ARTIFICIAL AERATION OF AUCKLAND'S LAKES

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ABSTRACT

Through effective management of source waters, suppliers can improve raw water quality thereby reducing the overall cost of treatment and, ultimately, the cost to the consumer.

Watercare manages ten man-made lakes, which combined can provide up to 480,000m^3/day of water for treatment at three main Water Treatment Plants.

These lakes are susceptible to seasonal stratification, which historically resulted in elevated iron and manganese concentrations and unpleasant taste and odours. These could not be sufficiently removed by the downstream treatment processes, therefore the aesthetic quality of the treated water deteriorated.

From 1974, Watercare implemented artificial aeration systems in each of its lakes in order to prevent stratification over the summer period. The systems successfully reduced iron and manganese concentrations and prevented unpleasant taste and odours.

As the systems ran continuously between October and April, this was identified as an area where efficiency gains could be realised. In 2007, a revised aeration strategy was developed that successfully minimised energy consumption while maintaining water quality.

Further strategies for improving the efficient aeration and management of Auckland's lakes are also being investigated.

KEYWORDS

Source management, lakes, aeration, energy, turnover.

1 INTRODUCTION

Watercare Services Limited is New Zealand's largest company in the water and wastewater industry. Watercare supplies bulk water to the Auckland region, an area of approximately 340 square kilometres through a bulk water network. Currently, six Local Network Operators supply this bulk water to the people of Auckland through local reticulation networks.

An average of 370,000m^3 of water daily is abstracted from 12 sources comprising 10 man-made lakes, the Waikato River and an aquifer.

The lakes, with depths ranging from 18m to 60m, are split evenly between the Hunua Ranges in the south of the region and the Waitakere Ranges in the west.

The dams retaining the lakes were constructed between 1910 and 1977. Combined, the lakes can hold up to 96,000,000m^3 of water.

Water can be abstracted through a number of intakes located at various depths along the height of the valve tower in each lake. This enables the abstraction depth to be varied in response to changes in water quality, thereby ensuring the highest quality water is abstracted.

The lakes serve as the first barrier in the treatment process since sediment particles settle down on the bed of the lake and enteric coliforms die off in 2-3 hours in strong sunlight and around 10 hours in more turbid water (Twort et al., 2000).

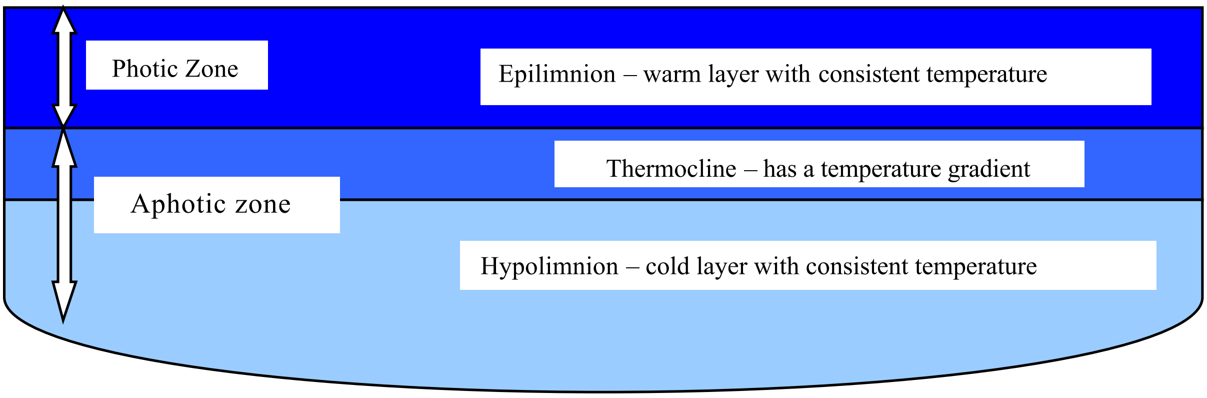
2 STRATIFICATION

2.1 LAKE STRATIFICATION

Stratification is the process by which three distinct temperature layers are formed in a water body. The warmer epilimnion forms at the surface, due to solar radiation warming the water. The depth to which sunlight can penetrate the water is known as the photic zone and the region below this being the aphotic zone.

