Preventing possible *Didymosphenia* transport into Lake Manapouri: Estimated flow limits for the Waiau Arm and Mararoa River

NIWA Client Report: CHC2005-110
August 2005

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Biosecurity New Zealand

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Executive Summary

Didymosphenia geminata, an exotic freshwater alga from North America, is currently proliferating in the Mararoa and lower Waiau Rivers, Southland. *D. geminata* has now been found in the lower reaches of the Waiau Arm of Lake Manapouri. Diversion of Mararoa River water into the Waiau Arm (for power generation at Deep Cove) is most likely to have facilitated this translocation. The Guardians of Lake Manapouri, Meridian Energy Ltd and Biosecurity New Zealand have raised concerns over the likely impact of *D. geminata* on the aesthetic and ecological values of Lake Manapouri and the alga's potential to then transfer to other waterbodies should the diversion of Mararoa water continue.

The following study was commissioned to determine at what flow in the Waiau Arm (toward Lake Manapouri) *D. geminata* would rapidly sink and thus not be transported beyond Zone 1 (as defined by Kilroy and Blair 2005) in the Waiau Arm. This flow would then be used as a diversion cap for Mararoa River waters to allow some continuation of use of Mararoa waters for power generation whilst minimising the risk of spread of *D. geminata* to Lake Manapouri. The study consisted of the following parts:

- Hydrodynamic modelling to determine the maximum allowable upstream flows from the Mararoa River through the Waiau Arm to Manapouri, such that sinking *D. geminata* cells would be deposited on the bed of the channel within the confines of Zone 1 (as defined in Kilroy and Blair 2005) where deposited cells are already present.

- An analysis of flow records in relation to peak flows required to slough *D. geminata* to estimate a maximum flow in the Mararoa River above which all diversion of water should cease. This analysis is necessary because of the potential for greatly enhanced sloughing rates, and associated increased flux of *D. geminata* into the Waiau Arm, when the Mararoa is 'in fresh'.

Based on these analyses, we recommend the following:

1. All diversion of Mararoa water into the Waiau Arm of Lake Manapouri should cease once flows in the Mararoa River (measured at the Cliffs water level recorder station) reach 42 m^3/s. At flows less than this when diversions are permitted, most suspended *D. geminata* should settle out by about half-way along Zone 1. This short settling distance, plus the 7.3 km from the end of Zone 1 to the lake, gives a high 'margin of safety' for protection of Lake Manapouri from the possible waterborne transport of *D. geminata* down the Waiau Arm.

2. Following a fresh/flood event, diversion of Mararoa water back into Lake Manapouri should not resume until the river is clear of large floating/suspended mats of *D. geminata*. This

should be determined by an independent observer familiar with the river's 'natural' suspended mat densities.

3. A detailed underwater survey should be carried out of the Waiau Arm to validate the hydrodynamic transport modelling and accurately delineate how far up the Waiau Arm *D. geminata* has been carried to date.

1. Introduction

Didymosphenia geminata, an invasive freshwater alga from North America that forms noxious growths, was first found in New Zealand at sites in the Mararoa and lower Waiau Rivers, Southland, in October 2004. Subsequent surveys found that *D. geminata* had also been translocated into the lower reaches of the Waiau Arm of Lake Manapouri (Kilroy and Blair 2005). Diversion of Mararoa River water into the Waiau for subsequent power generation at Deep Cove is most likely to have facilitated the movement of these cells into the arm.

D. geminata has a habitat preference for clear, shallow, nutrient-poor flowing water exposed to high sunlight (see Kilroy 2004). However, early taxonomic literature refers to *D. geminata* occurring in both lakes and rivers (Cleve 1894-96, Hustedt 1930), and there is at least one report of a massive bloom of the species along a lakeshore (see Kilroy 2004). The Guardians of Lake Manapouri, Meridian Energy Ltd and Biosecurity New Zealand have raised concerns over the likely impact of *D. geminata* on the aesthetic and ecological values of Lake Manapouri and the alga's potential to act as a source population for translocation of cells to other waterbodies, should this species be able to colonise and grow on the Manapouri lakeshore.

