TECHNICAL COMMITTEE AGENDA

WEDNESDAY 1 AUGUST 2018

1:30 pm ORC Council Chamber

Level 2, Phillip Laing House, 144 Rattray Street, Dunedin

Membership

Cr Andrew Noone	*(Chairperson)*
Cr Ella Lawton	*(Deputy Chairperson)*
Cr Graeme Bell	
Cr Doug Brown	
Cr Michael Deaker	
Cr Carmen Hope	
Cr Trevor Kempton	
Cr Michael Laws	
Cr Sam Neill	
Cr Gretchen Robertson	
Cr Bryan Scott	
Cr Stephen Woodhead	

Disclaimer

Please note that there is an embargo on agenda items until 8:30 am on Monday 30 July 2018. Reports and recommendations contained in this agenda are not to be considered as Council policy until adopted.

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1. APOLOGIES

2. LEAVE OF ABSENCE

3. ATTENDANCE

4. CONFIRMATION OF AGENDA

5. CONFLICT OF INTEREST

Members are reminded of the need to stand aside from decision-making when a conflict arises between their role as an elected representative and any private or other external interest they might have.

6. PUBLIC FORUM

7. PRESENTATIONS

8. CONFIRMATION OF MINUTES

Recommendation

That the minutes of the meeting held on 21 September 2017 be received and confirmed as a true and accurate record.

Attachments

1. Technical Committee Minutes - 13 June 2018 **[8.1.1]**

9. ACTIONS

Status report on the resolutions of the Technical Committee:

Report No.	Meeting	Resolution	Status
Leith Flood Protection Scheme Dundas Stage Programme	13/06/2018	*b) The request by the University of Otago for ORC to delay construction of the Dundas Street stage of the Leith Flood Protection Scheme is declined.*	
An assessment of the Clean Heat Clean Air program's effectiveness	13/06/2018	*b) That this report be used to inform the review of ongoing financial incentives for Air Quality, proposed for 2018/2019 in the 2018-2028 Draft Long-Term Plan.*	

Attachments

Nil

10. MATTERS FOR COUNCIL DECISION

NIL

11. MATTERS FOR NOTING

11.1. Director's Report on Progress

Prepared for:	Technical Committee
Report No.	EHS1821
Activity:	Governance Report
Prepared by:	Dr Jean-Luc Payan, Manager Resource Science (acting) Dr Ben Mackey, Manager Natural Hazards (acting) Chris Valentine, Manager Engineering
Date:	26 July 2018

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1. Précis

This report presents an update on the following matters:

1. Study on the time of incursion of *Lindavia intermedia* (lake snow);
2. Leith Flood Protection Scheme;
3. $PM_{2.5}$ air quality monitors installed in Otago;
4. Central Otago Stock Truck Effluent Disposal Sites; and
5. Rees - Dart River Natural Hazards.

It is recommended that this report is received and noted.

2. Study on the time of incursion of *Lindavia intermedia* (lake snow)

"Lake snow" has been discussed at various Council meetings over the last two years[1]. A lake snow workshop for stakeholders and researchers was held at ORC offices in Dunedin in December 2016. The workshop discussed aspects associated with the lake snow phenomena that has developed in some of Otago's largest alpine lakes in recent years.

A principal outcome of this workshop was the identification of priority research areas required to progress understanding of lake snow, with a view to developing management interventions in the future. Of the priority work streams identified by workshop participants, ORC staff identified the following components as being of highest priority for direct funding by ORC, more detail is given in Appendix A.

- Comprehensive examination of NZ diatom samples, collections, reports
- Historical dynamics of *L. intermedia* in NZ lakes from which it has been reported using paleolimnological diatom analysis of dated sediment cores.
- Literature review of shifts in lake phytoplankton to increased dominance by (*Lindavia*-like) centric diatoms (e.g., climate connection)
- Comprehensive literature review on diatom polysaccharide overproduction from similar situations overseas
- Supporting citizen science

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[1] ORC, Report # 2017/0568, Presented to Technical Committee on 8 February 2017
ORC, Report # 2017/0705, Presented to Technical Committee on 22 March 2017
ORC, Report # 2017/0802, Presented to Technical Committee on 14 June 2017
ORC, Report # 2017/1019, Presented to Technical Committee on 13 September 2017
ORC, Directors Report, Presented to Technical Committee on 31 January 2018

ORC commissioned Dr C Kilroy (NIWA) to examine NZ diatom collections to try to confirm the time of the incursion of *L. intermedia* into New Zealand.

The study involved the examination of 40 samples from the Vivienne Cassie diatom collection (held at Landcare Herbarium, Lincoln), spanning 1970 to 1991, 144 samples from the NIWA diatom collection, spanning 1998 to 2013, and a further 35 recent samples held at NIWA.

Key findings were:

- the species was not detected in 97 samples that were collected before 2002, including samples from at least six sites that are currently known to be positive;
- the earliest records of *L. intermedia* in New Zealand lakes remain the two samples collected in 2002 from Lakes Hayes and Aviemore (Reid 2005, Novis et al. 2017a);
- by 2005, *L. intermedia* was already widespread in New Zealand, as determined from its presence in the outlets of nine lakes with a broad geographical spread, from Lake Moawhango (North Island) to Lake Gunn (South Island);
- collections from 2006 to 2018 showed further lakes positive for *L. intermedia* (in addition to the lakes already identified as being affected by lake snow) although prior negative samples were not available for all of the lakes;
- to date, Lakes Waikaremoana and Moawhango are the only North Island lakes positive for *L. intermedia*, and this may be partly because of lack of samples;
- lakes in the Bay of Plenty and Waikato regions were negative in 1999, and remain negative (as of 2016).

The study has provided further evidence supporting the proposal that *L. intermedia* is a recently introduced species in New Zealand. The work complements the genetics work undertaken by Landcare Research (Appendix A, sub-program 1.i)

The experts "lake snow" workshop is being reconvened by ORC in August, to discuss findings from recent work undertaken; further research work planned; whether the research programme can be accelerated and if further work is required to identify potentially feasible methods to manage the effects of lake snow.

3. Leith Flood Protection Scheme

Engineering works on the Union to Leith Footbridge stage of the Leith Flood Protection Scheme are progressing. The right bank wall buttresses are now completed, along with the terraces under and upstream of the Information Technology Services (ITS) building. Work is now progressing on the placement of scour resistant rock riprap in the bed of the river. The contractor (Downer NZ Ltd) advises that the works are expected to be completed by mid-October.

Figure 1: Construction of walls and terraces upstream of the Information Technology Services (ITS) building.

Figure 2: Construction of ground beam to support cellular confinement to enable landscape planting and balustrade on left bank upstream of the Information Technology Services (ITS) building.

Detailed design and hydraulic modelling for the culvert and associated works at Dundas Street Bridge are on target for completion in July. The construction works will be tendered in August with the works to be undertaken this Summer.

Public consultation for Forth Street to Harbour amenity improvements got underway on Tuesday 24 July. Public consultation will be open for one month using ORC's online consultation platform.

4. $PM_{2.5}$ air quality monitors installed in Otago

Two $PM_{2.5}$ air quality monitors have been installed in Otago, one in Alexandra and one in Central Dunedin. These monitors will be gathering data on the amount of the 'fine' fraction of particulates in the air, those particles less than 2.5 microns in diameter. This work is being done in preparation for the upcoming amendments to the National Environmental Standard for Air Quality as it is anticipated that $PM_{2.5}$ limits will be introduced.

On 30 May, an air monitor measuring $PM_{2.5}$ was installed in Alexandra, alongside the current PM_{10} monitor at the Alexandra Primary School. The monitor was installed in conjunction with the launch of NIWA's Community Observation Networks for Air (CONA), an initiative to involve students in a citizen science air quality programme. The CONA programme was the subject of a council workshop held on 3 May 2018.

Figure 3: ORC's air quality monitoring site in Alexandra. The $PM_{2.5}$ monitor is on the right and the PM_{10} monitor is on the left.

Preliminary hourly data from the $PM_{2.5}$ monitor show that when PM_{10} is high, the majority of it falls within the $PM_{2.5}$ size fraction; when PM_{10} is at lower levels, $PM_{2.5}$ may make up about 50-60% of PM_{10}. Since most $PM_{2.5}$ is the result of incomplete combustion, this result indicates that combustion sources such as solid-fuel heating appliances are a dominant contributor to pollution in Alexandra.

