Mechanical Destratification For Reservoir Management:
An Australian Innovation

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Abstract

The low-velocity, high efficiency mechanical destratification system, with flexible draft tube, developed by Water Engineering And Research Solutions Pty Limited (WEARS Australia) has demonstrated in a number of applications the benefits of the system, both for oxygenation of benthic layers to reduce dissolution of iron and manganese, and for the control of algal blooms by pumping the surface layers down into light-limiting zones.

Introduction

Artificial destratification involves mixing the water body to dissipate thermal layers, with the aim of achieving a uniform temperature and oxygen gradient over the depth of the storage. The benefits are:

- Autumn turnover is eliminated and therefore anoxic and toxic water is prevented from mixing through the water column.
- Water drawn off is of more uniform quality and therefore potentially easier to treat.
- Blue Green Algae is controlled and the use of chemicals or PAC eliminated.
- Metals such as manganese (Mn) and Iron (Fe) are oxidized out of the water.
- Fish habitat in the reservoir is improved
- Cold water with low DO released from the lower levels of a dam, which can upset fish migration patterns downstream (Mobley et al, 1995, Greene et al, 1997), is minimized.
- Ecological balance of a degraded storage is restored.

Over the past 40 years attempts to artificially destratify dams and reservoirs have been made with limited success. Adaptations of mechanical impellers were made where little was known of flow rate requirements, jet velocities, optimum location and direction and operating protocols. Bubble plume systems, with either an air curtain or point aeration have been used in Australia and overseas. These compressed air destratification systems consume high energy (about 100kW in a typical medium size dam). However, McAuliffe and Rosich (1990) reported that bubble plume systems have had limited success in reducing undesirable algal species in a little over 50% of cases, and have reduced manganese, iron or sulphides in only 69% of cases. Blackman, (2001) reported that only 53% of compressed air systems were successful to some extent and only 11% of dam managers reported that they were fully satisfied with the success of the system in their dam. Many bubble plume installations stand idle since their ability to solve the problem has not been realised, and their operating costs are high. Thus the only viable alternative was seen to be expensive treatment of the poor quality raw water at the treatment plant

A New Development

An Australian-owned company; WEARS Australia, has, in recent years, developed and internationally patented a large Surface Mounted Destratification Impeller system, or SMDI, specifically designed for reservoir destratification, that is currently achieving a 100% success rate in terms of:

- Increased efficiency compared with traditional aeration systems,
- Improved raw water quality thereby reducing treatment costs, and
- Minimizing the reservoir managers risk of toxic algal blooms

This new technology uses a low energy (4-8kW) mechanical circulation system that efficiently and effectively moves water through the thermocline; i.e. the thermal barrier between surface water and bottom water thereby artificially destratifying the whole of the storage.

Unlike traditional aeration systems that attempt to raise anoxic bottom water from the hypolimnion, often loaded with dissolved metals, such as reduced iron (Fe) and manganese (Mn) as well as nutrients, to mix with the water high in dissolved oxygen (DO) at the surface, the WEARS system moves DO saturated surface water to the hypolimnetic bottom region where high biological oxygen demand (BOD) and high chemical oxygen demand (COD) occur. By removing the surface layer and directing flow to the hypolimnetic bottom layers the: (i) rate of transfer of oxygen at the surface interface is increased, (ii) nett DO distribution throughout the whole storage is maximized, and (iii) nutrients (which feed algal blooms) are not brought to the surface and made available for algal growth at the euphotic zone.

Top-down circulation is desirable in the control of Cyanobacteria or Blue Green Algae The surface layer, where algae breed, is sucked in and discharged below the euphotic zone. The algae are thereby light-limited, transported through turbulent flow, and subject to an instantaneous pressure change. This creates an environment that is unfavorable for the cell growth and the life cycle of Cyanobacteria is disrupted.

