# Review of the NSW Cold Water Pollution Strategy

WRL TR 2025/06, February 2025

By F Chaaya

UNSW Water Research Laboratory

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# 1 Introduction

Natural reservoir stratification in the warmer summer months result in the formation of two distinct layers in the water column characterised by temperature and density gradients (Figure 1-1) (MacIntyre and Hamilton, 2024). Cold water pollution (CWP) occurs when water is released from the deeper, colder layer (known as the hypolimnion) of a stratified reservoir into the downstream riverine environment (Ryan *et al.*, 2001; Preece and Jones, 2002; Preece, 2004). Australia and NSW-specific investigations have demonstrated downstream temperature suppression of up to 16 °C below natural river temperatures (Lugg and Copeland, 2014; Michie *et al.*, 2023).

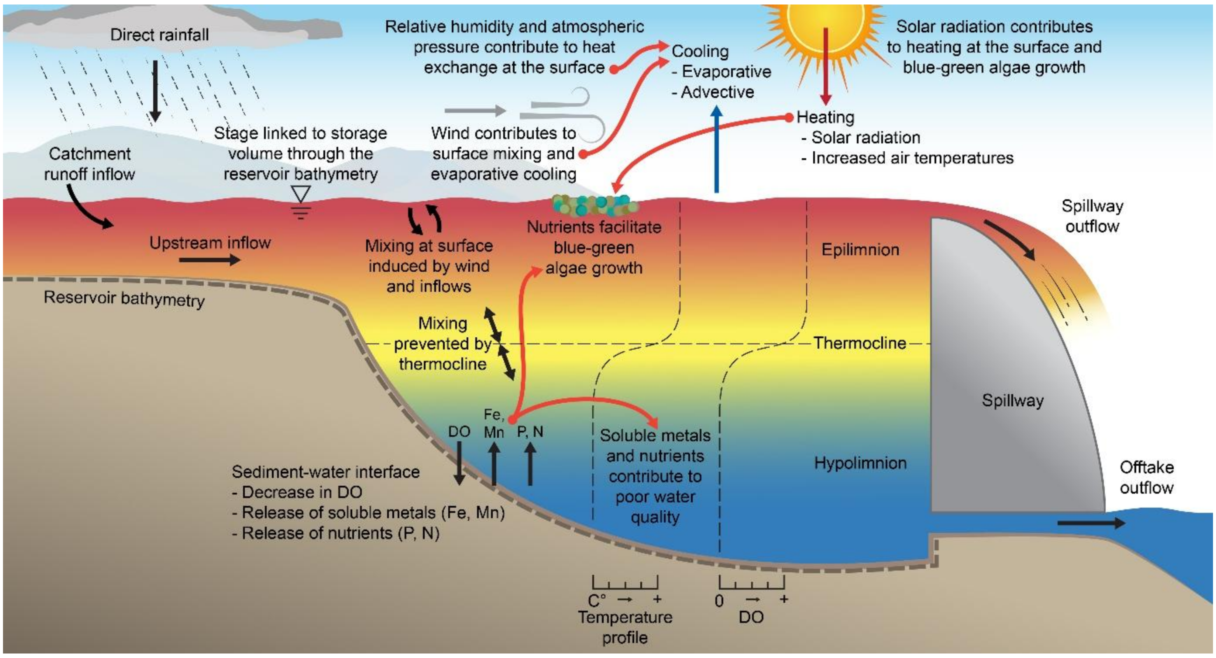


**Figure 1-1 Conceptual diagram of the water quality impacts of reservoir stratification**

The effects of CWP can extend for 100s of kilometres downstream of stratified dams, resulting in pervasive ecological, social and cultural impacts to over 2,000 km of mainstem rivers cumulatively in NSW. Ecological impacts attributed to CWP have been recognised and investigated for over 20 years in NSW (Ryan *et al.*, 2001; Preece and Jones, 2002; Preece, 2004). Native fish populations are particularly sensitive to temperature changes due to impacts on their physiology and behaviour (Todd *et al.*, 2005; Michie *et al.*, 2020b, 2020a, 2023). These impacts include reductions in fish reproduction (Boys *et al.*, 2009), growth and metabolism (Clarke and Johnston, 1999), and the survival and development of eggs and larvae (Koehn *et al.*, 1995; Todd *et al.*, 2005). In the worst case, CWP can result in fish mortality due to cold shock impacts (Michie *et al.*, 2020b).

In response to these impacts, the NSW Cold Water Pollution Strategy (the "Strategy") was developed in 2004 (NSW Cold Water Pollution Interagency Group, 2012) with the overarching aim to address and mitigate the impacts of CWP in NSW. Despite the recognition of the issue and the intent to mitigate the impacts of CWP through actions planned for Stage One (2004 to 2009) and Stage Two (2010 to 2015) of the Strategy, CWP still remains a critical issue in NSW.

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney was engaged by the NSW Department of Primary Industries and Regional Development – Fisheries (DPIRD Fisheries) to systematically review and summarise the actions and results of the Strategy, with emphasis on Stage One and Two deliverables. All available prior reports and outputs were independently reviewed, the summary of which is provided in this report. Where not specifically referenced, findings in this technical report have come from:

- Cold Water Pollution Strategy in NSW: Report on the implementation of Stage 1 (NSW Cold Water Pollution Interagency Group, 2012)
- Report on the implementation of Stage 2 of the NSW Cold Water Pollution Strategy (NSW Cold Water Pollution Interagency Group, 2017)

Some of the information used in this review was provided through direct communication with DPIRD Fisheries and WaterNSW, including reference to a number of WaterNSW internal reports which could not be directly reviewed by WRL at the time.

# 2 Framework of the NSW Cold Water Pollution Strategy

A key objective of the *Water Management Act 2000* (WM Act) is the protection of water sources and their associated ecosystems. In response to this objective, the *State Water Management Outcomes Plan* (SWMOP; 2002) was developed under the WM Act to set out the over-arching policy, targets, and strategic outcomes for the development, conservation, management, and control of the State's water sources. Additionally at this time, the NSW Government approved Water Sharing Plans that provided for the provision of environmental flows which represented a significant first step towards restoring the health of aquatic ecosystems. However, if the water released from large storage dams is too cold, the full benefits to the health of aquatic ecosystems would not be realised. Acknowledging this risk and the broader impact, the SWMOP contained targets which required water managers in NSW to address CWP (Table 2-1).

**Table 2-1 SWMOP targets pertaining to cold water pollution**

| Target | Description |
|---|---|
| *Target 26* | Dams responsible for cold water pollution identified, a priority listing prepared, and action initiated to ensure that the temperature regime below these dams is kept within the 20th to 80th natural percentile range for each month (or within bounds determined by site specific investigations), by ensuring: |
| *Target 26a** | Structural modification of at least two priority dams |
| *Target 26b** | Improved operational protocols established for priority dams with existing temperature management infrastructure |

*Target 26a and 26b of the SWMOP demonstrated the intent for implementing actions to mitigate cold water pollution; however, these were general in nature and were subsequently superseded through the inception of the NSW Cold Water Pollution Strategy in 2004 (NSW Cold Water Pollution Interagency Group, 2012).

For SWMOP Target 26, Preece (2004) assessed over 3,000 dams and weirs in NSW and identified 28 dams for CWP mitigation (Figure 2-1). Nine dams were identified as high priorities for CWP works, with a further 14 listed as moderate, and five considered as displaying less severe impacts. However, at the time (2004), no cohesive statewide strategy existed to guide the implementation of CWP mitigation measures at priority dams in a manageable way.

The NSW Government subsequently sought the endorsement of the Strategy to manage the impacts of cold water releases from the State's largest dams. The statewide framework aimed to manage the impacts of cold water releases from priority dams through a long-term and incremental program of investigation, works, and improved operating practices. Additionally, the 25-year staged approach aimed to allow Government agencies and dam operators to negotiate and implement discrete 5 year programs of investigation and works at targeted priority dams, with each program based on analysis of outcomes from the previous program, assessment of priorities for future works, and consideration of agreed funding requirements, cost sharing arrangements, and budgetary constraints.

The Strategy was endorsed by the NSW Government in 2004. The approved Strategy outlined the program management framework regarding the scope of Stage One activities; funding avenues; protocols for communication, monitoring, and reporting; as well as the governance structure for reviewing program progress and the development of subsequent 5 yearly programs. Although the Strategy was endorsed by the NSW Government, no public facing document was released at the time. The Cold Water Pollution Strategy in NSW: Report on the implementation of Stage One (NSW Cold Water Pollution Interagency Group, 2012) is the first public document that details the scope, aims, and objectives of the NSW Cold Water Pollution Strategy (2004).

