Assessment of risk of phytoplankton blooms in the Waiau Arm immediately upstream of the MLC

following excavation of a new parallel channel

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Executive summary

Meridian Energy Ltd (Meridian) is planning excavation works (a parallel channel) just upstream of the Manapōuri Lake Control structure (MLC) to improve the conveyance and reliability of flow releases to the Lower Waiau River at different lake levels in accordance with existing resource consent conditions. The types of flows released include minimum flows, lake and flood flows, recreational flows and flushing flows, all of which assist with managing nuisance periphyton growth and which have benefits for river health. However, the current channel depth and alignment and gravel accumulation in the Waiau Arm immediately upstream of the MLC have been identified as the primary physical constraints affecting flow conveyance and reliability, particularly for flushing flows. Meridian proposes to reduce these constraints by constructing a new deeper channel adjacent to and parallel to the Waiau Arm, removing accumulated gravel and providing for any necessary maintenance of the Waiau Arm channels.

Increased depth of the new parallel channel and reduced flow in the two existing channels (main and south) following the excavation were predicted to lead to reduced water velocities compared to those currently experienced at equivalent rates of flow in the Waiau Arm. This report presents an assessment of the potential effects on water quality of lower water velocity in the parallel, main and south channels, following the excavation. The main issue is the extent to which lower water velocities would increase the risk of development of phytoplankton blooms in the Waiau Arm immediately upstream of MLC.

Water velocities in the excavated channels were quantified using a hydraulic model, run by Damwatch Engineering (Damwatch), which simulated water velocities following construction of the new parallel channel and in the channels currently. The model output included mean water velocity in all the channels (i.e., three channels following excavation, and the two channels that currently exist) under eight scenarios of Waiau Arm flow and lake level.

Data on phytoplankton in the Waiau Arm (represented by water column chlorophyll *a* concentration) were collated from Environment Southand and Meridian monitoring programmes. These data were used to establish a relationship between chlorophyll *a* and estimates of mean water velocity in the main Waiau Arm (from an existing model).

The frequency of occurrence of chlorophyll *a* >2 mg/m^3 was used as an indicator of risk of phytoplankton blooms.

The relationship between chlorophyll *a* and estimates of mean Waiau Arm water velocity indicated a high risk of chlorophyll *a* >2 mg/m^3 (>50% occurrence) when water velocity in the Waiau Arm was <0.02 m/s, some risk in water velocities of 0.02 to 0.04 m/s (up to 25% occurrence) and little or no risk in velocities >0.04 m/s. There was also low risk of chlorophyll *a* >2 mg/m^3 in the winter months (June to August) compared to the rest of the year.

Using water velocities predicted from the Damwatch model, the risk of chlorophyll *a* >2 mg/m^3 in the channels immediately upstream of the MLC was calculated as the average percentage of time (or number of days per year) under high, some, or no risk. Risk was calculated for the two existing channels and for the parallel, main, and south channels following excavation. The results suggested increased risk of phytoplankton blooms in the channels following excavation over the risk in the existing channels, with three to five times the number of days under high-risk conditions.

Once the channel excavation is completed it is expected that the increased risk of phytoplankton blooms in the new parallel channel arrangement will be largely offset by the improved conveyance and reliability of flow releases to the Lower Waiau River. Flow releases that are part of current flow management in the Lower Waiau River will provide a “core” set of flow releases that will, in most cases, reduce and /or delay the risk of phytoplankton blooms developing in the parallel, main, and south channels immediately upstream of MLC.

The larger flushing flows would re-set the risk of phytoplankton blooms to very low, with a residual effect of several days. Addition of the parallel channel will also support continued monthly recreational flows scheduled for the fourth Sunday in each month from October to April. Most recreational flows released in the past seven seasons have been associated with increased water velocities in the Waiau Arm and have replaced much of the water in the Waiau Arm with Lake Manapōuri water, which would have re-set the risk of phytoplankton blooms to very low.Note that the risks calculated in this report are averaged risks based on seven years of data. The risk of phytoplankton blooms developing the Waiau Arm, including the channels upstream of MLC, will be lower in years when lake inflows are higher, and vice versa. Year to year differences have not been quantified.

1 Introduction

Meridian Energy Limited (Meridian) releases flows through the Manapōuri Lake Control Structure (MLC) to the Lower Waiau River (LWR) in accordance with existing resource consent conditions. The types of flows released include minimum flows, lake and flood flows, recreational flows and flushing flows, all of which assist with managing nuisance periphyton growth and which have benefits for river health. However, the current channel depth and alignment, and gravel accumulation in the Waiau Arm immediately upstream of the MLC, have been identified as the primary physical constraints affecting flow conveyance and reliability, particularly for flushing flows.

Meridian proposes to reduce these constraints by constructing a new deeper channel adjacent to and parallel to the Waiau Arm, removing accumulated gravel and providing for any necessary maintenance of the Waiau Arm channels.

This "parallel channel" option has been selected following a robust assessment of alternatives and advice from multiple technical specialists. The option has been selected as it minimises the duration of works within the wet channel of the Waiau Arm. As such, it has been assessed as the least effects option for releasing suspended and deposited sediment to the LWR during the excavation works, while appropriately managing all other environmental effects.

Excavation of a parallel channel on the dry riverbank on the true left will add a third channel to the two (the main and south channels) that currently convey water from the Waiau Arm upstream to the MLC (Figure 1-1).

The potential effects of fine sediment from the excavation on biota in the Lower Waiau River have been assessed by Hoyle et al. (2023). In addition, the issue has been raised of the effect on water quality of lower water velocities in the new parallel channel and main and south channels than in the existing main and south channels once the excavation works are completed. Increased depth of the new channel, and reduced flow in the main and south channels is expected to lead to reduced water velocities compared to those seen in the existing channels at equivalent rates of total volumetric flow in the Waiau Arm. Reduced water velocities may increase suitability of the waterways for development of algal (phytoplankton) blooms. Phytoplankton blooms are already a concern in the Waiau Arm closer to Lake Manapōuri at times of low flows.

This report provides an assessment of the effects of reduced water velocities on the risk of phytoplankton growth to undesirable levels in the new parallel channel and main and south channels following excavation. The assessment is based on hydraulic modelling of water velocities in the two existing channels and in the three channels following excavation. The modelled water velocities are combined with existing data on river flows, lake levels and chlorophyll *a* (representing phytoplankton abundance). The assessment is presented in four sections:

1. Section 2 presents a summary of the outcomes of the hydraulic modelling (i.e., predicted water velocities in the channels following excavation compared with that in the existing channels).
2. Section 3 describes an analysis of existing data on phytoplankton (represented by chlorophyll *a* concentrations) in the Waiau Arm in relation to water temperature and water velocity. The analysis included defining a level of chlorophyll *a* that could be used to assess risk of blooms and then exploring relationships between chlorophyll *a*

and water temperature and water velocity, which could be used to inform the risk of phytoplankton blooms.