In an effort to maintain the health of the Waiau Arm and reduce the risk of spreading *D. geminata* up into the lake, Meridian Energy Ltd and Biosecurity New Zealand have commissioned NIWA to estimate the maximum allowable upstream flows from the Mararoa into the arm (i.e. a 'flow cap'), such that sinking *D. geminata* cells would be deposited on the bed of the channel within the confines of Zone 1, as defined in Kilroy and Blair (2005) (where deposited cells are already present). If this flow cap could be defined, then some use of the Mararoa water for power generation might still be possible as the chance of hydraulic transport of the *D. geminata* cells to Lake Manapouri would be minimised. The calculations, assumptions and supporting information are described in this report.

In preparing the present evaluation, it also became apparent that any flow cap placed on the diversion would not allow for the occurrence of a 'fresh' or flood event in the Mararoa River that could slough large mats of *D. geminata*. These mats could then be transported into the arm within the flow cap set by settling velocities which would significantly increase the flux of *D. geminata* to the Arm (and increase the chance of having floating mats which could entangle in the macrophytes or blow up toward the lake). Thus, a further analysis was also carried out to estimate a maximum flow in the Maraora River above which all diversion of water should cease because of the potential for greatly enhanced sloughing rates.

For the purpose of this report 'downstream' in the Waiau Arm refers to the direction from Lake Manapouri towards the Manapouri Level Control structure (MLC), that is, the direction of natural flows before the construction of the MLC; 'whereas' upstream is from the MLC towards Lake Manapouri, in the direction of flow of diverted Mararoa River water into the lake.

2. Summary of approach

A four-stage process was adopted to develop the recommended 'flow caps'.

1. Determination of *D. geminata* sinking velocities.

2. Hydrodynamic modelling to calculate settling distances in the arm as a function of different velocities in the Waiau Arm.

3. Modelling the relationship between settling distances and lake-ward flows in the Waiau arm for different lake levels.

4. Calculating likely sloughing flows for *D. geminata* in the Mararoa River based on a frequency distribution curve of flows and empirical results on the magnitude of change in flow necessary to slough periphyton in the Waiau and other rivers.

3. Determination of *Didymosphenia* sinking velocities

Sinking velocity of live cells and fragments of *D. geminata* were determined from laboratory experiments, as follows.

Fresh material of intact *D. geminata* colonies was collected from the Mararoa River by Bill Jarvie (Fish & Game), and transported to the biosecurity containment facilities at NIWA Christchurch. Fragments from the colony (similar in size to those observed in the field) and individual cells were placed into a graduated column of 12^{o}C water and the time taken to sink a defined distance was recorded. Repeat measurements were made on a range of cell and fragment sizes in order to determine the *slowest*, and therefore the most conservative, sinking rate.

Sinking velocity was then calculated as a function of distance traveled down the experimental cylinder over time. The slowest sinking velocity of a cell and stalk was 0.8 mm/s.

4. Transport and flow cap modelling

4.1. Area modelled

Zone 1 in the Waiau Arm was defined by Kilroy and Blair (2005) as the area from the MLC area to 2.3 km west of MLC (Figure 1). With the exception of two samples, all samples containing *D. geminata* from the April 2005 survey were confined to this area of the arm. For the purpose of the modelling, Zone 1 was further defined as the area downstream of the old confluence of the Mararoa River delta with the Waiau River to 1.8 km along the arm towards the lake. Based on bed profile data (courtesy of Dr Alan Hunt, Maunsell Limited) it was decided to use the reach between cross section (CS) 30 and the end of Zone 1 as the reach of the Arm over which sinking of *D. geminata* cells could be allowed to occur (Figure 2). The wide, shallow part of the Arm between the MLC and CS 30 was excluded because of the possibility that cells deposited on the bed could be re-suspended by the faster currents and in shallower depths that characterize that part of the channel.

4.2. Assumptions

Information from CS 42 (see Figures 1 and 2) was used for calculation of channel geometry in this model. CS 42 is in the deeper part of the Waiau with an approximate water depth of 9m and is the nearest cross section within our Zone 1 that has been surveyed. In the absence of further survey information, we assumed that the geometry at this cross section (i.e., CS 42) is typical of the whole of Zone 1 of the Waiau Arm.

In order to estimate maximum allowable upstream flows to allow for complete sinking of *D. geminata* within the confines of Zone 1, the following assumptions and simplifications have been made.

1. The water surface is assumed to be horizontal between Lake Manapouri and the MLC for the purposes of estimating water depths and cross-section areas within the Waiau Arm as a function of lake level.