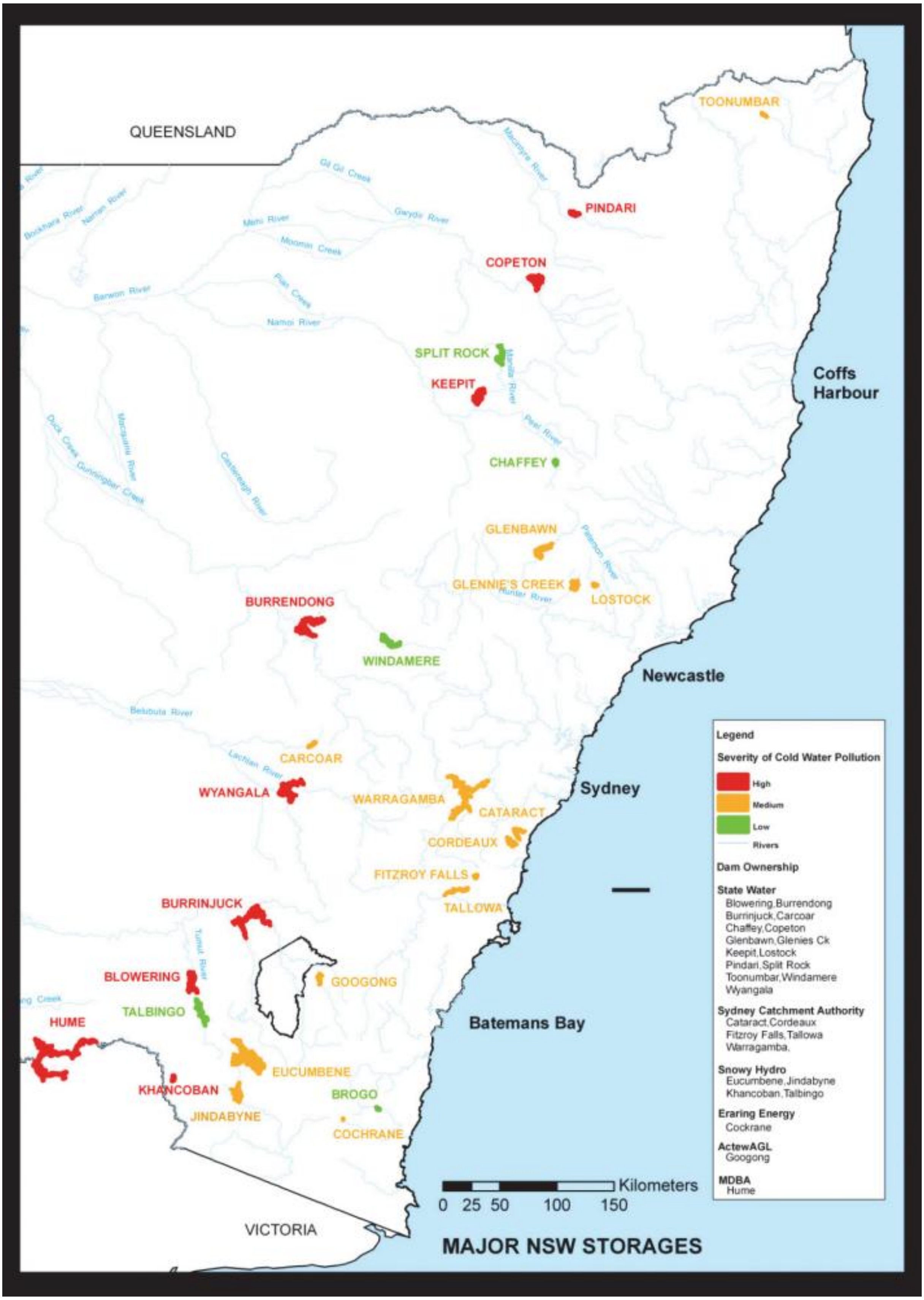


**Figure 2-1 NSW dam identified for cold water pollution impacts, updated from Preece (2004) by CWPIAG (2012)**

# 3 Stage One (2004 to 2009)

Information pertaining to the governance and legislative framework, activities, tasks, recommended actions and outcomes of Stage One of the Strategy was primarily obtained from a report that summarises Stage One implementation (NSW Cold Water Pollution Interagency Group, 2012). Where available, other reports and documents were obtained and reviewed (see Section 6).

## 3.1 Activities

Stage One of the Strategy aimed to address targets stipulated in the SWMOP, as well as to form the foundation for a monitoring and governance framework. Outcomes included:

- Recognising and prioritising dams causing severe CWP.
- Planning and implementing CWP mitigating infrastructure at priority dams.
- Developing and implementing operating protocols for dams with already existing multi-level offtake (MLO) capabilities.
- Developing a governance framework and Cold Water Pollution Interagency Group (CWPIAG) to assist with the strategy implementation.
- Providing a forum to achieve a coordinated, whole-of-government response to CWP.
- Implementing and maintaining a temperature monitoring network.

The Terms of Reference (TOR) of the CWPIAG listed specific objectives to address these outcomes, including:

- Monitor implementation of actions identified in Stage One and outcomes achieved which include:
    1. Trial and verification of low cost solutions at Burrendong
    2. Implementation of works at Keepit Dam
    3. Implementation of works at Tallowa Dam
    4. Implementation of works at Jindabyne Dam
    5. Implementation of improved operating protocols at six dams
    6. Implementation of structural modifications at six dams
- Develop performance criteria and targets for releases from dams.
- Coordinate a review of the Strategy at the end of Stage One and report review outcomes to NSW Cabinet (via Water CEOs and Minister for Natural Resources).
- In consultation with dam owners, determine which dams are to be investigated in each subsequent 5 year stage of the Strategy.
- Identify critical issues and set parameters for each detailed dam investigation.
- Consider outcomes of each detailed investigation and in consultation with dam owners, agree on recommendations for the most suitable option for each dam.
- Regularly report to Water CEOs on Strategy progress.
- Prepare reports and present recommendations to NSW Cabinet (via Water CEOs and Minister for Natural Resources) regarding options, priorities and timeframes for priority dams over 20 to 25 years in 5 year stages.

Table 3-1 provides a summary of the actions and tasks, as outlined in the Stage One implementation report, as well as the nature of their success relative to the scope of Stage One of the NSW Cold Water Pollution Strategy. A number of these actions were transitioned through to Stage Two, as discussed in the Stage One Summary (see Section 3.2).

**Table 3-1 Key tasks, recommended actions and outcomes as part of Stage One of the Cold Water Pollution Strategy**

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Regulatory framework | Legislative amendments | Yes | - | *Water Managements Act 2000* amended via insertion of Section 100(3) that enables the Minister to specify the dams where CWP activities must be undertaken over a nominated time frame, monitoring and reporting on actions taken, and where specific ongoing operating protocols are to be implemented.<br><br>Water CEOs were made responsible for the Strategy implementation; however, this group was later abolished with responsibility shifting to the Senior Officers Group on Water. The CWPIAG managed Strategy implementation on a day-to-day basis, with the TOR developed. |
| Evaluation of lower-cost options | Burrendong Dam | No | Yes | Modelling trials of design options completed indicating feasibility of thermal curtain. Concept design completed. Further design activities and construction delayed to Stage Two. |
| Cold water pollution mitigation works | Burrendong Dam | No | Yes | Initiation of works was dependent on finalisation of thermal curtain investigations to be conducted in Stage Two. |
| | Keepit Dam | No | Yes | Option development and evaluation completed. Preferred MLO option chosen. Construction of MLO scheduled to commence in 2011. |
| | Tallowa Dam | Yes | - | Bubble plume destratification successfully implemented (2005 to 2009) as part of CWP mitigation works at Tallowa Dam.<br><br>Bubble plume decommissioned upon completion of environmental flow release infrastructure upgrades (2009), which included fish passage and selective withdrawal capabilities that mitigated CWP releases. |
| | Jindabyne Dam | Yes | - | Works completed at the dam offtake in 2006 to mitigate CWP releases. |
| Other structural modifications | Implement modification at 6 dams with existing selective offtake capabilities | No | No | GHD proposals largely rejected due to cost and/or operational constraints. |

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Dam operations | Management guidelines | Yes | - | *Guidelines for Managing Cold Water Releases from High Priority Dams* developed. The Guidelines aimed to assist decision making in regards to:<br>• Clarifying what is and is not CWP<br>• Develop CWP mitigation infrastructure performance standards<br>• Assisting dam operators to develop and assess site specific operating protocols for CWP mitigation<br>Guidelines could not be tested through Stage One due to insufficient temperature infrastructure and data. Testing and development on guidelines were carried through to Stage Two. |
| | Work approvals | Partially | Yes | Matrix of work approval conditions completed.<br>CWP conditions included in Work Approvals for 7 dams: Copeton, Keepit, Split Rock, Wyangala, Glenbawn, Glennies Creek, and Lostock. |
| | Develop and implement revised operating protocols at six dams with existing selective offtake capabilities | No | Yes | DCCEEW (Water) developed draft protocols for Pindari, Chaffey, Split Rock and Windemere dams.<br>WaterNSW developed draft protocols for Glenbawn Dam and Glennies Creek Dam.<br>DCCEEW (Water) rolled out dam works approvals with conditions to implement operating protocols.<br>WaterNSW conducted trials at Glennies Creek Dam in the 2009/10 irrigation season.<br>DCCEEW (Water) and WaterNSW identified monitoring network and data gaps that required resolution prior to implementing operating protocols at six dams.<br>WaterNSW advised that obligations under the Algal Strategy (RACC Plan) require releases from below the thermocline during algal blooms, which opposes requirements for CWP mitigation. |

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Temperature monitoring | Develop and install temperature monitoring stations | No | No | Basic monitoring needs were identified (Hardwick et al., in prep) to guide planning and operation of CWP mitigation infrastructure.<br><br>Funding for monitoring infrastructure and ongoing maintenance and data collection was generally not achieved in Stage One. WaterNSW installed thermistor chains at Wyangala Dam and Blowering Dam in 2010. |
| Cost-Benefit Analysis | Undertake economic analysis of Stage One & Two activities | Yes | - | Assessment completed by Hill (2009) – determined a positive Net Present Value (NPV) of $15 M to $33 M and a Benefit Cost Ratio (BCR) of 1.74 to 2.64 for Stage One activities. Additional benefits beyond fish improvement (e.g. recreational benefits due to improved water quality and habitat benefits) were not quantified which would have resulted in a higher BCR. |
| Preparation for Stage Two | Identify priority dams for investigation | Yes | - | Dams identified and endorsed by Water CEOs (Copeton, Wyangala, and Blowering) for CWP investigations. |

## 3.2 Stage One summary

The primary achievements from Stage One were:

- Completion of CWP works at two dams: Tallowa and Jindabyne
- Investigation of upgrade works at two dams: Burrendong and Keepit
- Legislative amendments to WMA 2000 to formalise the regulation of CWP
- Development of Guidelines for Managing Cold Water Releases from High Priority Dams
- Development of governance structure to guide Strategy implementation
- Completion of CWP Cost Benefit Analysis

Stage One actions carried forward to Stage Two were:

- Construction of an MLO at Keepit Dam and development of operating protocols.
- Finalisation of investigations into the Burrendong Dam thermal curtain including the assessment of operation and maintenance implications. Development of a program for construction and operation.
- Investigate two priority dams for CWP mitigation out of Copeton Dam on the Gwydir River, Wyangala Dam on the Lachlan River, and Blowering Dam in the Murrumbidgee catchment.
- Scope, cost, and implement a program to test and evaluate infrastructure operating protocols.
- Finalisation of operating protocols for six dams that already have selective off-take capability: Pindari, Glenbawn, Glennies Creek, Windamere, Split Rock and Chaffey dams.
- Development of a monitoring program including progressing installation of required monitoring infrastructure.