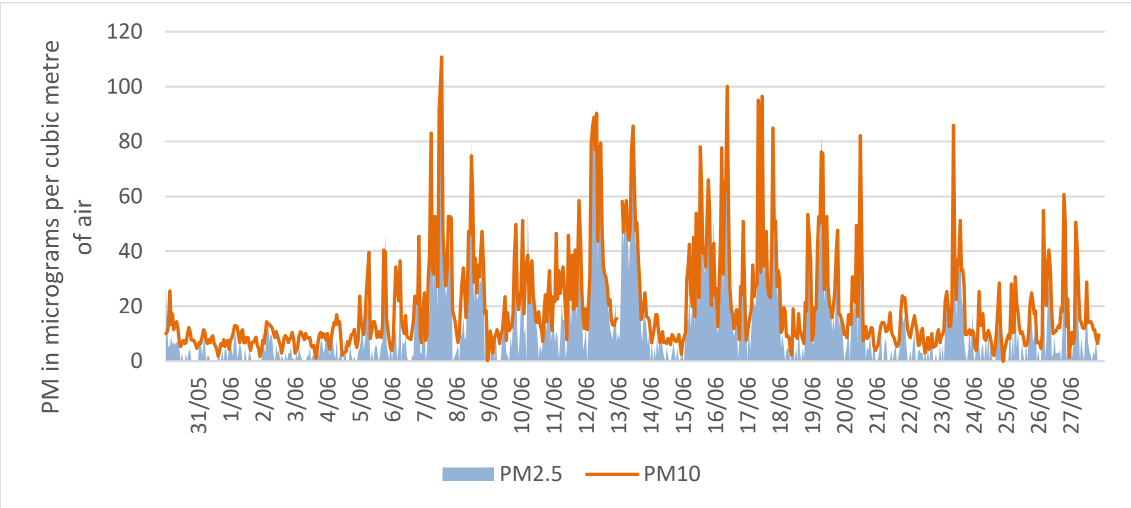

Figure 4: Hourly $PM_{2.5}$ (blue shaded) and PM_{10} (orange line) data for Alexandra from the end of May 2018 through the end of June 2018 show the relationship between the two size fractions being monitored.

A second $PM_{2.5}$ monitor was installed on 13 July in Central Dunedin alongside the current PM_{10} monitor (Figure 5). The monitor is a Teledyne T640X and uses optical methods of sample analysis. Preliminary data will be downloaded in two weeks.

Figure 5. New $PM_{2.5}$ monitor in Central Dunedin is shown on the right along with the existing PM_{10} monitor on the left.

5. Central Otago Stock Truck Effluent Disposal Sites

Work is progressing on construction of the SH85 site at Brassknocker Road. The access road culvert extensions have been installed with earthworks underway on the site. Long lead items have been procured, including receiving pit, screen, storage tank and site lighting.

A meeting has been held with New Zealand Transport Agency, Central Otago District Council (CODC), Queenstown Lakes District Council and Otago Regional Council to agree site selection criteria in relation to an additional stock effluent disposal site.

The proposed site on Ripponvale Straight would provide coverage to stock movements to and from Omarama via SH8 and to and from Hawea along SH6. CODC advised they would rather see two sites, one on SH8 around Bendigo/Tarras area, and one on SH6 at an appropriate location north of Cromwell. It was discussed that ORC have funding to construct one further site. Engineering staff are engaging with the Road Transport Association to seek further clarification on stock movements along SH6, SH8 and SH8A to inform CODCs recommendation of a further site.

Figure 6: Culvert pipes installed on Stock Truck Effluent Disposal Site access road along SH85.

6. Rees-Dart River Natural Hazards

In early July a new three-year plan to investigate, manage and adapt to the natural hazards posed by the Rees and Dart Rivers was initiated with site visits and community meetings. Natural hazards staff organised a 'report back' meeting with local residents who rely on the Glenorchy-Kinloch Road and who had raised concerns through Long Term Plan submissions about the danger posed to the road by the rivers. Recent erosion has necessitated urgent works to be carried out by QLDC in order to arrest erosion of the road in places, and a meeting with QLDC staff was held where respective plans were shared.

Positive outcomes of these meetings included an agreement to work with QLDC transport staff to align our respective work in order to maximise protection to the road while a longer-term plan is worked on. In the mean-time, work to re-align the rivers where necessary will continue. Plans are in place to carry out a channel diversion away from the road on the Dart River this winter. A second piece of work involves extending an incomplete groyne on the Rees River which will allow the flood protection infrastructure downstream to perform as designed and protect the Glenorchy-Paradise road from flood damage. Funding for this work has been provided for in the Wakatipu River management budget for 2018/19 and subsequent years.

Figure 7: Participants view the effect of the advancing Dart River delta at the historic wharf at Kinloch on 6 July 2018. Sediment has built up in this part of Lake Wakatipu over the past several years.

On 6 July residents were given the opportunity to take ORC and QLDC staff and Councillors Laws and Lawton on a ‘field trip’ around sites of concern and demonstrate critical flood and erosion protection infrastructure which they consider worthy of reinforcing. In turn, residents were asked to consider the technical information presented to them, including the multiple-hazard setting of Kinloch and Glenorchy and the inevitable advance of the river delta into the margins of both settlements. The fact that there are many options available for mid-long-term management of these risks, and that it was often a trade-off of cost vs time bought, was discussed. These will be outlined and discussed formally with residents over the next three years to form a comprehensive ‘hazardscape’ approach to the area.

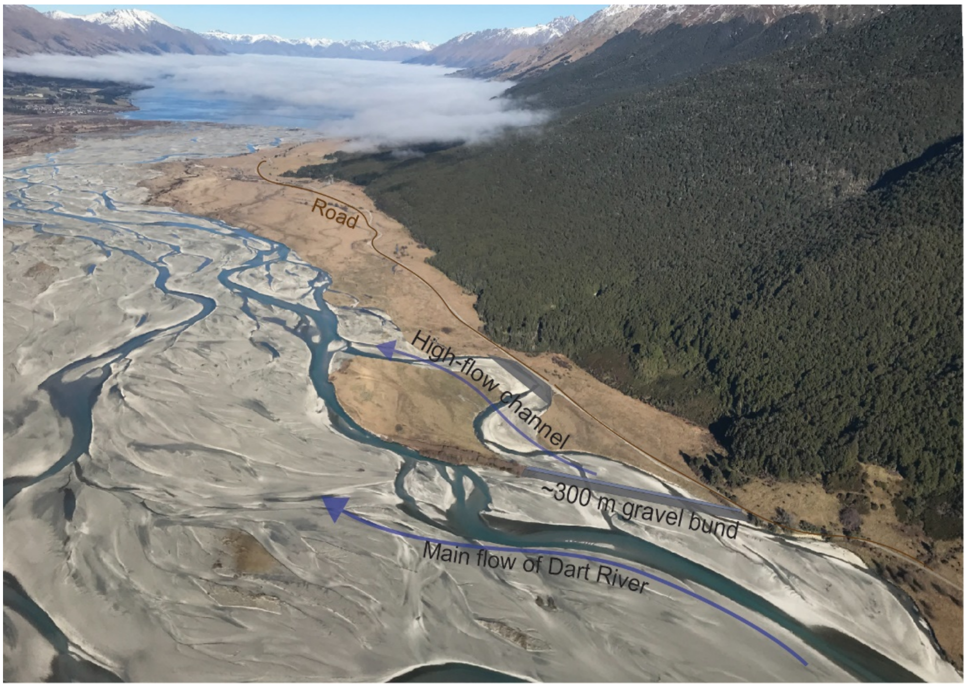

Figure 8: Proposed works to protect the Glenorchy-Kinloch Road from the Dart River.

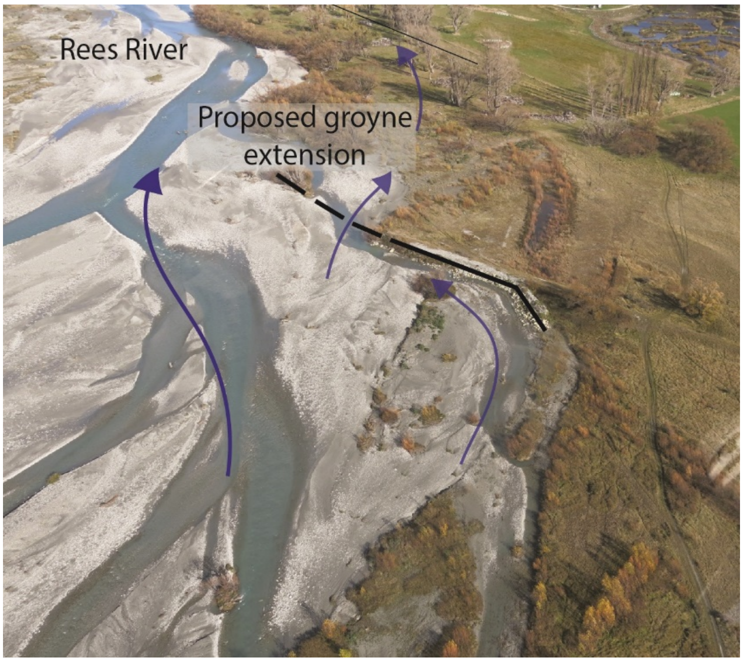

Figure 9: Proposed groyne extension adjacent to the Rees River.

