Waituna Science Advisory Group Maximum Lagoon Trigger Level

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Brief: To set a maximum level for managing the ecological health of the lagoon, noting that it can be opened at any level under that if the need arises e.g. to flush nutrients from the lagoon

Key questions to answer:

1. What is your maximum recommended level for the lagoon if we can open **and** close it?
2. What is your maximum recommended level for the lagoon if we can **only** open it?

Revised: 6 September 2017

Response from the Waituna Science Advisory Group (SAG):

The SAG recommends an interim increase in the trigger level to 2.5 m a.s.l. This recommendation is valid for both Q1 (able to open and close lagoon) and Q2 (only able to open lagoon) Our assessment is based on the current knowledge of the lagoon.

How the interim recommendations were derived

Initially, the SAG had a tight, time 10-day frame within which to provide these recommendations (Dec. 9 to 19 2016). SAG members Marc Schallenberg, Hugh Robertson, Nick Ward, David Burger and Nicki Atkinson contributed to discussions via a web-based platform, while Katrina Robertson supported our work. The recommendations stated above have been supported by the SAG members who contributed to the discussion on the web-platform.

Subsequently (April-September 2017), the SAG undertook further research and analysis to verify its earlier recommendation.

Data sources used:

The analyses used to support the recommendations were carried out using bathymetry, LIDAR elevations, water levels and opening durations supplied by Environment Southland. Water clarity data and information on *Ruppia* depth distributions were obtained from Schallenberg & Tyrrell (2006), Robertson & Funnell (2012), Schallenberg unpubl. data, Gerbeaux (1993) and Sutherland et al. (2014). Data on the response of *Ruppia* to lagoon opening events since 2008 was also assessed, based on the annual macrophyte monitoring that is undertaken by NIWA (e.g. Sutherland et al. 2016). In addition, the Environment Southland hydrological model for the lagoon (developed and run for us by Chris Jenkins) was hindcast to estimate the likely duration and frequency of historical 'high water events' if the lagoon trigger level had been set to 2.5 m, 2.7 m and 3.0 m during the spring/summer period. As we have been asked to provide an interim trigger level, there has been no accounting for long term sea level rise in our analysis.

Key values considered:

The SAG derived a list of key values of Waituna Lagoon to be considered when deriving a trigger (maximum) water level for the lake, including fish migration, *Ruppia* and submerged macrophyte community, fringing wetland emergent plant community, various habitats for threatened fish, bird and plant species, etc. While the analysis mainly focused on the health of the submerged and emergent plant communities with a view to maintaining and enhancing the ecological integrity of Waituna Lagoon, a number of other values were also quickly evaluated (refer Table A1). The SAG suggests that a fuller analysis of all key values (e.g., using multi-criteria decision analysis or similar) should be carried out in future with respect to developing a comprehensive hydrological management strategy and plan for Waituna Lagoon.

Lagoon water level effect on opening duration

The SAG was initially concerned that the lake level at opening could affect the opening duration and that, consequently, raising the trigger level might result in longer openings due to increased scouring of the gravel bar at the opening site. However, an analysis of the existing data showed no significant relationship between water level at opening and opening duration (Fig. 1). Therefore, it was assumed that raising the trigger level would not increase the risk of longer openings occurring. Thus, it was decided to focus the SAG's analysis on the potential direct impacts of raising the trigger level on submerged and emergent plant communities, and other values listed in Table A1.