New tasks identified by the CWPIAG for Stage Two were:

- Develop a monitoring, evaluation, and reporting (MER) strategy including funding the installation, data collection and maintenance of monitoring equipment and development of temperature growth models for priority dams to quantify the effectiveness of implementing the Strategy.
- Standardise the economic approach to benefits and costs of mitigation measures to better cost and attribute value to future investigations and works.
- Develop the Strategy into a program to be rolled out over the next 5 to 20 year period.

# 4 Stage Two (2010 to 2015)

Information pertaining to the governance and legislative framework, activities, tasks, recommended actions and outcomes of Stage Two of the Strategy was primarily obtained from a report summarising Stage Two's implementation (NSW Cold Water Pollution Interagency Group, 2017). This report summarised both the actions introduced through Stage Two, as well as those carried over from Stage One that were not implemented or completed. Additionally, this report identifies actions that were to be undertaken in Stage Three of the Strategy.

## 4.1 Activities

Table 4-1 provides a summary of the new and carried-over tasks and activities undertaken as part of Stage Two, as discussed in the Stage Two NSW Cold Water Pollution report (NSW Cold Water Pollution Interagency Group, 2017).

**Table 4-1 Key tasks, recommended actions and outcomes as part of Stage One of the Cold Water Pollution Strategy**

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Regulatory framework | Murray-Darling Basin Plan | - | - | Schedule 10 of the Basin Plan outlines the significance of water temperature outside natural ranges as a key river health stressor with a key cause being the release of stored water from large dams.<br>The Basin Plan's target criteria is for the monthly median water temperature to be within the range of the 20th and 80th percentile of the natural monthly water temperature (Schedule 11 of the Basin Plan). |
| Assessments completed | Khancoban Dam | Yes | - | Investigations by Snowy Hydro Limited demonstrated Khancoban Dam discharges were heavily influenced by cold water inflows from the Murray 2 Power Station that could not be mitigated. The CWPIAG reviewed these findings and reclassified the dam from 'high priority' to 'no mitigation proposed'. |
| High Priority Dam Investigations | Copeton Dam | Partial | No | Three high priority dams endorsed for mitigation investigation in Stage Two. WaterNSW completed an options study at Copeton Dam, with further design development proposed in Stage Three. |
| | Wyangala Dam | No | No | Infrastructure investigations deferred to Stage Three. |
| | Blowering Dam | No | No | Infrastructure investigations deferred to Stage Three. |
| Cold water pollution mitigation works | Burrendong Dam | Yes | - | Thermal curtain successful constructed and installed as part of Stage Two for $3.8 M.<br>Master's degree student investigated ecological effects of curtain (2013 to 2015).<br>Testing of the curtain in Stage Two proved difficult due to low (drought) dam water levels. |
| | Keepit Dam | No | No | Concept designs developed for gated ports on existing dam outlets to provide MLO capabilities.<br>Stage Three activities involve completion of detailed designs which were expected to begin in 2020. |

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Dam operations | Management guidelines | Yes | - | Evaluation of *Guidelines for Managing Cold Water Releases from High Priority Dams* indicated that the guidelines were not appropriate for application.<br><br>The guidelines were revised to a 5 day rolling cumulative temperature anomaly (draft version).<br><br>The new metric was to be tested in Stage Three for finalisation. |
| Dam operations | Blue Green Algae | Yes | | WaterNSW evaluated the operating constraints imposed on cold water pollution mitigation by the presence of cyanobacteria in storages, wherein water is released from below the thermocline during algal blooms resulting in cold water pollution releases.<br><br>Further assessment of the algae and CWP management interplay was identified for Stage Three. |
| | Work approvals | Partial | Yes | CWP conditions included in work approvals for nine dams: Pindari, Copeton, Keepit, Split Rock, Burrendong, Windamere, Wyangala, Blowering and Burrinjuck, with some overlap with Stage One works approvals.<br><br>WaterNSW agreed to monitoring obligations for works approvals in Stage Two for the above dams.<br><br>Operating and reporting conditions are incorporated into the Snowy Water Licence 2010 for Jindabyne and Tantangara Dams managed by Snowy Hydro Limited.<br><br>Works Approvals for the Sydney drinking water supply dams of Cataract, Cordeaux and Warragamba consider the needs of drinking water supply as a priority relative to CWP mitigation under the *Water Management Act 2000*. |
| | Develop, implement, and assess revised operating protocols at six dams | Partial | No | Operating protocols developed and tested for Pindari, Split Rock, Chaffey, Windamere, Glenbawn, and Glennies Creek where selective offtake capability already existed.<br><br>Evaluation of revised operating protocols to determine their effectiveness in mitigating CWP was delayed to Stage Three. |

| Outcome | Action | Completed | On track | Notes |
|---|---|---|---|---|
| Monitoring | Develop and implement MER Strategy | Partial | No | Progressively installed water temperature monitoring infrastructure (60+ HOBO© loggers; 10 continuous permanent loggers) around priority dams.<br>Responsibility of maintaining network and data management passed from DCCEEW (Water) to WaterNSW in July 2016.<br>MER strategy yet to be developed or funded beyond installation of temperature loggers. |
| Develop Strategy | Develop 20 year+ Plan | Partial | No | Stage Three activities recommended for next 5 years.<br>20 year plan yet to be developed for Strategy implementation. |
| Cost-Benefit Analysis | Undertake economic analysis of CWP activities | No | No | No progress made on developing an economic analysis template to standardise the approach to evaluating the benefits and costs of CWP mitigation. |

## 4.2 Stage Two Summary

The primary achievements from Stage Two were:

- Construction of the thermal curtain at Burrendong Dam, including initial monitoring of its operational effectiveness.
- Detailed investigation and re-classification of CWP at Khancoban Dam.
- Continued installation and maintenance of temperature monitoring equipment at large water storages across NSW.
- Development and implementation of operating protocols for dams with multi-level offtakes to deliver best management in water temperature releases.
- Evaluation of the guidelines for managing cold water releases from high priority dams.

A number of Stage Two actions were planned to be carried forward to Stage Three, as introduced in the Stage Two report. However, the CWPIAG stopped meeting around 2017, with activities related to the CWP Strategy (2004) largely ceasing at this time. As a result of this, there was no report produced for Stage Three. WRL consulted with DPIRD Fisheries and WaterNSW regarding the status of the actions proposed for Stage Three.

Table 4-2 summarises the Stage Two actions planned for Stage Three, with commentary on their current status. Most of the information under "Current Status" was provided through direct communication with DPIRD Fisheries and WaterNSW, including reference to a number of WaterNSW internal reports which could not be directly reviewed by WRL at the time.

**Table 4-2 Summary of Stage Two actions planned for Stage Three**

| Dam (where applicable) | Action | Current status |
|---|---|---|
| Keepit Dam | Construction works on the multi-level offtake were delayed to late 2020 following completion of the dam safety upgrade activities. | Construction works were not funded and have yet to proceed. Resulting from the IPART-approved CWP mitigation options assessment study for Keepit, Copeton and Blowering Dams (WaterNSW, 2024a, 2024b), conducted during the 2022-2025 determination period, WaterNSW is currently seeking funding approval to progress the next stage of activities. The proposal for Keepit Dam includes detailed design and approvals activities for the preferred option (aeration system powered by renewable energy) in the 2026-2030 IPART Determination Period. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. |
| Burrendong Dam | WaterNSW to conduct a full review of the operation and effectiveness of the thermal curtain including an updated operating protocol. Further post-graduate evaluation proposed. | Following continued operations and maintenance serviceability issues, WaterNSW decommissioned the thermal curtain in 2022. WaterNSW completed a CWP management options study for Burrendong Dam in 2022 (WaterNSW, 2022), which compared the preferred alternative options against reinstating the thermal curtain. The study recommended the |

| Dam (where applicable) | Action | Current status |
|---|---|---|
| | | preferred option of an MLO with automated sliding plates. The detailed design and construction of this CWP mitigation solution option on the existing offtake tower is proposed during the 2026-2030 IPART Determination Period. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. |
| Copeton Dam | WaterNSW planned to undertake further investigations to develop a preferred solution. | WaterNSW completed further CWP mitigation options assessments for the three high priority CWP sites (Keepit, Copeton and Blowering Dams) during the 2021-2025 IPART Determination Period (WaterNSW, 2024a, 2024b). WaterNSW has requested funding for Copeton Dam during the 2026-2030 IPART Determination Period to complete detailed design and approvals activities in readiness for construction of the preferred CWP mitigation solution (aeration system powered by renewable energy) post-2031. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. |
| Wyangala Dam | WaterNSW planned to undertake further investigations to develop a preferred solution. | WaterNSW has requested funding during the 2026-2030 IPART Determination Period to undertake a CWP mitigation options study and to complete preliminary concept designs for Wyangala Dam. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. |
| - | Development of an economic analysis template to standardise the approach to evaluating the benefits and costs of CWP mitigation for individual storages. | As part of the CWP mitigation options study for Blowering, Copeton and Keepit Dams, WaterNSW conducted a cost-benefit analysis in 2024 of the preferred options assessed (WaterNSW, 2024b). This preliminary economic analysis output provided verification of the top three ranked options initially ranked via a multi-criteria analysis (MCA) process. Further work in the future on improving ecological benefit values is thought to improve cost benefit outcomes. |
| - | Development of a monitoring, evaluation, and reporting (MER) strategy including funding the installation, data collection and maintenance of monitoring equipment for the priority dams to quantify the effectiveness of Strategy implementation. | No MER Strategy has been developed. |
| - | Testing the 5 day rolling cumulative temperature anomaly metric. | Initial testing occurred early in Stage Three; however, formal acceptance of the metric has yet to occur. |

| Dam (where applicable) | Action | Current status |
|---|---|---|
| - | Updating the NSW Cold Water Pollution Guidelines to assist with dam operation and reporting against works approval requirements in annual licence compliance reports | The Guidelines have yet to be updated. |
| - | WaterNSW to develop a 20 year Asset Strategy to plan for the delivery of water supply infrastructure works including CWP mitigation. | WaterNSW completed their *20 Year Infrastructure Options Study: Rural Valleys* in 2018 (WaterNSW, 2018a); and subsequently completed the CWP Mitigation Options Assessment Report in 2020 (WaterNSW, 2020). |
| - | WaterNSW to evaluate the operating protocols for dams that already have selective off-take capability for their effectiveness at reducing downstream CWP. | Selective off-take operational protocols were formalised by WaterNSW in 2017. Their assessment is still required to confirm effectiveness. |
| - | Evaluation of the impacts of blue-green algae on the effectiveness on CWP mitigation strategies. Blue-green algae primarily limits the use of selective withdrawal due to conflicting management protocols. | Formal assessment has yet to occur; however, WaterNSW developed the *Cold Water Pollution Operating Protocol: Managing cold water pollution and cyanobacteria in WaterNSW rural storages with variable offtake* structures in 2018 (WaterNSW, 2018b). |

Given the time elapsed between the completion of Stage Two (2015) and time of writing of this report (2025), these actions and objectives should be more formally reviewed.