The colder hypolimnion forms at the bottom and the intermediary layer, with a temperature gradient, is called the thermocline, as shown in Figure 1, below.

Figure 1 - Lake stratification layers



Theoretically, the temperature throughout the lake should decrease with depth, reflecting the profile of solar energy absorption (Ragotskie 1978), but in reality the temperature throughout the epilimnion is consistent.

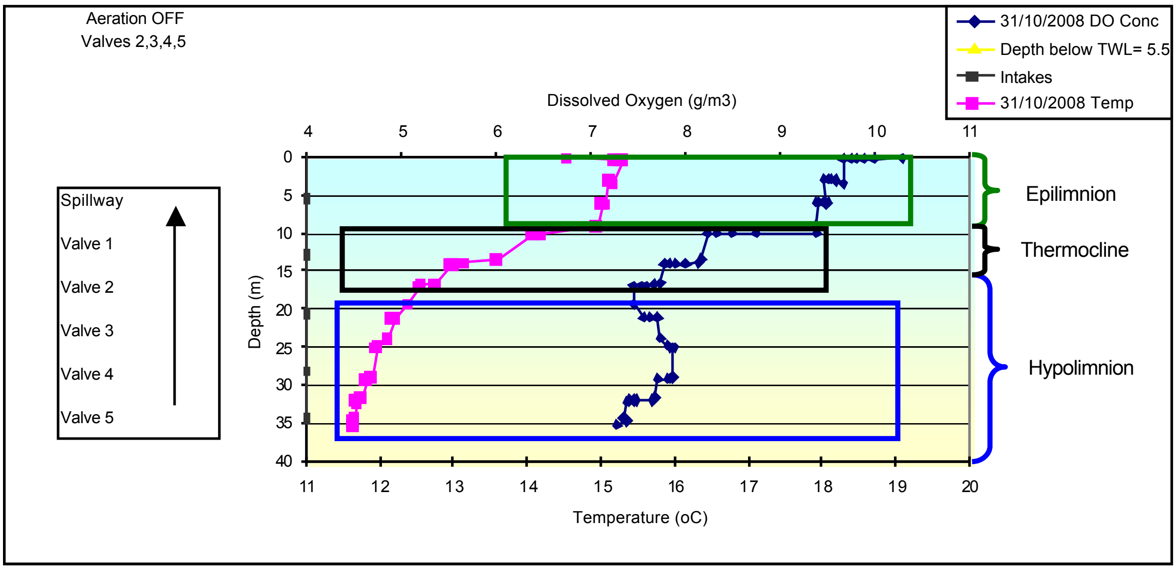
If time was not a factor, diffusive heat transport on a molecular level would distribute the temperature throughout the lake but this is a slow process requiring a time period in the order of a month for the transport of heat over a vertical distance of one metre (Boehrer & Schultze 2008). The consistent temperature throughout the epilimnion is mainly a result of natural mixing by the wind. This also ensures that the epilimnion contains sufficient concentrations of dissolved oxygen (DO). Oxygen is also introduced into this layer through photosynthesis by algae and cyanobacteria.

Warmer water in the epilimnion is less dense and so floats on top of the colder layers below. The depth of the epilimnion is limited to the depth at which the force of the wind is equal to the positive buoyancy of the warmer water (Lampert & Sommer 2007).

Continental lakes have warmer and shallower epilimnia (Hutchinson 1957), but New Zealand lakes typically have oceanic thermal profiles with relatively cool epilimnia mixed to relatively deep depths by frequent strong winds from the maritime climate (Jolly & Irwin 1975).

Mixing does not occur between the layers, so the colder hypolimnion also contains less DO than the epilimnion. The temperature and DO differences at the onset of stratification in Wairoa can be seen as seen in Figure 2.

Figure 2 - Onset of stratification in Wairoa



The sunlight, warm temperature, and high DO concentrations make the photic zone within the epilimnion the ideal environment for the growth of algae and cyanobacteria. They will not survive in the aphotic zone, since they require sunlight for photosynthesis.