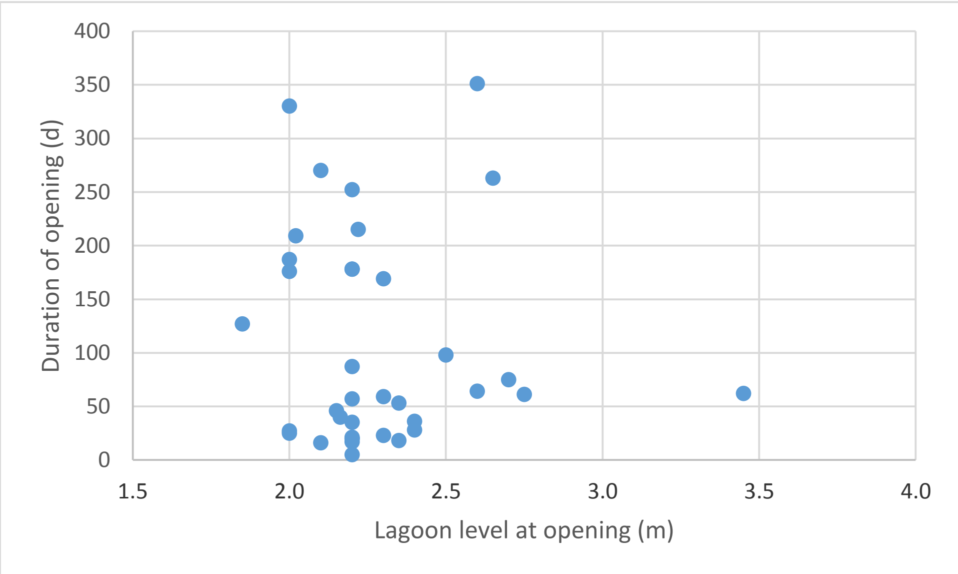

Figure 1. A biplot of water level at opening (measured at the Waghorn Rd. level gauge) and the duration of opening. Data from Environment Southland. Based on anecdotal evidence, it was expected that duration of opening would be positively correlated with lagoon level at opening. This was not supported by the data.

Relationship between water level and water clarity

In shallow lakes and lagoons, wind events increase wave energy and shear stresses at the sediment-water interface, resulting in wind-induced sediment resuspension, which reduces water clarity while the sediments remain in suspension (Hamilton & Mitchell 1996). Hypothetically, by raising the trigger level, the lake depth would episodically increase above its current maximum depth, reducing wind- and current-induced sediment resuspension at those times. By episodically reducing the shear stress on the lake bed, raising the level of the lake should to some extent increase the water clarity of the lake, however the hypothesised increase in clarity may or may not compensate for the effect of increasing water depth on the light climate experienced by macrophytes. To test whether higher lagoon levels increase water clarity, we compared Environment Southland's lake turbidity data from 2003 to 2015 at times when the lagoon was open (low water levels), filling (intermediate water levels) and full (high water levels). The data show no significant differences in turbidity (a rough indicator of water clarity) when the lake was in any of those states (Fig. 2). Thus, there appears to be no effect of water level on turbidity, indicating no effect on sediment resuspension. This result is probably due to samples having been collected on generally calm days (e.g., the maximum recorded turbidity in the dataset is only 27 ntu), which may not reflect the turbidity conditions during strong wind events. Nevertheless, the data indicate that any increase in turbidity due to wind-induced resuspension is probably short-lived in the lake, with resuspended sediment rapidly settling out of the water column when winds, turbulence and currents decrease.

Acknowledging that the lack of effect of lagoon level on turbidity in the ES dataset is probably due to sampling bias (avoiding sampling during wind events) and acknowledging that raising the lagoon level would reduce shear on the sediment water interface, we were prepared to accept an increase in water clarity on the order of 5% (annually) as a result raising the trigger level to around 2.5 m.

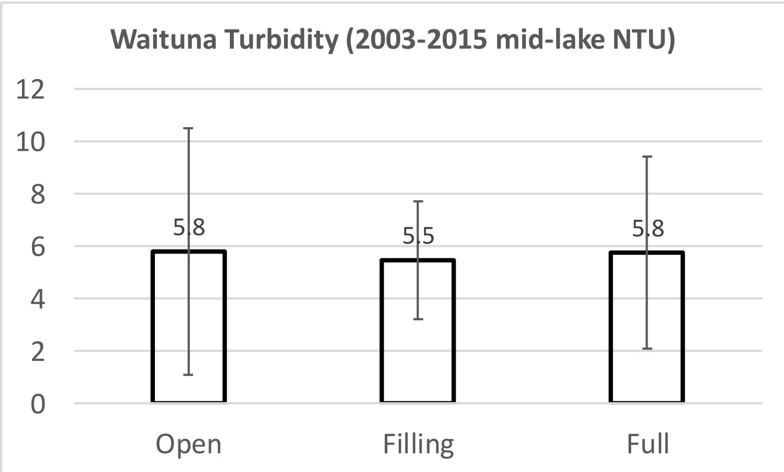

Figure 2. Comparison of average mid-lake turbidity measurements from 2003 to 2015 at times when the lake was open to the sea (low water levels), when it was filling (intermediate water levels), and when it was full (high water levels). Error bars = 1 standard deviation. There is no significant difference in turbidity that can be attributed to water levels during these three states. The numbers on the graph indicate the average turbidity values in each state. Data from Environment Southland.