3. The assessment of the potential effects of reduced water velocities in the excavated channels is provided in Section 4. The assessment was based on the relationships developed in Section 3 and required some assumptions, which are explained.

4. Section 5 is an evaluation of the overall risk of phytoplankton blooms in the three channels following excavation of the parallel channel. The evaluation takes into account the improved conveyance and reliability of flow releases to the Lower Waiau River that the excavation is intended to provide.

Figure 1-1: Configuration of the channels following the proposed excavation. The main and south channels currently convey all water from the Waiau Arm to the MLC. After excavation of the new channel, the main and south channels will continue to convey smaller proportions of the flow than at present. Refer to text below for more detail.

2 Hydraulic modelling of channels before and after excavation

To inform an assessment of effects on water quality (and specifically on water column chlorophyll *a*) Damwatch has modelled mean velocity in water passing through to the MLC currently and under the parallel channel proposal (Clunie 2023).

Currently, water splits into two channels before arriving at the MLC (Figure 1-1). The **main channel** to the north carries most of the water and the **south channel** carries an increasing proportion of water as lake levels rise. The parallel channel option involves excavation of a **new channel**. The model provided estimates of the percentage of water passed to each channel and the flows and water velocities in each.

After excavation, the two existing channels would be retained in addition to the new channel. Under positive flows (from Lake Manapōuri) the new channel would carry the largest proportion of the water. Under negative flows (towards Lake Manapōuri) flow would be more equally shared between the main and new channels.

The Damwatch model was run for eight scenarios of flow and lake level in the Waiau Arm. The scenarios and results (modelled water velocities) are summarised in Table 2-1. The modelled water velocities are mean values across the extent (i.e., length and depth) of each of the channels. The model output also included estimates of the average water depth across the area of the channels under each scenario (data not shown but included in later discussion).

In summary, the modelling confirmed that re-distribution of the flow following excavation would lead to lower water velocities than currently experienced in the main channel and south channel. The lower water velocities would occur under flows from the lake and towards the lake.

It is noted that the mean velocities modelled for the new parallel channel and the main and south channels following excavation are generally higher than those estimated within the Waiau Arm as a whole (see right hand column in Table 2-1)[1]. Table 2-1 also highlights that water velocity in the existing channels is consistently higher than within the Waiau Arm as a whole.

[1] The Waiau Arm as a whole refers to the length of the Waiau Arm to which Spigel et al. (2006) applied their calculations of volume, water depth and water velocity. Spigel et al. (2006) assumed that the Waiau Arm as 9240 m long from the entrance to the lake at Pearl Harbour to close to the MLC. The bed profile illustrated in Spigel et al. (2006) indicates that the distance reaches to about 200 m downstream of the old confluence with the Mararoa River, and therefore includes an overlap with the existing channels. This report focuses on the part of the Waiau Arm immediately upstream of the MLC (as illustrated in Figure 1.1). The term "immediately upstream of MLC" is therefore used to specifically refer to that past of the Waiau Arm that comprises the existing channels (main and south) or the channels following excavation (main, south and parallel (new channel)).

Table 2-1: Summary of flow and lake level scenarios modelled by Damwatch, with summary results (as modelled water velocities). Based on Tables 1, 2 and 3 in Clunie (2023). Negative flows and water velocities mean that flow in the Waiau Arm is towards Lake Manapōuri. For comparison, the right-hand column shows mean estimated water velocities in the Waiau Arm as a whole, calculated using the method in Spigel et al. (2006) (see text).

Scenario	Flows (m^3/s)			Lake level (m)	Location (channel)	Modelled flows (m^3/s)		Modelled water velocities (m/s)		Mean water velocity Waiau Arm
	Waiau Arm	Mararoa	MLC			Existing	After excav-ation	Existing	After excav-ation	
1. Low lake level, flow towards MLC	10	6	16	176.8	Main	8.8	2.0	0.18	0.03	0.034
					South	1.4	0.3	0.14	0.04	
					New		7.7		0.06	
2. High lake level, flow towards MLC	10	6	16	178.6	Main	6.2	3.0	0.04	0.02	0.021
					South	2.3	1.2	0.04	0.02	
					New		5.2		0.03	
3. Low lake level, flow towards lake	-10	26	16	176.8	Main	-8.6	-4.5	-0.16	-0.09	0.034
					South	-1.4	-0.7	-0.11	-0.06	
					New		-4.8		-0.04	
4. High lake level, flow towards lake	-10	26	16	178.6	Main	-5.7	-4.0	-0.04	-0.03	0.021
					South	-3.2	-2.1	-0.04	-0.03	
					New		-3.6		-0.02	
5. Low_medium lake level, low flow towards MLC	5	11	16	177.2	Main	4.0	1.3	0.07	0.02	0.015
					South	1.0	0.3	0.05	0.01	
					New		3.4		0.02	
6. Medium_high lake level, low flow towards MLC	5	11	16	178.0	Main	3.4	1.5	0.04	0.01	0.012
					South	1.3	0.5	0.03	0.01	
					New		2.9		0.02	
7. Low_medium lake level, low flow towards lake	-5	21	16	177.2	Main	-4.1	-3.4	-0.06	-0.05	0.015
					South	-0.9	-0.7	-0.04	-0.03	
					New		-0.9		-0.01	
8. Medium_high lake level, low flow towards lake	-5	21	16	178.0	Main	-3.7	-3.3	-0.03	-0.03	0.012
					South	-1.1	-0.9	-0.02	-0.02	
					New		-0.6		-0.004	

3 Effects of water velocity and other factors on phytoplankton in the Waiau Arm

3.1 Data

3.1.1 Chlorophyll *a* data

We used existing data on phytoplankton in the Waiau Arm (represented by water column chlorophyll *a* concentration) combined with flow and lake level data. The chlorophyll *a* data comprises:

- data collected by Environment Southland (ES) at three sites in the Waiau Arm since July 2018, at monthly intervals (the ES dataset, *n* = 157 as of March 2023);
- data collected in a programme of summer monitoring (January to March) run by Meridian as part of their consent monitoring programme (at three sites, since 2020), at fortnightly intervals (the Meridian dataset, *n* = 90 as of April 2023).[2]

Two site locations (nearest to the MLC (2.3 km upstream) and 2.8 km downstream from Pearl Harbour) coincide in the ES and Meridian programmes. The third site is just downstream of Home Creek in the Meridian programme and just upstream of Home Creek (i.e., closer to Lake Manapōuri) in the ES programme.

