Lake Hayes Remediation

Options Overview Report

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REFERENCE

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View across Lake Hayes towards the south

1.0 PRÉCIS

The Otago Regional Council (ORC) is developing a programme to improve water quality in Lake Hayes, with an overall objective of making the lake swimmable at all times. To achieve this objective, ORC has identified two mechanisms; improving the quality of water entering the lake, and addressing the historic accumulation of nutrients in lake sediments. This report addresses the second component, whilst still acknowledging that improvements in land and waterway management in the upstream catchment will be required if meaningful improvements to the water quality of Lake Hayes are to occur.

Human activity has resulted in Lake Hayes becoming enriched in minerals and nutrients over the last 70 years. Of particular concern is an accumulation of phosphorous (P) in lake-bed sediments, which in some years can lead to algal blooms in the lake. An ORC Technical Committee report[1] examined the potential of 3 lake remediation methods previously evaluated by NIWA and other scientific experts. For the purposes of this report, an additional method has also been reviewed (as listed in Table 1-1).

Table 1-1 Technical methods considered for the remediation of Lake Hayes water quality. Methods examined in the 2018 ORC Technical Committee report are marked with an asterisk.

1. Water Augmentation*	Augment the flow of Mill Creek with water from the Arrow River.
2. Destratification*	Artificially mix the lake water column, keeping it well oxygenated and preventing thermal stratification from occurring.
3. Hypolimnetic withdrawal	Nutrient-rich and oxygen depleted water is taken from depth within the lake, and then discharged into Hayes Creek via a cascading bed of gravels and weirs designed to re-oxygenate these waters.
4. Sediment capping*	Transforming dissolved P in the water column into a non-bioavailable form through the addition of chemicals.

This report provides a comprehensive assessment of all 4 methods, using information provided by previous authors, and further investigations to determine how each method could practically be implemented. Further work has also been undertaken to determine the likely costs to construct and operate any equipment required. The risks associated with each method have been clearly identified, along with an assessment of how likely they are to succeed.

Either a single method, or a combination of methods may be selected as the preferred option for improving water quality within Lake Hayes. A summary table is provided in section 9.0 which lists 8 potential implementation options, and identifies the likely costs of each, the key risks involved, and the speed with which it will help the lake recover. This table has been designed to allow for easy comparison and to inform the decision-making process.

This report also considers the costs and benefits of continuing to monitor lake water quality over time. Although this is not a lake restoration method in itself, it is listed as a separate, stand-alone method, so that it can be considered as part of any decision-making process. Monitoring would also form part of any remediation program, and the costs of lake monitoring are therefore included in all 8 implementation options listed in section 9.0.

[1] Mackey, B., 2018. Lake Hayes Restoration, ORC Technical Committee Paper, 1 August 2018. See section 3.0 for a full list of references.

2.0 INTRODUCTION

Lake Hayes is a small lake located about 3 km to the south of Arrowtown, in the Wakatipu Basin (Figure 2-1). The depression within which the lake sits was carved by glacial activity, about 20,000 years ago. The lake is approximately 3 km long and 1 km wide, with a maximum depth of 33 m. The primary inflow is Mill Creek, while the outlet is via Hayes Creek which flows for just 1.5 km before discharging to the Kawarau River. Mill Creek has a mean flow of approximately 0.43 m^3 per second (cubic meter per second), while the lake has a total volume of 55,100,000 m^3.

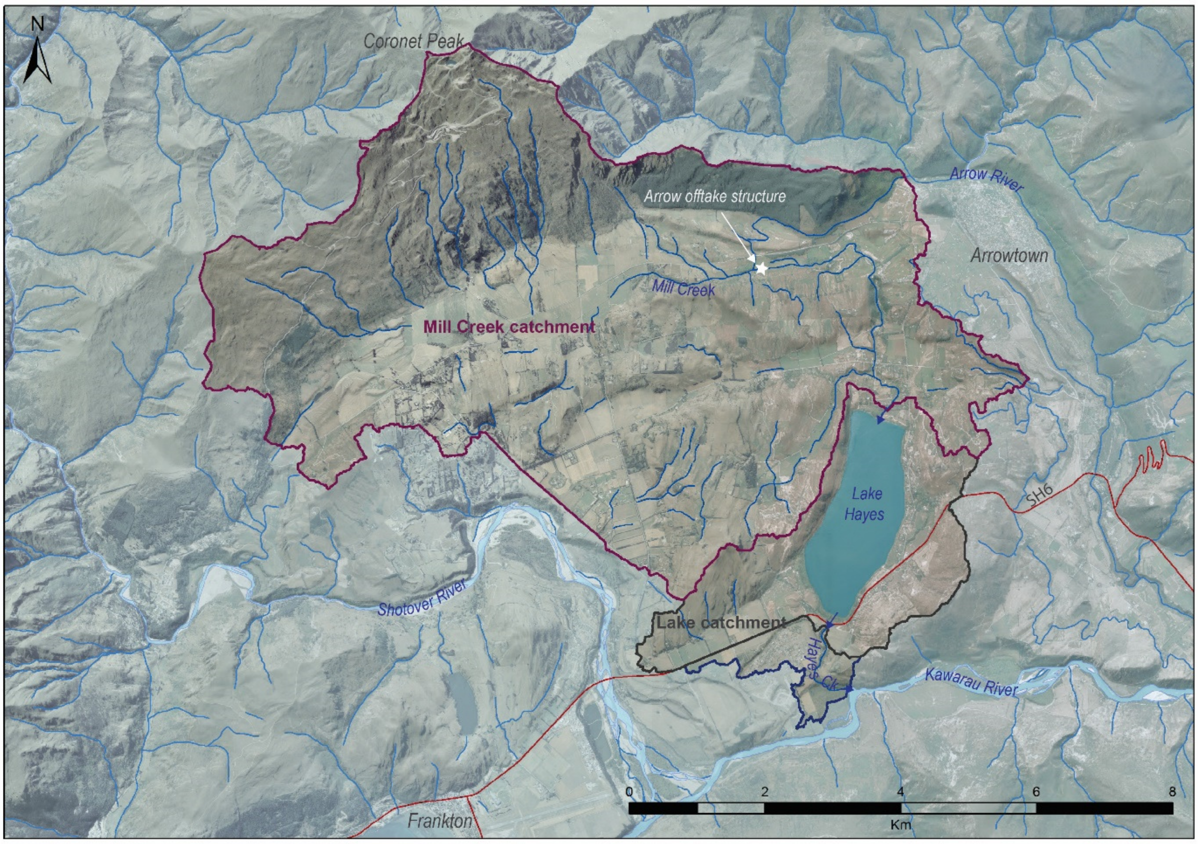


Figure 2-1 Map showing natural extent of the Lake Hayes and Mill Creek catchments. Source: ORC.

2.1 WATER QUALITY PROBLEM

Lake Hayes has become enriched in nutrients over the last 70 years – particularly phosphorous (P). This has occurred primarily as a result of human activity, including historical fertilizer application, industry, septic tank effluent from nearby residences, and removal of wetlands and riparian plantings.

The physical characteristics of the area mean that runoff from the surrounding catchment will drain reasonably quickly to Lake Hayes, and then be 'stored' in the lake for a long period (months or even years)[2] before exiting via Hayes Creek. This provides an opportunity for P which enters the lake via surface runoff (generally bound to sediment) to descend to the bottom of the lake, where it can accumulate in lake-bed sediments.

Over summer, Lake Hayes (like most deep lakes) becomes 'thermally stratified' – where a warmer surface layer forms, and overlies cooler water on the bottom of the lake. In Lake Hayes,

[2] The theoretical mean residence time for water in Lake Hayes is 3.8 years (Gibbs, 2018a).

the bottom water oxygen-depleted, allowing P to be released from lake-bed sediments into the water column, feeding algal blooms which can affect the colour of the lake, turning it a brown or greenish colour, and cause scums on the surface. Under certain circumstances, types of algae can produce toxins which can cause rashes, nausea and be potentially deadly for dogs if ingested. These processes can have a significant impact for locals and visitors, due to the popularity of this area for recreation and other activities.

2.2 PROJECT DEFINITION

Otago Regional Council (ORC) has been investigating remediation methods to inhibit algal growth in the lake, with an overall objective of making the lake swimmable at all times. A range of potential intervention methods have been identified through previous reports (as listed in section 3.0), produced for ORC and the Friends of Lake Hayes Society.

This report provides an overview of four technical methods that have been identified by specialist lake scientists as suitable for improving water quality in Lake Hayes. Each method has been assessed for its risk potential, costs and likelihood of success. Additional information has been gathered to help with this assessment, including from potential suppliers and contractors with the skills and experience to implement the various technical methods available.

Technical methods which are considered suitable for improving water quality in Lake Hayes are listed in Table 1-1. Together with the ‘do minimum’ approach (i.e. continue to monitor and evaluate), these are discussed in sections 4.0 to 8.0.[3]

A single method, or a combination of methods, may be put into effect as an ‘implementation option’. Section 9.0 lists potential implementation options, and summarises the likely cost, key risks, and the likelihood of success, to allow for easy comparison and to inform any decision-making process.

None of the methods outlined below help to resolve the ongoing issue of nutrients (including P) entering the lake from Mill Creek. A separate program of work is underway by ORC to identify contemporary sources of catchment-derived nutrients, and implement methods which will improve the quality or water entering the lake via Mill Creek.

[3] The objective of each technical method is listed in Appendix 8. Sections 4.0 to 8.0 describe how these will help to reach the overall objective (making the lake swimmable).

Figure 2-2 3D view of Mill Creek (blue line) where it enters Lake Hayes. Source: Google Earth.

3.0 PREVIOUS WORK

The following sections have drawn heavily on information provided by previous authors and other experts. The primary references used to inform this report are listed in Table 3-1. Other material and advice was provided by Andy Bruere, Lakes Operations Manager, Bay of Plenty Regional Council.

Table 3-1 References relating to the water quality of Lake Hayes, used to inform this report

Author and year	Title	Prepared for
Castalia Strategic Advisors, 2018.	Economic Assessment of Lake Hayes Remediation (updated, November 2018)	ORC
Gibbs, M., 2018a. (NIWA)	Lake Hayes Water Quality. Remediation options.	ORC
Gibbs, M., 2018b. (NIWA)	Lake Hayes Water Quality. Expansion on remediation options.	ORC
ORC and QLDC,1995.	Lake Hayes Management Strategy	ORC / QLDC
Schallenberg, M., and Schallenberg, L., 2017.	Lake Hayes Restoration and Monitoring Plan.	Friends of Lake Hayes Society Inc.
Mackey, B., 2018	Lake Hayes Restoration	ORC Technical Committee

3.1 SCIENCE

Declining water quality has made Lake Hayes the subject of many studies over the past few decades. This includes scientific studies, management strategies, and restoration strategies. This report has primarily drawn on the 2017 review by Schallenberg and Schallenberg which provides a summary of the lake's history, the decline in water quality, and potential remediation options. In addition, the technical methods described in this report are drawn from the 2 reports prepared in 2018 by Max Gibbs (NIWA for ORC), which provide a review of the Schallenberg report, and further evaluate remediation options.