Energy Requirement

The small model, SMDI-2.5, is powered by a 1.1KW electric motor and is capable of destratifying a storage volume of up to 4,200ML, the larger SMDI-5 with a 4KW motor will destratify a storage of approximately 18,500ML. Outstanding results in larger reservoirs of over 30,500ML have been achieved with the close-coupled SMDI-5 and there opportunity now exists to solve problems in very large storages greater than 100,000ML. The system incorporates variable speed drives with smart programmable electronics enabling impeller speed to be set and controlled so flow rates match storage capacities thus eliminating unnecessary power consumption. Once a uniform thermal profile has been established, static head due to the density gradient is reduced to almost zero and so the required power is reduced even further.

Figure 1 below, compares the power inputs of a typical bubble plume system with those of an SMDI for various volumes of storage. The reason for the dramatic difference in energy requirements is the exploitation of the principles of hydraulics and fluid dynamics in the liquid phase and the elimination of the inefficiency of air compression.

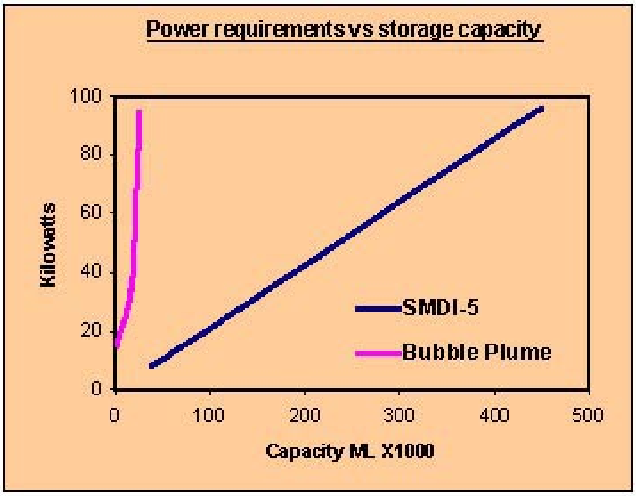


Figure 1. Power requirements of: SMDI-5, and compressor driven Bubble Plume destratification methods, versus storage capacity. Bubble Plume data compiled from actual installations. [Chichester Dam NSW, Bundanoon NSW, Suma Park NSW and others, (Data from Blackman 2001)]

A preliminary design and scoping study (Elliott 1997) compared operating costs of artificial destratification methods proposed for Chaffey Dam near Tamworth NSW and is summarized in Table 1. This study was carried out prior to the new hydrodynamic tapered-twisted carbon-fibre blade profile that was developed in 2001, but still demonstrated that the method had the potential to use only 12% of the power of compressed air systems.

		WEARS	Typical Air Diffuser
No of units		4	1
Power	kW	12	100
Flow	m^3/s	30	40
Efficiency	m^3/s per kW	2.5	0.4
Location		Pontoon	Dam floor
Draft Tube		Yes	No
Power cost	annual	$15,704 *	$87,360 **

Table 1. Cost comparison of the WEARS system with air diffuser for Chaffey Dam (1997) .
Since this study the efficiency of the SMDI has been greatly increased by an improved impeller design and further capital and operational cost savings have been realised.
(*) Operating continuously. (**) Operating 2/3 of the year.

Horizontal Distribution Of Dissolved Oxygen

Warm, oxygen-rich surface water pumped downwards by a mixer will mix to some extent with cooler, lower DO water near the bottom of the jet. It will then find its neutral buoyancy level and flow radially outwards as an intrusive gravity current, thereby transferring DO horizontally. There is very little turbulence and therefore very little mixing between layers beyond the immediate vicinity (approx 180 m radius) of a bubble plume, and the same should be true of a mechanical mixer. Thus it can be expected that a single mixer will have an effect on the DO profile as well as the temperature profile of the whole storage.