3.1.2 Flow data

Flow data used were from Site 79719 Waiau at Manapōuri Struct TW (Waiau at MLC) and Site 79737 Mararoa at Cliffs. Waiau Arm flow was calculated as Waiau at MLC minus Mararoa at Cliffs. Lake levels were from Site 79707 Lake Manapōuri at Supply Bay.

3.2 Chlorophyll *a* threshold for indicating increased risk of undesirable phytoplankton levels

Chlorophyll *a* concentrations in individual samples from the Waiau Arm have varied from <0.3 mg/m^3 (representing an ultra-microtrophic lake environment in the system of Burns et al. (2000)) to >5 mg/m^3 (representing a eutrophic lake environment).

Based on the year-round ES dataset, chlorophyll *a* rarely exceeds 5 mg/m^3 (<2% of samples) but exceeds 2 mg/m^3 for about 25% of the time. Below, <u>frequency of occurrence of chlorophyll *a* >2 mg /m^3</u> is used as an indicator of the state of the Waiau Arm in terms of phytoplankton. The reasons are:

- 2 mg/m^3 is the threshold separating Bands A and B of the phytoplankton attribute (for annual median chlorophyll *a*) in the NPS-FM;
- chlorophyll *a* has never exceeded 2 mg/m^3 during summer monitoring (since 2020) at a site in Lake Manapōuri (part of the Meridian monitoring programme), consistent with lake state of microtrophic to oligotrophic as assessed using ES data (Hogsden and

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[2] The summer programme of water quality in the Waiau Arm as a condition of MTAD consent 206156 (Appendix A, B(i). The data on chlorophyll a data currently collected as part of that programme is not a condition of the consent. Collection of water samples for subsequent measurement of chlorophyll a was voluntarily added to the monitoring in 2020 by Meridian, following advice that the data would be useful in interpreting patterns seen in other measured parameters, particularly if criteria indicating declining water quality were triggered.

Kilroy 2022). Lake Manapōuri can be considered as being at a “baseline” state for comparison with conditions in the Waiau Arm.

3.3 Factors influencing phytoplankton growth

Important factors that influence phytoplankton growth in the Waiau Arm include water temperature, season, and water velocity.

- Water temperature and season: algal cell growth rates increase as water temperature increases. Therefore, all other things being equal we expect that algal blooms will develop more rapidly in warmer water temperatures. Higher light levels in the summer months also promote algal growth.
- Water velocity: slow water velocity promotes phytoplankton growth by increasing the time available for cell division *in situ* (i.e., longer water residence time); faster water velocities impede the development of high cell densities in the water column because cells are continuously transported downstream.

While this assessment mainly concerns the effects of water velocity on the risk of chlorophyll *a* attaining undesirable levels, the interacting effects of temperature and season also need to be taken into account.

3.3.1 Water temperature and season

Surface water temperatures on the day of sample collection were available for both the ES and Meridian dataset. In the ES dataset chlorophyll *a* was >2 mg/m^3 in <10% of samples when the water temperature was <13 °C but in almost 42% of samples when water temperature was >13 °C. All but one of the samples in the Meridian dataset were collected in water temperature >13 °C; chlorophyll *a* was >2 mg/m^3 in 32% of samples.

The following patterns were noted across the combined datasets (Figure 3-1).

- The few samples (n = 6) with chlorophyll *a* >5 mg/m^3 were collected when water temperature was >16 °C.
- Above 18 °C, chlorophyll *a* concentration varied widely but was always >0.75 mg/m^3.

Consistent with the temperature pattern, the ES data indicate that chlorophyll *a* is more likely to exceed 2 mg/m^3 in the Waiau Arm in the summer months (December to March, ~35% samples >2 mg/m^3) than in the winter months (June – August, ~7% samples >2 mg/m^3). Rates of exceedance in spring and autumn were intermediate (~23%).

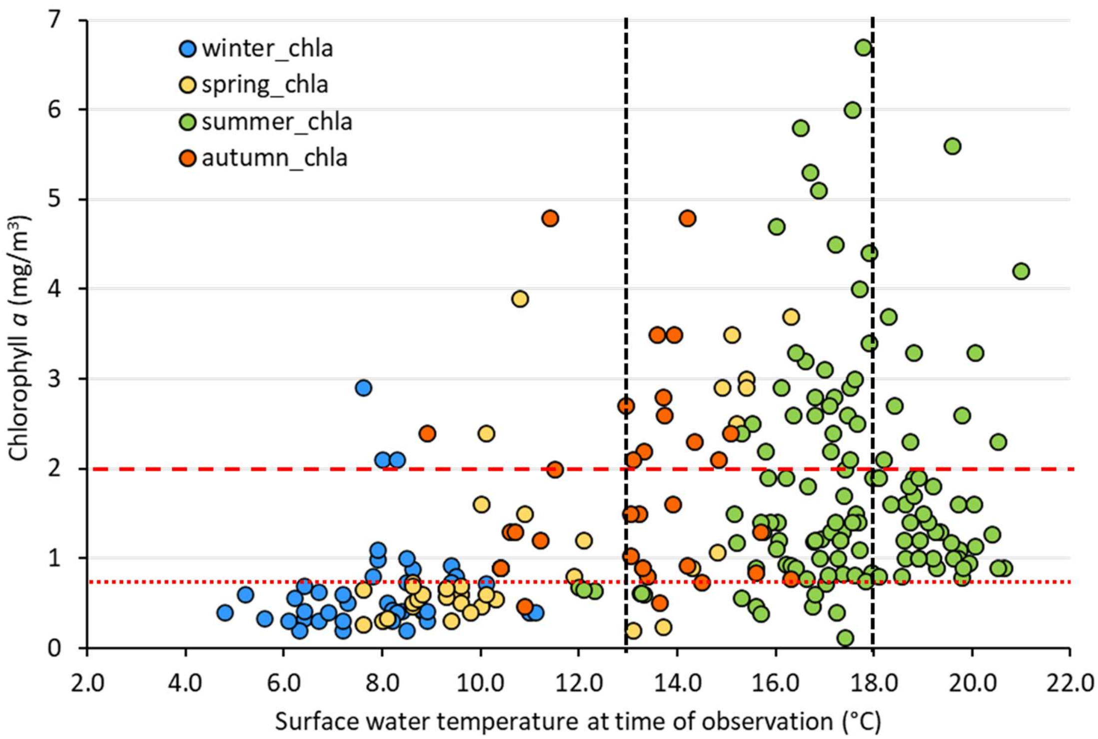

Figure 3-1: Relationship between chlorophyll *a* and surface water temperature at the time of sample collection in the Waiau Arm. Combined data from the Meridian and ES monitoring programmes sites in the Waiau Arm. The red dashed line is the 2 mg/m^3 threshold. The left hand vertical black dashed line at 13 °C shows that 2 mg/m^3 was exceeded more often above this temperature than below. The lower red dotted line is approximately 0.75 mg/m^3. The right hand black dashed line shows that chlorophyll *a* has always exceeded this level in temperature >18 °C. Months of seasons: winter: June – August; spring, September – November, summer, December – March; autumn, April – May.