3.2 ECONOMIC ASSESSMENT

An economic assessment of the benefit of remediation using three technical methods (augmentation, destratification and sediment capping) was undertaken by economic experts Castalia in 2018 for ORC. The key findings of this report were that:

- *The state of water quality in Lake Hayes in the absence of remediation is uncertain. Therefore, three no-intervention scenarios for the lake ('stable', 'natural recovery', and 'deteriorates') were compared against potential remediation methods.*
- *The three remediation methods investigated are, in general, economically viable, in that the benefits of improved water quality outweigh the costs of remediation.*
- *Recreational activities will see the greatest positive benefits of remediation.*
- *The primary beneficiaries of improvements to water quality are concentrated around the lake and nearby residents.*

4.0 MONITOR AND EVALUATE (NO LAKE INTERVENTION)

4.1 DESCRIPTION

The 2017 Schallenberg report concludes that Lake Hayes may be approaching a recovery tipping point, although it also states that it is still unknown how long it will take for the lake to achieve consistently high water clarity. The Schallenberg report notes that the lake experienced extremely clear waters in 2009/10 and 2016/17 years. Gibbs (2018a) also notes that the release of DRP from the sediment has been slowly decreasing since 2011.

ORC is deploying a permanent water quality monitoring buoy in the lake during the 2018/19 summer, and also expanded its sampling program. The buoy is expected to be operational by April 2019. Additional data from continuous and sample type monitoring will help track physical, chemical and biological changes in the lake over time. In particular, it will help to identify any long-term trends in water quality (noting that it may take some years for these to become apparent).

Monitoring data will be used to inform subsequent decisions about whether (and how) other methods should be implemented, and to potentially optimise any remediation efforts. Monitoring can also be used alongside other methods to determine their effectiveness, and to inform operational decisions, such as timing of critical decisions and operations.

Figure 4-1 Monitoring buoy similar to that to be installed in Lake Hayes by ORC

Monitoring and evaluation could be described as the ‘do minimum’ approach. It has been identified as a separate, stand-alone method so that it can be considered as part of any decision-making process – it should not be discarded simply because there is a perceived need to ‘do something now’. A period of intensified monitoring may help to identify the most effective intervention option, or alternatively confirm whether the lake is recovering naturally, and active intervention is not warranted. Monitoring and evaluation is included in all of the implementation options outlined in section 9.0.

4.2 MONITORING OUTCOMES

As for other methods, taking steps to reduce the amount of P which enters Lakes Hayes will be an important part of improving the overall water quality in this catchment.[4] If this could be achieved, then the total mass of P in the lake will gradually reduce over time, although it is likely that this process will be influenced by a range of environmental factors and food web interactions.[5]

However, it is uncertain how long such a natural recovery process will take, given the current levels of P in the lake. In addition, it may be unrealistic to expect that the supply of phosphorous from the catchment will be significantly reduced any time soon.

The monitor and evaluate approach would help to quantify any 'natural' improvement (or degradation) in the lake. It may help to inform later decisions, but by itself, it will not lead to any direct changes in water quality. As a result, improvements in water quality may take longer than with active intervention, and water quality will continue to fluctuate from year to year.

[4] ORC is currently undertaking work to better understand the main source of nutrients in the Lake Hayes catchment. See https://yoursay.orc.govt.nz/lakehayes/forum_topics/lake-hayes-catchment-a-new-study

[5] For example, Schallenberg (2017) describes a possible mechanism for this, where the *Ceratium* alga helps to transfer P from bottom waters to the surface, which in turn allows P to be flushed out of lake via outflow of water into Hayes Creek.

4.3 COST AND RISK ANALYSIS – MONITOR AND EVALUATE

Cost		Land acquisition		Resource Consent		Comment
Capital[6]	Operational	Issues	Cost	Likely issues	Cost	
• Purchase and install monitoring buoy: $86,000 • Updates to ORC website to display real-time data: $4,000 • Communications / stakeholder relations: $4,000 • Contingency cost: N/A - this method has already been costed and commissioned. **Total: $94,000**	• Maintain and service buoy: $15,000 • Sampling program: $10,000 • Contingency: $5,000 • Publicity and Communications $15,000 **Total: $45,000**	N/A	N/A	Consent for the monitoring buoy was obtained in 2018. Issues to address included: • Noise • Colour • Reflective light • Position • Navigational safety	Cost to obtain consent (including staff time, planning advice, and consent fees): $6,000 **Total: $6,000**	• There is a risk that this approach may not meet the expectation of residents and the wider public that direct action should be taken to improve water quality. • The approach relies primarily on a successful catchment management program. • It does not provide a mechanism for addressing years where DRP levels are high, either due to inflows, or mobilisation of P already in the lake due to lake stratification. • As noted above, it is difficult to determine the likely timeframe to meet the overall objective (swimmable water at all times). • There is some uncertainty about whether the lake is actually recovering naturally, and the speed of that recovery. • The monitoring buoy will be a highly visible structure in the lake. It may be damaged (either by accident or intentionally) or fail to provide a continuous supply of data.

[6] In this report, capital costs refer to the initial construction costs

5.0 TECHNICAL METHOD 2 - ARROW WATER AUGMENTATION

5.1 DESCRIPTION

This method involves augmenting the flow of Mill Creek with water from the Arrow Irrigation Company irrigation scheme.[7] Water would be taken from the company's pipeline where it crosses Mill Creek (Figure 2-1, Figure 5-1), about 4.5km upstream from the creek's outlet into Lake Hayes. Water from the Arrow River is low in nutrients compared to water in Mill Creek and Lake Hayes, and therefore 'cleaner'. Monitoring also shows that water in the Arrow is colder than that in Mill Creek.

Council approved funding in the 2018-2028 Long Term Plan to undertake physical works, to preserve the potential to add Arrow water to Mill Creek should this method be selected. Installation of a 130m long pipe and a discharge structure to Mill Creek was completed in January 2019, prior to golf course development by Millbrook Resort. If this work had not been done prior to golf course development, the option to add Arrow water to Mill Creek would have been lost. Some follow-up work would be required to make the offtake operational.[8]

This method has 2 main benefits:

- Clean water being added ('augmented') to Mill Creek, and therefore increasing the volume of water passing through Lake Hayes – i.e. clean water from the Arrow River would displace (flush) a greater volume of nutrient-rich lake water than would occur otherwise.
- If the temperature in Mill Creek as it entered Lake Hayes was sufficiently cool to cause Mill Creek water to plunge to the lowest part of the lake, it could oxygenate the bottom waters.[9] It is expected that the oxygenated water would reduce the likelihood of anoxic conditions[10] and the associated release of P from lake bed sediments. It is thought that the benefit associated with this process would be greater during the spring and summer months.

The overall cost associated with this method is low, compared with other methods.

[7] The scheme takes water from the Arrow River and pipes it across the Wakatipu Basin for irrigation purposes.

[8] There is a 10m section of pipe that has not been connected, which is where the control valves would be located.

[9] The target zone for the cooler Mill Creek water (i.e. deeper waters) is also influenced by lake currents, which are susceptible to wind and changes in the temperature profile of the lake over the year. The greater the temperature difference between Mill Creek and the Lake, the deeper the plunging waters are likely to penetrate.

[10] where water is depleted of dissolved oxygen

Figure 5-1 Arrow Irrigation Company pipeline as it crosses Mill Creek, January 2019. Credit: D Hanan

5.2 LIKELIHOOD OF SUCCESS

An evaluation of previous reports and other literature suggests that this method, if implemented to its fullest extent, would have some positive effects on lake water quality, mainly through additional flushing and the addition of cleaner water to the lake. If applied consistently throughout the year, the additional water in Mill Creek would help to improve the water quality in this waterway (and consequently Lake Hayes).

These potential positive effects need to be balanced against a range of factors which create risk in terms of this method being able to meet the overall objective (as listed in section 5.3). In particular, there is a risk associated with accessing water from the Arrow River over the longer term, particularly during the summer period which is when augmentation is most likely to provide some benefit in terms of improved lake water quality. In summer months there is increased demand from other users of Arrow irrigation water, and flows in the Arrow River are comparatively low.

It is noted that the environmental risk associated with this method is relatively low, as it simply augments an existing natural process.

The risks listed below assume that the augmentation method was chosen as a stand-alone option. It is recognised that augmentation is compatible with a range of other methods, and this is discussed further in section 9.0.

5.3 COST AND RISK ANALYSIS – ARROW WATER AUGMENTATION

Cost		Land acquisition		Resource Consent		Risks, including time to meet the overall objective
Capital	Operational	Issues	Cost	Likely issues	Cost	
• Physical works already completed in Mill Creek: $200,000 • Additional work to connect to pipe and make operational: $50,000 • Staff time: $20,000 to date, $10,000 to come. • Contingency cost: N/A - most of the structure has already been built. **Total: $280,000**	• Annual cost to purchase water: $20,000.[11] • Contingency: $2,000 • Publicity and Communications $3,000 **Total: $25,000**	N/A	N/A	• Cultural / ecological impact of transferring water from the Arrow catchment to the Lake Hayes catchment. • Mitigating physical effects due to increased stream flow.	$15,000 **$15,000**	• Water availability may be limited, particularly in summer when poor lake water quality is more likely to occur, and remediation is therefore more urgently required. • The Irrigation Company's ability to supply water from the Arrow River may be further reduced, as their deemed permit expires in 2021. This could significantly affect the quantity of water available for augmentation. • Potential minimum-flow requirements for the Arrow River. • If less water is available, then the unit cost may increase. • The success of this method is, in part, determined by the temperature difference between water from the Arrow river (in the irrigation pipeline) and water in Mill Creek. • Even if the Arrow water does cool Mill Creek to some extent, it may not be enough to cause the outflow from Mill Creek to plunge towards the bottom of Lake Hayes. • The distances involved, and the potential for warming as the water passes via the pipeline and Mill Creek to Lake Hayes may reduce the impact of this method. This risk is greater during the warmer summer period, when remediation is more likely to be required. Therefore, there is a risk that, on its own: i. this method will not adequately oxygenate the water at the bottom of the lake, and therefore ii. P will continue to be released from lake bed sediments as a result of thermal stratification within the water column. • This process will need to run over many years to be effective. Schallenberg (2017) suggests that flushing will displace approximately 7% of the entire lake volume annually. • Work may be required to improve the capacity of the Hayes Creek outlet, to offset additional inflows to Lake Hayes and avoid excessively high lake levels.

[11] This assumes the full amount (as suggested by the Irrigation Company) was available, at their suggested rate of 0.5 cents per m^3.