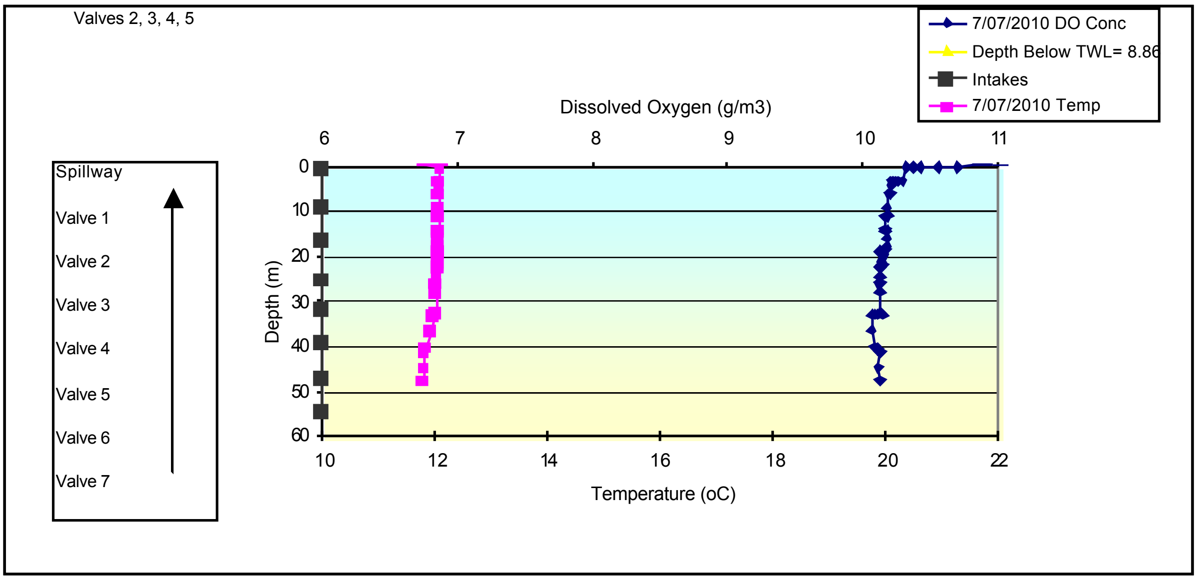
Certain algae and, more significantly, cyanobacteria produce compounds that cause the water to have an unpleasant taste and odour. In large concentrations, such as cyanobacterial blooms, the risk of raw water quality deterioration increases. Certain species of cyanobacteria can also produce harmful cyanotoxins.

When the algae and cyanobacteria in the epilimnion die, they sink to the bottom of the lake where they undergo bacterial decomposition. This process depletes the already low DO concentration within the hypolimnion until the layer becomes anoxic.

Independent of temperature, below DO concentrations of around 6mg/l, particulate iron and manganese will begin to solubilise (Gibbs et al., 2006). This is due to the reduction/oxidation process. This process can also lead to the production of hydrogen sulphide which further deteriorates the taste and odour of the water.

During the autumn/winter, the temperature of the epilimnion cools allowing mixing of the layers to occur. This continues until the temperature and DO concentrations throughout the lake are consistent, as shown for Mangatangi in Figure 3.

Figure 3 – Mangatangi winter temperature and dissolved oxygen concentration



Decomposed organic matter, taste and odour compounds and the soluble iron and manganese previously contained in the hypolimnion now becomes distributed throughout the lake. Not only does this provide an abundance of nutrients to stimulate growth of further algae and cyanobacteria leading to further risks of taste and odour compounds and cyanotoxins, but it means poor quality water will now be abstracted irrelevant of which intake is used. This has a number of impacts on the downstream water treatment process and supply.

Cyanotoxins, in sufficient concentrations, present risk to public health. They can be removed by expensive Granular Activated Carbon filters, if they form part of the treatment process. If not, the source must be isolated and alternate supplies provided. This may lead to supply restrictions.

Decomposed algal/cyanobacterial organic matter, if not removed prior to disinfection with chlorine, may result in the formation of disinfection by-products, in particular trihalomethanes.

The mixing of the higher DO in the epilimnion with the lower DO of the hypolimnion and oxygenation through exchanges with the atmosphere, for example in open process vessels, converts soluble iron and manganese back into particulate form. If this is not removed by the treatment process, it will collect in the distribution system, eventually leading to discoloured water complaints from consumers.