Effects of trigger level at 2m

Up until February 2017, Waituna Lagoon operated under a resource consent with a maximum water level of 2.0 m.

Extensive monitoring of the aquatic macrophytes, water chemistry and water levels has occurred since 2008. A summary of information on lagoon ecology and the effect of spring-summer events on macrophyte abundance was described in the *Ecological Guidelines for Waituna Lagoon* (Waituna Lagoon Technical Group 2013) as well as recent monitoring reports by NIWA (e.g. Sutherland et al. 2016).

The graphic below (Fig 3) illustrates the relationship between the duration of opening events (days open) and the frequency of *Ruppia* occurrence at the monitoring sites (% of sites sampled where *Ruppia* was present). When the lagoon is open for prolonged periods the abundance of *Ruppia* and other macrophytes decreases, reducing the abundance of keystone species for maintaining lagoon health. It has been observed that low water levels instead enhance nuisance slime algae and can lead to marine sand intrusion.

The reduction in macrophyte abundance is due to a 30% loss in available habitat associated with lower water levels, competition with slime algae which prefer higher salinities, and suppressed growth and reproduction of *Ruppia* cause by high salinities. As such the Waituna Lagoon Technical Group guidelines for Waituna Lagoon recommended to minimise the risk of the lagoon being opened during spring and summer (Waituna Lagoon Technical Group 2013). This recommendation has been endorsed from the ongoing monitoring of aquatic plants (Sutherland et al. 2016), which concluded '*the ecological health objective target of > 30-60% macrophyte cover has been successfully achieved through the management of the lagoon openings, in particular, ensuring that the lagoon remained closed during the growing season*'.