3.3.2 Water velocity

In the Waiau Arm, water velocity depends on the combination of flow rate and the level of Lake Manapōuri (which influences depth in the Waiau Arm). As lake level increases, water velocity at a given flow decreases as water backs up in the Waiau Arm. Mean water velocity in the Waiau Arm (i.e., across the entire length of the Arm) at different flows can be estimated using the method set out by Spigel et al. (2006), using estimates of water volume and surface area across a range of lake levels. The estimates show that differences in mean water velocity are relatively small across the range of lake levels compared to the differences in velocity associated with changes in flow (Table 3-1). For example:

- at a lake level of 177 m, mean water velocity is predicted to increase from 0.032 to 0.064 m/s as flow increases from 10 to 20 m^3/s;
- the same velocity difference (an increase from 0.031 to 0.063 m/s) at a flow of 15 m^3/s requires lake level to fall by 2.6 m (i.e., across the whole lake range from 178.6 m to 176 m).

In other words, flow in the Waiau Arm is the primary determinant of mean water velocity and lake level has a relatively small effect.

Table 3-1: Example of estimated water velocities in the Waiau Arm under different combinations of lake level and flow. Velocities calculated using equations in Spigel et al. (2006). The grey-shaded cells highlight the example in the text above.

Waiau Arm flow (m^3/s)	Lake level (m a.s.l):	Estimated mean water velocities (m/s) at different flow and lake level combinations					
		176	176.8	177.0	177.5	178	178.6
1		0.004	0.003	0.003	0.003	0.002	0.002
2		0.008	0.007	0.006	0.006	0.005	0.004
5		0.021	0.017	0.016	0.014	0.012	0.010
10		0.042	0.034	0.032	0.028	0.024	0.021
15		0.063	0.051	0.048	0.042	0.036	0.031
20		0.084	0.068	0.064	0.056	0.049	0.042
25		0.105	0.085	0.080	0.070	0.061	0.052
30		0.126	0.101	0.096	0.084	0.073	0.062
40		0.168	0.135	0.128	0.111	0.097	0.083
60		0.253	0.203	0.192	0.167	0.146	0.125

We used the ES and Meridian chlorophyll *a* datasets to check for relationships between chlorophyll *a* and estimated mean water velocity. The aim was to identify (if possible) mean water velocities corresponding to the chlorophyll *a* threshold of interest of 2 mg/m^3.

There was a negative relationship between chlorophyll *a* and mean water velocity at all three Meridian sites. The strongest relationship was at the site closest to Lake Manapōuri, where estimated mean velocity in the past 5 days explained almost 60% of the variance in chlorophyll *a*. The relationships at the other two sites were weaker (38% and 35% of the variance explained). The ES data showed a similar pattern. The combined datasets yielded a relationship that explained about 35% of the variance in chlorophyll *a* (Figure 3-2).

At all sites cases of lower-than-expected chlorophyll *a* at low water velocities (i.e., bottom left of Figure 3-2) indicated that other factors were likely limiting phytoplankton growth at times.[3] Some of these were observations made in autumn, winter and spring.

Averaging water velocity over the five days prior to each chlorophyll *a* observation (as shown in Figure 3-2) yielded stronger relationships than with averages over longer periods (e.g., 10 days) or than with velocity at the time of each observation. This accounted for the time required for phytoplankton to grow and suggested that, in favourable conditions, growth can be quite rapid.

Figure 3-2 shows that, within this current dataset, chlorophyll *a* >2 mg/m^3 never occurred when mean water velocity averaged over the 5 days prior to sample collection was >0.04 m/s. At lower water velocities the proportion of samples with chlorophyll *a* >2 mg/m^3 increased:

[3] The plotted data pattern indicated that quantile regression would be more appropriate, but the dataset is still too small to run this successfully.

- water velocity >0.04 m/s – 0% of samples
- water velocity 0.03 – 0.04 m/s – 9% of samples
- water velocity 0.02 – 0.03 m/s – 24% of samples
- water velocity <0.02 m/s – 53% of samples.