6.0 TECHNICAL METHOD 3 - LAKE DESTRATIFICATION

6.1 DESCRIPTION

As noted in section 2.1, over summer Lake Hayes can become thermally stratified – where a layer of warmer surface water overlies cool, anoxic water on the bottom of the lake. This method seeks to artificially mix the lake water column, keeping the lake oxygenated (to levels above 5 g/m^3), which prevents P from changing to the dissolved state. Thermal stratification is still likely, but significantly reduced. The method does not aim to remove phosphorous from the lake. However, it is thought that the creation of currents within the lake, through artificial mixing will help to keep bottom waters well oxygenated, which consequently keeps the phosphorus bound in the lake bed sediments and out of the water column.[12]

There are various mechanisms which can be used to mix the lake water. However, the method investigated here is to create an air curtain through the lake, achieved by blowing compressed air along a perforated pipe which lies across the bed of the deepest part of the lake (Figure 6-1).

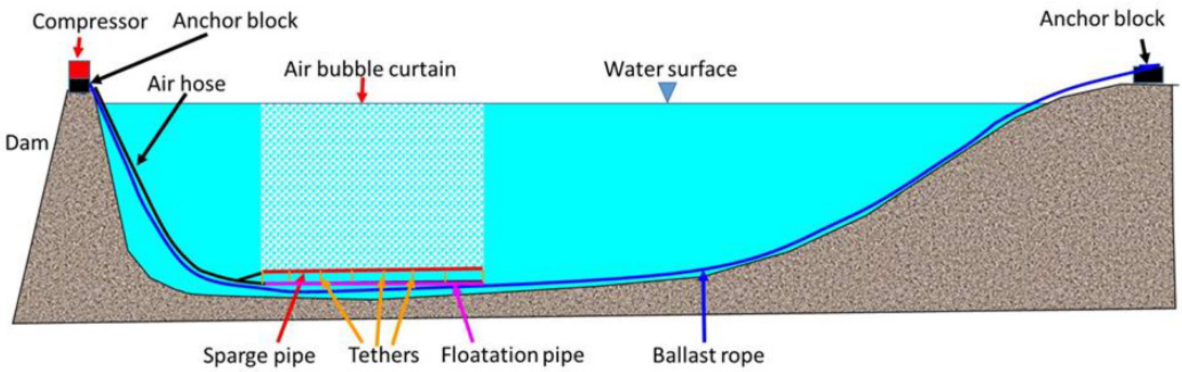


Figure 6-1 Schematic diagram of a bottom-mounted air curtain aerator system, aligned through the deepest part of the lake. From Gibbs (2018a).

Additional investigations have been completed to determine how such a system could be installed in Lake Hayes, given the unique characteristics of the lake and the surrounding area. The main components required for this method are an industrial-scale compressor, a shed designed for noise reduction, and pipes to transport and then deliver the air into the lake. The requirements for this system are explained in Appendix 1, and a step-by-step description of how this option works is provided in Appendix 2. Figure 6-2 shows the main components required for this option, with a suggested location for the compressor (between SH6 and the Wakatipu Rowing Club) identified. A possible alternative is Bendemeer Bay, although there is likely to be noise and visual impacts for neighbouring properties at this location.

[12] Creating artificial currents within the lake helps to minimise thermal stratification (where phosphorous in the lake sediment can change state from solid to dissolved reactive phosphorous (DRP), which in turn stimulates algal blooms).

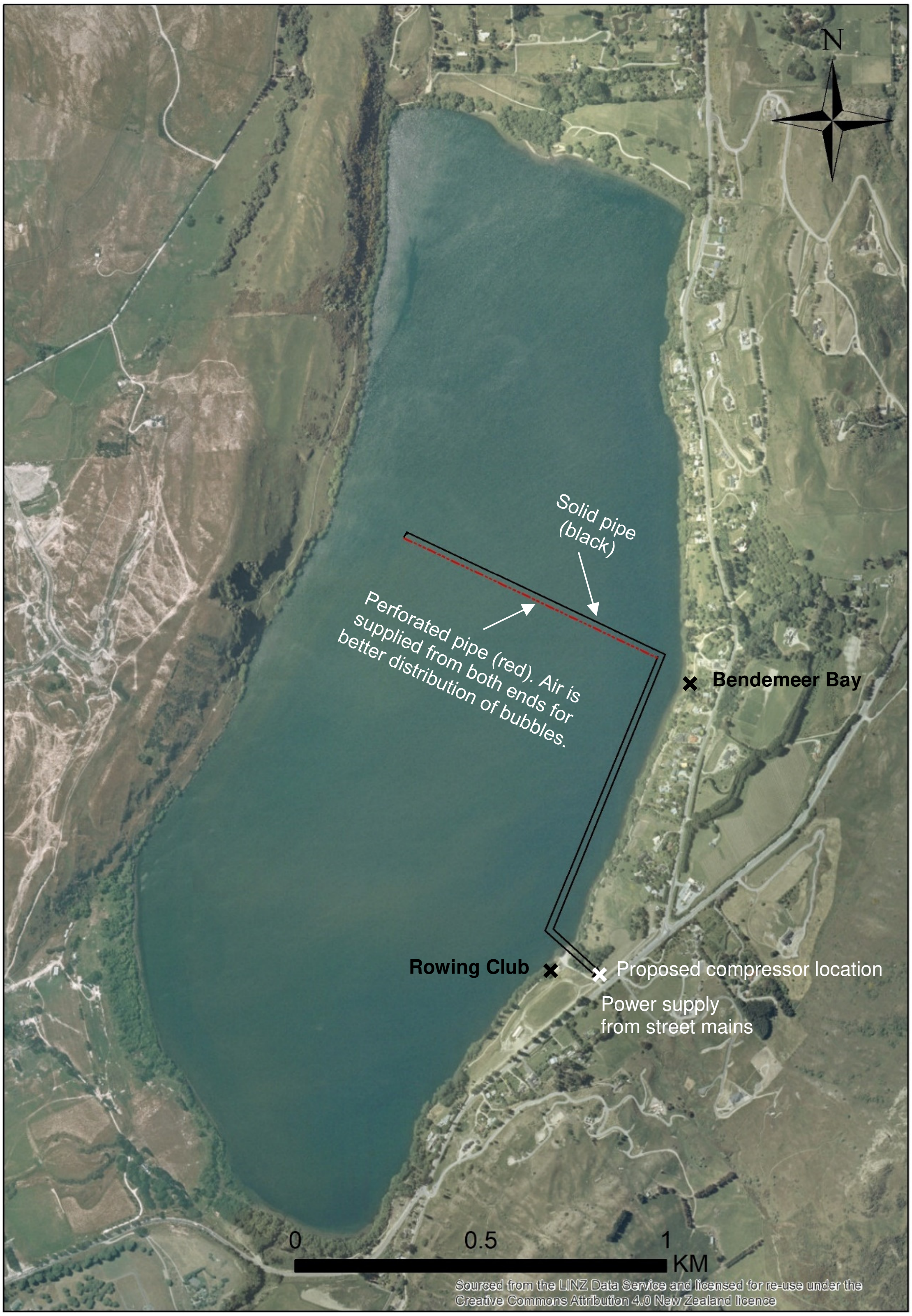


Figure 6-2 Potential positioning of the bubble curtain aeration line[13]

[13] The system shown here has been informed by design requirements specified in Gibbs (2018a) and a quote to meet those requirements, as provided by AshAir. Further investigation may determine that a simpler (and cheaper) system would be sufficient to prevent thermal stratification occurring.

6.2 LIKELIHOOD OF SUCCESS

To be successful, this option would require artificial mixing of the lake to prevent the release of DRP from sediments at the bottom of the lake. Instead, P will remain bound in the lake bed sediments and not be released into the water column.

This option appears to have a reasonably high likelihood of success, and it has been used successfully in several other lakes, including Lake Waikopiro (Hawkes Bay) and several Auckland City Council drinking water reservoirs.[14] If the intention is to eventually remove the air curtain, then a reduction in organic matter and P from the upstream catchment will also be required. The system would be less successful if catchment management was not undertaken simultaneously.

The method could be used in conjunction with other options such as augmentation.

There are several critical risks to bear in mind when considering this option (as explained in section 6.3). Careful monitoring of the lake's water quality, together with precise management of the equipment would be required to ensure ongoing success.

[14] Andy Bruere, Lakes Operations Manager, Bay of Plenty Regional Council and Gibbs (2018a)

6.3 COST AND RISK ANALYSIS - DESTRATIFICATION

Cost		Land acquisition		Resource Consent		Risks, including time to meet the overall objective
Capital	**Operational**	**Issues**	**Cost**	**Likely issues**	**Cost**	
• Purchase equipment (compressor, piping): $232,000 • Installation of equipment, including soundproof shed: $204,000.[15] • Project Management: $60,000 • Contingency: $40,000 • Liaison and negotiation with QLDC $15,000 • Design and peer review $25,000 • Arrange procurement $15,000 **Total: $591,000**	• Maintenance & operations: $61,500 p.a. • Publicity and communications $15,000 **Total: $76,500 p.a.**	Equipment needs to be located near the lake, probably on QLDC reserve land A lease agreement between ORC and QLDC would be required, and would need to be publicly notified.	**Total: $20,000**	• Equipment needs to be sited in a sound-proof building 4.8m x 3.6m x 2.4m high. This needs to be in a position that has limited or no visual impact on residents or visitors. The location on the reserve land adjacent to the show grounds is preferred. Bendemeer Bay is not considered suitable due to the proximity of houses. • Compressor operates at 77dBA which is very loud talking (almost shouting). • A resource consent from QLDC would be required for construction on reserve land. • A resource consent from ORC may be required for disturbance of the lake bed.	$60,000 **Total: $60,000[16]**	• Operational timing is critical. If start-up is delayed after thermal stratification is established, the air curtain will bring nutrient-rich bottom water to the surface, stimulating phytoplankton growth, which will deplete oxygen in the lake. This risk can be reduced if the operation of the compressor was linked to real-time data from the monitoring buoy. • The operation of the air curtain system is dependent on an operational compressor and an uninterrupted power supply. • The surface of the lake will be affected by a line of water disturbance above the pipe. • The compressor will be noisy and will require a specifically engineered building and possibly environmental bunds to minimise sound. • Consent and lease agreement costs could be larger than anticipated, especially if there is opposition to the proposed location. • The required duration of operation is largely unknown. Gibbs (2018a) suggests 5 – 10 years. • The system may not promote mixing across the whole lake (and therefore be less effective). • It is unlikely (but possible) that mixing the lake water column (i.e. 'stirring up the

[15] Section 2.2 describes the method used to determine likely costs of purchasing and installing equipment.

[16] This cost includes ORC processing costs (staff time and consultants), preparation of an Assessment of Environmental Effects (AEE) and a hearing (assuming there is no appeal).

						lake') will bring suspended particles from the lower part of the lake to the surface, thereby reducing water clarity. • Over time, this process will reduce the amount of phytoplankton in the lake, making the water column clearer (see Appendix 2). • There could be other unintended ecological consequences.