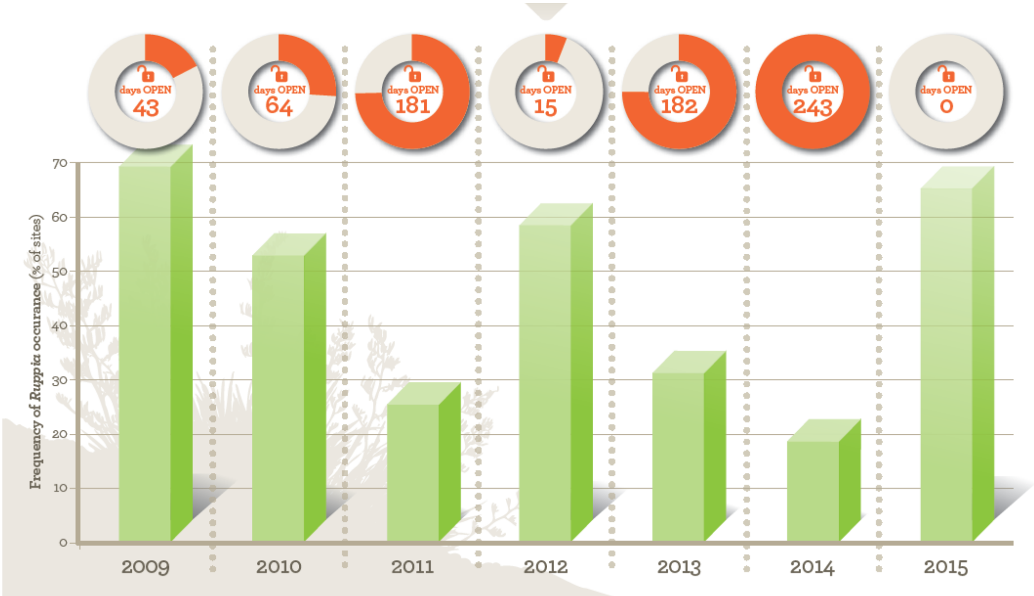

Figure 3. Percentage of *Ruppia* monitoring sites in which *Ruppia* occurred from 2009 to 2015. The numbers above the bars indicate the number of days per year that the lagoon was open to the sea, indicating that *Ruppia* occurrence at the sites declined markedly in years when the lagoon was open around half the time or more. Source: http://www.doc.govt.nz/Documents/conservation/land-and-freshwater/wetlands/arawai-kakariki-report-card-awarua-waituna-water.pdf

How raising the trigger level can provide a mechanism to reduce the frequency of spring-summer opening events

One mechanism to mitigate the risk associated with spring-summer opening events, is to increase the maximum water level when opening occurs. This would 'buy time' by allowing for water levels following storm/rainfall events to naturally recede via seepage through the gravel barrier bar and, therefore, preventing a spring-summer opening.

Figure 4 illustrates how a higher trigger level allowed for the lagoon to remain closed in the 2014-2015 summer, which subsequently led to macrophyte recovery. The duration of high water (>2m) was c. 12 days. In this instance, the lagoon did go above 2.2 m, but discussion between stakeholders led to the system remaining closed, and water naturally receding via seepage.

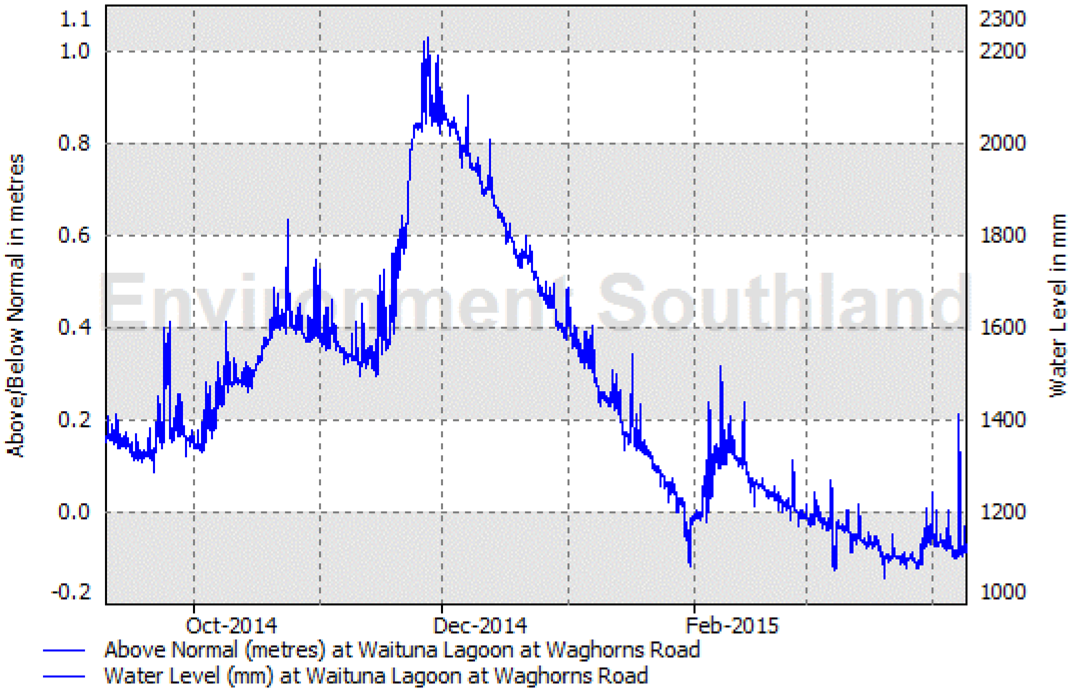

Figure 4. Waituna Lagoon water levels in spring and summer 2014/15, showing how lagoon levels receded via seepage when the lagoon wasn't opened at its trigger level of 2.0 m. Source: Environment Southland.