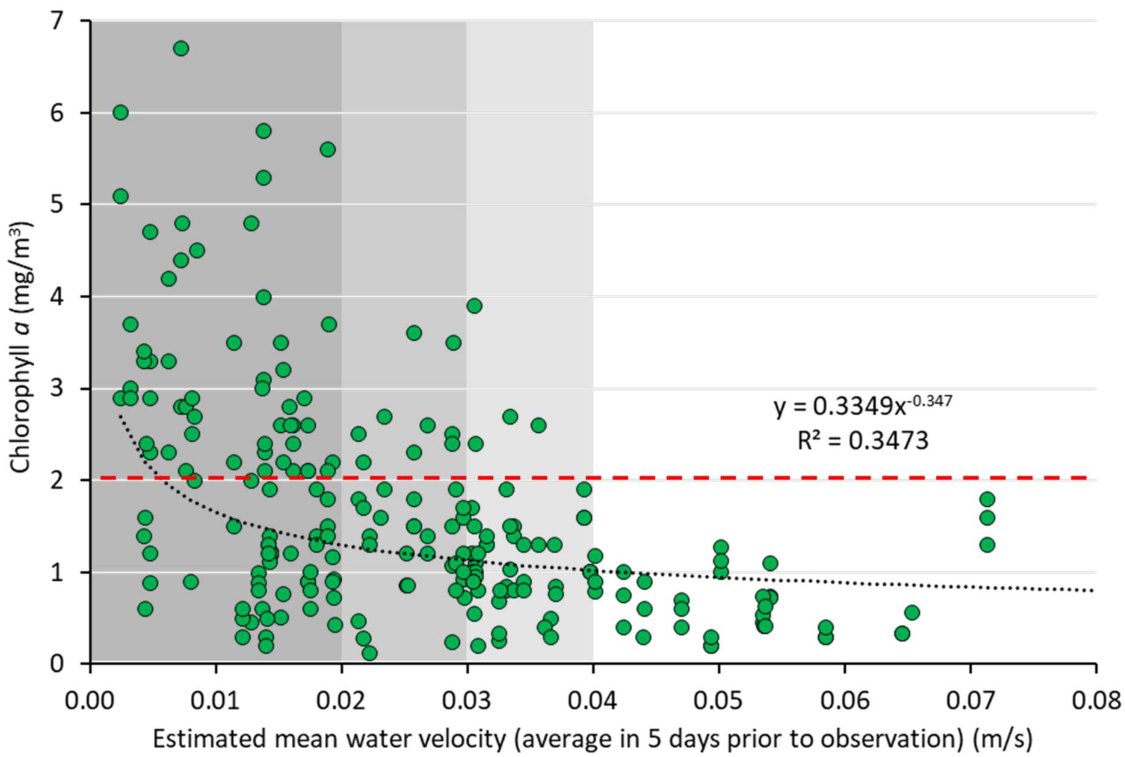

Figure 3-2: Relationship between chlorophyll *a* and mean water velocity averaged across the five days prior to sample collection. Combined data from the Meridian and ES monitoring programmes sites in the Waiau Arm. The red dashed line is the 2 mg/m3 threshold. The grey shaded areas indicate water velocity bands for which there appears to be increasing risk of exceedance of chlorophyll a >2 mg/m^3 (darker shading = higher risk). The black dotted line shows the best fit line (power relationship) corresponding to the equation relating chlorophyll a to water velocity.

As noted above, mean water velocity is strongly controlled by flow in the Waiau Arm. Consequently, flow was as strong a predictor of chlorophyll *a* as mean water velocity (i.e., estimated from flow and lake level; data not shown). We considered water velocity as a predictor rather than flow because the relationship between Waiau Arm flow and water velocity differs in the channels around the MLC from that in the Waiau Arm itself.

3.4 Duration of water velocities under different lake levels and flows

The risk of increased occurrence of chlorophyll *a* >2 mg/m^3 depends not only on water velocity but also on the duration of the combination of lake level and flow that leads to the specified water velocity as modelled by Damwatch. Durations were calculated as percentages of time by classifying the flow record from December 2017 to April 2023[4] into 11 flow classes and six lake level classes.

Because it was identified above that the risk of chlorophyll *a* >2 mg/m^3 is low in the winter months regardless of flows, the exercise was repeated excluding winter data (June, July, August). Exclusion of winter flow and lake level data made a small difference to the pattern of percentages. In particular, the time spent under flows >20 m^3/s towards the lake (i.e., negative) was higher in winter than at other times, and the time under flows towards MLC (all flows) proportionately lower. The percentages excluding the winter months were used first in the assessment and are shown in Table 3-2.

Table 3-2: Percentage of time the Waiau Arm has been within nominated flow ranges at different lake level ranges in non-winter months (September to May). Data from December 2017 to April 2023. Blank cells mean that there were no data in that combination of flow and lake level class. Grey-shaded and blue-shaded cells show the ranges enclosed by the eight scenarios for which water velocity was modelled by Damwatch (Table 1). Pink cells highlight the two combinations that occurred most frequently. Lake levels of 176.8 and 178.6 define the main operating range of Lake Manapōuri.

	Percentage of time in different lake level ranges (in m a.s.l.)						
Flow (m^3/s)	**<176.8**	**176.8 - 177.2**	**177.2 - 177.5**	**177.5 - 178.0**	**178.0 - 178.6**	**>178.6**	**Total %**
>-20		<0.1	1.2	1.3	0.9		3.5
-20 to -10		0.4	2.1	4.5	2.9	<0.1	10.0
-10 to -5		1.3	3.0	2.8	1.8	<0.1	8.9
-5 to -2		1.2	2.5	2.4	0.7	<0.1	6.8
-2 to 0		0.6	1.8	1.5	0.7	<0.1	4.5
0 to 2		0.4	2.3	1.6	0.4	<0.1	4.7
2 to 5	0.1	3.0	6.5	2.1	0.4	<0.1	12.1
5 to 10	3.0	6.3	8.8	2.7	2.3	0.1	23.3
10 to 20	3.6	2.4	1.2	1.3	2.2	0.2	10.8
20 to 100	0.1	0.4	0.4	1.1	1.4	2.1	5.6
>100			<0.1	0.2	0.6	8.9	9.7
Total %	6.8	16.0	29.8	21.6	14.2	11.4	100

[4] The flow data were extracted to correspond to the time frame of the chlorophyll *a* data available with a lead in period.

4 Assessment of potential effects of the modelled velocities on risk of chlorophyll *a* >2 mg/m^3

4.1 Assumptions and caveats

In relating the above analysis back to the Damwatch modelled velocities in Table 2-1, the following assumptions have been made.

- The chlorophyll *a* – velocity relationships and thresholds discussed above also apply to the area of the Waiau Arm around the MLC and the site of the excavation, even though the relationships were derived from chlorophyll *a* observations farther up the Waiau Arm.
- The outputs from the relatively simple modelling outlined by Spigel et al. (2006) are comparable to the outputs from the Damwatch models. The following statement in Clunie (2023) (page 6) supports this assumption: "in the deeper Waiau Arm upstream of the delta area, average velocities for a 10 m^3/s flow rate are 0.02 to 0.04 m/s over the lake range". Average velocities for the Waiau Arm as a whole calculated using the Spigel et al. (2006) approach were almost the same (0.021 to 0.042 m/s at 10 m^3/s).
- Estimated water velocity averaged over the water column in the deeper parts of the Arm has the same relationship to velocity in surface waters (where phytoplankton blooms are usually observed) as the average water velocity modelled by Damwatch in the shallower channels nearer to the MLC.
- Water temperatures in the channels post-excavation will be at least comparable to or possibly higher than those measured in surface waters of the deeper parts of the Waiau Arm under similar water velocities. There is potential for higher temperatures at times of low velocities because the Damwatch modelling has indicated that water in the channels will be relatively shallow compared to that in the main part of the Waiau Arm (Clunie 2023).[5]

A caveat is that the effect of nutrient availability (in particular, nitrogen and phosphorus) is a source of variability in the chlorophyll *a* data that is not accounted for. For example, under negative flows in the Waiau Arm, nutrients could be introduced in water from the Mararoa River, which might exacerbate phytoplankton growth. Chlorophyll *a* in the Waiau Arm near to Pearl Harbour could also be influenced by local nutrient inputs (e.g., from Home Creek). No analysis has been carried out to investigate either of these possibilities.

4.2 Assessment of effects

The assessment is based on the modelled velocities in Table 2-1, the chlorophyll *a* – velocity relationship and thresholds in Figure 3-2, and the durations of different lake level / flow combinations in Table 3-2.