Other comments:

- The inclusion of a variable speed compressor with a Programme Logic Controller (PLC), linked to the buoy information would allow the 'bubble rate' to be adjusted, depending on the temperature profile and DO readings at various depths in the lake.
- The system will probably need to be operated from spring (probably October) through to autumn (March). The actual time of operation would be determined by the monitoring data.
- It is noted that the air curtain only has a minor effect on oxygenating the lake. The oxygen-depleted waters which rise from the base of the lake are re-oxygenated as they flow across the lake surface.
- The surface temperature is likely to fall, possibly by 1 °C. This may not be noticed by swimmers and other lake users.
- Once the overall objective has been achieved, the shed, compressor and other associated infrastructure may not be required.
- Bubble hole size is important as well as the amount of air delivered through the line. Too little and the plume may not form; too much and the bubbles may disrupt the integrity of the plume, reducing its efficiency.

7.0 TECHNICAL METHOD 4 – HYPOLIMNETIC WITHDRAWAL

7.1 DESCRIPTION

As described by Gibbs (2018a, 2018b), the concept behind this method is relatively simple, and involves nutrient-rich water being drawn up through a pipe, from the anoxic (or hypolimnetic) zone within Lake Hayes. The pipe would cross the lake (beneath the surface), and discharge to Hayes Creek just above the culvert which passes under SH6 (Figure 7-1). This method is the only system that actively removes P from the lake.

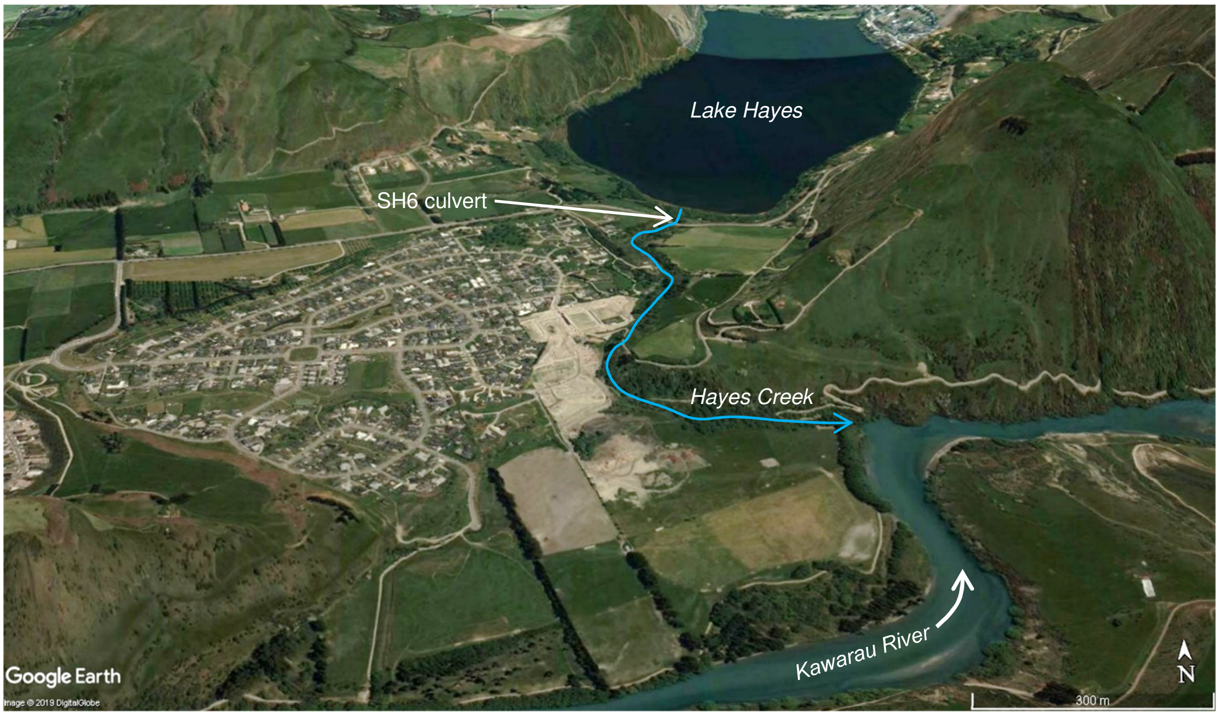


Figure 7-1 3D image showing Lake Hayes, and its outlet (Hayes Creek) which flows into the Kawarau River. Source: Google Earth.

7.2 CONSTRUCTION REQUIREMENTS

This method would require the construction of a weir and associated flanking walls near the start of Hayes Creek. The weir would need to be designed to maintain the lake within its current range. The pipe would pass through the wall, as shown in Figure 7-2.[17] A valve would enable the flow of water from the bottom of the lake to be controlled, or even stopped if required.

An inspection of the outlet area (Figure 7-3) indicates that such a system may be constructible, although further hydraulic and engineering investigations would be required to determine the specific design. The inspection shows that the diameter of the hypolimnetic withdrawal pipe could be as large as 400mm, although a larger pipe would cost more and have a greater visual impact.

It is noted that flow in Hayes Creek can, at times, be restricted by the design and capacity of the SH6 culvert, with an associated impact on lake level. A critical construction requirement

[17] Ensuring that the pipe remains completely submerged is a fundamental part of the design and installation of the withdrawal system.

would be to ensure that this method did not exacerbate any current lake level issues – ideally any structures built as part of this approach would actually help to mitigate these issues.[18]

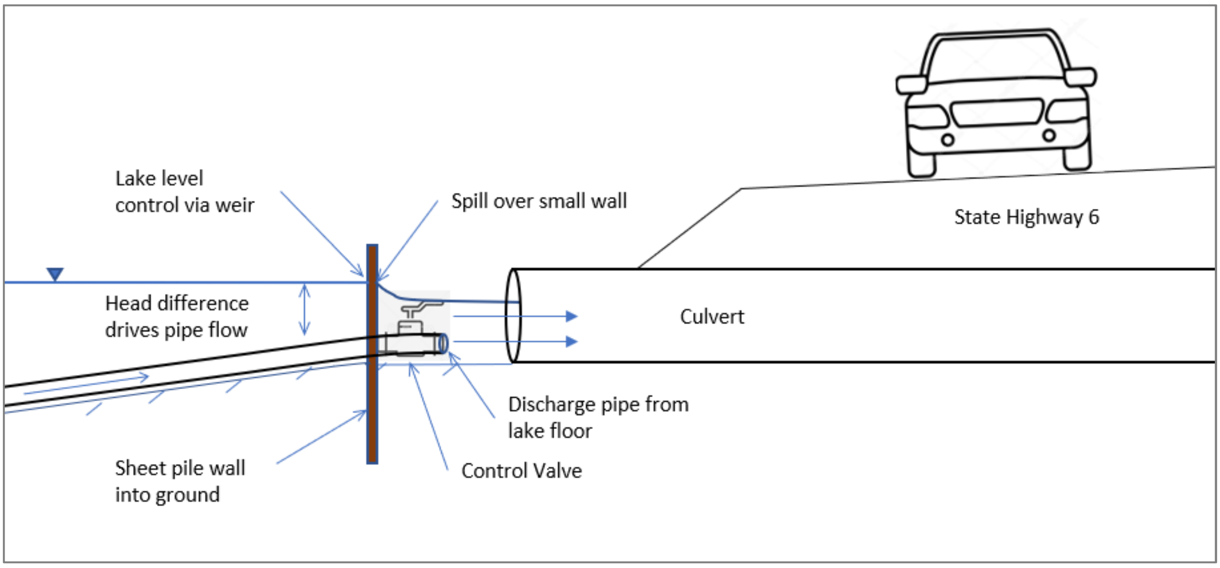


Figure 7-2 Long-section showing discharge point from the hypolimnetic withdrawal pipe, and SH6 culvert.

[18] See https://www.odt.co.nz/regions/queenstown/unsightly-lake-hayes-work-progress

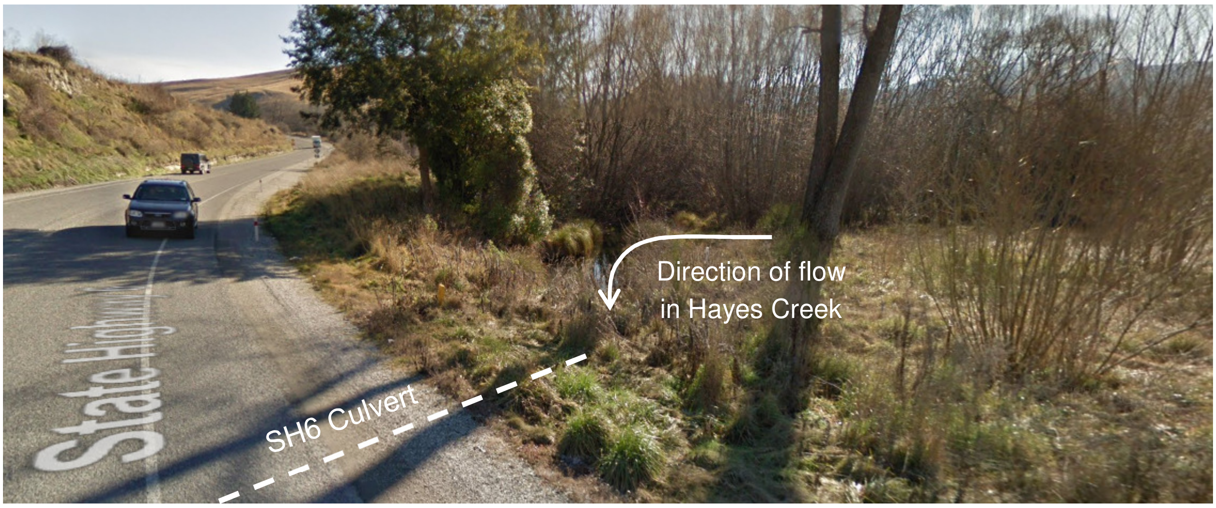


Figure 7-3 **Top: General view of Hayes Creek, upstream of SH6. Bottom: Closer view of the potential location for the weir and flanking walls, just upstream of SH6.**

7.3 TREATMENT REQUIREMENTS

For most of the year the discharge water from this method will be relatively clean, and would therefore have little detrimental effect on the receiving waters of Hayes Creek. However, during the summer period the water which is drawn from the bottom of the lake may have high DRP levels, and may also contain small quantities of hydrogen sulphide. The water discharged into Hayes Creek may therefore need to be treated. Treatment could simply involve allowing the surface and hypolimnetic waters to mix naturally. Alternatively, it may involve aerating the water by cascading it over small dams along the creek (downstream of SH6 - Figure 7-4), and/or agitating across a stone bed or, if necessary, artificially forcing oxygen into the water via a small compressor and aeration hose.

Figure 7-4 View of Hayes Creek, downstream of the SH6 Culvert.

7.4 LIKELIHOOD OF SUCCESS

Gibbs (2018b) states that if it was physically possible to implement, then this technique would have a high probability of successfully improving the long-term water quality in Lake Hayes. A literature review undertaken by Gibbs revealed that this technique has been used successfully in Europe and North America. The risks associated with this method are discussed in section 7.5.