Parallels can be drawn between this discussion and the coastal inundation and erosion climate change issues (e.g. retreat/protect) that other parts of Otago currently face. The changing economic landscape must also be considered, with the roading network at the head of Lake Wakatipu playing an increasingly important role in tourism, as well as rural access.

7. Recommendation

a) *That this report be received and noted.*

Endorsed by: Dr Gavin Palmer
Director Engineering, Hazards & Science

Attachments

1. Lake Snow Programme of Work **[11.1.1]**

11.2. Lower Waitaki Plains Aquifer

Prepared for: Technical Committee
Report No. EHS1822
Activity: Environmental - Regional Plan: Water Quality
Prepared by: Dr Jean-Luc Payan, Manager Resource Science (acting)
Date: 19 July 2018

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1. Précis

ORC has recently carried out an 18-month qualitative investigation for the Lower Waitaki Plains Aquifer, to provide guidance on nutrient management. The resulting technical report (attached) highlights the outcomes of the groundwater quality monitoring and analysis.

2. Background

The Lower Waitaki Plains Aquifer is mainly unconfined and hosted in quaternary river deposits made of gravel, sand and silt and overlying relatively impervious tertiary sediments.

The aquifer is inferred to be recharged by rainfall, irrigation returns, high flow events from the Waitaki River and foothill creeks.

The main groundwater flow direction is following the topography and is from the west/south-west towards the north-east/east as shown in Figure 1.

The results of the age dating samples (Figure 1) show that the groundwater is young (between two and seven years old).

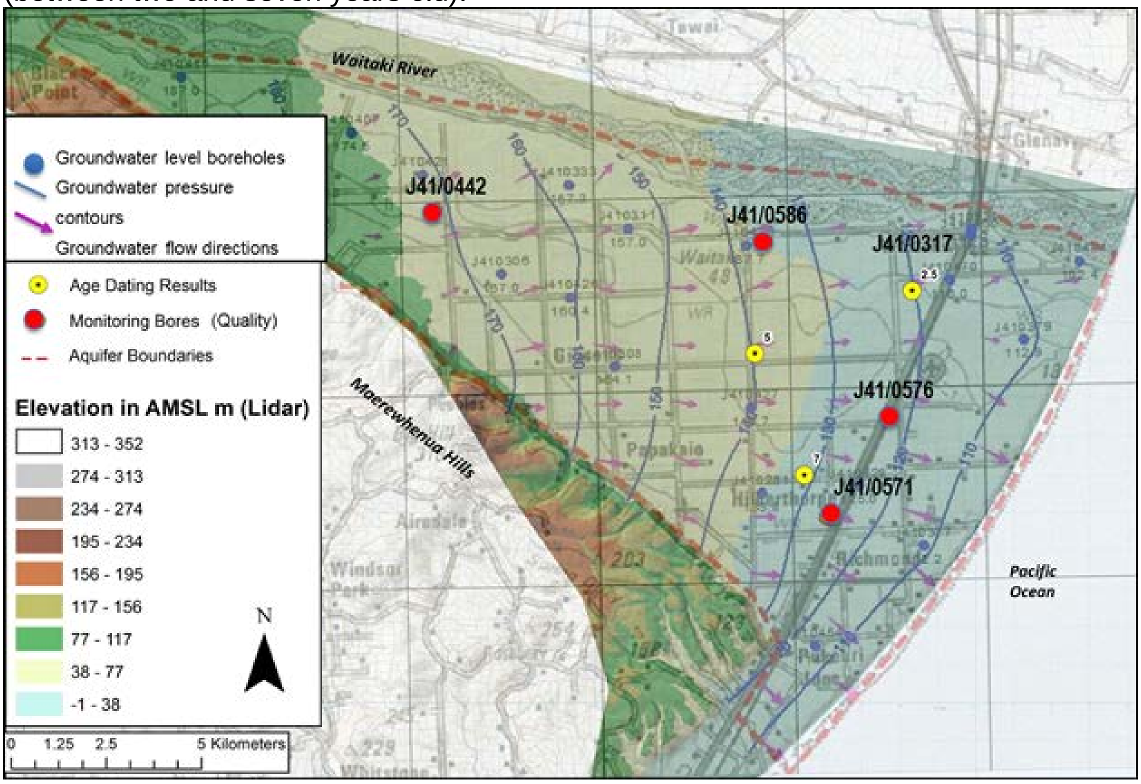

Figure 1 - Map of the Lower Waitaki Plains Aquifer, with topography, flow directions, monitoring bores and age dating results

The predominant activity over the Plains is dairy farming, covering approximately 70% of the area in 2015. The Lower Waitaki Irrigation Scheme delivers water to more than 200 stakeholders and extends over 20,000 ha.

3. Discussion

Nitrate concentrations

A rise of the nitrate-N concentrations from approximately 2 to 5 mg/l, correlated to the elevation of the water table, has been observed between 1997 and approximately 2000 on the long-term monitoring bore (J41/0317 on Figure 1). This could be caused by an increased drainage linked to the development of the irrigation scheme (increase in irrigation), providing less opportunity for pasture uptake and consequently more nitrates to be flushed into the aquifer. Since 2001, the aquifer state appears more stable. In particular, the nitrate-N concentrations in the aquifer storage seem to fluctuate around 5 mg/l and to have reached a relative equilibrium with the nitrogen inputs. The apparent stabilisation of the nitrate-N concentrations needs to be confirmed by longer timeseries: the current timeseries is not long enough to identify a clear and definite trend (the concentration is slightly declining between 2011 and 2015, and rather increasing between 2016 and 2018).

The data collected with the extended monitoring network between July 2016 and January 2018 show that the nitrate-N median concentrations range between 0.99 and 6.6 mg/l within the aquifer between the most up-gradient bore and the most down-gradient one. This trend is attesting to the impact of intensive land use and irrigation on the plains, with a cumulative effect along groundwater flow paths towards the ocean.

The nitrate-N concentrations are below the NZ Drinking Water Standards Maximum Acceptable Value of 11.3mg/l of nitrate-N.

Escherichia Coli (*E. coli*) concentrations[1]

The Lower Waitaki alluvial aquifer is used for drinking purposes by the community and private landowners; the water is occasionally consumed without any treatment. The aquifer is identified as having a value of human use without treatment in Schedule 3A of the Regional Plan: Water.

According to the long-term monitoring data (J41/0317 in Figure 1) and to the new monitoring bores, recurrent faecal contamination events with *E. coli* concentrations above the NZ Drinking Water Standards (Maximum Acceptable Value< 1 cfu[2]/100 ml) have been detected over the last 20 years.

It is anticipated that these microbial contaminations may be linked to factors such as sub-standard bore head protections, border dyke irrigation over macro-porous soils, or/and sub-standard effluent management practices.

The contamination has been signalled to the landowners and to the Lower Waitaki Irrigation Company. Discussions have also been carried out with the Waitaki District Council and the Southern District Health Board. A bore head protection brochure was also distributed to landowners.

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[1] The Regional Plan: Water currently requires complying with nitrogen discharge thresholds by 2020 but has no limit set for *E. coli* levels in aquifers

[2] Colony forming units

Recent testing (June 2018, not covered in the attached report) to determine the source of *E. coli* contamination in the aquifer gave inconclusive results. This was due to the low concentration of *E. coli* in the samples at the time of testing (Table 1). It is planned to continue testing for the source of contamination when the *E. coli* concentration is high enough.

Table 1: *E. coli* concentrations in the June 2018 (latest) samples from the groundwater bores monitored by the ORC (refer to Figure 1 for location)

Well number	E. coli concentrations (cfu/100ml)
J41/0571	<1
J41/0576	<1
J41/0586	<1
J41/0442	2
J41/0317	<1

4. Recommendation

This report be received;

2. *The findings presented in the report "Lower Waitaki Plains Aquifer Summary of the Groundwater Quality Monitoring (July 2016 - January 2018)" be noted.*

Endorsed by: Gavin Palmer
Director Engineering, Hazards & Science

Attachments

1. Lower Waitaki Plains Aquifer_-_ Summary of the Groundwater Quality Monitoring **[11.2.1]**

11.3. Lake Hayes Restoration

Prepared for:	Technical Committee
Report No.	EHS1824
Activity:	Environmental - Regional Plan: Water Quality
Prepared by:	Dr Ben Mackey, Manager Natural Hazards (acting)
Date:	26 July 2018

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1. Précis

The ORC is developing a programme to improve the water quality in Lake Hayes, which suffers from periodic algal blooms caused by accumulated phosphorous in lake bed sediments. There are two components to this work; improving the quality of water entering Lake Hayes from Mill Creek and addressing the historic accumulation of nutrients in lake sediments.