# 5 Summary of responsibilities and governance

Responsibilities of contributing parties were assigned as part of the Cold Water Pollution Strategy governance framework. These include:

- Water CEOs Group – responsible for implementing the Strategy
    - This became the responsibility of the Senior Officers Group on Water, following the abolition of the Water CEOs Group
    - WRL is unaware of the continued operation of the Senior Officers Group on Water at the time of writing (2025)
- Interagency Group – managed the implementation of the strategy on a day-to-day basis and reported back to the Senior Officers Group on Water
    - Originally convened under direction of the Minister for Infrastructure, Planning and Natural Resources (now the Minister for Lands and Water)
    - Interagency Group ceased meeting around 2017
- DCCEEW (Water) – held responsibility to coordinate NSWs response to the Strategy. This responsibility was transferred to WaterNSW in 2016.

# 6 Summary of key reports and documents

A number of reports and documents were produced as part of Stage One and Two of the Strategy. These include:

- NSW Cold Water Pollution Strategy – Report on the implementation of Stage One
    - https://water.dpie.nsw.gov.au/__data/assets/pdf_file/0009/456912/NSW-Cold-water-pollution-strategy-stage-one.pdf
- NSW Cold Water Pollution Strategy – Report on the implementation of Stage Two
    - https://www.researchgate.net/publication/319889854_NSW_COLD_WATER_POLLUTION_STRATEGY_Report_on_the_implementation_of_Stage_2_2010-2015_NSW_Cold_Water_Pollution_Interagency_Group_Cold_Water_Pollution_report_on_implementation_of_Stage_2_of_the_Cold_Water
- Options studies for Burrendong dam
    - GHD MLO options study - unsighted by WRL
    - Manly Hydraulics Laboratory physical 3D model study of floating curtain – unsighted by WRL
    - Thermodynamic study of Burrendong (Connell Wagner) – unsighted by WRL
- Options studies for Keepit Dam
    - Manly Hydraulics Laboratory thermodynamic study of Keepit – draft released by MHL, sighted by WRL
    - Manly Hydraulics Laboratory refined thermodynamic modelling study - unsighted by WRL
- Options studies for Tallowa Dam
    - Unsighted by WRL
- Guidelines for managing cold water releases from high priority dams
    - https://publications.water.nsw.gov.au/watergroupjspui/bitstream/100/91/1/NSW_Cold_Water_Pollution_Strategy_-_Guidelines_for_managing_cold_water_releases_from_high_priority_dams.pdf
- Operating protocols to mitigate cold water pollution for dams with multi-level offtakes
    - Unsighted by WRL
- Snowy Hydro Limited final report regarding reclassification of Khancoban from “high-priority”
    - Unsighted by WRL
- WaterNSW 20 year Infrastructure Options Study Rural Valleys – Summary Report
    - https://www.waternsw.com.au/__data/assets/pdf_file/0019/132616/20-Year-Infrastructure-Options-Study-June-2018.pdf

# 7 Dams considered a priority due to cold water pollution impacts

At the initiation of Stage One, 28 dams were identified as key contributors to CWP in NSW (Preece, 2004). Offtake depth and discharge volume were used to categorise dams as high, moderate and low priority (Figure 7-1).

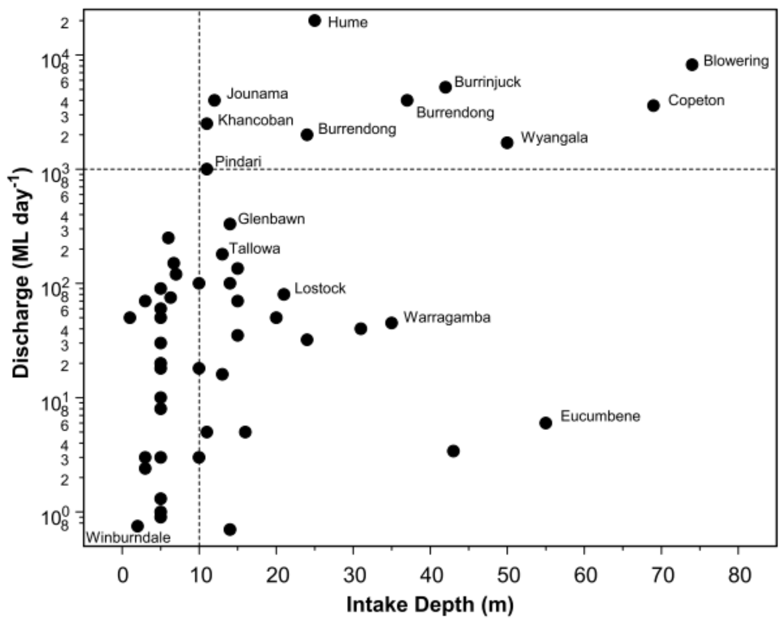


**Figure 7-1 Cold water pollution impact severity and prioritisation based on intake depth and discharge (Preece, 2004)**

As part of Stage One, the CWPIAG adapted these prioritisations and developed a priority evaluation matrix for identifying priority dams for Stage Two and beyond. The matrix, for each dam, considers:

- Size of problem – as per priorities defined in Preece (2004)
- Conservation and environmental values
- Practicality and opportunities
- Effectiveness of works
- Community factors
- Cost of preferred options

From Stage Two and beyond, the dams were to be prioritised under this scheme. Based on this, the following dams were classified as high priority:

- Burrendong
- Keepit
- Blowering
- Copeton
- Wyangala
- Hume
- Burrinjuck
- Pindari

Moderate and low priority dams are included in Appendix 2 of the Stage Two report (NSW Cold Water Pollution Interagency Group, 2017).

# 8 Summary of activities for high priority dams

Table 8-1 summarises the activities undertaken at each of the high priority dams identified through Stages One and Two of the Strategy. WRL consulted with DPIRD Fisheries and WaterNSW regarding the current status for each dam, noting that no formal Stage Three assessment had occurred. Some of the information under “Activity” was provided through direct communication with DPIRD Fisheries and WaterNSW, including reference to a number of WaterNSW internal reports which could not be directly reviewed by WRL at the time.

**Table 8-1 Summary of activities for high priority dams**

| Dam | Multi-level offtake | Activity | CWP mitigated |
|---|---|---|---|
| Pindari | Yes | Pindari was identified as one of six dams with selective withdrawal capabilities. Structural modifications to improve selective withdrawal functionality were proposed, however were deemed not to be required.<br><br>Operating protocols designed to mitigate cold water pollution using existing selective withdrawal infrastructure were developed as part of Stage One.<br><br>Operating protocols were further developed and tested as part of Stage Two. The success of these were not reported. Further improvements to these protocols were anticipated post Stage Two with additional data collection.<br><br>No further assessment has occurred regarding the effectiveness of revised operating protocols since Stage Two. | Partially |
| Copeton | No | One of three high-priority dams identified for Stage Two mitigation activities by the CWPIAG priority matrix.<br><br>WaterNSW completed options studies as part of Stage Two; however, further design investigations deferred to Stage Three.<br><br>Further mitigation options investigations, preliminary concept designs and cost benefit analysis for the shortlisted options have been completed by WaterNSW since Stage Two (WaterNSW, 2024a, 2024b), with WaterNSW seeking funding for detailed design and approval works for the preferred solution (destratification system powered by renewable energy) during the 2026 to 2030 IPART Determination Period. WaterNSW is awaiting IPART’s Determination in June 2025 for requisite funding. | No |
| Keepit | No | As part of Stage One, a range of investigations were undertaken to explore options for cold water pollution. It was decided that a multi-level offtake would be the most suitable option. | No |

| Dam | Multi-level offtake | Activity | CWP mitigated |
|---|---|---|---|
| | | Construction of the multi-level offtake was delayed through to Stage Three.<br><br>Further mitigation options investigations, preliminary concept designs and cost benefit analysis for the shortlisted options have been completed by WaterNSW since Stage Two (WaterNSW, 2024a, 2024b), with WaterNSW seeking funding for detailed design and approval works for the preferred solution (destratification system powered by renewable energy) during the 2026 to 2030 IPART Determination Period. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. | |
| Burrendong | No | Options studies to mitigate CWP at Burrendong dam were carried out as part of Stage One.<br><br>A thermal curtain was installed in 2014 as part of Stage Two. Assessment of the effectiveness of the thermal curtain was ongoing at the completion of Stage Two. WaterNSW decommissioned the thermal curtain in 2022 due to ongoing maintenance issues that limited effective operation.<br><br>WaterNSW completed a CWP management options study for Burrendong Dam in 2022 (WaterNSW, 2022), comparing the preferred alternative options against reinstating the thermal curtain.<br><br>WaterNSW has proposed the detailed design, approvals and construction of automated sliding plates on the existing offtake tower during the 2026 to 2030 IPART Determination Period. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. | No |
| Wyangala | No | One of three high-priority dams identified for Stage Two mitigation activities by the CWPIAG priority matrix.<br><br>Investigations into mitigation options were not completed in Stage Two.<br><br>WaterNSW has requested funding during the 2026 to 2030 IPART Determination Period to undertake a CWP mitigation options study complete preliminary concept designs. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. | No |
| Burrinjuck | Yes | Burrinjuck was identified as having existing infrastructure (MLO) that could be utilised to assist CWP mitigation.<br><br>At the completion of Stage Two, operating protocols aimed at mitigating CWP were not yet completed and have since been documented in 2017. | Partially |
| Blowering | No | One of three high-priority dams identified for Stage Two mitigation activities by the CWPIAG priority matrix.<br><br>Investigations into mitigation options at Blowering were deferred past Stage Two. | No |

| Dam | Multi-level offtake | Activity | CWP mitigated |
|---|---|---|---|
| | | WaterNSW completed the CWP mitigation options study following Stage Two (WaterNSW, 2024a, 2024b), with WaterNSW seeking funding for detailed design and approval works during the 2026 to 2030 IPART Determination Period. WaterNSW is awaiting IPART's Determination in June 2025 for requisite funding. | |
| Hume | No | No actions were carried out for Hume Dam through Stage One and Two, as the dam's operations are controlled by the Murray-Darling Basin Authority and are outside of NSW government jurisdiction.<br><br>Hume Dam is considered a high risk CWP site in NSW. In line with existing work approval requirements, WaterNSW has made a submission to the MDBA for their 4 year Action Management Plan process to support inclusion of the proposed CWP mitigation options study for Hume Dam. If successful, this proposed activity will be assessed by IPART as prudent and efficient for incorporation into Murray Valley bulk water charges for the 2026 to 2030 IPART Determination Period. | No |