This method could be combined with flow augmentation (section 5.0), as this would provide for additional 'flushing' of the lake with clean water (even when it was not stratified), and lead to a faster recovery of the lake (see also section 9.0). As the system may only require minor energy inputs (e.g. if a compressor was required to deliver oxygen to the water), it offers a lower long-term operating cost solution which can be used throughout the year.

7.5 COST AND RISK ANALYSIS – HYPOLIMNETIC WITHDRAWAL

Cost		Land acquisition		Resource Consent		Risks, including time to meet the overall objective
Capital	Operational	Issues	Cost	Likely issues	Cost	
Supply and lay a pipe over 1km: $300,000[19] Construct Aeration Beds $19,600 Flanking Wall: $110,000 Investigate design and arrange procurement $80,000 Contingency: $84,000 **Total: $593,600**	Includes visual inspections, stream maintenance and scientific monitoring. $10,000 Publicity and communications $10,000 **Total: $20,000**	• Consent would also be required to place the pipe in the bed of Hayes Creek. • Easements will be required. • Possible opposition from iwi, interest groups or members of the public regarding how the pipe is to be placed and what the effect is likely to be on the Kawarau River.	**Total: Up to $20,000**	• Visual impact of placing the pipe on the bed of Hayes Creek. • Further treatment of the water may be required if the discharge is not satisfactory. • The size of the pipe to effectively remove the P requires further investigation. The cost of this option goes up significantly depending on the size of the pipe required.	$30,000 to $50,000 **Total: Up to $50,000**	• In the short to medium term, the lower levels of the lake will continue to become anoxic, which will cause the release of P. Therefore, algal blooms are still possible. • The success of this method depends on how rapidly it can withdraw P from the system. • P will primarily be withdrawn from the lake during the summer period, when high DRP levels occur. During this period, the water drawn from the lake may be significantly different (in terms of clarity and odour) to the relatively clear-flowing Hayes Creek. • At other times, this method will continue to remove suspended solids from depth, which may reduce the clarity of water in Hayes Creek. • This method may need to be operational for some time before a noticeable difference in lake water quality can be seen. • There would be visual impacts associated with the weir, and the pipe being placed in Hayes Creek. • The hydraulic performance and flow rate of this method will need to be determined.

[19] This assumes a 400mm pipe is used.

8.0 TECHNICAL METHOD 5 – SEDIMENT CAPPING

8.1 BACKGROUND

This method involves transforming DRP in the water column into a non-bioavailable form,[20] through the addition of chemicals (commonly alum). This method was trialled in Lake Hayes in 2010 (Gibbs, 2018a). In that experiment, 'floc' formed rapidly and then settled through the water column over a period of a day. The alum floc adsorbs DRP and aggregates particulate material, including zooplankton and algal cells, as it settles to the lake bed. The addition of alum into the lake is thought to take several days, and occurs as a one-off application, which would need to be repeated between 5 and 20 years, depending on how much P has entered the lake.

8.2 PREVIOUSLY DOCUMENTED APPLICATION METHODS

One method for applying alum is by boat. However, if alum is applied to the surface, the floc that forms absorbs DRP and aggregates particulate materials including zooplankton and algal cells, which then settle to the lake bed. It is estimated that the alum would circulate within the lake for some time before reaching the lake bed. Surface application of alum is more likely to attract zooplankton and beneficial algae to the floc, which is not favourable. In addition, surface application by boat would be slow and cumbersome.

An alternative option is to trickle feed the alum into Mill Creek, via a storage tank and dosing plant. The advantage of this option is that it would limit the dosing of the lake surface. Instead, the cooler waters of Mill Creek tend to plunge to lower levels of the lake rather than disperse over the surface. However, given the geographic setting of lower Mill Creek, this approach also has some major challenges, including the visual impact of locating a dosing plant on the margin of Mill Creek, and transporting alum to the plant on large trucks via the narrow, steep gravel road to the Lake Hayes Reserve.

These application methods are discussed in Gibbs (2018a, 2018b) and Schallenberg (2017).

8.3 DIRECT INJECTION METHOD

Further investigation has identified a potential cost-effective way to apply alum, via a pipeline which would be temporarily laid out at a suitable depth across the lake (Figure 8-1). The target depth is likely to be the top of the hypolimnetic zone, where the alum would be most effective in terms of locking up DRP.

This approach would involve using a pump to transfer alum from a tanker truck out into the lake, and the alum would disperse through holes in the pipe. Three suitable distribution locations for tanker truck and pumps to be set up have been identified; Lake Hayes Reserve, Bendemeer Bay and the Rowing Club. From these central points, the pipe could either be laid out in straight lines, or as shown in Figure 8-2, rotated around a centre pivot in order to increase the coverage area. All equipment would be removed from the lake and reserve areas following each application.

As noted above, issues with the access road to the Lake Hayes Reserve may mean that it is not possible to apply alum from that point. The major application point is more likely to be from Bendemeer Bay, being the deepest part of the lake.

[20] i.e. it is not able to taken up by plants.

An additional benefit of this approach is that the dosing rate can be altered as the DRP level changes over time. Targeted alum dosing would reduce operating costs, and deliver the maximum benefit of the treatment. As above, the dosing would need to be repeated, as fresh sediment inputs from the catchment bury the alum layer in the lake sediments. The actual quantity of alum is determined by the amount of DRP in the water column, and therefore the amount of alum required will vary.

The 2017 Schallenberg report estimates that 856,400 litres of alum would be required per application. This equates to approximately 97 tanker loads, to be delivered to the 3 distribution locations. This would occur over a relatively short period, which may generate public concern.

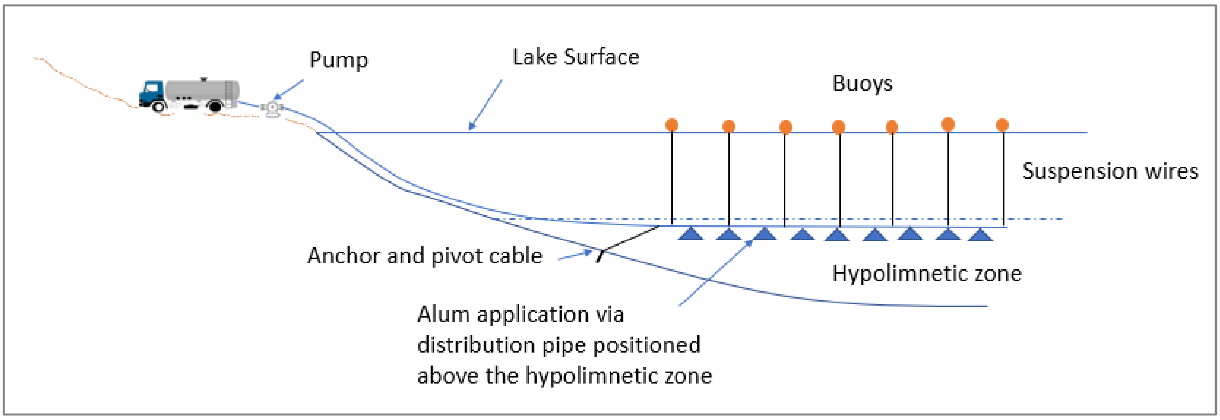


Figure 8-1 Schematic diagram of alum direct injection method

8.4 LIKELIHOOD OF SUCCESS

Previous work undertaken for ORC and the Friends of Lake Hayes (section 3.0) indicates that if it could be practically implemented, alum dosing would have an immediate positive effect on lake water quality, by immobilising P in bed sediments.

The table shown in section 8.5 has been prepared based on the assumption that direct injection at depth was used for delivery of alum. Before this method could be implemented, additional lake current data would need to be collected to optimise the positions of the dispersal pipes.

It is noted that other delivery methods are available (section 8.2), and that these would have a slightly different combination of costs and risks, and may take longer to meet the overall objective.[21]

[21] For example, investigations undertaken for this report suggest that the cost to construct a dosing plant on Mill Creek, and upgrade the access road could be as high as $800,000.

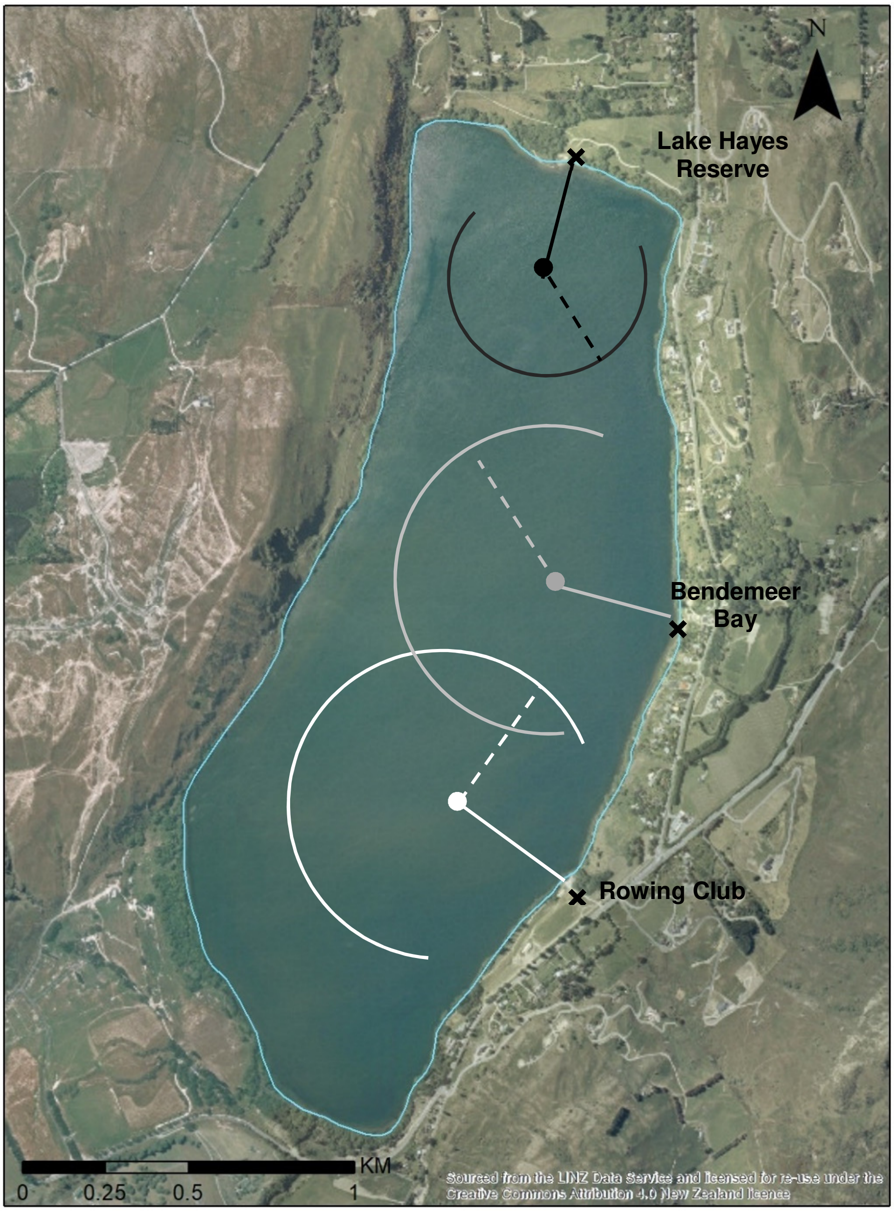


Figure 8-2 Possible layout plan for direct injection of alum from 3 center pivot points (circles), linked to a shore-based tanker and pump system.