Iron And Manganese

The most recently completed project (late June 2002), for the Hunter Water Corporation, was installed to overcome high soluble manganese concentration. A close-coupled SMDI-5 system was installed in Chichester Dam, with a volume of 22,500ML and currently draws 4-5kW of electrical power In this instance the original bubble plume system was achieving satisfactory raw water quality results, however a cost benefit analysis favored the WEARS' SMDI system which uses only ~8.5% of the power during peak season. The bubble plume system is expected to be decommissioned.

Figure 3. SMDI-2.5 installation at the CS Energy Swanbank power station reservoir.

An SMDI-2.5, (Fig 3) unit was installed by CS Energy in Swanbank Dam, their primary storage for plant cooling water, to remove the problem of manganese build-up in the power plant cooling tower. McAlpine (pers comm, 2000.) reported a 5% increase in plant efficiency and removal of the risks to staff from toxic Blue Green Algae contact.

Algal Control

Results following installations of the recently developed SMDI-2.5, and the SMDI-5, show that they have not only exceeded desired outcomes in both thermal and chemical destratification, but have performed exceptionally well in the control of Cyanobacteria. Report on the installation of a SMDI-2.5 in the Timor Dam (2,000 ML) in central NSW indicates successful Blue Green Algal control. Tighe (2000)

Blue green algal counts, which had been historically high, are now continually low (Figure 4). Since the WEARS system was installed there have been no significant blue green algal blooms, and Cyanobacteria has been held at near zero counts since 1999, apart from an identified 'wash-in' event, where 100mm of rainfall in a 24hr period occurred in the upstream catchment and a rapid increase in cell numbers occurred. However within a few days the count was again near zero due to the impact of the SMDI system.

A saving in excess of $25,000 each year has been realised by eliminating the use of powdered activated carbon (PAC) which was previously used to overcome taste and odour problems associated with algal blooms. Tighe (2001).

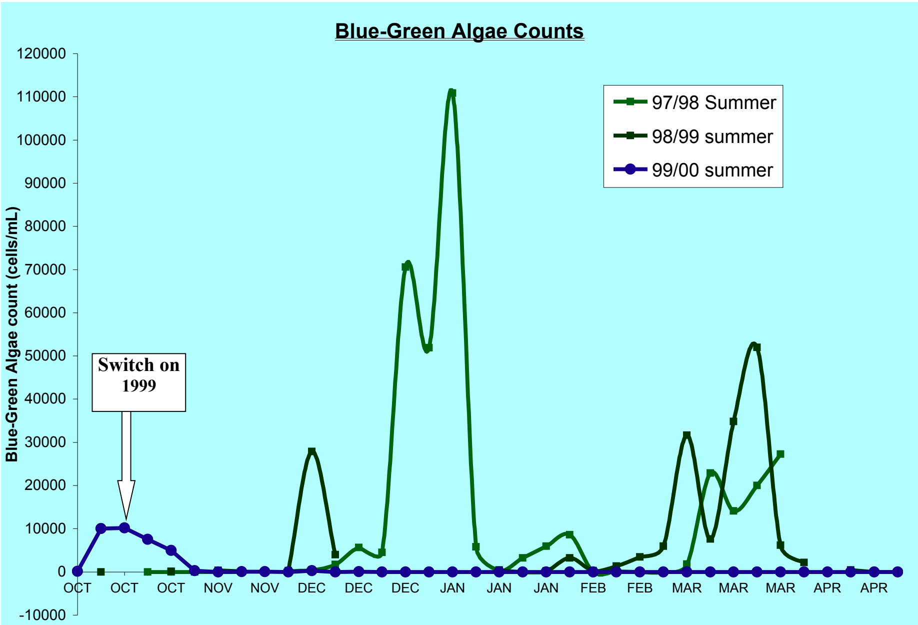


Figure 4: Blue green algal counts in Timor Dam, for summer periods between1997-2000.