This paper focusses on the second aspect of the remediation programme. Three intervention options have been identified by ORC to address the water quality problems attributable to legacy nutrients within lake sediments.

These three options are (i) flushing the lake with irrigation water, (ii) immobilising phosphorous by capping lake sediments with alum, and (ii) destratifying and oxygenating the lake by aeration. These options have been assessed by a lake expert, who has described the practical measures needed to make them operational.

This report summarises the underlying theory and effect of each potential intervention option and outlines the associated costs and risks. The physical infrastructure or actions required to give effect to each option is described, and an implementation timeline for each of the three options is presented. The costs and benefits of each option have been evaluated from an economic perspective, and if successfully implemented, generally have a high benefit/cost ratio given the high recreation demand on the Lake.

All options will require additional funding for capital work and ongoing costs. It is proposed to formally consult with relevant communities on both the preferred remediation option(s) and funding mechanisms. A communication plan for this aspect is included, which if approved, is scheduled for September this year.

Notably, the remediation options described here are intended to address the build-up of phosphorous on the lake bed caused by historic land use. Separate work streams focus on identifying contemporary sources of catchment-derived nutrients, and improving the monitoring of Mill Creek and Lake Hayes.

2. Background

Lake Hayes is a 2.7 km^2 lake 10 km east of Queenstown. The total Lake Hayes catchment is 63 km^2 in area, of which 52 km^2 (82%) is drained by Mill Creek (Figs. 1-2). Set in the middle of the rapidly developing Wakatipu basin, the lake is picturesque, and has traditionally been a drawcard for tourists, fishermen, and recreationalists.

Fig. 1. View southwest across the mid part of Lake Hayes from Bendemeer Bay, July 2018.

Historic fertilizer application and industry in the catchment contributed to an accumulation of phosphorous in lake-bed sediments. Under certain conditions phosphorous is released into the water column, feeding algal blooms, currently dominated by the dinoflagellate alga *Ceratium*. There is a strong community desire to prevent algal growth, and improve the water quality in the lake for aesthetic, environmental, and recreation reasons. Lake Hayes has a long history of monitoring and study, and there is community support for intervention - to actively remediate the lake and return it to a consistently swimmable state.

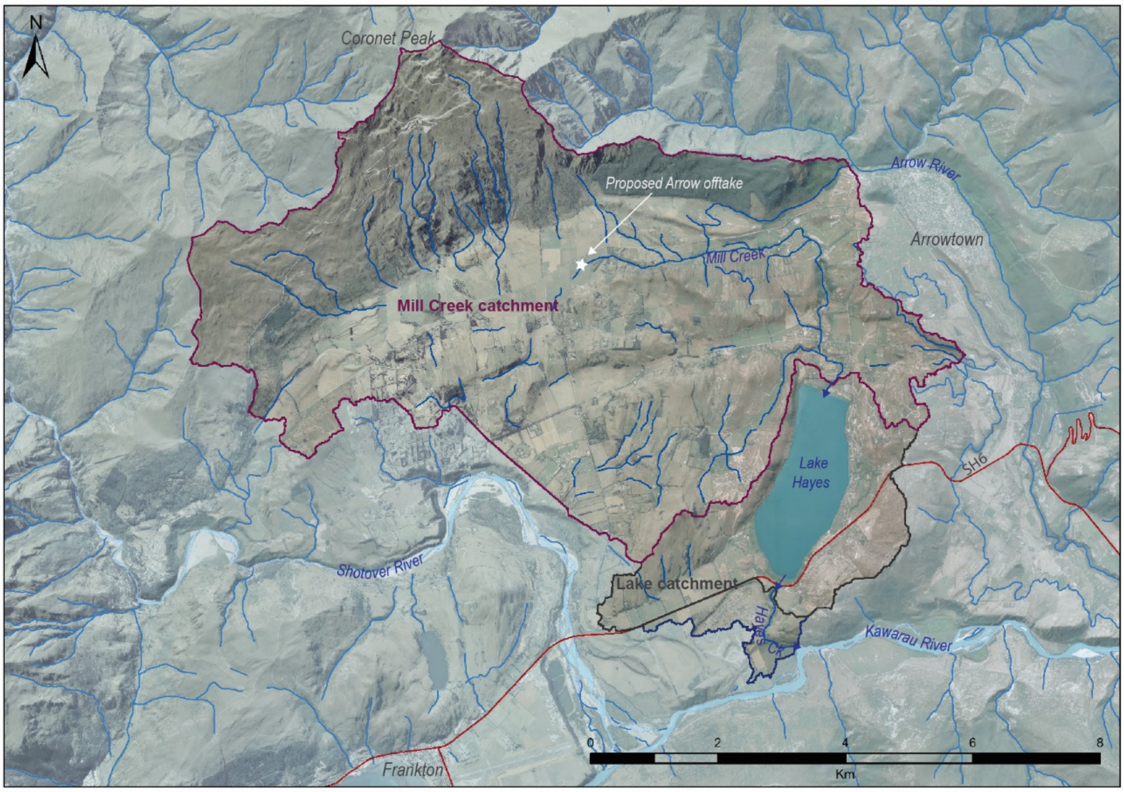

Fig. 2: Map of Lake Hayes catchment and surrounding features. Catchment extents defined by Lidar topography and there may be variations due to drains or stormwater infrastructure near the margins.

As previously reported[1], the Otago Regional Council (ORC) has investigated a range of potential intervention options with the goal of inhibiting algal growth. Three intervention options have now been identified:

- Augment inflow to the lake with water from the Arrow irrigation scheme (flushing).
- Cap and bind the phosphorous in the bed sediments by spreading an aluminium compound across the lake (capping).
- Enhance vertical mixing of the water column to prevent the development of unmixed layers of water and anoxic conditions which cause the release of phosphorous (destratification).

As part of the 2017−18 Annual Plan, these options were investigated. This work included a review by a lake expert from NIWA, an economic assessment of the benefit of remediation and each intervention option by economic experts Castalia, and ongoing development of a lake model.

This report reviews the theory and objectives behind each intervention option, and outlines implementation considerations, costs, and risks. Public consultation about the preferred option and funding mechanism will be required, and a consultation plan is included.

[1] Environmental Science Committee report 2009/070 'Lake Hayes' prepared by R. Ozanne.

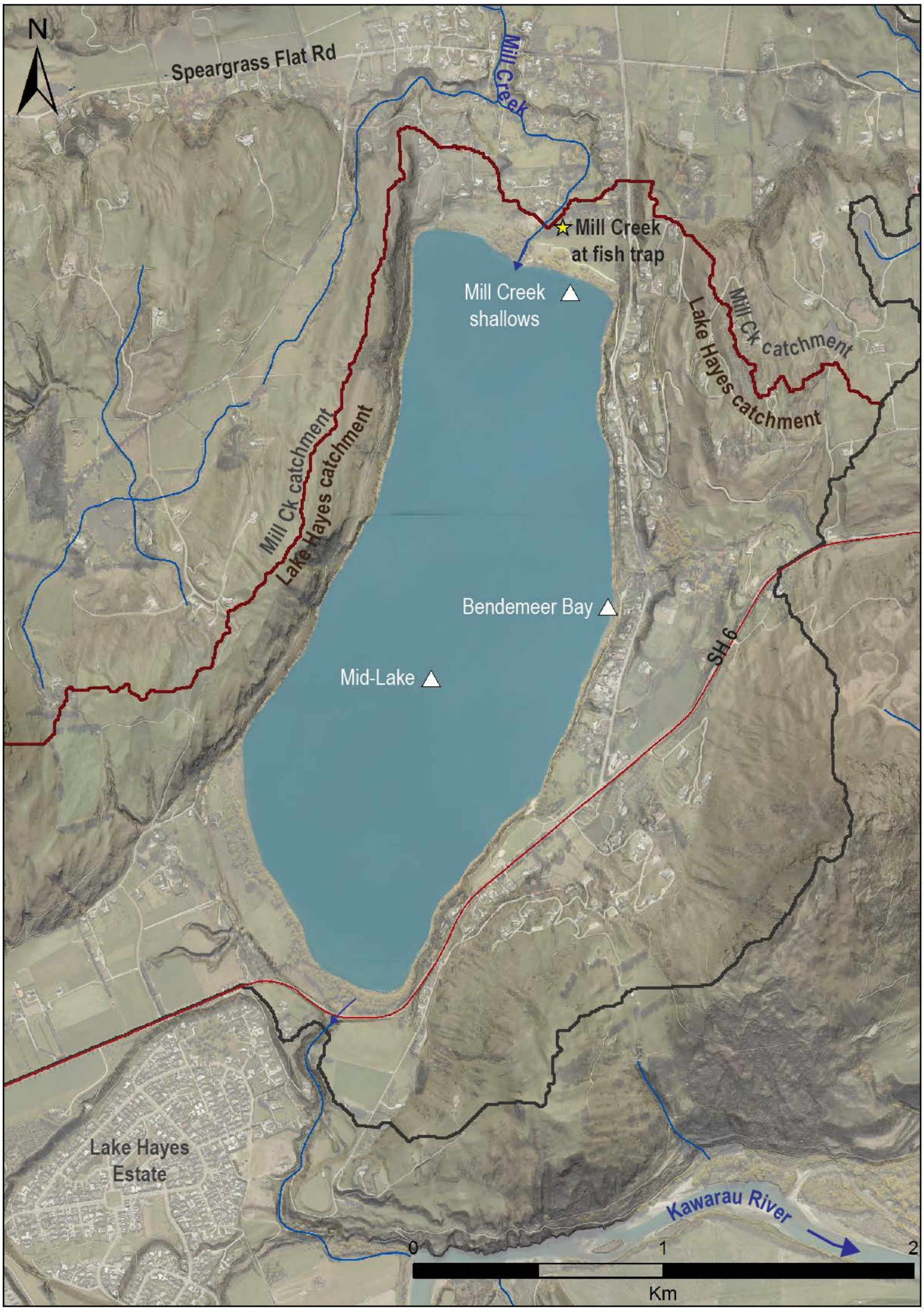

Fig. 3: Map of Lake Hayes and surrounds. Existing lake sample locations are shown by white triangles.