The most prevalent risk from stratification is consumer complaints of unpleasant taste and odour. Taste and odour compounds can be effectively removed through the use of Powdered Activated Carbon (PAC). The odour compounds adsorb onto the PAC, which are then removed through the treatment process. However, treatment with PAC is expensive.

These risks to water quality and the associated treatment costs can all be minimised through the prevention of stratification.

2.2 DESTRATIFICATION

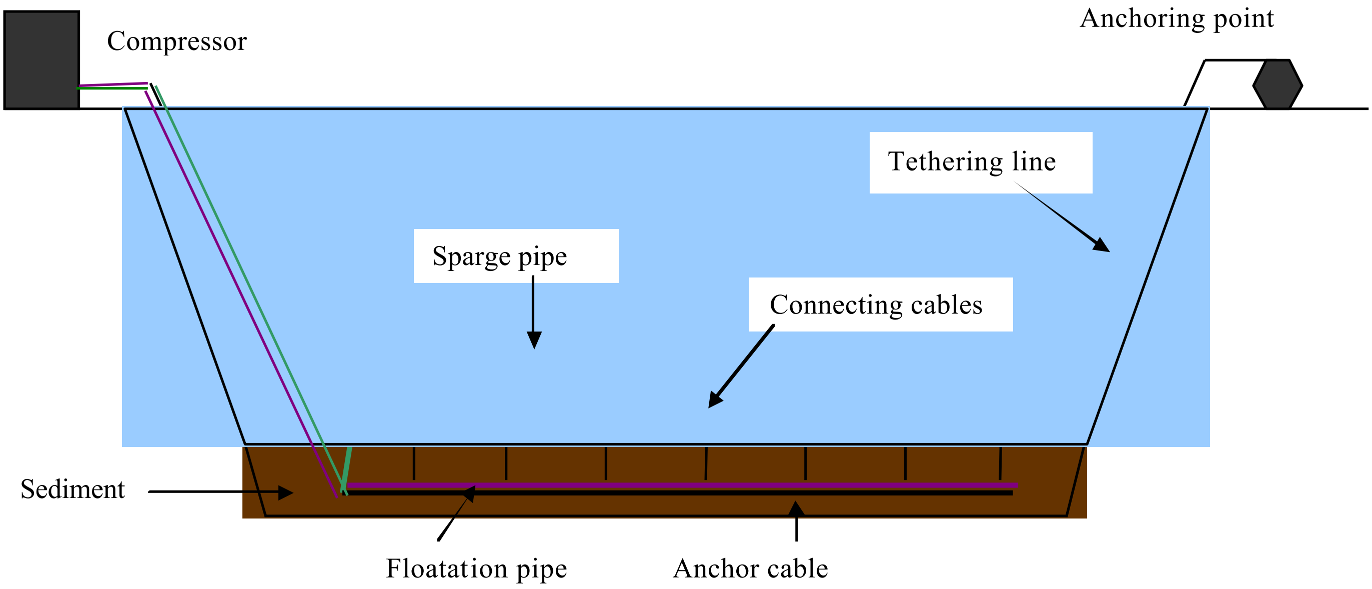
Stratification can be prevented or, if established, can be disrupted through artificial mixing of the layers. As well as ensuring temperature and DO levels throughout the lake remain consistent, the mixing also helps control cyanobacteria numbers as the movement of water caused by the mixing redistributes some of the cyanobacteria from the photic zone into the aphotic zone, where in the absence of sunlight, they die.

Historically, as a result of stratification, Watercare's lakes were susceptible to elevated levels of iron and manganese and unpleasant taste and odours.

To improve the quality of water in the lakes, Watercare installed bubble plume aeration systems at each lake from 1973. Due to mains electricity not being available, diesel powered systems were installed in the final lakes, by 2000.

The aeration systems comprise a compressor, which is manually controlled by a Watercare employee; a sparge pipe (drilled with a series of small holes) connected to an open-ended floatation pipe and a metal anchor cable. When lowered into the water, the floatation pipe fills with water. This combined with the weight of the metal cable is enough to anchor the system in place, as shown in Figure 4.