[5] Modelled water depths in the channels (averaged over all channels) range from 2.2 to 2.6 m depending on scenario. Water depth at the monitored sites in the Waiau Arm range from 6.5 to 14 m (approximately, depending on lake level and site location). Temperature stratification has been noted on occasion in summer, especially at the site nearest to MLC (e.g., Hogsden and Molineux 2022). Water temperatures down to 2 – 3 m depth can be 2 – 5 °C higher than at deeper locations. This implies that under slow water velocities the same solar radiation may have an enhanced warming effect in shallower water compared to that in deeper waters. This is analogous to the observed pattern in rivers of warmer temperatures in lower flows (Booker and Whitehead 2022).

In addition, we note the effects of water temperature on phytoplankton (Figure 3-1). Higher water temperatures associated with shallower waters could exacerbate the risk of chlorophyll *a* exceeding 2 mg/m^3 when water velocities are suitable.

Risk was assessed in three steps:

1. The water velocities from the Damwatch model (Table 2-1) were assigned a risk (from Figure 3-2):
   - High risk of phytoplankton blooms = water velocity of 0.02 or <0.02 m/s (to be colour coded red)
   - Some risk = water velocity of 0.03–0.04 m/s (to be colour coded orange)
   - Low risk = water velocity >0.04 m/s (to be colour coded green).
2. The modelled water velocities were overlaid on the matrix of lake levels and flow combinations shown in Table 3-2, and risk (colour coded as above) was assigned to all the cells. The resulting five matrices (one for each of the channels in the existing condition and one for each of the three channels following excavation of the parallel channel)) are presented in Appendix A.
3. The total percentage of time expected at each level of risk was calculated for each channel in the existing scenario and following excavation of the parallel channel by summing the percentages of time (as shown in equivalent cells in Table 3-2) in all cells colour coded red, orange or green (numbers or arrows showing risk) on the matrices in Appendix A. Total percentages were converted into days at each risk level (Table 4-1).

Table 4-1: Assessment of the number of days per year (on average) when each channel under each excavation scenario may be under high, some or low risk of developing chlorophyll *a* >2 mg/m^3. Assessment based on modelled average water velocities under each scenario.

		Days per year (excluding winter)			Days per year (including winter)		
Excavation scenario	Channel	High risk	Some risk	Low risk	High risk	Some risk	Low risk
Existing	Main	12	48	213	16	64	284
	South	26	41	206	34	53	277
Parallel channel	Main	61	81	131	82	98	184
	South	73	86	113	97	106	162
	New	78	92	103	101	127	137

4.3 Commentary

4.3.1 Effects of water velocity: existing channels (for comparison)

- In the existing channels at flows of greater than 10 m^3/s in either direction, there appears to be little risk of phytoplankton growth (chlorophyll *a*) exceeding 2 mg/m^3 at any time. Water velocities are predicted to equal or exceed 0.04 m/s at all times (Table 2-1).
- The risk increases at flows lower than 10 m^3/s but is still low down to 5 m^3/s though with some risk in the south channel, which has the lowest velocities (Table 2-1).
- The highest current risk in both channels is at medium – high lake levels (>178.0 m) especially when flows are between -5 and 5 m^3/s, but likely extending to flows >5 m^3/s.
- Based on water velocity, the existing main channel is at high risk of developing phytoplankton blooms for less than 5% of the time (~12 days excluding winter) and the smaller south channel for <10% of the time (~26 days) (Table 4-1).

4.3.2 Effects of water velocity following excavation

- After excavation of the parallel channel, water velocities in the new, main and south channels are predicted to be lower than in the existing channels under all eight scenarios.
- The risk pattern is complex because the flow is split into three channels. For example, at low and negative flows (towards the lake), flow in the new channel becomes very low relative to the main channel (e.g., scenarios 7 and 8 in Table 2-1), leading to low velocities and higher risk of phytoplankton blooms. When flow is towards MLC, the new channel takes more flow than the main channel (e.g., scenarios 1 and 6 in Table 2-1), and higher risk is in the main channel.
- This translates to high risk of phytoplankton blooms for ~22% of the time (~60 days annually excluding winter) in the main channel, for ~27% of the time (73 days) in the new channel, and for ~29% of the time (78 days) in the south channel (Table 4-1).

4.4 Summary of effects assessment

For the new parallel channel and the main and south channels following the excavation, the combination of modelled water velocities and the chlorophyll *a* – velocity relationship suggested substantial increased risk of phytoplankton blooms over the risk in the existing channels. The predicted number of days per year under high risk of phytoplankton blooms in the post-excavation main and south channels was three to five times higher than that predicted for the existing main and south channels.

Modelled water depth (averaged across the channels) is less than 2.5 m in the parallel channel option. The shallow depths (compared to those in the Waiau Arm as a whole) could increase the risk to more than that suggested from water velocity alone, because of the risk of warmer temperatures at times. While the existing channels are even shallower, the effect of temperature would enhance phytoplankton growth only when velocities are low: if phytoplankton is continuously washed downstream it cannot accumulate to form blooms.

It should be noted that the overall risk of phytoplankton blooms, post-construction, in the new parallel channel and the main and south channels is often lower than that in the Waiau Arm as a whole, based on water velocities. The reason is that under most flow and lake level scenarios, averaged water velocities in the Waiau Arm as a whole (based on the Spigel et al. (2006) calculations) are lower than those predicted by Damwatch in the channels upstream of MLC (right hand column in Table 2-1).

5 The effect of flow releases

Following excavation of the proposed parallel channel the increased risk of phytoplankton blooms in all three channels will be reduced by managed flow releases that are part of current flow management in the Lower Waiau River. Potentially useful flow releases are the larger flushing flows for periphyton management, and the smaller recreational flow releases.

5.1 Periphyton flushing flows.

The proposed excavation works are expected to improve conveyance and reliability of a range of consented flow releases across different lake levels, including flushing flows to the Lower Waiau River to assist in periphyton management during the summer/autumn period (November to May).[6] Key points follow.

1. The current protocol for monitoring and management of nuisance periphyton in the Lower Waiau River provides for the release of up to four flushing flows in each season (between November and May) in response to Amber or Red status[7] in the river.

2. In the past seven seasons (i.e., November 2016 – May 2017 through to November 2022 – May 2023), fewer than 1.5 flushing flows per season have been released (on average). Low lake levels precluded releases following at least 15 reports of Red status in the river during those seasons, sometimes for prolonged periods.

3. Red status in the river coincided with high-risk conditions in the Waiau Arm for about 40% of the time and with some risk for an additional 40% of the time. This suggests that increased reliability of flushing flow releases following the excavations (i.e., flow releases will be feasible across a wider range of lake levels)[8] is likely to have a beneficial effect in the Waiau Arm as well as in the Lower Waiau River.