The assessment of intervention options is running in parallel with other workstreams related to Lake Hayes, in addition to ongoing State of the Environment monitoring and

Contact Recreation monitoring. Two new initiatives were approved in the 2018-2028 Long Term Plan; a catchment nutrient study, and installation of a lake monitoring buoy.

3. Previous work

Declining water quality has made Lake Hayes the subject of numerous studies over the past few decades. This includes management strategies (ORC/QLDC 1995), scientific studies (e.g., Caruso, 2000, Bayer et al 2008), and restoration strategies (Bayer and Schallenberg. 2009). A recent review by Schallenberg and Schallenberg (2017 – Appendix C) was commissioned by Friends of Lake Hayes organisation, and provides a thorough summary of the Lake's history, the decline in water quality, and potential remediation options. A select bibliography is attached as Appendix E.

A 2018 NIWA report (Gibbs, 2018 – Appendix B), prepared for the Otago Regional Council, reviews Schallenberg and Schallenberg (2017), and further evaluates remediation options. Much of the detail in the following sections draws upon information in these two recent reviews.

4. Water quality problem

Lake Hayes is a glacially carved depression in the Wakatipu basin. In its natural state, Lake Hayes was a clear lake with exceptional water quality. Various land use changes over the past century have increased the concentration of key nutrients in the bottom sediments of Lake Hayes, notably phosphorous (P). Phosphorous has been delivered to the Lake adhered to sediment via the erosion of soils, enriched in nutrients by fertilizer application. Phosphorous has also been added to the lake inflow directly, primarily as cheese factory waste during the early 20th Century. This problem is referred to as legacy phosphorous, as much of the accumulation of phosphorous in the Lake occurred over previous decades, but is a major contributor to water quality problems today. If no phosphorous was entering the Lake currently, the phosphorous in the lake sediments would still be an issue, as algal blooms in Lake Hayes are linked to the availability of phosphorous in the lake water.

Under well oxygenated conditions, phosphorous binds with iron and manganese oxides in lake sediment. It is not released into the water column, and thereby unavailable for biologic process, including feeding algal growth. One of the key issues at Lake Hayes, is that over summer the Lake is thermally stratified, with cold bottom waters (hypolimnion) and warmer surface waters (epilimnion) separated by a sharp temperature gradient at depth called a thermocline. Decomposing matter on the lake bed can use all available oxygen in the bottom waters, leading to anoxic conditions. Under these anoxic conditions, Phosphorous in bed sediments is released from the sediment via a reversal of a REDOX reaction, and phosphorous is added to the water column as Dissolved Reactive Phosphorous (DRP), where it is bio-available, and can stimulate algal growth over summer months. As temperatures cool in the autumn this stratified state ends, and the lake water overturns and is well mixed by wind and density effects over the winter period.

The various lake remediation options reviewed here seek to interrupt an aspect of the release of legacy phosphorous, keeping it bound in the lake sediment and out of the water column. Minimising the flow of nutrients going into the Lake today is a critical component of Lake Hayes restoration, and the focus of a separate work stream. Specifically, identifying the source and quantity of nutrients entering the Lake via Mill

Creek and its tributaries will be the focus of a 2018-19 catchment water quality study, building upon earlier studies by Caruso in 2000. Reporting on water quality in the Lake Hayes catchment is scheduled for the following year (2019-20).

5. Arrow water augmentation

The first identified option for Lake Hayes remediation involves augmenting the flow of Mill Creek (which flows into the head of Lake Hayes) with water from the Arrow Irrigation Company irrigation scheme (Fig. 2). The Arrow scheme takes water from the Arrow River, and pipes it across the Wakatipu Basin for irrigation purposes. The Arrow water is low in nutrients compared to the present Lake Hayes water.

Adding cleaner water to the lake has two identified benefits with respect to improving water quality. First, adding clean water to Mill Creek will increase the volume of water passing through Lake Hayes, and decrease the residence or turnover time of water in the lake. If the added water is cleaner than the lake water, it will increase the rate at which nutrients are flushed from the lake – essentially clean Arrow water will displace nutrient-rich lake water. Over time, this will incrementally flush nutrients from the lake. Schallenberg and Schallenberg (2017) estimate the augmented water will flush 7% of P in the surface waters annually.

The second benefit is that if the temperature of Mill Creek is sufficiently colder than Lake Hayes water, it will plunge to the Lake's bottom waters due to the greater density of the cold water. This has the effect of adding oxygenated water to the bottom waters, decreasing the potential for the onset of anoxic conditions, and the associated release of P from the lake bed sediments. Gibbs (2018) notes that the plunging plume of creek water can entrain lake water as it plunges, increasing the effective volume of the plunging oxygen rich water by up to a factor of four above the Creek flow alone. Creek water, combined with entrained lake water, has the potential to deliver enough oxygen to the deep waters to prevent anoxia.

Council approved funding in the 2018-2028 Long Term Plan to enable physical works to preserve the Arrow irrigation flushing option – the offtake infrastructure needs to be installed prior to golf course development by Millbrook resort in September 2018[1]. Work to install the offtake pipe and discharge structure is currently being undertaken to meet the Millbrook development schedule, and involves installation of a ~200 m long 450 mm diameter pipe, and a concrete discharge structure submerged in a pond adjacent to Mill Creek (Fig. 2). The assessment and consultation on all options presented here is proposed to be undertaken in late 2018. The Arrow water offtake infrastructure is being installed with the understanding that significant follow up work will be required to make the offtake operational, and it may not be the preferred remediation option following consultation. ORC has not committed beyond the $100,000 enabling works, and operationalising the offtake will take further decisions of Council.

Arrow water augmentation is arguably the lowest risk of the three options, as it augments a natural process, rather than seeking to disrupt lake processes. It is also the one which will take longest to have an effect on water quality, and will need to run over many years

[1] See 'Lake Hayes Restoration'. ORC Technical Committee item 11.3. 13 June 2018

to be effective. Of note, Arrow water augmentation is complementary to both the destratification and sediment capping options.

The effectiveness of this option will be maximised if the temperature of the Mill Creek water entering Lake Hayes is sufficiently cool to enable it to plunge to the lake depths, and oxygenate the basal waters. If this does not occur and the Mill Creek water says near the surface, the added clean water will still have an effect of flushing nutrients from the Lake's surface waters.

Physical risks relate to the potential for increased stream flow to lead to erosion of the bed or banks of Mill Creek, which could entrain sediment and increase the flow of P into Lake Hayes. This risk is best controlled by manipulating when the offtake water is utilised, for example avoiding times when the stream is otherwise high due to rainfall.

The other practical consideration is the availability of water. Preliminary discussions with Arrow Irrigation Company indicate water will be available on an 'as available' basis, i.e., when there is surplus water not required for irrigation. This may limit the quantity of water available for flushing, particularly during summer months. In addition, the Arrow Irrigation Company currently takes water from the Arrow River using a deemed permit, which is set to expire in 2021. Minimum flow requirements for the Arrow River may limit how much water the AIC is able to take, which could affect the quantity available for flushing.

The cost to install the Arrow offtake and discharge structure is estimated by Friends of Lake Hayes at $100,000, which includes design, materials, and installation. Further work will be required to make this option operational, and will include telemetered valve control, discharge consents, and legal agreements. The annual cost to purchase water has been estimated at $30,000.

The offtake pipe and discharge structure need to be in place by September 2018. It is estimated to make the offtake operational will take an additional 6 to 12 months. If this option is approved, flushing could be operational from mid to late 2019.