Figure 4 - Schematic of Watercare aeration system

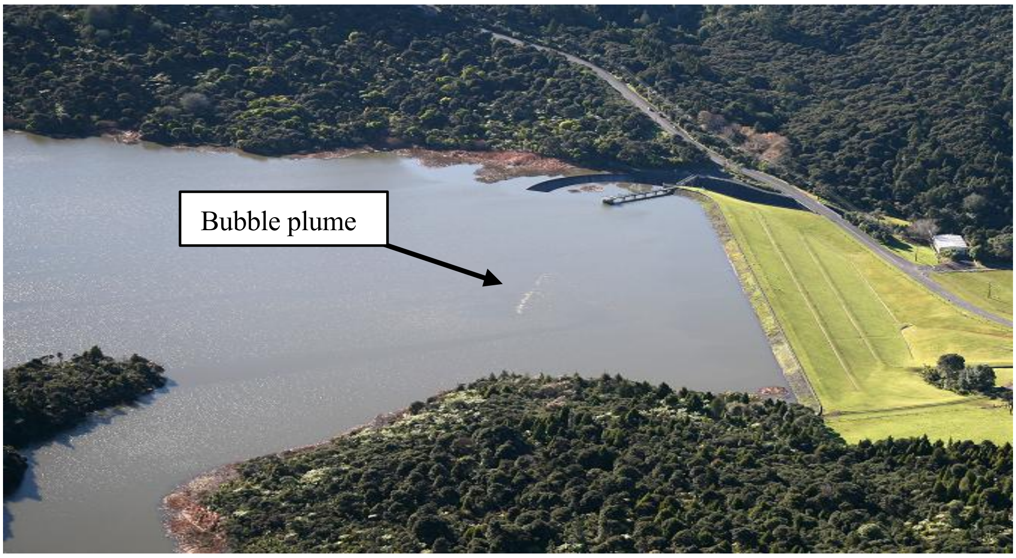


The cable, sparge, and floatation pipes are bound closely together at the entry point to the lake. At the bottom of the lake, the length of the connecting cable increases to one metre so that the sparge pipe floats above the sediment, preventing disturbance of the sediment during operation.

In the winter period the sparge pipe is raised for maintenance purposes. To enable this, air is pumped into both the sparge and the floatation pipes. This provides sufficient buoyancy to lift the system to the surface.

In order to aerate the lakes, compressed air is pumped through the sparge pipe to create a bubble plume, as shown in Figure 5, below. This promotes mixing within the lake thereby preventing stratification from occurring.

Figure 5 - Bubble plume at Lower Nihotupu



2.3 AERATION STRATEGY

The aeration systems were very effective in destratifying the lakes, with iron and manganese concentrations successfully reduced to acceptable concentrations, no unpleasant taste or odours and algae and cyanobacteria remained low, with the exception of Lower Nihotupu which was susceptible to occasional cyanobacterial blooms.

The operating strategy was simple, with the systems switched on in October and run continuously until March/April.

While successful, this strategy was not considered to be the most efficient as switching on aeration too early results in unnecessary energy consumption and too late may mean stratification occurs.

To address this, prior to summer 2007/2008, the aeration strategy was reviewed with two drivers in mind. Firstly to maintain the high level of water quality in the lake and secondly to reduce unnecessary energy consumption.

The revised strategy needed to be tailored to each lake due to the variation in the size of the lakes, the onset of stratification, the size of the compressors, and the ongoing aeration needs throughout the summer.

The size of the compressor was the most significant factor in aerating the lakes. A report for Watercare determined that each compressor should be sufficiently sized to destratify the lake in 10 days. The report also identified the aeration capacity requirements for each of the Lakes. (Hunter Water 2007). An investigation was then carried out to identify the capacity of the existing compressors (Mechanical Technology Limited 2007) as shown in Table 1, below.