4. Flushing flows of the size defined in the protocol (i.e., mean 24 h flow >120 m^3/s, peaking at >160 m^3/s) will replace all the water the Waiau Arm (with lake water) within 6–12 hours depending on lake level and flow in the Mararoa River (using the calculation method in Spigel et al. 2006).

5. Flushing flows of this size would re-set the risk of phytoplankton blooms to very low, with a residual effect of several days. A residual effect is expected because clean lake water (i.e., with low chlorophyll *a*, often <0.5 mg/m^3 in summer (Meridian dataset)) would persist in the Arm following the flushing flow, extending the time required for chlorophyll *a* to develop into a "bloom".

6. If four flushing flows could be released during each summer season this could reduce the average period of high-risk conditions under both excavation scenarios by 25 days or more, assuming a 5–7-day residual effect after each flushing flow. This residual time is a "best guess", assuming a doubling time in phytoplankton cells of 2 days or more

[6] For details refer to: Protocol developed under Water Permit 206156 condition 7 version 16 November 2018 (Protocol for controlled releases of voluntary supplementary flows form the Manapouri Lake Control (MLC) structure to the Lower Waiau River).

[7] Amber and Red status in the Lower Waiau River are defined from the results of monitoring of periphyton at three sites in the Lower Waiau River, as described in the protocol. Amber = alert, periphyton cover is approaching nuisance levels; and Red = response required as nuisance levels have been reached.

[8] Noting that such flow releases will still be subject to lake levels being high enough and cannot be provided at some very low lake levels.

(from Figure 1 in Appendix I of Spigel et al. 2006, and other literature values, e.g., Stenuite et al. 2007).

5.2 Recreational flows

Monthly recreational flows are scheduled for the fourth Sunday in each month from October to April. These releases have been provided relatively consistently in the past (because they are small releases) and are included in the calculations described in Sections 3 and 4 above. The parallel channel option will support the continued release of recreational flows. The following points have been considered.

1. Recreational flows are typically approximately 35–45 m^3/s (at MLC) for 24 hours. If the entire flow is provided from Lake Manapōuri all water in the Waiau Arm would be replaced at lake levels up to 177.5 m (Spigel et al. 2006), which would re-set the risk of phytoplankton blooms to very low. The risk-reduction effect would be reduced at higher lake levels, or if some of the flow is provided from the Mararoa River (which could lead to increased risk – see below).

2. We looked at the composition of flows (i.e., lake water vs. Mararoa water) in 28 recreational flows released since December 2017. In half of these releases, flow from the lake was sufficient to replace most of the water in the Waiau Arm over the 24-hour period, at the lake level at the time.

3. Twenty-four of the 28 recreational flows (i.e., ~85%) were associated with water velocities in the Waiau Arm that were in the low-risk range for phytoplankton blooms (see Section 3.3.2 above). This is because higher water velocities during the releases interrupted periods of lower water velocities (e.g., in the high-risk range). In these cases, conditions in the Waiau Arm would have been re-set to the start of a new period when phytoplankton blooms might develop.

4. The four recreational flows that did not have this re-setting effect were released during periods when Mararoa River water was already being turned up towards Lake Manapouri (i.e., negative flows in the Waiau Arm). The water for the recreational flow releases therefore included a high proportion of water from the Mararoa River. Reversing the flows to enable a recreational release at MLC led to lower water velocities than in the preceding days and therefore did not reduce the risk of phytoplankton blooms.

5. Since December 2017, 12 of a potential 40 recreational flows were not released. In seven cases, flows were already high on the day scheduled for a recreational release. In five cases, lake levels were very low.

5.3 Summary

In summary, management of flows in the Lower Waiau River in accordance with existing resource consents and, in particular, the expected improved conveyance and reliability of flow releases than at present, will following excavation of the proposed parallel channel, provide a core set of flow releases that will, in most cases, reduce and/or delay the risk of phytoplankton blooms developing in the post-excavation channels immediately upstream of MLC.

In summary, once the channel excavation is completed it is expected that the increased risk of phytoplankton blooms in the new parallel channel arrangement will be largely offset by the improved conveyance and reliability of flow releases to the Lower Waiau River. Flow releases that are consented and part of current flow management in the Lower Waiau River will provide a “core” set of flow releases that will, in most cases, reduce and /or delay the risk of phytoplankton blooms developing in the newly excavated channels immediately upstream of MLC.

Further points to consider are:

- Flow and lake level conditions that indicate high risk in the channels also indicate risk of chlorophyll *a* >2 mg/m^3 in the Waiau Arm itself (the deeper section closer to Lake Manapōuri) because water velocities are likely slightly lower than those modelled for the channels under the same flow and lake level combinations. The existing Meridian summer water quality monitoring programme in the Waiau Arm (see Section 3.1.1 for more details) would provide additional relevant data for determining whether there is a potential problem.

- Based on data from the Waiau Arm (Figure 3-1, Figure 3-2) high-risk situations (i.e., when water velocities fall below 0.02 m/s in either direction, and water temperature is >13 °C), do not necessarily lead to chlorophyll *a* >2 mg/m^3, but the probability increases beyond these velocity and temperature thresholds.

- The discussion in Sections 5.1 and 5.2 above suggests that one explanation for low chlorophyll *a* concentrations when water velocities are in the high-risk range may be related to the composition of water in the Waiau Arm. Recent replacement of water in the Waiau Arm by clean Lake Manapōuri water (from either managed or natural releases) is expected to re-set conditions in the Arm so that phytoplankton bloom development is slower. The implication is that the averaged periods of high-risk conditions for the two excavation scenarios presented in Table 4-1 represent worst case scenarios.

- The risks calculated in Sections 3 and 4 of this memo and summarised in Table 4-1 are averaged risks based on seven years of data. The risk of phytoplankton blooms developing the Waiau Arm including in the channels upstream of MLC post-excavation will be lower in years when lake inflows are higher, and vice versa. Year to year differences have not been quantified.

6 Acknowledgements

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Appendix A Risk diagrams for all channels under existing conditions and after excavation of the parallel channel

The five matrices below show how risk was assessed for existing main and south channels and for the new, main, and south channels after excavation of the parallel channel.

Water velocities (m/s) predicted by the Damwatch model are shown as numbers in the appropriate cells (aligned to the sides of the cell according to the selected flow and lake level scenario). Arrows indicate the direction of increasing risk as flow decreases.

- Red numbers or arrows = high risk
- Orange numbers or arrows = some risk
- Green numbers or arrows = low risk.

