions of storage levels and the likelihood of CWP events.

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