Experimental systems, using a prototype impeller blade designed and installed by WEARS at Myponga and Happy Valley SA, have also shown a positive effect in controlling BGA even though these early systems produced less than half of the mass flow rate of the commercial units currently available. Since switching on at Myponga in 1998, the incidence of copper sulphate dosing has been reduced from an average of 4 times per year to only one (Mr. Bob Cuthbert, Storage Manager, pers comm. 1999) which represents a saving of $120,000 in copper sulphate dosing, at a cost of about $1/kg applied.

The Toowoomba City Project

In Toowoomba, on Queensland's Darling Downs, regular algal blooms at the city's three water supply dams resulted in the Toowoomba City Council reassessing its strategies and ability to deal effectively with an organic contamination event. Council's current response plan for algae outbreaks is multilevel, in that it involves both management of the storages by source substitution between the three storages and treatment by chlorination. Toowoomba's water supply is sourced from an aquifer under the city and surface water storages. The surface storages, Lakes Cooby, Perseverance and Cressbrook, provide up to 85% of requirements.

When a storage reaches algal alert level-three (the highest alert level), the storage is taken off line and an alternative supply is selected. If other storages are simultaneously in alert level conditions, a decision is made to take water from the lowest risk storage and to treat it using chlorine. This response plan is limited and there is the possibility that all three water storages might be impacted simultaneously by either level-three algae counts, toxicity, metals in solution or taste and odour compounds.

Design and installation of the traditional type destratification system, using bubble plume technology, was estimated to cost $200,000 per storage, with annual operating (power) costs approximately $20,000 – $30,000. An alternative technique would be to install a PAC facility, at the Water Treatment plant, with the high cost of the activated carbon and the ancillary equipment and process required.

Council's eventual decision to install the WEARS system was influenced largely by the long-term benefits of destratification and the energy savings associated with that system. It was not just a case of avoiding one or two BGA contamination events, but a case of eliminating the incidences of BGA outbreaks. Council felt that the WEARS system was the best way to do that. (Dinsey 2002).

Description of the work

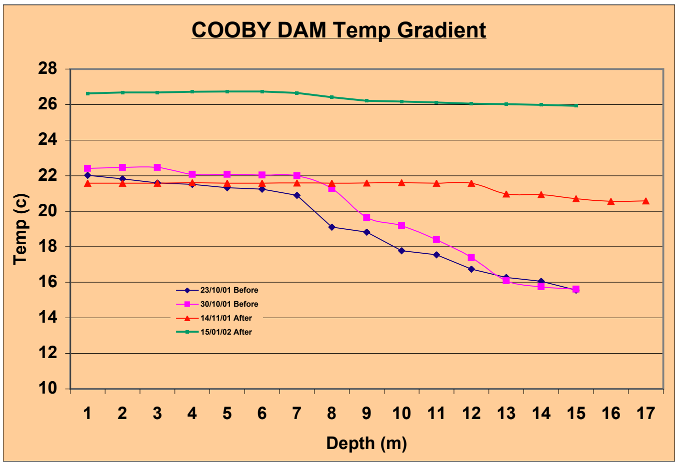
In May 2001, the Council accepted a proposal submitted by WEARS for the design, manufacture, installation and commissioning of low-energy mechanical systems for Lake Cooby and Lake Perseverance. The units incorporate large diameter axial flow impellers located approximately two metres below the water surface. The impellers rotate at a constant, relatively low speed, depending on flow requirement. To achieve the anticipated design flow rates of between 10,000 and 15,000 litres per second, the installations at both storages comprise two units attached by a walkway, with the two contra-rotating impellers each driven by 4KW motors.