# 9 Operations and protocols for dams with existing multi-level offtakes

As part of the intended outcomes of Stage One, six dams with existing MLOs were reviewed, with draft protocols developed to assist operators with mitigating CWP. These dams were:

- Pindari Dam
- Glenbawn Dam
- Glennies Creek Dam
- Windamere Dam
- Split Rock Dam
- Chaffey Dam

The lack of consistent temperature data and a continuous monitoring network meant it was difficult for DCCEEW (Water) and WaterNSW to implement and test these operational protocols as part of Stage One. As well as this, structural modifications to these MLOs for the purposes of improved protocols and CWP mitigation were rejected due to cost and/or operational constraints relative to the anticipated benefits.

As part of Stage Two, operating protocols for the aforementioned six dams were developed, tested and used. Further improvements were expected as the protocols were reviewed, and better data was acquired. Updating the operating protocols was to tie in closely with the continually developing guidelines, which includes a better understanding of the operational effects of blue-green algae management relative to CWP mitigation and the release of water from below the thermocline during algal blooms.

Figure 9-1 represents a generic set of operating protocols/guidelines for those dams fit with MLOs, extracted from (Hardwick et al., 2011).

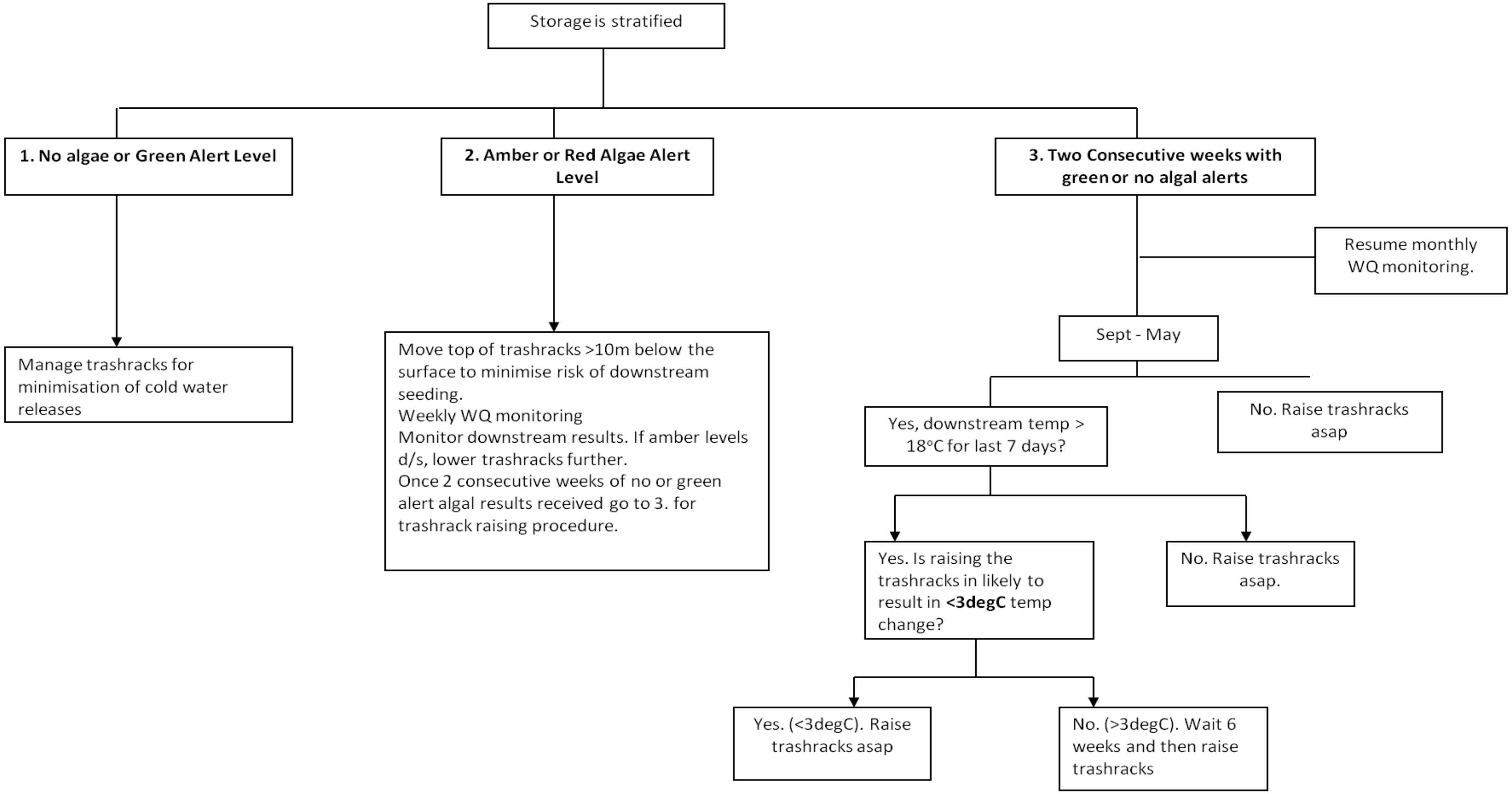


**Figure 9-1 Generic operation protocols for dams fit with a multi-level offtake (Hardwick et al., 2011)**

# 10 Guidelines for managing cold water releases from high priority dams

As part of Stage One, the CWPIAG developed guidelines for managing cold water releases from high priority dams. The guidelines aimed to:

- Provide guidance to dam operators responsible for the management of CWP mitigation infrastructure (multi-level offtakes and destratification systems) to assist in the development of appropriate operating protocols.
- Provide guidance to engineers and designers evaluating and designing CWP mitigation infrastructure, with particular attention to performance criteria.
- Clarify the definition of cold water pollution to assist with performance assessment of mitigation infrastructure.

The guidelines stipulated that dam asset managers would be granted works approvals on the basis of having implemented protocols for CWP mitigation, rather than quantitative temperature outcomes. Future works approvals may need to consider ecologically-based guidelines.

Stage One original guidelines were for downstream releases to be between a 20$^{th}$ to 80$^{th}$ percentile range of the “expected natural” temperature regime, derived from either:

- Field measurements collected prior to dam construction
- Measurements from local tributaries or upstream rivers outside the influence of the reservoir stored water

Hourly or daily averages were considered operationally unachievable. Monthly averages were adopted, however these were subsequently determined to have no ecological relevance. As such, the guidelines developed in Stage One were rejected from further use in Stage Two, with a 5 day rolling anomaly proposed. The ecological validity of this method was not confirmed during Stage Two, with further assessment proposed for Stage Three.

The guidelines outlined the need for baseline data and monitoring to effectively assess CWP. These recommendations were partially implemented as part of Stage Two, with the introduction of a larger monitoring network of temporary and fixed temperature stations. Any review or improvements made to the guidelines should consider these data and monitoring requirements, and the expansion of the temperature logging network.

Further improvements to the guidelines should consider a realistic and operationally applicable definition of success. WRL’s literature review (Chaaya and Miller, 2022; Chaaya *et al.*, 2025) discusses the definition of success in terms of mitigating CWP, and can be summarised by the following:

- Water temperatures measured upstream and downstream of a reservoir are rarely consistent with each other in terms of magnitude and timing. The reservoir acts as a significant heat (energy) sink, resulting in variability of the temperature of water entering and being released from the dam. The significant volume of water contained in the reservoir results in time lags and daily variations between upstream and downstream temperatures.

- Minimum ecological thresholds that affect fish physiology, behaviour and breeding patterns should be considered.
- An active artificial destratification system may be deemed successful if isothermal conditions are created.

# 11 Lessons learned from Stages One and Two of the NSW Cold Water Pollution Strategy

A number of lessons were learned through Stages One and Two of the Strategy. These are summarised below:

- Limited resourcing for personnel, infrastructure upgrades and monitoring activities limited the delivery of the Strategy, especially given the subsequent realisation that CWP was an expensive issue to mitigate.
- Cold water pollution is a complicated issue, primarily arising from the thermal stratification of dams and the release of water from below an established thermocline. Part of the complications experienced during Stage One and Two arose from a lack of in-depth understanding of:
  - Why dams stratify, and what are the main drivers of stratification processes.
  - The optimum part of the water column to release water from and how to achieve this consistently.
  - In-reservoir algae management, mitigating algae release, and how these operations conflicted with cold water pollution mitigation.
  - Quantification of the ecological impacts of CWP.
  - The need for, costing of, and operation of expensive mitigation infrastructure.
- The issue of CWP management was larger and more complicated than the time allocated to fix or address it.
- Artificial destratification via bubble plumes was deemed an effective and proven approach, however high operating costs and associated carbon emissions limited its feasibility for further applications at the time.
- Considerable weight was given to selective withdrawal methods, especially MLOs, despite their relatively high capital cost and inability to mitigate CWP when algae management protocols were in effect.
- Attempts to mitigate CWP with limited available funding were either ineffective or failed entirely.
- Quantitative metrics comparing water temperatures upstream and downstream of the reservoir were:
  - Difficult to implement and monitor.
  - Not relevant or untested in terms of ecological outcomes.
  - Unachievable through the infrastructure and operating protocols used at the time.
- A lack of consistent and comparable data at the time made it difficult to quantify the effects of mitigation strategies and set achievable targets for dam managers.
- Economic analysis outlined basic monetary benefits of CWP mitigation, however further detailed assessments are recommended to quantify potential realised benefits with further attention required of social, cultural, and economic factors.