To explore the potential for the lagoon to resist opening at higher water levels, Environment Southland's Waituna Lagoon hydrological model (developed by Chris Jenkins) was used to hindcast the number and duration of water level events exceeding 2 m if higher trigger (2.5m, 2.7m, 3.0) levels had been applied (Table 1).

Table 1. Analysis of water level events exceeding 2.0 m, hindcast using Environment Southland's hydrological model. See Appendix 2 for model assumptions. Data from Chris Jenkins, Environment Southland.

	Annual average days above 2.0 m	**Annual average total events of 2.0 m**	**Average duration of events above 2.0 m (days)**	**Average number of spring openings per year**
Base Scenario Opened at 2.2 m	2.3	0.6	4.8	0.1
Scenario 1 Opened at 2.5 m	5.5	0.6	11.7	0.0
Scenario 2 Opened at 2.7 m	5.7	0.6	12.1	0.0
Scenario 3 Opened at 3.0 m	5.6	0.6	11.7	0.0

This analysis indicates, that as the maximum water level were increased to 2.5 m from the current trigger of 2.2 m, the total duration as well as the average event duration of events > 2.0 m would have roughly doubled, but the number of events wouldn't have increased. The average duration of these events (above 2.0m) was between 5 and 12 days. Crucially, however, raising the trigger level to 2.5 m would have avoided spring openings, with almost no further change in the behaviour of the system. Therefore, raising the trigger level to 2.5 m would increase the ability to keep the lagoon closed during spring/summer (when desired), helping to maintain *Ruppia* and other macrophytes during the key germination and growth period. Raising the trigger level above 2.5 m up to 3.0 m would not have resulted in any further benefit in this regard.

Effects of raising the trigger level on submerged plant habitat

A trade off from increasing the maximum trigger level, and having water levels >2.0m for longer than c. 10-day periods is an increase in light limitation, notwithstanding the potential for improved water clarity due to less resuspension of sediments during wind events (refer above).

To explore the effect of lagoon water level on the extent of the euphotic zone (the zone of lagoon bed that receives enough light for plants to grow), we developed a simple model based on the bathymetry of the lagoon and its marginal area (Environment Southland data), water level and trigger levels, and the relationship between light penetration and depth for Waituna Lagoon (Schallenberg et al. 2010; Sutherland et al. 2016). The water of Waituna Lagoon has a strong baseline level of light attenuation with depth due to high concentrations of humic acids and it has episodes of even greater light attenuation due to suspended sediments in inflowing water and those resuspended from the lake bed by wind and currents. Consequently, raising the lake level (increasing its depth) will change the area of the lake bed receiving enough light to allow *Ruppia* and other macrophytes to grow – the extent of submerged plant light habitat. The zone of plant growth in lakes is known as the littoral zone and is bounded by the upper elevation of the water level, above which submerged macrophytes cannot grow due to desiccation, and the lower level of light penetration, below which plants don't receive enough light to grow (also known as the euphotic depth). These boundaries are not strict because some macrophytes and/or their propagules can survive periods of desiccation and darkness and plants grow toward light and can thus to some degree overcome darkness at depth.

Based on repeated macrophyte surveys in Waituna Lagoon, Sutherland et al. (2016) estimated euphotic depth in Waituna Lagoon to be the depth to which 10% of surface light can penetrate (roughly 1.27 m depth). We added another 5% on to the euphotic depth to roughly account for an hypothesised increase in water clarity as a result of increasing the water level (refer above) to derive a euphotic depth for our plant habitat model of 1.34 m. However, the 2016 survey (Sutherland et al. 2016) did indicate that *Ruppia megacarpa* was growing at some deeper depths, for example at 1.70m water depth (site 1-1) and 1.55m (site 4-3). At these sites *R. megacarpa* had >90% cover abundance and the plant height was >1m. During the survey period (25-29 January 2016) the water level in Waituna Lagoon was also only ~1.2m above sea level (i.e. lagoon wasn't temporarily deep at time of survey). This suggests that the euphotic depth represented by the 10% light level does not apply strictly to plants that have established a high canopy height, but probably does apply to short plants and also to plant regeneration from propagules on the lagoon bed.