6. Lake destratification

As noted above, over summer Lake Hayes tends to become thermally stratified, with cool bottom water separated from warmer surface water by a thermocline. Destratification seeks to interrupt this lake stratification by artificially mixing the Lake. Preventing the stratification and subsequent deoxygenation of the bottom waters aims to keep phosphorous bound in the lake bed sediments, and out of the water column.

Any mechanism which can mix lake water can potentially disrupt the thermal stratification (e.g., water jets, propellers, aeration). The mechanism preferred by Gibbs (2018) is the formation of an air curtain, achieved by blowing compressed air along a perforated pipe which lies along the lake bed across the middle of the Lake (Fig. 4).

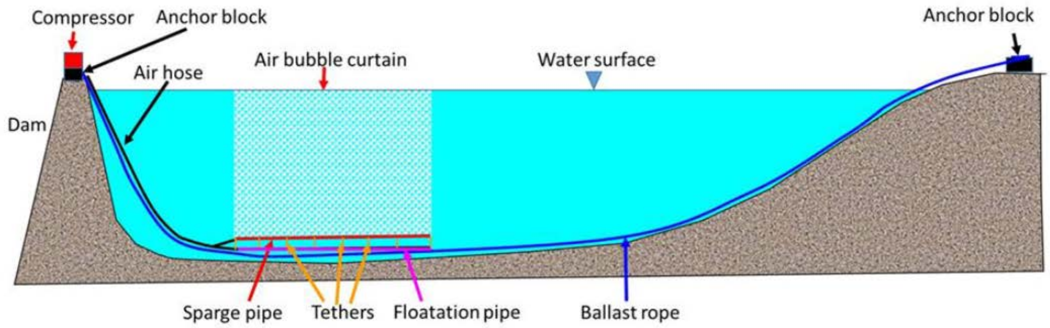

Fig. 4: Schematic diagram of a bottom-mounted bubble curtain aerator system. The ballast rope is anchored at both ends and orientated along the deepest part of the lake. From Gibbs (2018).

As air bubbles released along the bottom of the lake and rise and expand, they create a buoyant plume which entrains water, causing an upwelling of the bottom waters. These upwelling waters migrate along the lake surface away from the bubble line, setting up surface currents. At the lake edge these currents plunge due to hydraulic inertia, setting up a return flow along the bottom of the lake to the site of the air line (Fig. 5). Passage of the water along the lake surface results in absorption of oxygen from the atmosphere (Fig. 6), and oxygenated waters are carried down to the Lake's depths.

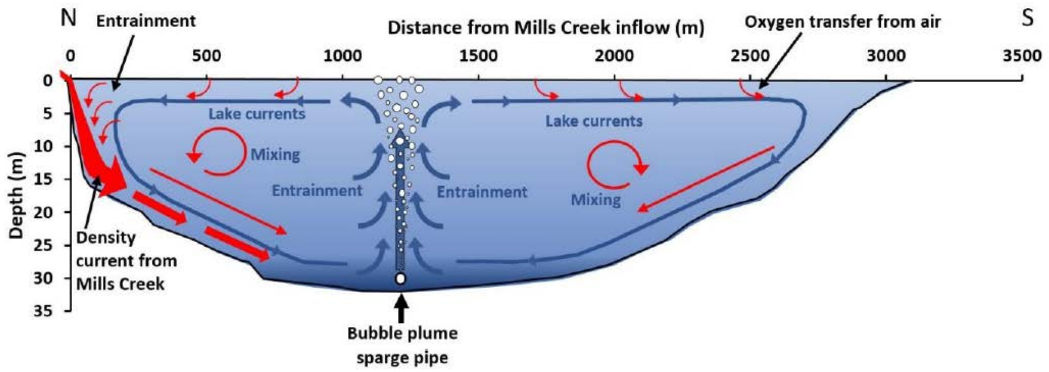

Fig. 5. Diagram of the likely flow paths in Lake Hayes with the bubble plume operating. Red paths are oxygenated water, with blue lines expected lake flow paths (From Gibbs, 2018)

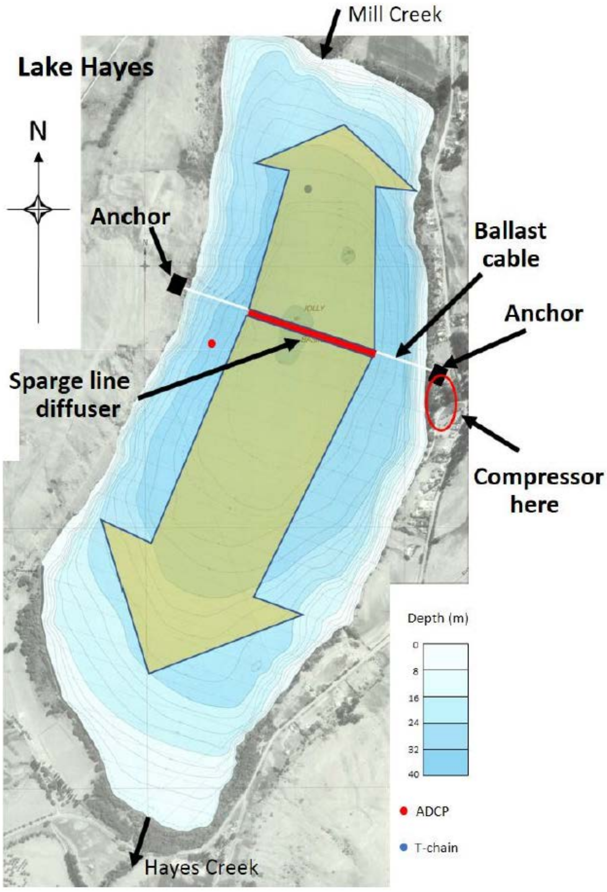

Fig. 6: Potential positioning of the bubble curtain aeration sparge line diffuser in Lake Hayes. The expected surface flow patterns are indicated by the green shaded arrows away from the line, while currents return along the Lake bed. From Gibbs (2018).

The objectives of destratifying the lake with an air curtain is to facilitate the flow of oxygen to the bottom waters, which prevents the anoxia and subsequent release of P from the sediments. Destratifying the lake also has the potential to interrupt the feeding and cell-division processes of the dinoflagellate *Ceratium hirundinella*, the algal species responsible for the recent blooms. It is thought *Ceratium* descends to the thermocline at night, accessing P in the bottom waters, before rising to the surface during the day and promoting algal blooms. Setting up large currents via the bubble curtain would prevent establishment of the thermocline, and in the process drag the cyanobacteria to depths at which it cannot survive due to lack of light.

Destratifying with an air plume has a range of secondary geochemical effects involving Nitrogen and organic Carbon, largely positive for water quality, which are documented in Gibbs (2018). Positive effects include a decrease in phytoplankton biomass, clearer water column, an increased depth range for plants (and associated small fish and zooplankton), and greater volume of oxygenated water which will increase the depth of habitat for mussels and fish.

Destratifying the lake interrupts a thermal stratification of the lake; this is a natural process which would occur over the summer months irrespective of the nutrient status. Mixing the lake homogenises the temperature, which will increase the average lake temperature, but decrease the surface temperature, as water heated by the sun is mixed through the water body. This may have an effect on recreation, as Lake Hayes is favoured for its warmer surface temperatures.

The timing of turning on the air curtain is critical. The compressor would be turned on in the spring, and is most efficient when the vertical temperature gradient in the lake is small. If the turn on is delayed until the thermocline is well established, then the air plume can entrain anoxic P-rich bottom waters, taking them to the surface and stimulating a phytophankton bloom.

Although mixing the lake will suppress the growth of *Ceratum* other lake algae will become dominant. The algae assemblage will shift from toxic blue green algae, to non-toxic green algae and diatoms.

Of the three options, destratification arguably induces the largest physical change to the Lake's natural condition, with associated effects for habitat and lake ecosystems. If the system is initiated at the wrong time of year, it can make water quality worse by stimulating blooms.

The physical infrastructure involves a compressor, which would need to be housed in a sound-dampening structure, with hoses leading to the lake bed. Compressor noise would need to be considered, as the proposal would see it running near continuously over the summer months. An electricity supply would be required to run the compressor. A potential site for the compressor infrastructure is the park area at Bendemeer Bay (Fig. 3) where there are existing QLDC-owned three-waters assets, and it is adjacent to the deepest part of the Lake.

The air plume produced by the compressed air bubble field would create a disturbance at the lake surface, which may be aesthetically detrimental on a lake renowned for its mirror-like surface. The density difference generated by adding air to the water is not sufficient to create a 'lack of buoyancy' hazard to swimmers or boats.

Fig. 7: Surface bubble field along a bubble plume aeration system installed in Lake Waikapiro, Hawke's Bay. Surface currents move bidirectionally away from the axis of the bubble plume. From Gibbs (2018), photo by Andy Hicks (HBRC).