Table 1 - Compressor operating limits

Lake	Capacity required to destratify lake in 10 days (l/s)	Existing system theoretical capacity (L/s)	Existing system destratification Period (Days)
Waitakere	20	20	10
Upper Huia	20	83	2
Lower Huia	60	27	22
Upper Nihotupu	25	83	3
Lower Nihotupu	55	66	8
Mangatangi	515	173	30
Wairoa	115	173	7
Hays Creek	11	173	1
Cosseys	135	158	9
Mangatawhiri	140	173	8

As the environmental temperature varies each year, it was considered that starting aeration in October may not be the most suitable time, so an appropriate trigger for starting aeration was required.

A report for Watercare recommended a DO alert level of 7mg/l and a trigger level of 6.5mg/l to start aeration (Gibbs et al., 2006). In order to minimise risk, 7mg/l was adopted as the trigger level. To identify changes in DO concentrations, depth monitoring of DO in each lake was increased to weekly from October.

It was considered that initially, short periods of operation would be sufficient, but as summer developed and stratification became more distinct, the system would be required to operate for longer periods. Lower Nihotupu was to run continuously throughout the summer due to historic susceptibility to cyanobacterial blooms.

An aeration strategy was then developed based on weekly operation, as shown in Table 2. The aeration was to run initially for a short period each week. If further signs of stratification became apparent the running period was increased by one day. This would continue until the system was running continuously.

Those compressors that did not meet the ten-day requirement, Waitakere was included as a precaution, were initially to run continuously for half their rated destratification period followed by intermittent operation. Upon further signs of stratification the system was run for the full destratification period followed by intermittent operation.

Table 2 - Aeration strategy

Lake	Destratification period (days)	First time min DO <7mg/l	Second Time min DO <7mg/l	Third time min DO<7mg/l	Fourth time min DO<7mg/l	Fifth time min DO<7mg/l	Sixth time min DO<7mg/l
Mangatangi	30	15 days continuous 5 days on 2 off	22 on then 6 on 1 off	continuous			
Lower Huia	22	11 days continuous then 5 days on 2 off	17 on then 6 on 1 off	continuous			
Waitakere	10	5 days continuous then 4 days on 3 off	10 days continuous 5 on 2 off	6 on 1 off	continuous		
Cosseys	9	4 days on 3 off	5 on 2 off	6 on 1 off	continuous		
Mangatawhiri	8	4 days on 3 off	5 on 2 off	6 on 1 off	continuous		
Wairoa	7	4 days on 3 off	5 on 2 off	6 on 1 off	continuous		
Upper Nihotupu	3	2 days on 5 off	3 on 4 off	4 on 3 off	5 on 2 off	6 on 1 off	continuous
Upper Huia	2	2 days on 5 off	3 on 4 off	5 on 2 off	6 on 1 off	continuous	
Hays Creek	1	2 days on 5 off	3 on 4 off	4 on 3 off	5 on 2 off	6 on 1 off	continuous
Lower Nihotupu	8	Continuous due to operational requirements					

An aeration operation timetable was developed to inform the Headworks Team when each system was to be turned on or off, an extract of which is given at Table 3. This was to be revised in line with results of routine DO monitoring.

Table 3 – Extract from the aeration operating timetable

	Day	Lower Huia	Waitakere	Lower Nihotupu	Upper Huia	Upper Nihotupu	Cosseys	Wairoa	Mangatangi	Mangatawhiri	Hays Creek
October 2007											
Mon	1	Turn off	Turn Off	Turn On	Turn Off	Turn Off	Turn On	Turn off	Turn off	Turn off	Turn on
Tues	2	Turn On				Turn On					
Wed	3								Turn on		Turn off
Thurs	4				Turn On	Turn Off					
Fri	5						Turn Off	Turn On			
Sat	6				Turn off						
Sun	7	Turn Off									
Mon	8		Turn on				Turn On		Turn off		Turn on
Tues	9	Turn On				Turn On		Turn off		Turn on	
Wed	10								Turn on		Turn off

A similar strategy was developed to stop the aeration during the autumn period. Rather than turning the aeration off in all lakes at once, only one lake in the Hunua and one in the Waitakere Ranges was stopped at a time. This would increase the time that aeration was carried out but was done to minimise the impact on the treatment process should unsatisfactory changes to water quality occur.

If no signs of stratification were evident after the first week, aeration in the next lake was switched off. If the second weeks samples were satisfactory, the aeration remains off and sampling reverted to the monthly winter programme. However, if signs of stratification became evident in either week, the aeration system would be restarted in line with the initial strategy and the lake is put to the back of the aeration stopping strategy.