2. The area and depth properties of cross section 42 are assumed to apply to the entire reach over which sinking takes place, i.e. between cross section 30 and the end of zone 1. This is a reasonable assumption based on the available survey information.

3. The sinking velocity of clumps of cells and associated stalks of *D. geminata* is taken as 0.8 mm/s, as determined above.

Figure 1: **Map of Waiau Arm showing locations of cross-sections referred to in description of sinking calculation.**

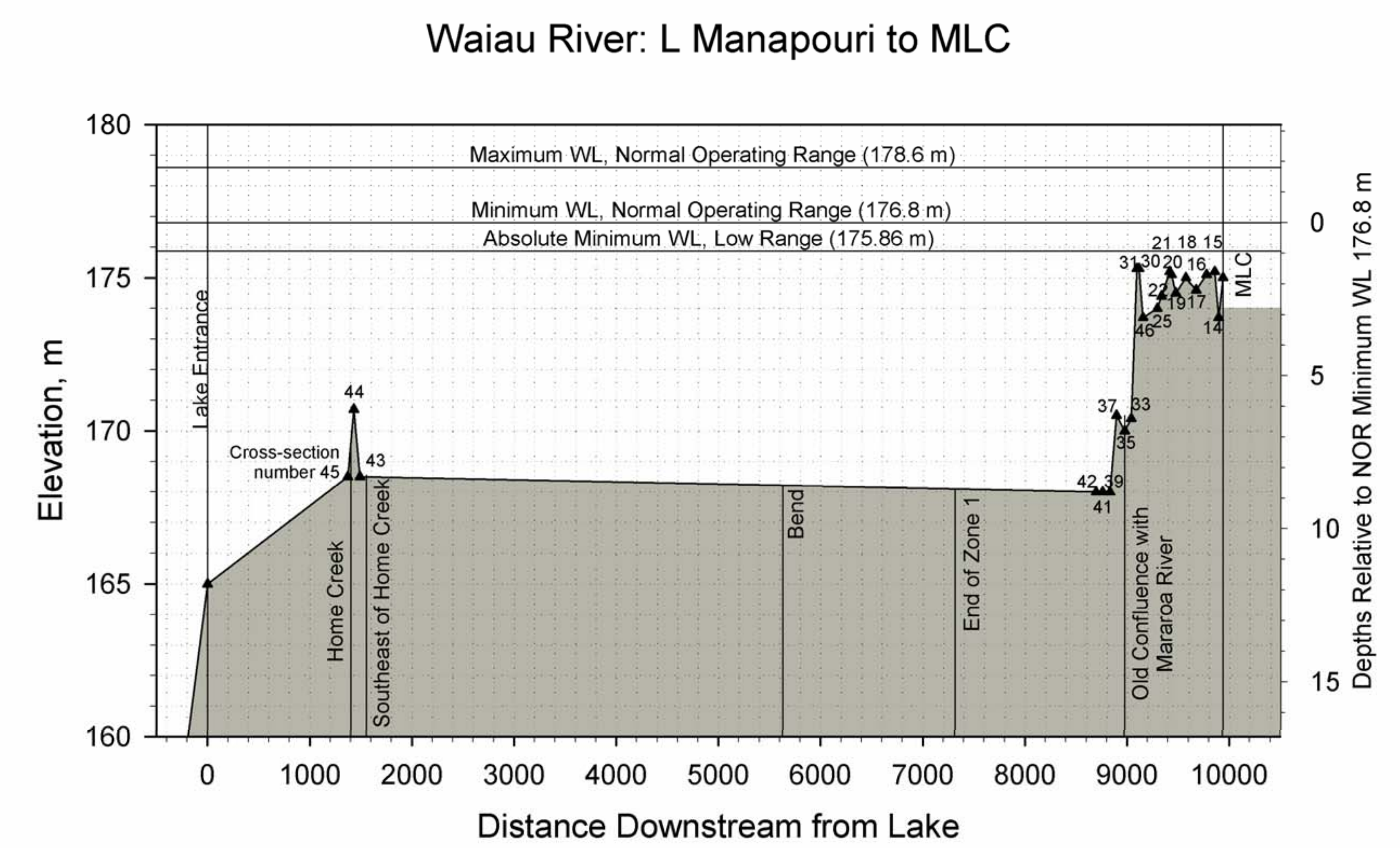


Figure 2: **Profile along Waiau Arm showing bed elevations from cross-section surveys supplied by Meridian, with additional information provided by Allan Hunt, Maunsell Limited. There are no cross-sections between CS 42 and CS 43.**

4. *D. geminata* cells are assumed to be transported upstream at the cross-sectional mean flow velocity. A well defined thalweg of higher velocities is not expected in the Arm because of the hydraulic geometry of the channel and low flows relative to cross-sectional area.