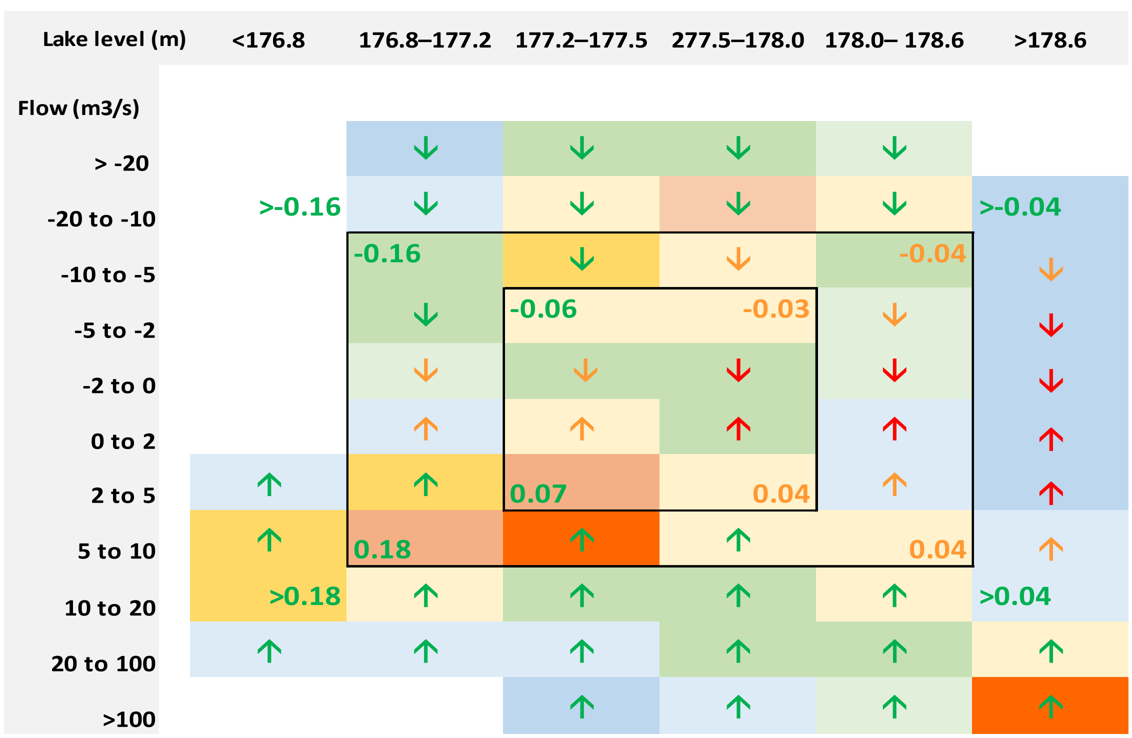
The black lines show the ranges enclosed by the eight scenarios for which water velocity was modelled by Damwatch (Table 2-1).

Coloured shading indicates the average percentage of time spent in that velocity and lake level range combination (key on the right of the first plot). The percentages apply to all months <u>excluding winter</u> (i.e., 273 days from September through to May). Overall risk is much lower in winter – see text. Blank cells mean that that flow – lake level combination did not exist.

KEY: % time under flow and lake level combination

<0.1	0.1 to 0.5	0.5 to 1	1 to 2	2 to 3	3 to 4	4 to 6	6 to 8	> 8

Existing, main channel



Existing, south channel

Lake level (m)	<176.8	176.8–177.2	177.2–177.5	277.5–178.0	178.0– 178.6	>178.6
Flow (m3/s)						
> -20		↓	↓	↓	↓	
-20 to -10	>-0.11	↓	↓	↓	↓	>-0.04
-10 to -5		-0.11	↓	↓	-0.04	↓
-5 to -2		↓	-0.04	-0.02	↓	↓
-2 to 0		↓	↓	↓	↓	↓
0 to 2		↑	↑	↑	↑	↑
2 to 5	↑	↑	0.05	0.03	↑	↑
5 to 10	↑	0.14	↑	↑	0.04	↑
10 to 20	>0.14	↑	↑	↑	↑	>0.04
20 to 100	↑	↑	↑	↑	↑	↑
>100			↑	↑	↑	↑

Parallel channel, main channel

Lake level (m)	<176.8	176.8–177.2	177.2–177.5	277.5–178.0	178.0– 178.6	>178.6
Flow (m3/s)						
> -20		↓	↓	↓	↓	
-20 to -10	>-0.09	↓	↓	↓	↓	>-0.03
-10 to -5		-0.09	↓	↓	-0.03	↓
-5 to -2		↓	-0.05	-0.03	↓	↓
-2 to 0		↓	↓	↓	↓	↓
0 to 2		↑	↑	↑	↑	↑
2 to 5	↑	↑	0.02	0.01	↑	↑
5 to 10	↑	0.03	↑	↑	0.02	↑
10 to 20	>0.03	↑	↑	↑	↑	>0.02
20 to 100	↑	↑	↑	↑	↑	↑
>100			↑	↑	↑	↑

Parallel channel, south channel

Lake level (m)	<176.8	176.8–177.2	177.2–177.5	277.5–178.0	178.0– 178.6	>178.6
Flow (m3/s)						
> -20		↓	↓	↓	↓	
-20 to -10	>-0.06	↓	↓	↓	↓	>-0.03
-10 to -5		-0.06	↓	↓	-0.03	↓
-5 to -2		↓	-0.03	-0.02	↓	↓
-2 to 0		↓	↓	↓	↓	↓
0 to 2		↑	↑	↑	↑	↑
2 to 5	↑	↑	0.01	0.01	↑	↑
5 to 10	↑	0.04	↑	↑	0.02	↑
10 to 20	>0.04	↑	↑	↑	↑	>0.02
20 to 100	↑	↑	↑	↑	↑	↑
>100			↑	↑	↑	↑

Parallel channel, new channel

Lake level (m)	<176.8	176.8–177.2	177.2–177.5	277.5–178.0	178.0– 178.6	>178.6
Flow (m3/s)						
> -20		↓	↓	↓	↓	
-20 to -10	>-0.04	↓	↓	↓	↓	>-0.02
-10 to -5		-0.04	↓	↓	-0.02	↓
-5 to -2		↓	-0.01	-0.004	↓	↓
-2 to 0		↓	↓	↓	↓	↓
0 to 2		↑	↑	↑	↑	↑
2 to 5	↑	↑	0.02	0.02	↑	↑
5 to 10	↑	0.06	↑	↑	0.03	↑
10 to 20	>0.06	↑	↑	↑	↑	>0.03
20 to 100	↑	↑	↑	↑	↑	↑
>100			↑	↑	↑	↑