Moving forward, addressing the issue of CWP must consider:

- Securing adequate resources and funding to ensure the outcomes of CWP mitigation are met.
- Targeted research to assist with the understanding and quantification of the causes and impacts of CWP.
- Achievable goals and targets that are:
    - Ecologically relevant.
    - Operationally feasible.
    - Implementable and monitored to demonstrate implications and inform adaptive management.
- Alternative mitigation solutions that address clashing algae management protocols relative to selective withdrawal infrastructure operation.
- A well maintained, on-going monitoring network collecting in-reservoir and downstream temperature data to quantify the effects of mitigation strategies and ensure targets are met.
    - Monitoring of additional water quality parameters (such as cyanobacteria) should be considered, as this impacts the effectiveness of the mitigation strategy employed.
- Detailed economic cost-benefit analysis to quantify and realise the monetary benefits of CWP mitigation, and justify the expected capital and operational costs.

# 12 Methods for mitigating cold water pollution

Two primary CWP mitigation methods were identified as part of Stages One and Two of the Strategy: selective withdrawal and artificial destratification. The following sections describe the two primary techniques used for each of these methods, with reference to their advantages and disadvantages for mitigating CWP as an overall reservoir management option. A review of artificial destratification methods undertaken by WRL provides further detail on each on these mitigation methods (Chaaya and Miller, 2022; Chaaya *et al.*, 2025).

## 12.1 Selective withdrawal

Selective withdrawal is a method by which water is selectively withdrawn from a particular depth in the reservoir to mitigate poor water quality release (US Army Corps of Engineers, 1986; Sherman, 2000; Boys *et al.*, 2009). Withdrawals from the surface mitigate CWP by preventing the release of cold water from deeper parts of the reservoir. In addition to mitigating CWP, this strategy also prevents the release of low dissolved oxygen water with high concentrations of problematic soluble metals and nutrients (Chaaya *et al.*, 2025). Selective withdrawal can also be used to prevent the release of potentially harmful cyanobacteria during bloom events, however this requires withdrawal from below the surface (where cyanobacteria dominate (Spigel and Imberger, 1987; Hamilton *et al.*, 2016)) which often results in the release of cold water (i.e. CWP).

Selective withdrawal is generally achieved through multi-level offtake infrastructure; however an alternative thermal curtain technology was explored as part of the Strategy.

### 12.1.1 Multi-level offtake

Multi-level offtakes (Figure 12-1) were the primary mitigation method considered as part of Stages One and Two of the Strategy. This infrastructure generally incurs significant capital costs, particularly if a retrofit is required, with the advantage of having lower operational costs (compared to artificial destratification alternatives). While multi-level offtakes have had demonstrated success for mitigating CWP, they also can carry the risk of entraining and releasing downstream potentially toxic cyanobacteria blooms. Water authorities generally prioritise the mitigation of cyanobacteria release downstream due to the risk to human health, the potential for seeding downstream water bodies and an increase in water treatment costs. This prioritisation consideration may greatly limit withdrawal from the surface, and thus, the ability to mitigate CWP. Moreover, this limitation is further compounded due to cyanobacteria blooms more frequently occurring in warmer months, when CWP mitigation methods are required. Further, sudden changes to withdrawal depth can result in the sudden introduction of cold water (known as “cold shock”), which can have significant impacts on fish populations downstream including mortality (Michie *et al.*, 2020b).

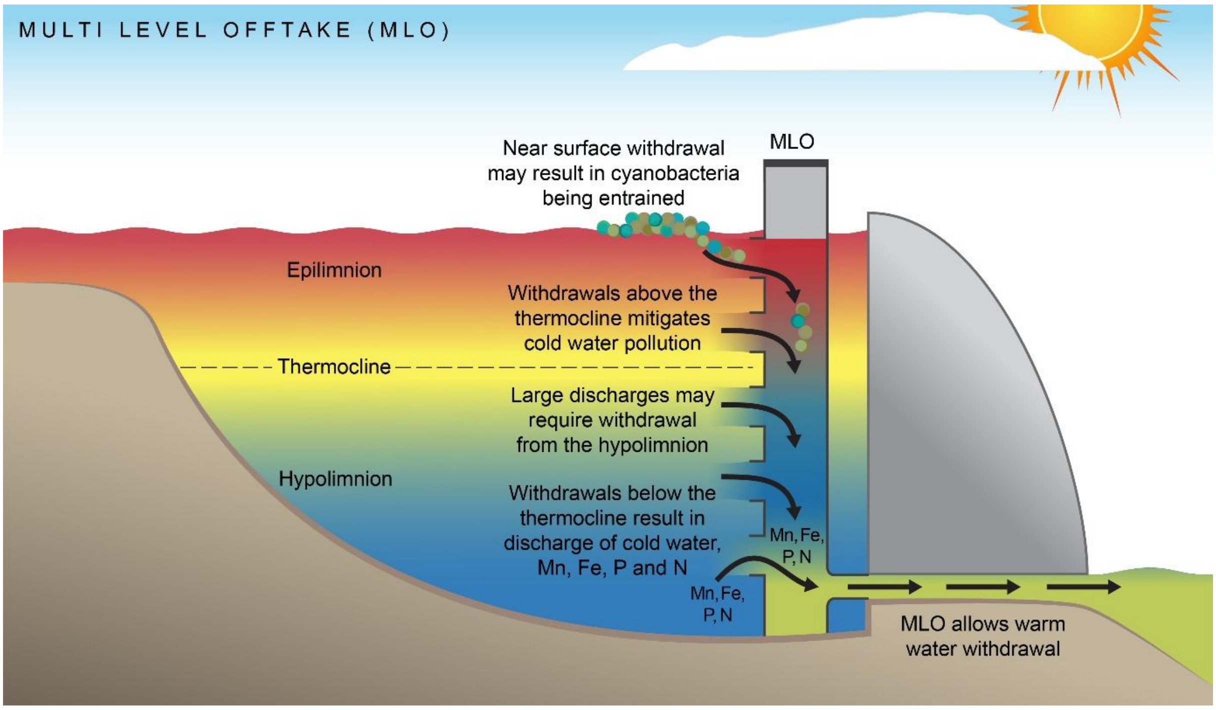


**Figure 12-1 Conceptual diagram of multi-level offtake operations (Chaaya *et al.*, 2025)**

Table 12-1 summarises the advantages and disadvantages of multi-level offtakes.

**Table 12-1 Advantages and disadvantages of multi-level offtakes**

| Advantages | Disadvantages |
|---|---|
| • Selective withdrawal from warm waters above the thermocline can CWP to the downstream environment (Sherman, 2000).<br>• Selective withdrawal can be utilised to avoid poor quality hypolimnion water.<br>• Selective withdrawal can be utilised to avoid discharging toxic cyanobacteria to the downstream environment, by withdrawing from waters below the surface (Preece, 2004).<br>• Multi-level offtakes could theoretically be operated as a means of restoring environmental flows (Olden and Naiman, 2010).<br>• Selective deep withdrawal could be used to enhance vertical mixing, which may improve the overall quality of water in the reservoir (Li et al., 2020; Li et al., 2018).<br>• Operationally lower cost than other alternatives. | • Effectiveness may be limited due to the inability to mitigate CWP and the release of cyanobacteria downstream concurrently.<br>• Potential for cold shock to cause fish mortality downstream (Michie *et al.*, 2020b)<br>• Retrofitting a dam with a MLO is considerably more expensive than alternative strategies (Sherman, 2000). For this reason, it is commonly perceived as a high-cost option to mitigating CWP (Sherman *et al.*, 2007; Olden and Naiman, 2010).<br>• Larger withdrawals can result in the entraining and withdrawal of unwanted waters, which may reduce the benefit of the MLO (Boys *et al.*, 2009; Olden and Naiman, 2010).<br>• Withdrawal volumes may be limited by temperature and water quality requirements, |

| Advantages | Disadvantages |
|---|---|
| | given each offtake point is limited to a particular flow rate.<br>• Time and labour are required to move bulkheads to adjust for variations in stratification structure and reservoir levels (Ryan *et al.*, 2001). May require one man-day of labour to adjust (Sherman, 2000).<br>• Maintenance may be complicated and laborious, depending on offtake depths. |

## 12.1.2 Thermal curtain

Thermal curtains were proposed as a low-cost alternative to retrofitting a multi-level offtake for selective withdrawal purposes. As part of Stages One and Two, a thermal curtain was designed and installed at Burrendong Dam to mitigate CWP downstream. Unfortunately, due to ongoing operations and maintenance issues, the curtain was later decommissioned and considered to be an ineffective alternative.

A thermal curtain operates under the same principal as a multi-level offtake, allowing withdrawal from the surface of a reservoir to prevent the release of cold water (Figure 12-2). In the case of Burrendong, an impermeable curtain was suspended around the offtake tower and lowered to a depth below the surface which prevented passage of water below this depth downstream (Sherman, 2000; Gray *et al.*, 2019).