Only sinking cells are considered; cells trapped in buoyant floating material are not accounted for. The trajectory of floating material will be determined by the interaction of surface currents and detailed channel-bank topography.

The model does not consider possible resuspension of cells after they have been deposited on the channel bed. While this seems to be a reasonable assumption for the slower horizontal velocities that occur in the deeper reaches of the Waiau Arm for upstream flows, we are not aware of the existence of data or information that would allow us to consider this question quantitatively.

Finally, depths used in the calculations correspond to the deepest part of the channel. This is conservative in the sense that it maximizes the required settling times. It is also consistent with the neglect of resuspension mentioned above, in that resuspension of cells from depths of 7 to 10 m at low flow velocities seems highly unlikely. On the other hand, it does not consider possible resuspension of cells that may have been deposited in shallower parts of the channel. The required energy for such resuspension might come from wind generated turbulence or waves. However, given the steepness of the channel banks, we believe that the likelihood of sustained upstream transport as a result of repeated deposition and resuspension within a narrow band of sufficiently shallow water near the channel's edge is very low.

4.3. Definitions

The following variables are introduced to explain the calculation of the sinking trajectory of a particle, as defined in Figure 3.

Q = magnitude of allowable upstream flow in the Waiau Arm (m^3/s)

A = cross-sectional area of the channel (assumed to be that of CS 42) (m^2)

U = cross-sectional average velocity = Q/A (m/s)

X = maximum allowable horizontal distance for sinking to take place (1800 m, the distance between CS 30 and the end of Zone 1)

w = sinking velocity (0.0008 m/s)

h = water depth of the channel (assumed to be that of CS 42) (m)

z = elevation of Lake Manapouri water surface (m asl)

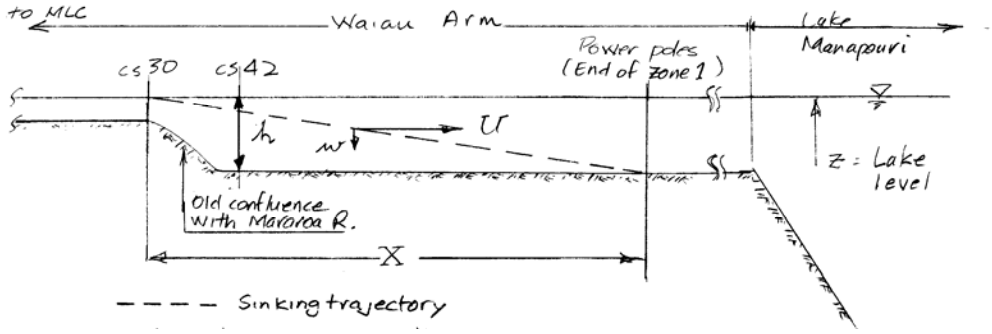


Figure 3: Stylised cross section of the Waiau Arm in the vicinity of the MLC defining the parameters for the hydraulic model.

4.4. Calculations

The basis of the calculation is that the time for sinking of *D. geminata* cells to the bottom of the channel (vertical transport) must be less than or equal to the time for the cells to be transported upstream from the start of Zone 1 (CS 30) to the end of Zone 1 (horizontal transport). Equating these two time scales gives an expression for the maximum allowable velocity:

$$U = wX/h \qquad (1)$$

and hence for the maximum allowable flow rate:

$$Q = UA = AwX/h \qquad (2)$$

Lake level z does not appear explicitly in either Equation 1 or 2. However, both water depth (h) and cross-sectional area (A) are functions of lake level, h = h(z) and A = A(z).