8.5 COST AND RISK ANALYSIS – SEDIMENT CAPPING

Cost		Land acquisition	Resource Consent		Risks, including time to meet the overall objective
Capital	Operational		Likely issues	Cost	
Set-up costs for alum delivery (includes pipes, buoys, generator, pump, fittings) $72,000 Investigate design and arrange procurement $40,000 Contingency: $8,000 **Total: $120,000**	Alum: $588,500 per application. Cartage (transport from Invercargill to Lake Hayes in truck and trailer units: $80,000 Staff (supervision & science): $38,500 Publicity and Communications $15,000 **Total: up to $722,000 per application.**[22]	Equipment to be temporarily located near the lake, on reserve land. Minimal, if any cost associated with this. **Total: $10,000 (TBC)**	• Discharge to water consent required. • Opposition from iwi and other interest groups. • Temporary visual impact of alum delivery. • Perceived negative health issues.	$50,000 to $100,000 (depending on appeals) **Total: Up to $100,000**	• Negative public perception - adding a chemical to a waterbody where people swim may be strongly opposed. • The cost of alum may be more than anticipated. The actual amount required is difficult to estimate, and total costs depend on how long dosing takes place and the concentration of the dose. • This method is considered suitable because the overall pH of Lake Hayes is in the correct range. However, if the lake's pH changed significantly, then toxic trivalent Aluminium could be released (low likelihood – high consequence). • Once the alum is applied the benefit is likely to be immediate. • The effect of alum on ecology in the application area is unknown and an unforeseen lake response may be evident (also low likelihood – high consequence). • There is a risk that this method may not be as successful as anticipated. However, the intent of the direct injection method is to reduce this risk by distributing the alum across the lake as widely as possible, and at the most effective depth. • Continued delivery of sediment (P) by Mill Creek would shorten its effective lifespan as alum would be buried – there is therefore also a need for catchment improvement.

[22] This is expected to reduce over time as the lake water quality improves. The longevity of the application is largely unknown. An application may last between 5 and 20 years.

9.0 IMPLEMENTATION OPTIONS

Methods which are considered suitable for improving water quality in Lake Hayes are discussed in sections 4.0 to 8.0. This section describes how one method, or a combination of these methods, may be put into effect as an implementation option.

This overview table has been created to provide a snapshot on relative costs, likelihood of success, key risks and summarise the more detailed tables above. The tables in the previous 5 sections should be referred to for detailed information.

The colour codes used to categorise capital and operating costs are as follows:

	Low-cost	Medium-cost	High-cost
Capital	$0 to $500,000	$500,000 to $750,000	>$750,000
Operational	$0 to $100,000	$100,000 to $200,000	>$200,000

The colour codes used to categorise the likely speed of recovery are as follows:

Fast	Medium/Fast	Medium	Medium/Slow	Slow

As noted elsewhere in this report, ORC has already allocated funds to specific items of work (including the cost of additional monitoring, and preserving the option of adding water from the Arrow River to Mill Creek). These costs are included in Table 9-1 to allow a comparison of the total cost associated with each option.

Although somewhat subjective, a column describing the ‘speed of recovery’ has been included. This is intended to allow a comparison of the speed at which each implementation option would help the lake move towards the overall objective, of making the lake swimmable at all times.

Table 9-1 Implementation options summary

Implementation Option	Capital Cost	Operating Costs	Speed of Recovery	Key risks	Comment
Option 1 • Monitor and Evaluate (No lake intervention)	$100,000	$45,000 p.a.	Slow	• Algal blooms may continue to occur over the short to medium term. • May not meet public expectation that 'something should be done'.	• Monitoring will help to understand chemical and biological processes occurring in the lake, and can be used to support future decisions. • Not a lake restoration method, but would help to determine the success of other options which may be implemented in the future. • Costs for this option are already accounted for in the 2018-28 Long Term Plan. They are included in this table to show the total costs associated with each option.
Option 2 • Augmentation • Monitor and evaluate	$395,000	$70,000 p.a.	Medium/Slow	• Algal blooms may continue to occur over the short to medium term. • Water may not be available, particularly at times when it is needed the most.	• The lake will recover faster than with Option 1, but the rate of recovery remains unknown. • Work to enable an offtake from the irrigation scheme has been completed. • Although augmentation by itself has a low to medium chance of success, when combined with other options it is more likely to help to expedite recovery of the lake.
Option 3 • Destratification • Monitor and evaluate	$771,000	$121,500 p.a.	Medium	• If the air curtain is activated at the wrong time, it may cause algal blooming to become more intense. • Mixing the water column may bring suspended particles from the lower part of the lake to the surface, which may reduce water clarity in the short term.	• There are environmental issues associated with locating and operating the equipment needed for destratification. • The system can be controlled using data from the buoy, to ensure that currents within the lake are established before stratification occurs.
Option 4 • Destratification • Augmentation • Monitor and evaluate	$1,066,000	$146,500 p.a.	Medium/Fast	• The risks listed for Option 3 apply here also. • Water may not be always be available for augmentation.	• The air curtain prevents the lake from stratifying, while augmentation provides additional clean water which will flush P from the lake, helping it to recover faster. • Monitoring provides guidance on how and when to activate the system. • The comments listed for Option 3 also apply here.

Table 9-1 (continued)

Implementation Option	Capital Cost	Operating Costs	Speed of Recovery	Key risks	Comment
• **Option 5:** Sediment Capping • Monitor and evaluate	$330,000	$722,000 per application.[23] Ongoing costs: $45,000 p.a.	Fast	• The treatment process may last a shorter period of time than anticipated. • As the actual amount of Alum required is difficult to estimate, the operational costs may be higher than anticipated.	• There are perception issues associated with discharging chemicals into the lake. If these issues could be overcome, this option has a high likelihood of success. • There would be a need to repeat the dosing process periodically (5-10 years), particularly if the current flow of nutrients into the lake via Mill Creek did not improve. • The direct injection method has not been tested elsewhere. It would require further evaluation to determine how best to implement such a system.
Option 6 • Sediment Capping • Augmentation • Monitor and evaluate	$625,000	$722,000 per application.[20] Ongoing costs: $70,000 p.a.	Fast	• The treatment process may last a shorter period of time than anticipated. • As the actual amount of Alum required is difficult to estimate, the operational costs may be higher than anticipated. • Water may not be always be available for augmentation.	• Comments listed for Option 5 also apply here. • In addition, adding clean, cold, oxygenated water into the lake may mean that dosing is not required as often. Direct injection at depth means there is less risk to beneficial lake algae in the surface waters. • The sediment capping / augmentation components would need to operate sequentially (summer / winter respectively). The purpose of augmentation is to assist in flushing of the lake between doses.
Option 7 • Hypolimnetic withdrawal • Monitor and evaluate	$763,000	$65,000	Medium	• In the short term the lake will continue to become anoxic at depth, with associated release of P. Algal blooms are therefore still possible. • The clarity and smell of water drawn from depth within the lake may have	• The only option that actively targets P for removal from the lake. • Although this system has worked in other places, further hydraulic and engineering investigations would be required to determine the specific design of the system components.

[23] As noted, the length of time between each application is unknown, but is expected to be somewhere between 5 and 20 years. Its success life is largely dependent on the amount of P entering the lake via Mill Creek. Operational costs during non-application years for this option will be significantly lower.

				a negative environmental impact, particularly for Hayes Creek. • Visual impacts of the weir and pipe.	• The success of this option depends on how rapidly P is withdrawn from the system. It may be some time before a noticeable difference in lake water quality can be seen.
Option 8 • Hypolimnetic withdrawal • Augmentation • Monitor and evaluate	$1,058,000	$90,000	Medium/Fast	• The risks listed for Option 7 generally apply here also. • Water may not be always be available for augmentation.	• Comments listed for Option 7 also apply here. • However, improvements in water quality may be observed sooner, due to a greater inflow from Mill Creek (allowing for a greater volume of water to be drawn from the lake, without lowering lake level).

10.0 DISCUSSION

The advantages, disadvantages, cost profile, and the adaptability of the implementation options listed above are discussed in this section, along with an assessment of how easy it would be to suspend or cease operations after initial implementation.

The first two options listed in Table 9-1 are both relatively inexpensive – both in terms of capital costs and operating expenses. In addition, ORC's 2018-28 LTP already accounts for some of these costs – there would be minimal (option 1) or no (option 2) additional cost from what is already specified in the LTP to activate these options. Neither of these two options are likely to result in a rapid improvement of lake water quality, at best a slow rate of recovery might be expected. However, they do provide for a great deal of flexibility – more intensive monitoring will help to inform future decisions, and augmentation can easily be integrated with other methods at a later date, if a decision was made to do so. A key benefit of these options is that they do not 'lock in' a particular approach – they can be suspended, or modified relatively easily. It is noted that little precedence could be found for using augmentation to remediate lake water quality. Gibbs (2018b) did not find any examples of a small inflow of clean water being used to manage the internal P load in a lake.

The third and fourth options listed in Table 9-1 centre on the destratification method. There are higher capital costs (mainly associated with the purchase and installation of the bubbler curtain), while operational expenses would be close to $100,000 p.a. The inclusion of the bubbler curtain would help to increase the rate of recovery, compared with options 1 and 2. However, the lake would require close attention to determine when the various components[24] should be activated, and to what extent. Accurate data from the monitoring buoy is therefore critical for the two options in this group. It is also possible that the bubbler would need to be operated every year, for a decade or more, to avoid the water quality issues described in section 2.1. The two options in this group do not necessarily prevent other methods from being implemented in the future, but it seems unlikely the bubbler curtain could be used in conjunction with other technical methods such as sediment capping or hypolimnetic withdrawal. The use of aeration to avoid lake stratification is a popular restoration technique in Europe and the USA, and several such systems have been installed in the North Island (Gibbs, 2018b).