Lake destratification is likely to be the most complex of the three options to implement. Physically, it will require a suitable compressor, power supply, and housing. The ballast rope and diffuser pipes will need to reach the 800m across the mid part of Lake Hayes, and be securely anchored at each end. A flotation pipe can be incorporated into the subsurface line to allow the apparatus to be automatically raised for cleaning or maintenance. Upfront costs for this system have been estimated at $250,000 to $300,000, plus power and maintenance costs. Intensive lake monitoring is required to optimise the time of year when the compressor is turned on, and this is likely to be provided by the lake buoy and associated monitoring.

Permission (likely from QLDC) would need to be obtained to locate the compressor housing near the lake. Laying cables or pipes along the bed of a lake is a permitted activity under the Regional Plan Water (13.2.1.2) if conditions about bank signage are met. Making the line operational by pumping air through it does not appear to need a specific resource consent.

If destratification is the preferred option, a site will need to be found, access obtained, and a compressor shed constructed and linked to a power supply. The compressor shed will need to be designed, and is likely to require approval and building consent from QLDC. A suitable compressor and the associated pipes and lines will need to be procured and assembled. The timing of starting destratification is critical as it need to occur in early spring prior to the establishment of the stratification. Depending on the time required to install the compressor and equipment, September 2019 or September 2020 are target times to turn on the compressor and operationalise the air bubble curtain.

7. Sediment capping

Sediment capping involves the addition of a compound or 'capping agent' to the lake bed sediments to sequester the phosphorous more securely into a non-bioavailable form than the lake sediments can alone. This technique seeks to immobilise the phosphorous in the lake bed sediment, so that even with the formation of anoxic bottom waters, the lake bed phosphorous remains stable and is not released to the water column.

Iron and manganese oxides are the metals in lake bed sediments which generally bind phosphorous under oxygenated conditions, but the process is reversible as oxygen levels drop, or with changes in pH. Other metal-based agents can irreversibly bind phosphorous, and are not affected by anoxic conditions. Added to the water column, a capping agent can sequester the P in that water to a non-bioavailable form before it falls out on the lake bed.

The most commonly used capping agent is aluminium sulphate (alum), which can be supplied in solution or as a granular product. The agent can be applied by spray, subsurface injection, or drip fed into streams. Gibbs (2018) describes three approaches to applying alum:

- Applied as single dose granular product in the winter, so alum forms a pre-emptive sediment cap that will intercept the DRP diffusing out of the sediments as oxygen concentrations reduce during the onset of thermal stratification
- Applied as a single dose of the liquid product via a surface spray or subsurface injection at the end of summer then the lake is strongly thermally stratified and all the DRP has been released into the bottom waters. This will

sequester all the DRP and irreversibly bind the P, which will settle on the sediment surface

- Applied as a liquid via a drip feed into the Mill Creek inflow. With careful management it will be transported to the bottom waters in the natural density current only when it will be able to sequester the DRP, thereby reducing the amount of product applied and focusing the product where it is needed.

Shallow draft boats, such as a jet boat or air boat could be used to systematically spray or spread the alum to the surface of Lake Hayes. Alternatively, the alum could be drip fed into Mill Creek, where the rate of application could be changed to suit flow and lake conditions. Gibbs (2018) notes that targeted applications of certain capping agents to accumulations of cyanobacteria in shallow water can prevent them from coming substantial blooms.

The application remains effective on the lake bed until it is buried by subsequent phosphorous rich sediment deposited on the lake bed. In Lake Hayes this capping agent longevity is estimated at 5-10 years.

The potential drawbacks of sediment capping are the potential for the release of toxic Al^{3+} ions under low pH conditions, and broader questions of whether adding a chemical compound to the lake or inflow stream is considered acceptable. Application of the alum by boat could take several weeks to complete, with associated noise and spraying effects. Adding the alum directly to Mill Creek would require housing for the alum, and equipment to control the rate of supply.

Alum is readily available as it is widely used in water supply treatment. The amount of alum required will need to be assessed against measurements of P at the time of application. Based on recent measurements of DRP in Lake Hayes bottom waters, the amount of alum required could range from 100 to 530 tonnes, at a cost of approximately $1000 per tonne. Application by boat would incur a large one-off cost, while drip feeding alum via Mill Creek would allow the cost to be spread over a period of years.

Injection or spray application of alum to Lake Hayes will likely cause a temporary conspicuous change in water colour or clarity, and therefore not qualify as a permitted activity under the Regional Plan Water (s 12.C.1.1). It will likely be a discretionary activity and require resource consent, with interested parties including DoC, Fish and Game, and Iwi.

If sediment capping with alum is the preferred intervention option, the application method will need to be determined which will in turn influence the timing of the treatment. If 6 months is allowed to obtain resource consent and procure the product and application contractor, a winter application could occur in mid-2019, or a late summer application in February 2020. If the Mill Creek injection is favoured timing is less critical, but a building will need to be constructed near Mill Creek to store the alum, with a mechanism to drop feed it into Mill Creek. Pending approvals to construct the building, this method could be operational by late 2019.

8. Economic assessment

The potential remediation options for improving Lake Hayes water quality were assessed by Castalia Strategic Advisors, an economic consulting firm (Castalia, 2018). Castalia were asked to undertake an economic assessment of the three remediation options described above, and to assess benefits of improved water quality. An additional component focussed on identifying the beneficiaries of improved water quality, and assessing how costs should be apportioned between groups of beneficiaries.

The approach involved three steps:

- Determine the counterfactual; what happens if there is no intervention?
- Qualitatively assess the costs and benefits that may occur if the remediation options are implemented, and identify which are economically material
- Quantify all the material costs and benefits to determine net benefits and benefit cost ratios.

Castalia's report (Attached as Appendix D) determined a cost benefit ratio for the three intervention options assessed against three future water quality scenarios: a continuation of the status quo, natural recovery, and a further deterioration of water quality.

Activities impacted by Lake Hayes water quality were grouped into four categories; Lake based recreation, local business sales, real estate, and tourism. The impact of varying states of water quality on each category was quantified. Lake based recreation was the most significant category affected by water quality, with a current annual value estimated at $1.34 million. Lake based recreation includes activities such as swimming, sightseeing, walking/running, cycling, rowing, kayaking, fishing, and multisport events. Improved water quality would increase both the volume and quality of recreation activities.

All but one intervention options indicated a positive benefit cost ratio (Fig. 8), particularly measured against the more adverse scenarios of stable water quality (continuation of existing situation), or a deterioration in water quality.

Table 1: Net present value (NPV) of Successful Remediation. NPV is the sum of the discounted values 30 years into the future.

	Flushing	Destratification	Low Cost Capping	High Cost Capping
Stable	$1,612,000	$2,105,000	$2,302,000	$681,000
Natural Recovery	$625,000	$1,001,000	$1,197,000	-$423,000
Deteriorates	$2,848,000	$3,585,000	$3,782,000	$2,161,000

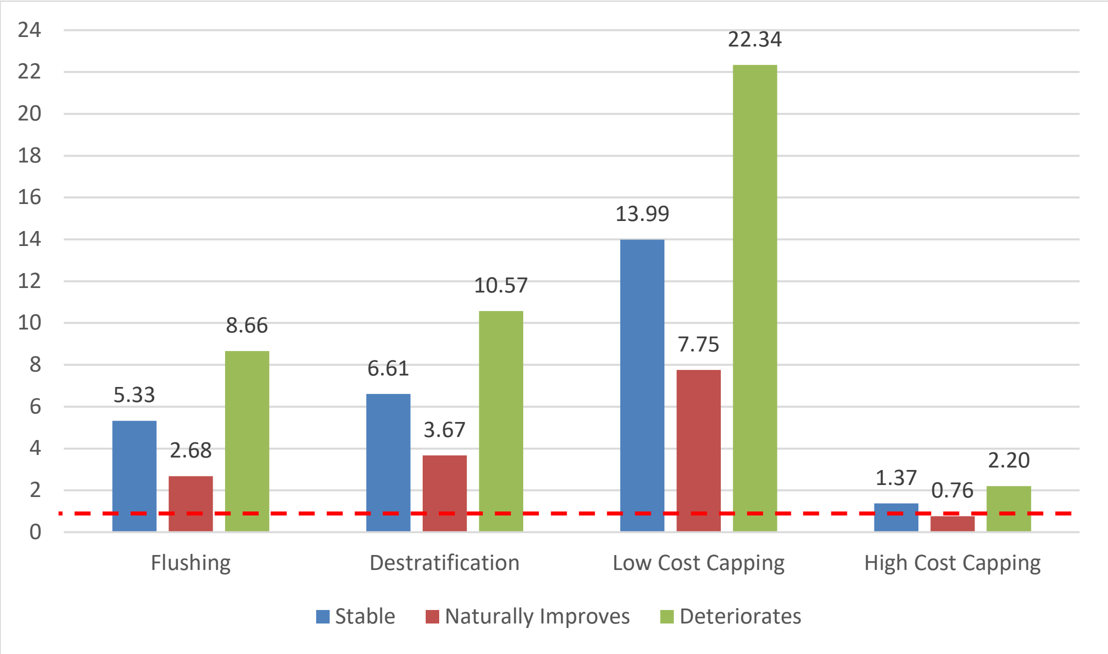

Figure 8: Benefit Cost Ratio (BCR) of successful remediation. A BCR of greater than 1 indicates the measure is economically viable.