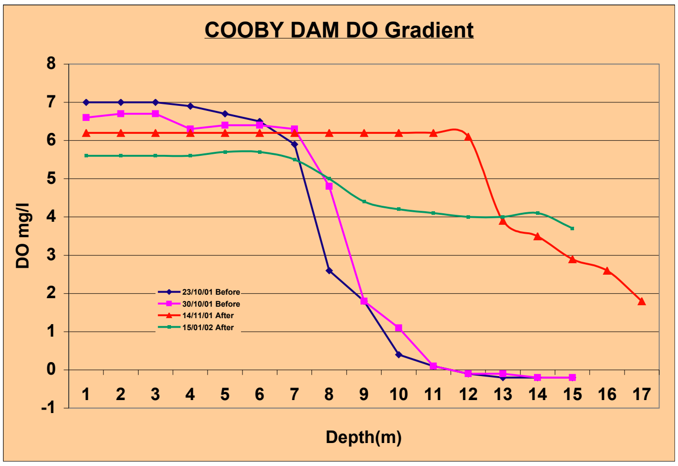
Council adopted this new strategy, instead of the PAC dosing plant at Mt Kynoch or a compressor type system, for several reasons. These included:

- Much lower power requirements of the WEARS reservoir systems resulting in about only 8-10% of the operating costs in terms of electrical energy;
- An ability to use the systems in larger, deeper water storages;
- Control of algal toxins and other water quality problems at the source rather than by treatment of downstream contaminated water at the PAC dosing plant;
- Water supplied to consumers between the water storages and the water treatment plant does not have to be treated independently;

To account for a stronger temperature gradient under Australian summer conditions, the design for the Cooby system was based on a flow rate of 12 cubic metres per second and the Perseverance system on a flow rate of 14 cubic metres per second. The units are designed to operate 24 hours per day all year round.

The dissolved oxygen gradients and temperature gradients for Cooby and Perseverance Dams respectively, clearly demonstrate the effect of the system in breaking the thermal and chemical strata. Figures 5,6,7 and 8 are derived from data collected by Toowoomba City Council's laboratory, courtesy of Mr. Alan Kleinschmidt, Lab Manager. The system was installed late in 2001 in each of these dams





and since this time raw water piped to the Mt Kynock Treatment plant has been greatly improved.

Figure 5. Temperature gradient before and after a WEARS Close Coupled SMDI-5 system was installed at Cooby Dam.

Figure 6. Dissolved oxygen gradient before and after a WEARS Close Coupled SMDI-5 system was installed at Cooby Dam.

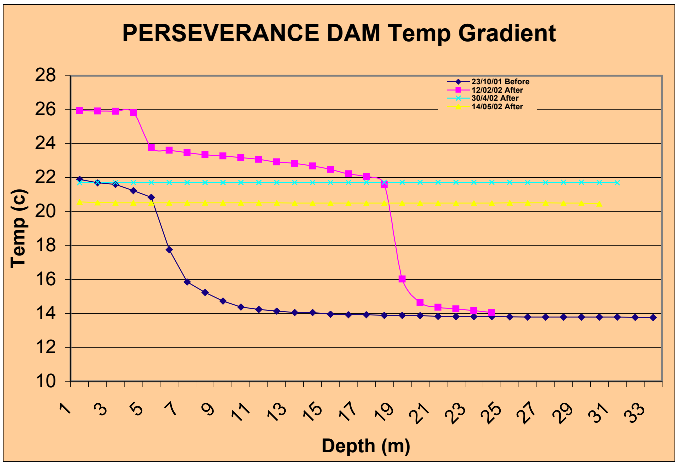


Figure 7. Temperature gradient before and after a WEARS Close Coupled SMDI-5 system was installed at Perseverance Dam.