Our model supports previous studies which showed that at the current trigger level, light attenuation in Waituna Lagoon is sufficient to reduce light below the light threshold for plant growth in the deeper areas of the lake bed (Schallenberg & Tyrrell 2006; Sutherland et al. 2016; Fig. 5), highlighting a potential risk to submerged macrophytes from raising the trigger level of the lake.

Our analysis shows that while raising the lake level increases the inundation area of the lake, providing more potential habitat, it also increases the dark zone (the zone below the euphotic depth; Fig. 5). While the potential habitat increases in absolute terms, the percentage of the bed of the lagoon that receives light decreases as the trigger level (and lagoon level) increases (Fig. 6).

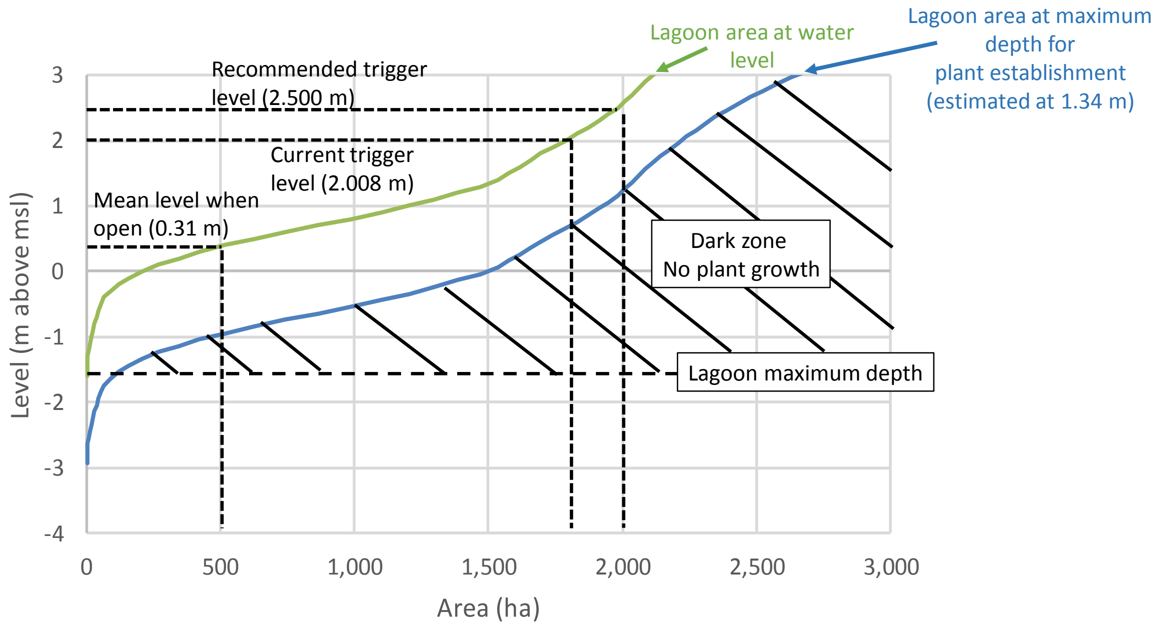

Figure 5. Change in plant habitat (growing area) with change in lagoon water level, showing the dark zone, which is deeper than the threshold for plant growth. The green line represents the lake water level and its corresponding area. The blue line represents the level of the lagoon bed at the threshold depth for plant growth, and its corresponding area. The mean lagoon level when open, the current and recommended trigger levels are also shown.