The revised strategy was implemented in October 2007.

2.3.1 RESULTS AND DISCUSSION

In order to be considered successful, the aeration strategy had to meet the two drivers, maintain water quality and reduce unnecessary energy consumption.

2.3.2 WATER QUALITY

The Drinking Water Standards for New Zealand 2005 (Revised 2008) lists the Guideline Value (GV) for iron and manganese as 0.2mg/l and 0.04mg/l respectively.

Water quality was considered to have deteriorated if the maximum concentration, in 2006/07, when aeration was run continuously, was below the GV but breached the GV in 2007/08. Water quality was considered to have improved if the converse was true.

As shown Table 4, iron concentrations deteriorated on three occasions and improved on one occasion. Manganese concentrations did not deteriorate but improved on nine occasions.

Table 4 - Maximum summer iron and manganese concentrations

Lake monitoring depth	Maximum Iron 06/07 (mg/l)	Maximum Iron 07/08 (mg/l)	Max Manganese 06/07 (mg/l)	Max Manganese 07/08 (mg/l)
Cosseys - Surface	1.290	1.07	0.14	0.13
Cosseys - 3m	1.130	0.97	0.11	0.09
Cosseys - 10m	1.280	1.10	0.14	0.15
Cosseys - 16m	1.220	1.10	0.13	0.15
Cosseys - 23m	1.270	1.10	0.13	0.17
Cosseys - 28m	1.480	1.20	0.17	0.17
Hays Creek - Surface	0.773	0.81	0.05	0.05
Hays Creek - 3m	0.774	0.82	0.05	0.05
Hays Creek - 10m	0.784	0.78	0.05	0.04
Hays Creek - 16m	0.940	0.86	0.05	0.05
Lower Huia - Surface	0.778	1.00	0.07	0.02
Lower Huia - 6m	0.569	0.92	0.06	0.02
Lower Huia - 11m	0.355	0.88	0.07	0.02
Lower Huia - 19m	0.360	0.91	0.08	0.02
Lower Huia - 28m	0.513	0.72	0.19	0.05
Lower Nihotupu - Surface	0.420	0.62	0.05	0.06
Lower Nihotupu - 4m	0.372	0.65	0.05	0.05
Lower Nihotupu - 10m	0.650	0.62	0.06	0.07
Lower Nihotupu - 16m	0.704	0.62	0.14	0.07
Mangatangi - Surface	0.120	0.14	0.02	0.01
Mangatangi - 9m	0.116	0.10	0.01	0.01
Mangatangi - 16m	0.111	0.14	0.02	0.01
Mangatangi - 24m	0.113	0.14	0.02	0.02
Mangatangi - 32m	0.120	0.14	0.01	0.02

Lake monitoring depth	Maximum Iron 06/07 (mg/l)	Maximum Iron 07/08 (mg/l)	Max Manganese 06/07 (mg/l)	Max Manganese 07/08 (mg/l)
Mangatangi - 39m	1.330	0.15	0.01	0.02
Mangatangi - 47m	0.200	0.17	0.05	0.02
Mangatangi - 55m	0.555	0.24	0.52	0.09
Mangatawhiri - Surface	0.146	0.12	0.02	0.03
Mangatawhiri - 3m	0.148	0.10	0.02	0.03
Mangatawhiri - 11m	0.142	0.14	0.02	0.03
Mangatawhiri - 19m	0.139	0.29	0.03	0.03
Mangatawhiri - 27m	0.165	0.33	0.04	0.06
Upper Huia - Surface	0.959	0.99	0.07	0.06
Upper Huia - 5m	0.194	0.71	0.03	0.03
Upper Huia - 17m	0.868	0.73	0.06	0.03
Upper Huia - 29m	0.874	1.00	0.12	0.05
Upper Nihotupu - Surface	0.532	0.45	0.05	0.04
Upper Nihotupu - 4m	0.492	0.42	0.02	0.01
Upper Nihotupu - 14m	0.501	0.46	0.05	0.04
Upper Nihotupu - 25m	0.508	0.46	0.05	0.04
Upper Nihotupu - 31m	0.503	0.46	0.05	0.04
Upper Nihotupu - 37m	0.787	0.52	0.12	0.09
Wairoa - Surface	0.427	0.43	0.08	0.13
Wairoa - 6m	0.341	0.43	0.08	0.04
Wairoa - 14m	0.397	0.46	0.07	0.11
Wairoa - 21m	0.391	0.46	0.07	0.12
Wairoa - 29m	0.375	0.47	0.07	0.16
Wairoa - 35m	0.374	0.48	0.08	0.20
Waitakere - Surface	0.685	0.50	0.05	0.04
Waitakere - 3m	0.684	0.50	0.04	0.03
Waitakere - 12m	0.691	0.53	0.08	0.04
Waitakere - 14m	0.731	0.57	0.06	0.06