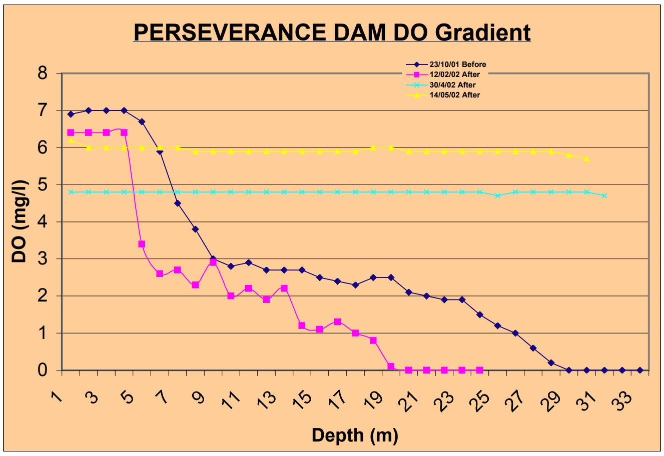
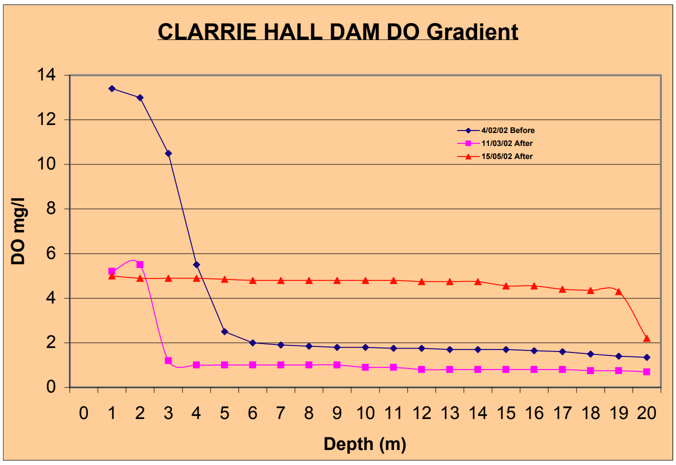


Figure 8. Dissolved oxygen gradient before and after a WEARS Close Coupled SMDI-5 system was installed at Perseverance Dam.

Figure 9. One of the WEARS SMDI-5s, to be coupled with another, being prepared for installation at Cooby Dam for the Toowoomba City Council.

Tweed Shire

Clarrie Hall Dam in the Tweed Shire in northern New South Wales had a single SMDI-5 installed early in 2002 . Given the dissolved oxygen and temperature gradient results shown in Figs 10 and 11, the indications are that improved raw water quality and cost savings will be realised, as with all installations to date.



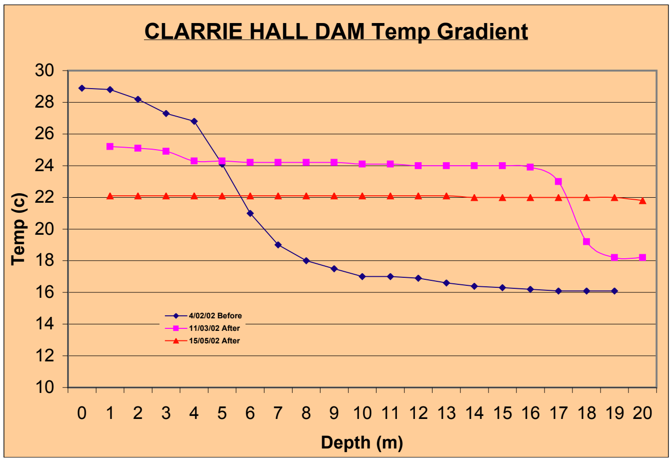


Figure 10. Temperature gradient before and after a WEARS SMDI-5 system was installed at Clarrie Hall Dam.

Figure 11. Dissolved oxygen gradient before and after a WEARS SMDI-5 system was installed at Clarrie Hall Dam.

Conclusion

Water management authorities are becoming increasingly more aware that the WEARS system is the most economic operational tool available to deal with problems associated with water storages such as: autumn turnover, metals in solution, eutrophication, Blue Green Algal blooms, all of which contribute to problems of taste, odour and quality, along with downstream cold water pollution or downstream cold water discharge, general raw water quality and reservoir ecological health. Problems that have traditionally been expensive to overcome in terms of ongoing costs and capital expense are now available to both large and small reservoir management authorities.

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