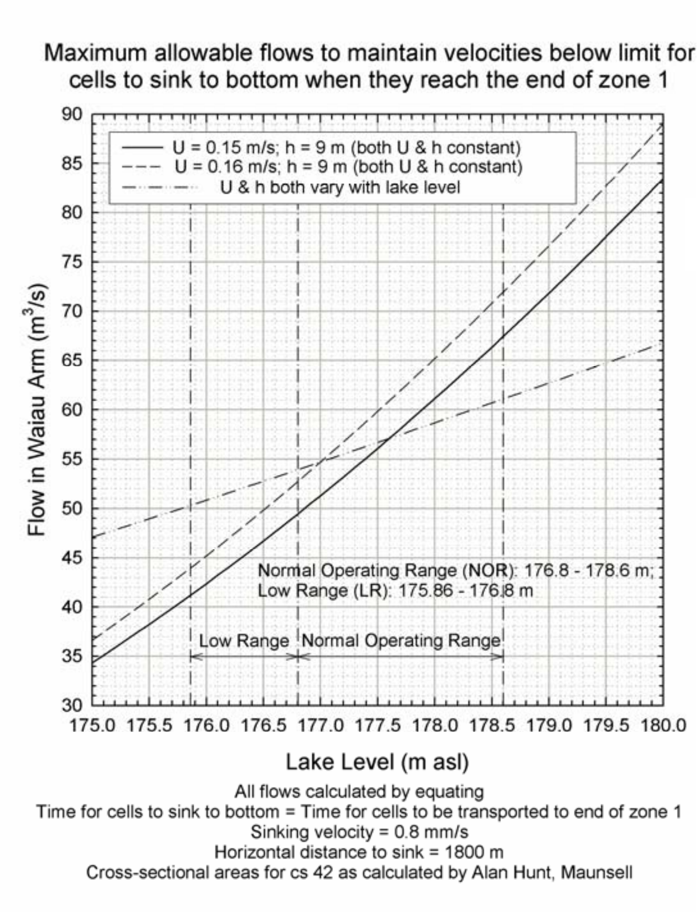
In order to determine the maximum allowable flow rate three sets of calculations were carried out using the relationships between lake level and cross-sectional area and water depth at CS 42, as supplied by Dr Alan Hunt, Maunsell Limited. The first two calculations assumed a constant value for water depth (h) in Equations 1 and 2, but accounted for variation of cross-section area, as lake level changed, in Equation 2. By using a sinking velocity (w) of 0.0008 m/s, a maximum horizontal distance (X) of

1800 m, and a water depth of 9 m, we calculate cross-sectional average velocity (U) at 0.16 m/s. The corresponding values of flow are solved for a range of lake levels and are shown in Figure 4A (dashed line). A second set of flows verses lake level were also calculated assuming a more conservative value of U at 0.15 m/s (solid line, Figure 4A).

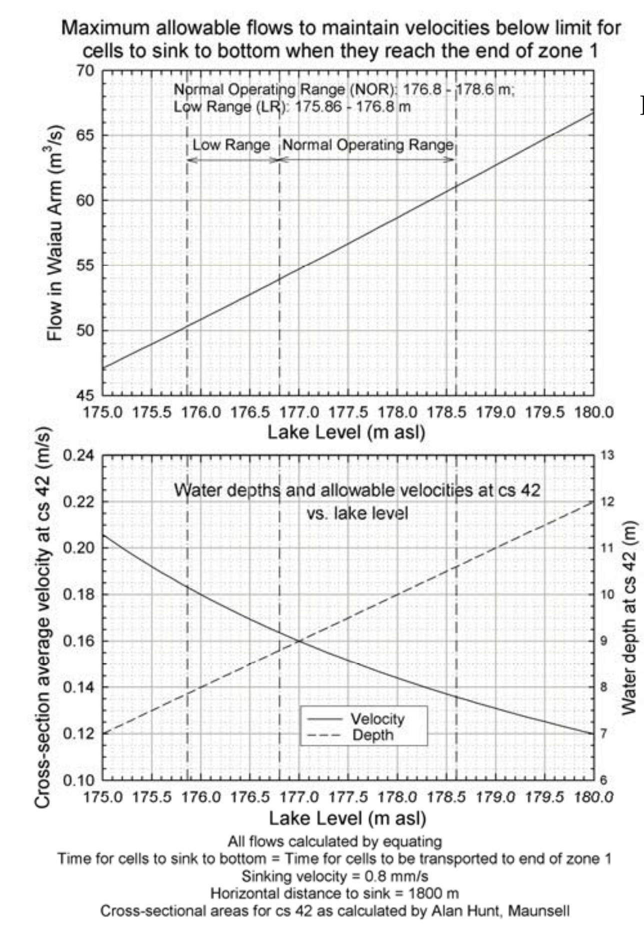
4.5. Determination of flow cap based on transport of cells