The geographic distribution of benefits was assessed based on visitor numbers and proximity to the lake, and proportions are detailed in Table 2:

Table 2: Geographic Distribution of Benefits of improved water quality in Lake Hayes

Area	Proportion of Benefits
Lake Hayes	43 percent
Lake Hayes South	31 percent
The District (QLDC residents)	13 percent
Outside of the District (Including ORC residents from outside QLDC, national and foreign tourists)	13 percent

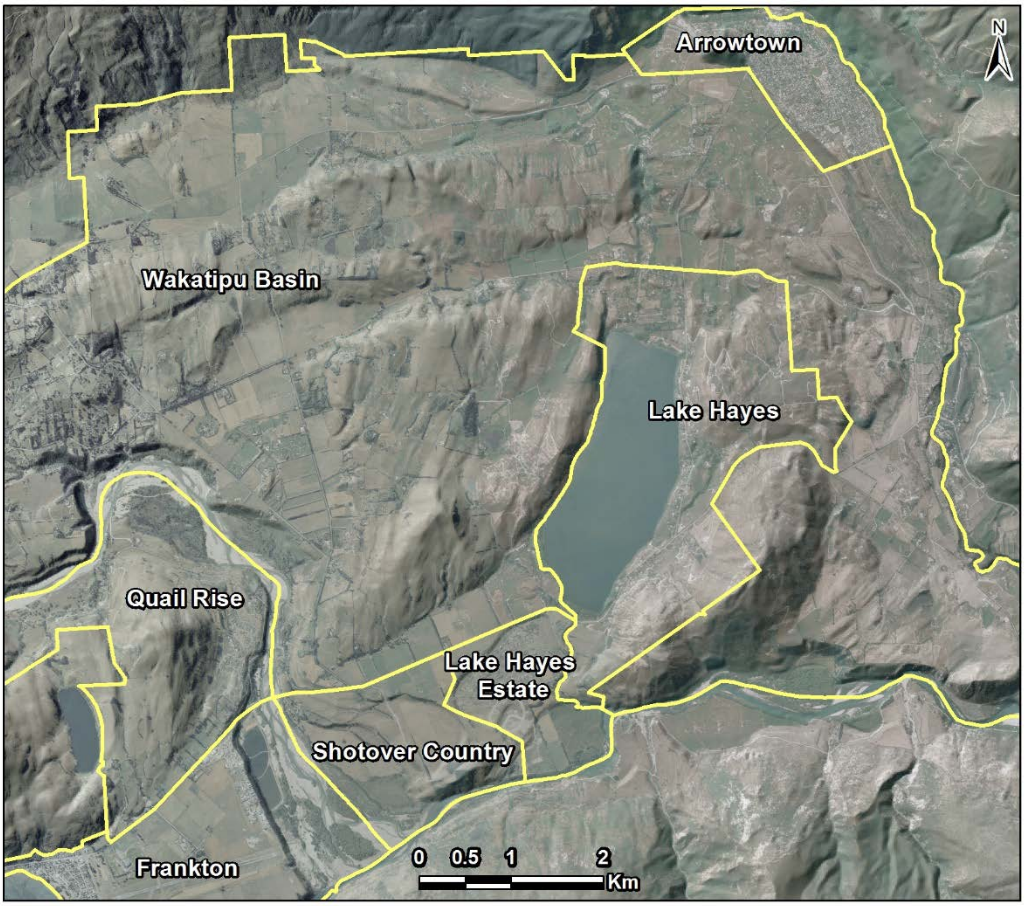

Fig. 9: Map of geographic areas around Lake Hayes referred to in Table 2. Boundaries are the 'Statistical Area 2' boundaries defined by Stats NZ. 'Lake Hayes South' includes Lake Hayes Estate and Shotover Country.

The Lake Hayes area largely surrounds Lake Hayes, with approximately 210 dwellings. The Lake Hayes South area includes the newer Lake Hayes Estate and Shotover Country subdivisions, which presently has approximately 920 dwellings.

It is proposed this geographic distribution of benefits of improved water quality is used to help identify mechanisms to fund the preferred remediation option(s). This may include an application to the national Freshwater Improvement Fund.

9. Other work programmes

The 2018-2028 Otago Regional Council Long Term Plan (LTP) provides for a study of the Lake Hayes catchment. The LTP also provides for installation of a monitoring buoy in Lake Hayes (Fig. 10), which is scheduled to be in place by late 2018.

Fig. 10: An example lake monitoring buoy (photo c/o Chris McBride).

The University of Waikato has been engaged to produce a process-based lake model for Lake Hayes, which is due to be completed in August 2018. This model will be used to assess the effectiveness of the intervention options, and optimise their implementation by modelling potential changes to lake conditions. It can also be used to establish targets for catchment nutrient loads.

Lake Hayes is monitored on monthly basis as part of the State of the Environment 'Trophic Lake Programme', this is a mid-water, boat-based sampling and includes depth profiles of dissolved oxygen and temperature (amongst other variables). Mill Creek at Shallows (Fig. 2) is monitored as part of the recreational water quality programme, with the lake sampled on a weekly basis (1 December to 31 March). In the 2018-2019 season it is proposed to run a concurrent faecal source tracking sampling programme to pinpoint the origin of any elevated *E.coli* results, and include an additional monitoring point at Bendemeer Bay.

10. Implementation timeframe

Implementation of any remediation option will depend on the results of consultation in relation to the preferred option, and funding mechanisms. A timeframe for identifying a preferred option is presented in Appendix A1. An implementation timeframe for each option is attached as Appendix A2. These timeframes are intended to assist with Council decision-making on options.

Currently Council have committed to the enabling work to preserve the Arrow Irrigation water augmentation option ahead of the golf course development. This involves the design and construction of an offtake pipe[1]. The pipe is to be constructed in September. Further Council decisions about which (if any) intervention option will be implemented will be required in late 2018 following public consultation.

11. Consultation plan

We propose to consult in parallel on both the remediation options and funding options. We would need to ensure awareness and an opportunity to participate Otago-wide as funding could potentially also be Otago-wide; however more intensive communications would be focused in the Lake Hayes/Lake Hayes Estate areas and the Queenstown

[1] Lake Hayes Restoration report provided to Technical Committee held on 13 June 2018.

Lakes area more broadly. This would include in-person meetings or drop-in sessions and targeted digital advertising.

YourSay is proposed to be the primary platform for consultation, with hard copy feedback forms also made widely available at key community centres within Queenstown Lakes, and published in the ODT and local newspapers in Queenstown Lakes. Previous experience has shown that the Queenstown Lakes audience is receptive to online communications. To ensure full awareness across Otago we would augment with a postcard into mailboxes region-wide, directing people to YourSay and including a phone number for requesting a hard copy feedback form.

The consultation material will need to be carefully considered to ensure clarity of both environmental and financial impacts, given the relative complexity of the subject matter.

A briefing would be provided to Queenstown Lakes District Council Councillors prior to this engagement.

12. Summary

This report summarises three potential options to improve water quality in Lake Hayes by addressing the historic accumulation of phosphorous in lake sediments. An economic assessment of remediation options has shown a positive economic case for intervention due to the high recreational use of Lake Hayes.

Public consultation about remediation options and potential funding mechanisms is proposed, to identify the community preference for which option to implement (if any), and how this work could be funded across the Lake Hayes area, Queenstown Lakes District, and the broader Otago Region. If a preferred remediation option is identified through consultation, depending on the option and how it is implemented, it is expected a remediation measure could be operational by late 2019 or 2020.

13. Recommendation

a) *This report is received and noted.*
b) *Council approves public consultation on the three outlined remediation options.*

Endorsed by: Gavin Palmer
Director Engineering, Hazards & Science

Attachments

1. Appendix A 1 - Lake Hayes Timeline - general **[11.3.1]**
2. Appendix A 2 - Lake Hayes Timeline - Implemetation **[11.3.2]**
3. Appendix B - Gibbs (2018) Lake Hayes NIWA Assessment **[11.3.3]**
4. Appendix C - Schallenberg and Schallenberg (2017) Lake Hayes remediation options **[11.3.4]**
5. Appendix D - Castalia (2018) Lake Hayes Economic Study **[11.3.5]**
6. Appendix E - Lake Hayes Bibliography **[11.3.6]**

12. NOTICES OF MOTION

13. CLOSURE