The use of sediment capping is at the core of the fifth and sixth options listed in Table 9-1. Capital costs associated with this group are not high, but the cost to purchase and transport the alum each time the lake is dosed has been estimated at more than $700,000 (possibly more, as noted above). An advantage of the sediment capping approach is that the alum dosing can be stopped at any time – for example if it was found to have negative side effects, or there were other environmental changes which made it less suitable / desirable. Previous experience shows that the alum dosing approach has a high likelihood of success in the short term, but may need to be continued (albeit on an intermittent basis) for some time. The approach is fairly adaptable – for example, sediment capping could be done once, to 'lock up' existing P in lake bed sediments, and then other methods (e.g. hypolimnetic withdrawal) could be used to maintain high lake water quality into the future. The equipment required to dose the lake could be stored offsite, ready for use if and when it was required. This technique has also been found to work successfully in a range of lake environments, both overseas and in New Zealand (Gibbs, 2018b).

[24] i.e. the bubbler unit / augmentation

The last two implementation options listed in Table 9-1 centre on the withdrawal of water from the hypolimnetic zone. Both options within this group have relatively high start-up costs, mainly associated with the purchase and installation of the withdrawal pipe. However, the operating costs for options 7 and 8 are low, comprising mainly regular inspections by technicians / scientists. Although these costs would likely continue over the long term, inspections could be scheduled with other routine work to keep them to a minimum. This is the only restoration technique considered that would reduce the P load in Lake Hayes. It would be relatively easy to fine-tune the withdrawal process (by altering the discharge flow rate), or to turn off the system completely if necessary. The withdrawal / augmentation option would operate sequentially (summer / rest of year respectively), and the withdrawal system could continue in perpetuity, at minimal cost, if needed. Gibbs (2018b) found that hypolimnetic withdrawal has been used successfully to reduce P levels in many lakes in Europe and the USA.

11.0 SUMMARY

Some robust scientific and economic studies have been undertaken in recent years to identify different approaches which could be used to remediate water quality in Lake Hayes (section 3.0). This comprehensive volume of work has been summarised in this report, in a format that can be easily understood, so that comparisons between these different approaches can be made.

A 'short-list' of 4 technical methods has been identified, and these methods have been assessed, along with the 'do minimum' approach of continuing to monitor and evaluate lake water quality. For each method, the information supplied by previous authors has been supplemented with additional investigative work to determine likely costs and construction methods. An assessment of potential risks has also been undertaken, and the likelihood of success has also been categorised, based on the best information currently available.

It is possible that more than one method may be required to make significant improvements in lake water quality. This report therefore describes how various combinations of methods could be put into effect as 'implementation options' (section 9.0). Again, critical information relating to the risks associated with these options is listed, along with an assessment of the likely speed of recovery.

This report does not make any recommendations on which methods or implementation options should be implemented. Rather, it summarises a wide range of information, which can be used to make future decisions about how to remediate lake water quality. It is noted that there are risks and benefits associated with any approach which may be chosen.

12.0 ACKNOWLEDGEMENTS

GHC Consulting would like to acknowledge the previous work of Castalia Strategic Advisors, Max Gibbs of NIWA, Marc and Lena Schellenberg on behalf of the Friends of Lake Hayes and ORC staff. We are also grateful for the practical guidance from Andy Bruere, Lakes Operations Manager, Bay of Plenty Regional Council and other suppliers whom have dedicated their time to assisting us with this project. A list of references used to inform this report is provided in section 3.

APPENDIX 1. COMPONENTS OF THE LAKE DESTRATIFICATION OPTION

Item	**Preferred location**	**Requirements**
Compressor	Lake Hayes Reserve	• A 132-kW variable speed compressor (Largo 132)  • Noise level: 77 dB(A), equivalent to loud talking (almost shouting). • Dimensions: 2800 x 1755 x 1960. • 3-phase, 400v electricity supply. This model compressor was selected based on the specifications set out in Gibbs (2018a), in regards to the amount of air required, hole diameter, and the length of aeration pipe.
Compressor shed	Lake Hayes Reserve	• Dimensions 4800 x 3600 x 2400 • Specifically designed for noise reduction • Ventilated. • Vehicle access. • Building consent (QLDC). • Comply with requirements of the Arrowtown – Lake Hayes Reserve Management Plan, 2013 (QLDC)
Air supply pipe	From compressor shed into the lake, then to Bendemeer Bay	• Air supply pipe extends a total distance of about 900 m. • On land, it would be buried to a depth of 600 mm.
Air curtain	Positioned through the deepest section of the lake	• Air curtain delivered through an airline with 1 – 1.5 mm holes drilled, through the upper side at 20 – 30 cm intervals along its length.

APPENDIX 2. HOW THE LAKE DESTRATIFICATION OPTION WORKS

Below is a simplified description of how the lake destratification option is intended to improve water quality in Lake Hayes. It is noted that the system and lake response is relatively complex and more detailed descriptions are provided in Gibbs (2018a and 2018b).

The ultimate objective of destratification is to oxygenate the full body of lake water. Oxygenated waters encourage a different algae assemblage to become established within the lake. These algae tend to create a positive effect on lake waters, and help them to improve more quickly than would occur naturally.

How it works:

1. The air curtain will cause currents to form, and mixing to occur in the lake, as illustrated in the following diagram.

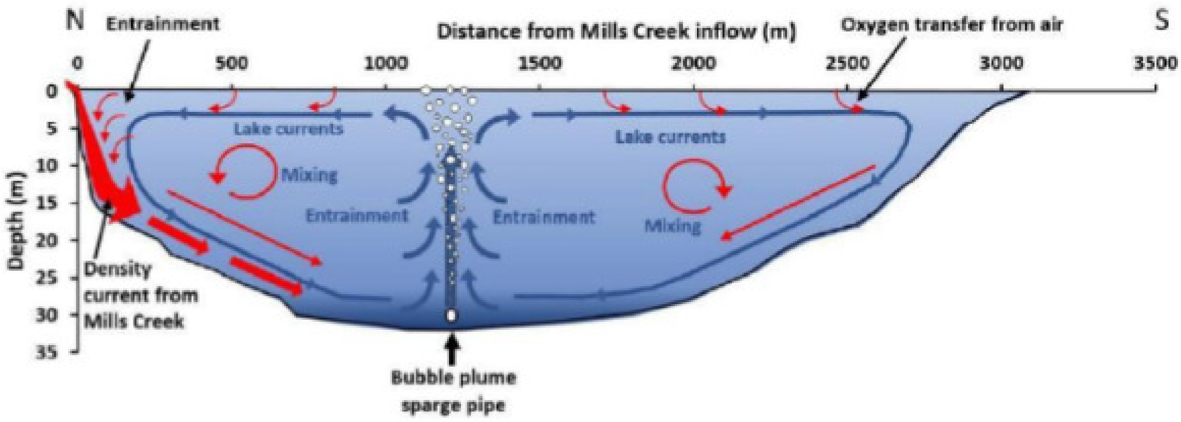


Diagram of the likely flow paths in Lake Hayes with the bubble plume operating. Red paths are oxygenated water, with blue lines expected lake flow paths (From Gibbs, 2018a).

2. These currents will circulate the algae and bacteria within the full depth of the lake. When the algae and bacteria are carried to depth, they die due to insufficient light.
3. When they die, they decompose aerobically, which means they emit CO_2[25], which will reduce the pH of the lake, which will reduce ammonia levels (i.e. nitrogen).
4. Over time, this process will reduce the amount of phytoplankton in the lake. With less suspended particles in the water column, the water column will be clearer, and also more oxygenated (due to a range of processes more fully explained by Gibb 2018a).
5. Light will therefore be able to penetrate deeper into the lake, and the amount of light will reduce gradually, rather than abruptly.
6. A clearer, more oxygenated water column will lead to higher levels of oxygen-producing algae in the lake.
7. As mobile DRP only forms under anoxic conditions, P will not be released from the lake bed, and will remain locked up in those sediments.
8. After a period of 5-10 years (assuming the input of organic matter and P from the upstream catchment is also reduced), the environment within the lake may be sufficiently stable, so that the air curtain system may not be required.

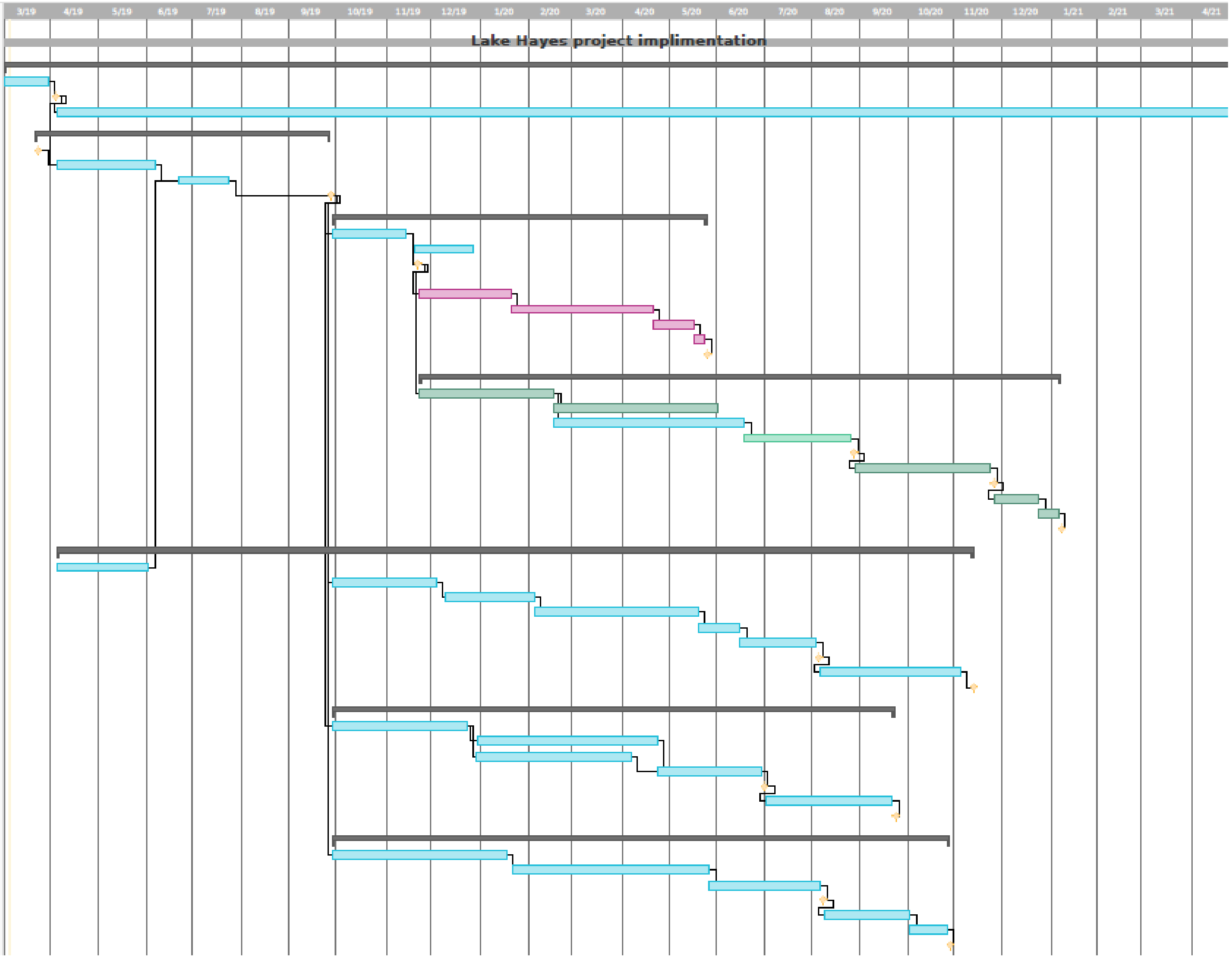
[25] rather than giving off methane, which occurs when they decompose under anaerobic conditions (i.e. without oxygen).