In the third set of calculations, variations of both water depth (h) and cross sectional area of the channel (A) with lake level (z) were accounted for. The relationship between velocities and water depths as a function of lake level is shown in Figure 4c. Increasing lake level corresponds to increasing cross-sectional area and to increasing depth. Increasing cross-sectional area means that for a given permissible velocity (U), a larger value for flow can be allowed for the greater depths. However, as depth increases, time taken for a *D. geminata* cell to sink to the bottom also increases, requiring a slower U in order to increase the horizontal travel time.

The first two calculated maximum allowable flows were unofficially presented to Meridian (B. Biggs telecom to Meridian 2 August 2005) and hence all three are presented here for comparison. The first two calculated flow rates are more conservative when lake levels are low, while the third calculated flow rate is more conservative during periods of high lake level. The third set of calculations (Figure 4b) is the more correct approach for calculating maximum allowable flow in the Waiau Arm and therefore it is recommended that this be used as a guide for permissible flows into the Waiau Arm from the Mararoa River. This result indicates that when the lake is low (<176 m), flow diversions from the Mararoa should be <50 m^3/s. However, at high lake levels flows could be as high as 60 m^3/s. These flows are much higher than occurs at present because of the turbidity limits (i.e., upstream flows are usually < 30 m^3/s), so flows in the Arm are seldom/never likely to have been high enough in the recent past to transport *D. geminata* past Zone 1. There are also issues of mat sloughing at these higher flows which need to be recognised and avoided with respect to transport and deposition in the arm (see next Section).



A)



B)

C)

Figure 4: **Graphs showing results from 3 calculations for maximum allowable flows required to limit the transport of sinking a *Didymosphenia* cell (sinking velocity 0.8 mm/s) to Zone 1. (A) Two curves (solid and dashed lines) calculated assuming a constant depth of 9 m for all flows and lake levels, constant horizontal velocities of 0.15 m/s (solid line) and 0.16 m/s (dashed line), but cross-sectional area varying with lake level; third curve (dash-double dot) allows for variation of depth, velocity, and cross-section area with lake level. (B) Third curve from (A) shown alone as a solid line (variation of depth, velocity and cross-section area accounted for). (C) Variation of depths and velocities with lake level corresponding to flows in (B).**

5. Determination of a flow cap for diversion from the Mararoa River based on likely enhanced *Didymosphenia* sloughing

The above modelling suggests a flow cap of 50 m^3/s for the Mararoa diversion. However, at such flows the river is in its 15^{th} percentile flow range, which means that it is at a relatively 'high' flow. Flows significantly higher than 3 – 6 × the preceding week of low flow can potentially slough large quantities of periphyton mats from the bed rivers (Biggs and Close 1989). If such sloughing were to occur in the Mararoa River, while still diverting flows up to the 50 m^3/s cap for upstream transport of *D. geminata*, then there would be a greatly increased probability of movement of floatable mats into the Waiau Arm. This should be avoided.

Recent monitoring in the Waiau River has suggested that mats of *D. geminata* are more strongly attached and more robust than native periphyton communities in other NZ rivers and flows of 5 – 10 × the average flow of the preceding week are required for significant sloughing of *D. geminata* to occur (Kilroy et al. 2005). If we use a conservative approach using a magnitude of flow increase of 5 ×, and assume that the mean annual 7-day low flow of 8.4 m^3/s (as measured at the Cliffs water level recorder) represents the 'worst-case' low flow period then we calculate that, once the Mararoa exceeds 42 m^3/s, then enhanced sloughing of *D. geminata* could be expected. Since 'baseflow' will be much greater than 8.4 m^3/s for most of the year, a cap of 42 m^3/s in the Mararoa River at which all diversion should cease is conservative for protection of the Waiau Arm from transport of large masses of *D. geminata*.