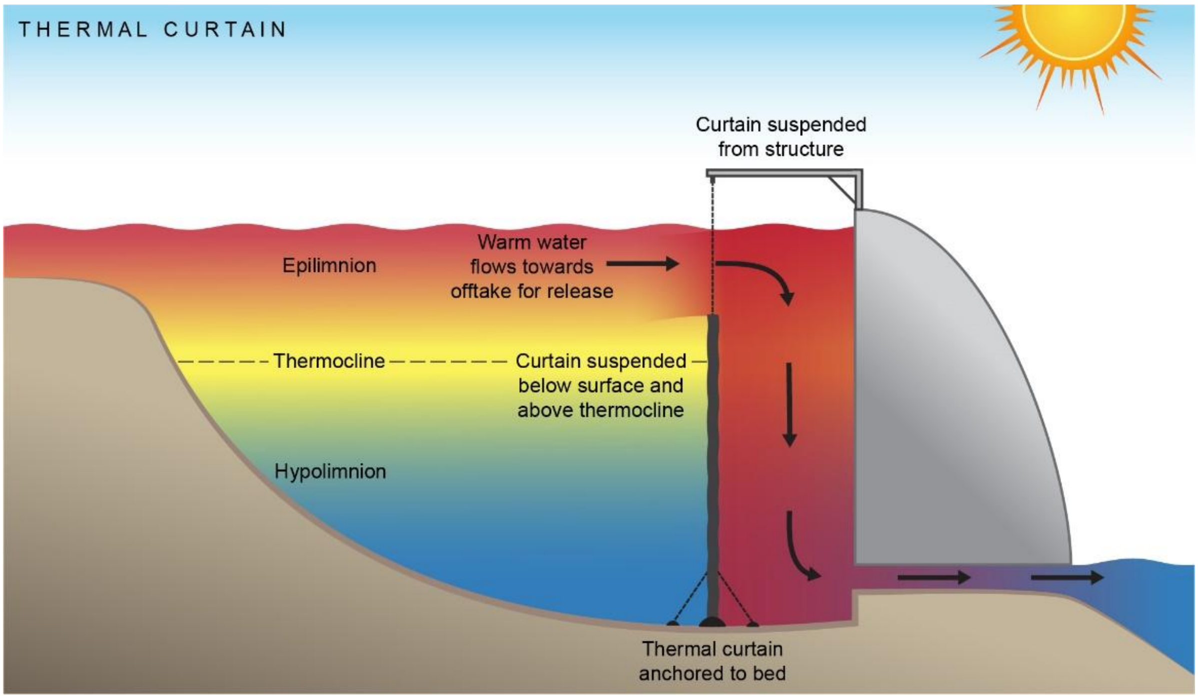


**Figure 12-2 Conceptual diagram of a thermal curtain**

While thermal curtains generally share the same advantages and disadvantages as multi-level offtakes (see Table 12-1) by nature of being a selective withdrawal method, they typically involve more complex maintenance operations, particularly for the curtain components anchored to the seabed. Additionally, thermal curtains do not provide the same level of risk mitigation for the release of cyanobacteria downstream. However, the installation of thermal curtains on an existing offtake tower can significantly reduce capital costs compared to retrofitting a multi-level offtake.

## 12.2 Artificial destratification

Artificial destratification is an alternative to selective withdrawal for mitigating CWP. It involves artificially mixing a stratified reservoir water column to ensure that the heating occurring at the surface can reach the reservoir bed (Pastorok *et al.*, 1982; Sherman, 2000; Chaaya *et al.*, 2025). This method allows withdrawal from any depth in the water column while mitigating the release of cold water.

In addition to mitigating CWP, effective artificial destratification can result in other water quality improvements both in the reservoir and in the downstream riverine environment. Destratification promotes oxygenation of water in deeper parts of the reservoir, a process which is otherwise limited in a stratified reservoir (Steichen *et al.*, 1979; Miles and West, 2011; Liu *et al.*, 2019). Increases to dissolved oxygen concentrations at the water-sediment interface at the reservoir bed mitigates the release of soluble metals such as iron and manganese (Beutel *et al.*, 2008; Bryant *et al.*, 2011; Li *et al.*, 2019) and nutrients such as phosphorus and nitrogen (Beutel *et al.*, 2008; Shi *et al.*, 2022) which degrade water quality both in and downstream of the reservoir (if released). Furthermore, artificial destratification has the potential to reduce potentially harmful cyanobacteria growth by limiting nutrient availability and removing cyanobacteria's competitive advantage in a stratified reservoir through their ability to regulate buoyancy (Visser *et al.*, 1996, 2016; Wallace and Hamilton, 1999).

The primary advantage of artificial destratification compared to selective withdrawal is the potential to prevent CWP at all times by maintaining a destratified water column. Additionally, artificial destratification generally has lower capital costs; however, this is offset by higher operational costs (compared to selective withdrawal) due to energy use. Advances in renewable energy (e.g. solar arrays and batteries) means that operational costs could potentially be converted into capital costs. Integrating renewable energy into the design of these systems is recommended for advancing financial and environmental sustainability.

Artificial destratification is generally achieved using bubble plumes or mechanical mixers. WRL's international literature review of artificial destratification systems provides detailed, systematic analysis of these systems (Chaaya *et al.*, 2025).

### 12.2.1 Bubble plumes

Rising bubble plumes are the most commonly employed technique for artificially destratifying a reservoir (Figure 12-3). Destratification is achieved by transporting compressed air through a pipe network to diffusers located in the deepest part of a reservoir. Air is released through small nozzles, creating plumes of rising bubbles which entrain cold water from the depth of the diffuser to the surface. As colder water detrains from the plume at the surface, it sinks to a level of neutral buoyancy and propagates away from the plume, setting up circulations that break down or prevent the formation of stratification (Chaaya *et al.*, 2025).

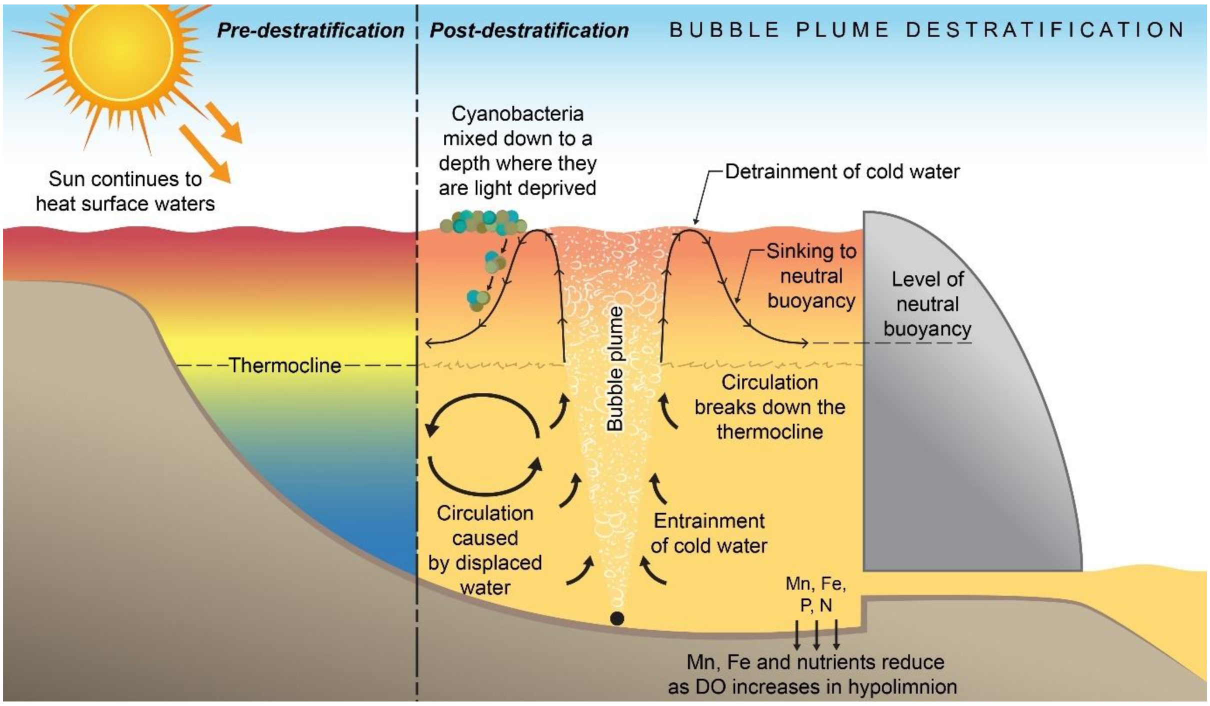


**Figure 12-3 Conceptual diagram of bubble plume artificial destratification**

WRL's systematic review of 138 destratification systems world-wide demonstrated that bubble plume destratification was the most effective overall destratification method. Additionally, destratification was demonstrated over a range of reservoir sizes, highlighting the technology's capability to be scaled effectively. A key link was drawn between successful thermal destratification (necessary for mitigating CWP) and correctly designed air flowrates based on the capacity of the reservoir in which the system was installed. High operational costs that scale with reservoir size have historically limited the success of these systems in larger reservoirs. However, advancements in renewable technology and the ability to optimize operations using variable speed drive compressors are expected to increase the effectiveness bubble plume destratification in larger reservoirs. Overall, correctly designed bubble plume destratification systems are considered to be the most effective means of mitigating CWP and other stratification-related impacts.

Table 12-2 summarises the advantages and disadvantages of bubble plume destratification.

**Table 12-2 Advantages and disadvantages of bubble plume destratification**

| Advantages | Disadvantages |
|---|---|
| • Proven to be effective in redistributing temperature throughout the water column, increasing deep water temperature in reservoirs and reducing CWP due to withdrawal at deep offtakes (Sahoo and Luketina, 2006; Miles and West, 2011). | • Circulation of anoxic and nutrient-rich waters to the upper layers of a reservoir can facilitate increased cyanobacteria and algal blooms by providing nutrients for growth (Barbiero *et al.*, 1996; Elliott and Swan, 2013). |
| • Restore oxygen to anoxic hypolimnion waters by physically mixing saturated surface waters to the bottom of the reservoir | • Toxic cyanobacteria may be mixed to the depth of an offtake that would otherwise avoid it, resulting in a discharge of toxic algae downstream. |

| Advantages | Disadvantages |
| --- | --- |
| (Ashby and Kennedy, 1993; Bryant *et al.*, 2011; Li *et al.*, 2019).<br>• Inhibit the release of iron, manganese and other nutrients from sediments by restoring oxygen to hypolimnion waters (Toetz and Summerfelt, 1972; Bryant *et al.*, 2011).<br>• Can be an effective method of controlling cyanobacteria growth. Mixing through the water column eliminates the buoyancy advantage held by cyanobacteria, and reduces growth rates by transporting algae to light-deficient depths (Ashby and Kennedy, 1993; Visser *et al.*, 2016).<br>• Bubble plume destratification attributed to lowering reservoir water pH, which facilitates an increase in green algae growth which is favourable compared to cyanobacteria (Pastorok *et al.*, 1982; Cowell *et al.*, 1987)<br>• Perceived as a low-cost alternative to retrofitting a MLO, based on initial capital investment (Sherman, 2000). However operational cost must be considered in these comparisons.<br>• Destratification can affect an increase in the heat budget of the reservoir, by mixing cold hypolimnion waters to the surface (Haynes, 1975). This can increase the overall efficiency of the system in warming the reservoir and mitigating CWP.<br>• Potential for reduced evaporation through lowered surface water temperatures. | • Intermittent or insufficient mixing can lead to favourable conditions for cyanobacteria growth (Lewis, 2004; Jöhnk *et al.*, 2008; Visser *et al.*, 2016).<br>• Operational costs increase significantly for larger and deeper reservoirs, due to the volume of water required to be destratified (Sherman, 2000; Ryan *et al.*, 2001).<br>• Limitations may exist for significantly large reservoirs based on power availability for the site at which the system is installed.<br>• System maintenance can be difficult, given most of the piping network is usually anchored close to the reservoir bed.<br>• Line failures or blockages may be laborious to remediate. Stratification can reinstate quickly, and water quality may be significantly worse than it would have been without the system (McAuliffe and Rosich, 1989).<br>• Rapid destratification can result in oxygen depletion due to mixing of hypolimnetic waters and high BOD sediments. This can result in fish-kills (Pastorok *et al.*, 1982). |