APPENDIX 3. COMPONENTS OF A HYPOLIMNETIC WITHDRAWAL SYSTEM

Item	Preferred location	Requirements
Weir and flanking walls	Located upstream of the Hayes Creek SH6 culvert.	• The weir would have a pipe passing beneath it, designed so that surface waters can still flow naturally over the top.
Pipe to the hypolimnetic zone - preferably the deepest part of the lake (~30m)	Along the lake bed to start of Hayes Creek.	• Pipe travels from the lake bed to the weir, before discharging to Hayes Creek. The pipe may need to be fixed into position using various weights and anchors.
Potential agitated river bed of stones	Downstream from the pipe discharge into Hayes Creek	• To aerate the water so that is re-oxygenated and hydrogen sulphide odour is treated.

APPENDIX 4. PROJECT IMPLEMENTATION TIMELINE

Lake Hayes project implimen...	start	end	0h	0%
No Lake Intervention (Monitoring...	**01/03/19**	**27/04/21**	**0h**	**0%**
Construct monitoring buoy	01/03	28/03	0	0%
Install and commission monitoring ...	02/04	02/04	0	0%
Monitoring operation	04/04	27/04	0	0%
Consulting	**21/03/19**	**25/09/19**	**0h**	**0%**
Council meeting to consider Lake H...	21/03	21/03	0	0%
Public consultation on options	04/04	05/06	0	0%
Evaluate and report to Council on c...	21/06	23/07	0	0%
Council decision (Council meeting ...	25/09	25/09	0	0%
Augmentation	**27/09/19**	**25/05/20**	**0h**	**0%**
Hydrological study	27/09	13/11	0	0%
Execute water take agreement with...	20/11	26/12	0	0%
Can project proceed without negati...	20/11	20/11	0	0%
If Yes ... Proceed to construction	**-**	**-**	**0h**	**0%**
Undertake AEE for a discharge to ...	22/11	20/01	0	0%
Prepare and apply for consent	21/01	20/04	0	0%
Construct take off control valve and...	21/04	15/05	0	0%
Augment commissioning	18/05	22/05	0	0%
Task complete	25/05	25/05	0	0%
If No... Consult findings of hydrol...	**22/11/19**	**06/01/21**	**0h**	**0%**
Assess engineering options for culv...	22/11	17/02	0	0%
Undertake detailed engineering des...	18/02	01/06	0	0%
Prepare and apply for consent	18/02	17/06	0	0%
Advertising tender	18/06	25/08	0	0%
Tender award	26/08	26/08	0	0%
Construction	28/08	23/11	0	0%
Complete culvert	24/11	24/11	0	0%
Complete construct take off valve ...	26/11	23/12	0	0%
Augment commissioning	24/12	05/01	0	0%
Augment complete	06/01	06/01	0	0%
De-stratification	**04/04/19**	**11/11/20**	**0h**	**0%**
In addition to general consultation ...	04/04	31/05	0	0%
Detailed design	27/09	03/12	0	0%
Prepare and apply for resource con...	10/12	04/02	0	0%
Consultation with affected parties	05/02	19/05	0	0%
Prepare tender documents	20/05	15/06	0	0%
Advertise tender and receive propo...	16/06	03/08	0	0%
Award tender	04/08	04/08	0	0%
Construction	06/08	03/11	0	0%
Commissioning	11/11	11/11	0	0%
Hypolymnetic Withdrawal	**27/09/19**	**22/09/20**	**0h**	**0%**
Assess engineering options for Hay...	27/09	23/12	0	0%
Prepare and apply for resource con...	31/12	22/04	0	0%
Undertake detailed engineering des...	30/12	06/04	0	0%
Advertise tender and receive propo...	23/04	29/06	0	0%
Award tender	30/06	30/06	0	0%
Construction	02/07	21/09	0	0%
Construction completed and comiss...	22/09	22/09	0	0%
Sediment capping	**27/09/19**	**27/10/20**	**0h**	**0%**
Undertake lake current study and d...	27/09	16/01	0	0%
Prepare and apply for resource con...	22/01	26/05	0	0%
Advertise tender and receive propo...	27/05	05/08	0	0%
Award tender	06/08	06/08	0	0%
Construct buoy and delivery lines	10/08	01/10	0	0%
Commence supply of Alum into Lake	02/10	26/10	0	0%
Task completed - assess results	27/10	27/10	0	0%



APPENDIX 5. FRESHWATER IMPROVEMENT FUND

The previous National Government in 2016 committed $100 million over 10 years to the Freshwater Improvement Fund, to improve the management of New Zealand's lakes, rivers, streams, groundwater and wetlands. The fund supports projects with a total value of $400,000 or more, that help communities manage fresh water within environmental limits.

At present the fund is now closed for applications, and the Ministry for the Environment (MfE) is currently unable to give any indication when the next Freshwater Improvement Fund round may be. It is noted that in September 2017, a $385,000 grant from the fund was made to improve and maintain the long-term health of the wider Upper clutha area.

If the fund was to re-open for applications, the current application criteria include the following:

- *The project must contribute to improving the management of New Zealand's freshwater bodies.*
- *The project must meet 1 or more of the following:*
  - *achieve demonstrable co-benefits such as:*
  - *improved fresh, estuarine or marine water quality or quantity*
  - *increased biodiversity*
  - *habitat protection*
  - *soil conservation*
  - *improved community outcomes such as to recreational opportunity or mahinga kai*
  - *reduction to current or future impacts of climate change*
  - *reduced pressure on urban or rural infrastructure*
- *increase iwi/hapū, community, local government, or industry capability and capacity in relation to freshwater management*
- *establish or enhance collaborative management of fresh water*
- *increase the application of mātauranga Māori in freshwater management*
- *include an applied research component that contributes to improved understanding of the impacts of freshwater interventions and their outcomes.*
- *The minimum request for funding is $200,000 (excluding GST).*
- *The fund will cover a maximum of 50 per cent of the total project cost.*
- *The project will be funded for a maximum period of up to 5 years after which the project objectives will have been achieved or the project will be self-funding.*
- *The project must achieve benefits that would not otherwise be realised without the fund or are not more appropriately funded through other sources.*
- *The effectiveness of the project and its outcomes will be monitored, evaluated and reported.*
- *An appropriate governance structure in place (or one will be established as part of the project).*
- *The applicant must be a legal entity.*

Similarly, the MfE Freshwater Improvement Fund website currently states that any projects would be assessed against the following criteria:

1. *The extent to which the project addresses the management of freshwater water bodies identified as vulnerable.*
2. *The project demonstrates improvement in the values and benefits derived from the freshwater body.*

3. *The extent to which public benefit is increased.*
4. *The project demonstrates a high likelihood of success based on sound technical information or examples of success achieved through comparable projects undertaken elsewhere.*
5. *The extent to which the project will leverage other funding.*
6. *The project will involve the necessary partner organisations to ensure its success.*
7. *The project will engage personnel with the required skills and experience to successfully deliver the project.*

Previously, applications have been assessed by a panel of experts, which then makes a recommendation to the Minister for the Environment who makes the final funding decision.

APPENDIX 6. DISTRICT PLAN REQUIREMENTS

Any permanent structure to be placed on the margins of Lake Hayes (including reserve areas) would need to comply with the requirements of the Queenstown Lakes District Plan. The area is zoned as *Rural Living Areas* with the *Community Facility* sub-zone overlying it.

The most relevant requirements of the District Plan in this area include the following:

Any building proposed to be located in the zone will be a controlled activity for example:

- *Must avoid mitigate adverse effects on the natural landscape and visual amenity values.*
- *Nature conservation values and the natural character of the environment.*
- *Night time noise levels must be below 40 dB* $L_{Aeq\ (15\ min)}$.
- *Consideration must be made for glare, screening setback distances and colour.*

APPENDIX 7. LAKE HAYES RESERVE MANAGEMENT PLAN REQUIREMENTS

RESERVES ACT:

The Reserves Act 1977 (s17) sets out the purpose of a reserve:

"for the purpose of providing areas for the recreation and sporting activities and the physical welfare and enjoyment of the public and for the protection of the natural environment and beauty of the countryside, with emphasis on the retention of open spaces and on outdoor recreational activities, including recreational tracks in the countryside"

ARROWTOWN – LAKE HAYES RESERVE MANAGEMENT PLAN REQUIREMENTS

Any activity or permanent structure to be placed within the reserve areas adjacent to Lake Hayes would need to comply with the requirements of the Arrowtown – Lake Hayes Reserve Management Plan, 2013 (QLDC). The most relevant requirements include the following:

- *A lease for the occupation of the reserve would be required. This would need to be publicly notified.*
- *Utility services should be placed underground, unless this is impractical due to exceptional circumstances.*
- *Management of the reserves should occur in a manner consistent with the Lake Hayes Management Strategy (1995), to improve the overall ecology and water quality of Lake Hayes.*

Policy 8 (Buildings) of the Arrowtown Lake Hayes - Reserve Management Plan includes the following:

8.1 Proposals for new structures shall consider effects on the park environment, potential increased demand for car parking in or adjacent to the park, and the impact of the additional facilities and requirements on the convenience and wellbeing of other park users. Proposals for new buildings, other than those permitted in this Management Plan, shall be publicly notified in accordance with the Reserves Act 1977.

APPENDIX 8. TECHNICAL METHOD OBJECTIVES

Technical Method	Objective(s)
1. Water Augmentation	• Add clean water to Mill Creek, to increase the volume of water passing through Lake Hayes, and displace a greater volume of nutrient-rich lake water than would occur otherwise. • Reduce the temperature in Mill Creek, so that when it enters Lake Hayes it will plunge to the lower parts of the lake and oxygenate the bottom waters, thereby avoiding the conditions which result in P being released from lake bed sediments.
2. Destratification	• Prevent thermal stratification from occurring, to maintain dissolved oxygen concentrations above 5 g/m^{-3} as a means for preventing the release of dissolved reactive P from the lake sediments.
3. Hypolimnetic withdrawal	• Reduce the availability of dissolved reactive P in the lake by discharging nutrient enriched bottom water from the lake via a pipe to the outlet, rather than discharging cleaner surface water.
4. Sediment capping	• Reduce the amount of P in the lake water column by flocking with alum, causing P to settle to the lake bed, and locking it in the sediment with the resultant active sediment cap.