The above Mararoa flow means that in summer, with a 16 m^3/s residual flow passed into the Waiau River as part of current consent conditions, the maximum flow that could be diverted into the Waiau Arm would be 26 m^3/s. In winter the residual flow in the Waiau has to be 12 m^3/s, so the maximum flow that could be diverted from the Mararoa would be 30 m^3/s. At such flow caps, our hydrodynamic modelling of *D. geminata* transport suggests that all suspended material (excluding floating mats) should settle within about the first half of Zone 1 of the Waiau Arm. This short settling distance at such flows, plus the large distance between the end of Zone 1 and the lake, gives a high 'margin of safety' for removal of suspended *D. geminata* before possibly reaching Lake Manapouri.

6. Discussion

The limitation of the hydrodynamic model is that it only takes into consideration sinking cells and fragments of *D. geminata*. However, *D. geminata* also forms thick mats consisting of cells, stalks and mucilage. Gas bubbles, produced as a by-product of photosynthesis become trapped in the mucilage sometimes resulting in positive buoyancy. These mats are then able to travel along the surface of the water until they are either broken up or forced below the surface and gas released before they begin to sink. These floating mats cannot be accommodated in this modelling and may not sink within Zone 1. We therefore recommend that alternative control mechanisms, such as a floating boom and sub-surface screening curtain, be considered to filter these mats from the flow.

The recommended flow cap for diversion from the Mararoa River was developed based on an assumed low flow of the Mean Annual 7-day Low Flow (MALF, which by definition only occurs on average one week out of 52) and a magnitude of flow change of 5 × MALF. Interestingly, diversion usually stops under the present operating rules when flows in the Mararoa exceed ~ 45 m^3/s because the silt/turbidity limit for Manapouri is breached (this limit is also set at a conservative level). This gives some degree of corroboration that the nominated flow for when *D. geminata* sloughing and transport is likely to be enhanced is mechanistically and empirically sensible. This is because similar velocities/tractive forces are required to suspended silts/sands as are required to slough periphyton mats of significant biomass (Francoeur and Biggs in press).

Another issue that needs to be considered is when flow diversion into the arm should be permitted to resume following a 'fresh' event. This flow is likely to be less than the flow when diversion ceases (42 m^3/s) because of residual, dislodged mats that will still be transported during the post-fresh/flood recession. To address this issue, we recommend that the river be monitored visually on a (perhaps) twice a day basis once flows drop to <42 m^3/s, and diversion only recommence once the flux of sloughed mats returns to a 'normal' level or less. An experienced, independent observer such as Bill Jarvie (Fish and Game) should be retained to make these observations.

A final issue that needs to be addressed is that our recommendations for settling distance are based on a mathematical model. This model should be tested with data collected from a detailed longitudinal survey of the bed of the Waiau Arm. This survey would quantify the extent of lateral, upstream, transport of *D. geminata* and should include more detailed underwater surveys of the beaches in Lake Manapouri on either side of the entrance of the Waiau Arm.

7. Summary recommendations

Based on modelling the settling rates of *D. geminata*, and flows in the Mararoa River that are predicted to initiate major mat sloughing, we recommend the following actions to Meridian Energy Ltd and Biosecurity New Zealand as part of management options to prevent the waterborne transport of *D. geminata* out of the Waiau Arm and into Lake Manapouri:

1. All diversion of Mararoa water into the Waiau Arm of Lake Manapouri should cease once flows in the Mararoa River at the Cliffs water level recorder station reach 42 m^3/s (**NB:** because of the need to release minimum flows in the Lower Waiau, this river flow limit would result in maximum flows into the Waiau arm of 26 m^3/s in summer and 30 m^3/s in winter which means that most suspended *D. geminata* should settle out in the first half of Zone 1 of the Arm. This short settling distance, plus the large distance from the end of Zone 1 to the lake, gives a high 'margin of safety' for protection of Lake Manapouri from the possible waterborne transport of *D. geminata* down the Waiau Arm).

2. Following a fresh/flood event, and associated sloughing of large quantities of *D. geminata*, diversion of Mararoa water back into Lake Manapouri should not resume until the river is clear of large floating/suspended mats of *D. geminata*. This should be determined by an independent observer who is very familiar with 'natural' suspended mat densities in the water column of the Mararoa River.

3. A detailed underwater survey should be carried out of the Waiau Arm to validate the hydrodynamic transport modelling and accurately delineate how far up the Waiau Arm *D. geminata* has been carried to date.

8. References

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