Taste and odours in the lakes were considered satisfactory since there were only two individual and unrelated reports of unpleasant taste and odours reported from the Local Network Operators across the region.

Based on these findings, the strategy was considered to have successfully met the water quality driver.

2.3.3 ENERGY CONSUMPTION

During the summer, aeration was eventually run continuously in five of the ten lakes (including Lower Nihotupu, which was run continuously throughout).

The staggered “turn off” phase meant that, in some lakes, the aeration ran throughout April and into May. Even with this extra period of operation, when compared with continuous operation between October and April, an assessment of the energy consumption of the electricity-powered systems identified that the new strategy resulted in significant reduction in energy consumption, as shown in Table 5. The revised strategy was considered to have successful met the energy driver.

Table 5 – Typical energy consumption of mains powered aeration systems

Lake	Continuous operation Oct-Apr (kWh)	Strategy 07/08 - Intermittent Operation Oct – May (kWh)	Variance (kWh)
Waitakere	65,817	26,754	-39,063
Lower Niho	101,175	106,485	5,310
Mangatangi	438,537	257,431	-181,106
Mangatawhiri	344,010	181,841	-162,169
Wairoa	300,783	161,846	-138,937

Cosseys	376,625	238,660	-137,965
Hays Creek	235,690	226,908	-8,782
Total	**1,862,637**	**1,198,665**	**-663,973**

The revised strategy was considered to be successful since it was consistent with Watercare's vision of continually striving for smart solutions that deliver high quality, reliable and efficient water, and wastewater to its customers. It was also consistent with Watercare's Sustainability policy and objectives since it uses energy efficiently, minimises emissions and reduces the Company's carbon footprint.

The strategy was revised in subsequent years to account for new compressors installed at a number of lakes. Similar water quality and energy savings were observed each year compared with continuous operation. There was a taste and odour issue associated with a cyanobacterial bloom in Lake Waitakere in summer 09/10, but as stratification did not set in, other factors are considered to have brought about this bloom.

2.3.4 FUTURE IMPROVEMENTS

While the revised aeration strategy is successful in maintaining water quality and reducing energy consumption, the ongoing implementation is reliant on routine manual sampling, manual update of the aeration operating timetable and manual operation of the compressors. The system can be improved further by automating these aspects.

The use of online water quality monitoring within the lakes would ensure that signs of stratification are identified immediately rather than when the next manual sample is taken. Online monitoring can also be used to provide early warning of cyanobacterial bloom development and therefore the potential risk of taste and odour and cyanotoxins.

The results of online monitoring could be linked to the Supervisory Control and Data Acquisition System to enable, where practical, the compressors to be started and stopped automatically when trigger levels are reached.

Watercare plans to commence trials of lake water quality monitoring systems throughout summer 2010/11, in a bid to improve further the management of Auckland's lakes.

3 CONCLUSIONS

The effects of lake stratification can adversely affect both the cost of treatment and the quality of water supplied to consumers.

Watercare's initial aeration system successfully prevented summer stratification and improved water quality, but the strategy was not the most efficient.

The revised aeration strategy, which used intermittent aeration based on the destratification capacity of the individual aeration systems, resulted in consistent water quality and a significant reduction in energy consumption compared with continuous operation.

It is anticipated that online monitoring and automation of the aeration systems will provide further energy savings and improved water quality for the people of Auckland.

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