## 12.2.2 Mechanical mixers

Mechanical mixers are an alternative method for reservoir destratification (Figure 12-4). Mixers, usually mounted near the surface of the reservoir, jet water from the surface to deeper sections of the reservoir (Toetz, 1977) or draw water towards the surface (Symons *et al.*, 1970). Similar to bubble plumes, water exits the jet and sinks or rises to a level of neutral buoyancy, setting up circulations which promote breaking down or preventing the formation of stratification. Mechanical mixers are often accompanied by a draft tube that extends below their mounted location to direct water to a desired depth (Brookes *et al.*, 2008) for increased effectiveness.

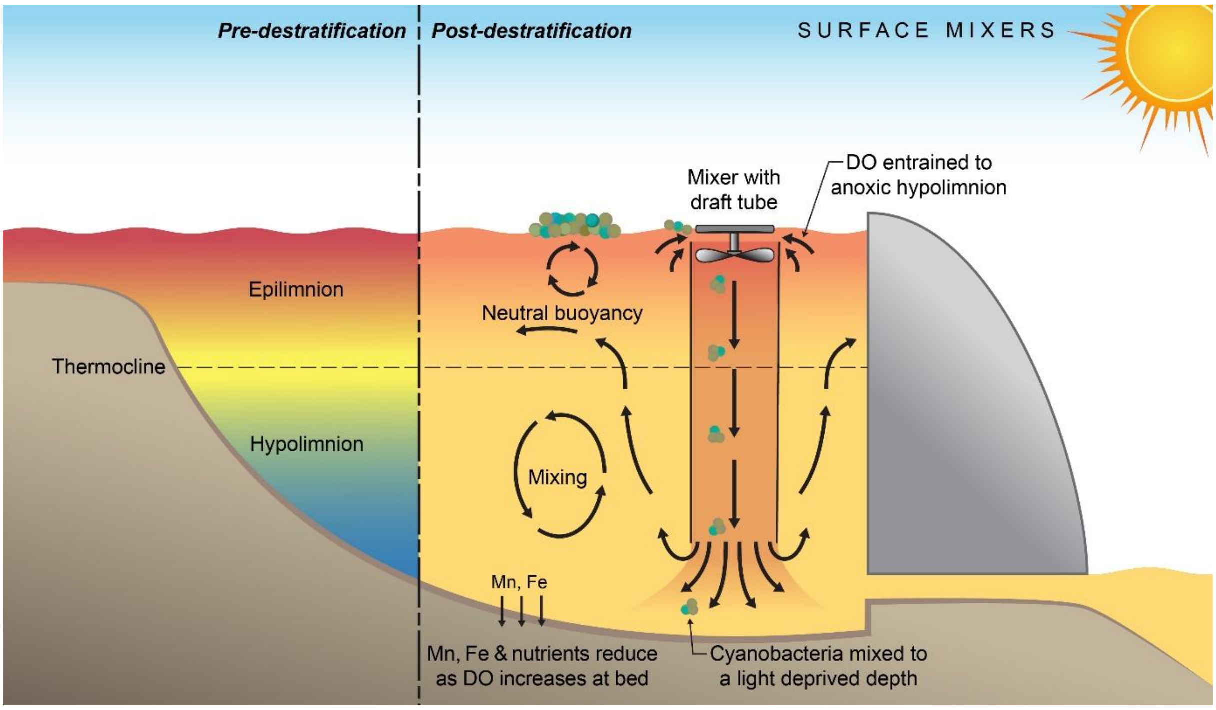


**Figure 12-4 Conceptual diagram of surface mixer artificial destratification**

While these systems operate in a conceptually similar fashion to bubble plumes, mechanical mixers produce more localised mixing effects. For this reason, bubble plumes are considered more feasible for large scale operations in larger reservoirs. The addition of a draft tube, generally required for deeper reservoirs where cold water pollution is prevalent, can complicate installation and operation where internal currents place a large load on the draft tube. Draft tubes can also have limited application in reservoirs that experience large water level fluctuations.

Table 12-3 summarises the advantages and disadvantages of mechanical mixer artificial destratification.

**Table 12-3 Advantages and disadvantages of mechanical mixer destratification**

| Advantages | Disadvantages |
|---|---|
| • Effective method of local destratification. Depending on the goal of the system, a surface mixer may be adequate to mix waters around an offtake (Mobley *et al.*, 1995).<br>• Maintenance of system likely to be significantly easier than the alternatives, given that most of this system is accessible at the reservoir surface.<br>• Draft tubes allow mixing to a desired depth, which can be of benefit in for cyanobacteria control. Mixing toxic algae to a specific depth can limit light exposure and inhibit growth. | • Incapable of achieving the 15% mechanical efficiency theoretically possible with bubble plumes (maximum 12%, (Stephens and Imberger, 1993)).<br>• Jets that penetrate close to the bed of the reservoir may erode and resuspend bottom sediments (Sherman, 2000).<br>• Can result in localised circulation cells (Lawson and Anderson, 2007), and thus be ineffective for whole-reservoir destratification.<br>• Localised effects may result in negative impacts in other parts of the reservoir (Suter |

| Advantages | Disadvantages |
| --- | --- |
| | and Kilmore, 1990), e.g. nutrient supply to toxic algae.<br>• Unconfined jets from surface pumps without a draft tube may be ineffective due to kinetic energy lost through turbulence as surrounding water is entrained (Kirke and El Gezawy, 1997).<br>• Modelling of specific reservoirs have shown that surface pumps may provide no benefit to algal control compared to bubble plumes (Antenucci *et al.*, 2001).<br>• Negative effect of suppressing favourable algae species as well as cyanobacteria (Antenucci *et al.*, 2001). |

# 13 Summary

Cold water pollution is a complex but important ecological and social issue to resolve. The impacts of CWP in NSW have been recognised and reported on for over 20 years. In this time, attempts to address the issue have primarily come through Stages One and Two of the NSW Cold Water Pollution Strategy, which aimed to:

- Prioritise dams at which CWP should be addressed.
- Implement CWP mitigation infrastructure and operations at high priority dams.
- Develop a governance framework and Interagency Group to coordinate the implementation of the strategy and whole-of-government response to CWP.
- Implement and maintain a temperature monitoring network.
- Develop guidelines and performance criteria to assist:
    - Dam managers in achieving mitigation goals.
    - Monitoring the implementation and success of mitigation operations.

Despite the recognition of the impacts of CWP and actions undertaken to address the aims outlined above, progress over the course of Stages One and Two has been limited. This was primarily due to:

- A lack of understanding of the complexity of the issue.
- A lack of appropriate resourcing and funding for staffing, studies, monitoring and mitigation infrastructure.
- A lack of existing data and monitoring to achieve a better understanding of the complex issue.
- Difficulty implementing mitigation guidelines.
- Difficulty achieving the quantitative performance criteria included in the guidelines.

Knowledge about CWP has advanced since the development of the Strategy, whilst a number of related actions and goals remain incomplete. These actions should be reviewed in a detailed manner for any additional progress since the completion of Stage Two. Drawing from the limitations observed and the lessons learned in reviewing the Strategy, ongoing and future mitigation efforts should concentrate on:

- Finalising a metric applicable to all high priority dams for the purposes of quantitatively measuring CWP and effectiveness of mitigation measures. This should consider ecologically significant temperatures and thermal regimes, as well as the interplay between asset operations, and quantifying compliance.
- Finalising guidelines including the previously mentioned 5 day anomaly metrics. The evolving nature of the guidelines to this day may have contributed to a lack of commitment to solutions.
- Updated protocols for existing multi-level offtake infrastructure based on an agreed CWP metric.
- Developing a detailed understanding of the operational limitations for CWP mitigation due to the presence of cyanobacteria in reservoirs and the operational constraints for dam owners under algal management guidelines, especially for selective withdrawal methods (multi-level offtake, thermal curtain).
- Exploring alternative mitigation strategies (artificial destratification) that present an opportunity to mitigate water quality degradation caused by stratification in reservoirs. Artificial destratification was largely ignored in favour of selective withdrawal methods due to the significant operational costs. These costs may be offset by additional benefits to water quality and via the use of renewable energy that wasn't available during Stages One and Two.

- Performing an in-depth economic assessment of the benefits of mitigating CWP, including previously considered ecological benefits, increased downstream water quality, and improved recreational value. If destratification is considered, multiple in-reservoir benefits should be realised, including improvements in recreational value, in-reservoir water quality, reduced evaporation and algae mitigation. Renewable energy sources should be considered in this economic assessment.

While this specific assessment was not included as part of the Strategy, the international literature review undertaken by WRL (Chaaya and Miller, 2022; Chaaya *et al.*, 2025) highlights the benefits of bubble plume destratification over alternative destratification or selective withdrawal methods.

Selective withdrawal methods, based on current algae management guidelines, are inherently limited by the presence of cyanobacteria. Mechanical mixers have typically been reported to result in more localised mixing. This, along with the need for large draft tubes in deeper reservoirs, limit their feasibility in large reservoirs where CWP is a significant problem. While the adoption of bubble plumes has been constrained by higher operational costs, incorporating renewable energy and optimised operations enhances their feasibility for large-scale applications.

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