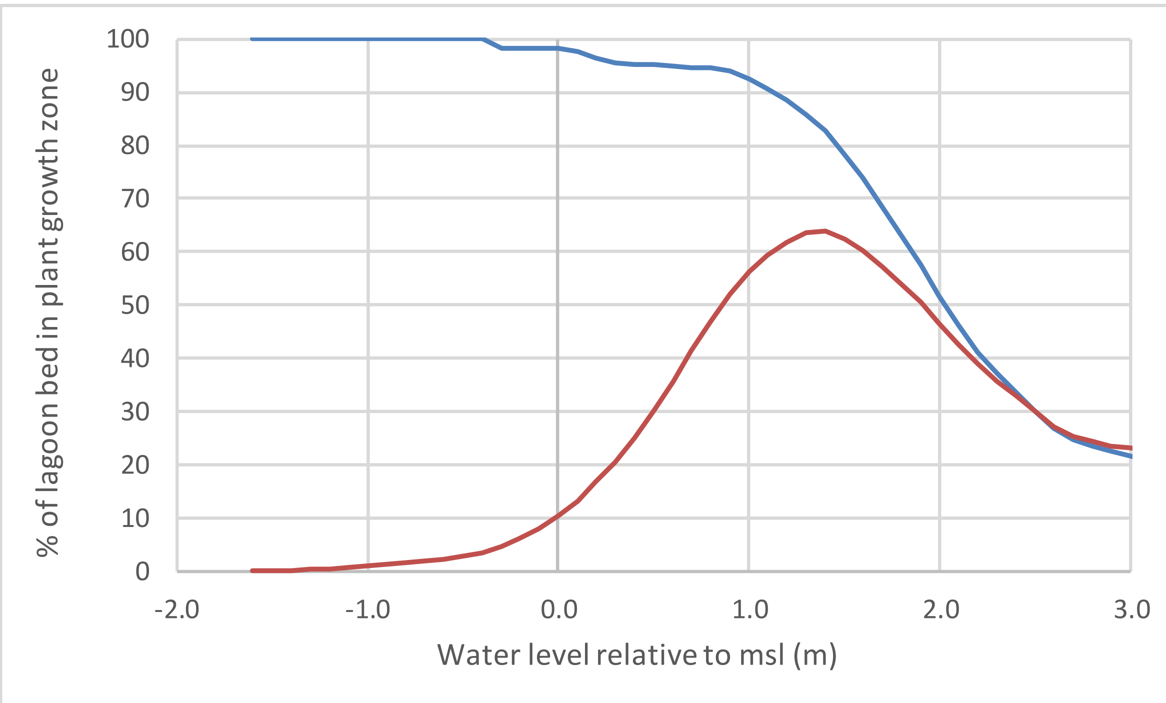

Figure 6. The change in the percentage of lagoon bed that is within the plant growth zone (see Fig. 5), as a function of water level. The blue line indicates the percentage of lagoon bed plant habitat at instantaneous water levels (indicated by the x-axis). The red line indicates the lagoon bed plant

habitat related to water level with habitat expressed as a percentage of a constant potential lagoon plant habitat area – in this example the area is the lagoon area at the trigger level of 2.5 m.

Our simple model of plant habitat (Fig. 6) shows that when the lagoon water level is equal to the current trigger level (2.008 m), around 50% of the wetted lake bed is within the euphotic zone and 50% is too dark to support plant germination or the growth of small plants (blue line). This percentage decreases to 30% of the lagoon bed as the water level increases to the recommended trigger value (2.50 m). This scenario would only reflect light conditions in the lagoon during rare excursions into the highest allowed water levels and would not reflect the annual average habitat availability. Nevertheless, Environment Southland's Waituna Lagoon Guidelines recommend maintaining a macrophyte coverage of 30-60% of the lagoon bed to safeguard the health of the lagoon. Therefore, the results of the model, although crude and subject to error, indicate that light limitation could impinge on lagoon health if the trigger level were to be set much above the recommended level of 2.5 m. The red line in Fig. 6 shows the percentage of the lagoon bed within the growth zone when the potential area for growth is equal to the lagoon area at a water level of 2.5 m. This shows that as the lagoon level declines below 2.5 m, potential macrophyte habitat is lost due to dewatering of progressively larger areas of the lagoon bed.

With our model (Fig 6), we have demonstrated the existence of trade-offs between the benefits to macrophytes of raising the trigger level and the degree to which plants in deeper parts of the lagoon may become light stressed as a result. The lagoon water level does appear to naturally sit at around 1.2-1.8m water depth (relative to sea level) when it is closed and so when the water level exceeds 2.0m, it is often only for relatively short periods (Fig. 7). Therefore, interpretations of the relationship between water level vs macrophyte cover in the lagoon that are based on our model should also account for the generally short duration of high water events, and the ability of tall plants to withstand a fluctuating light environment.

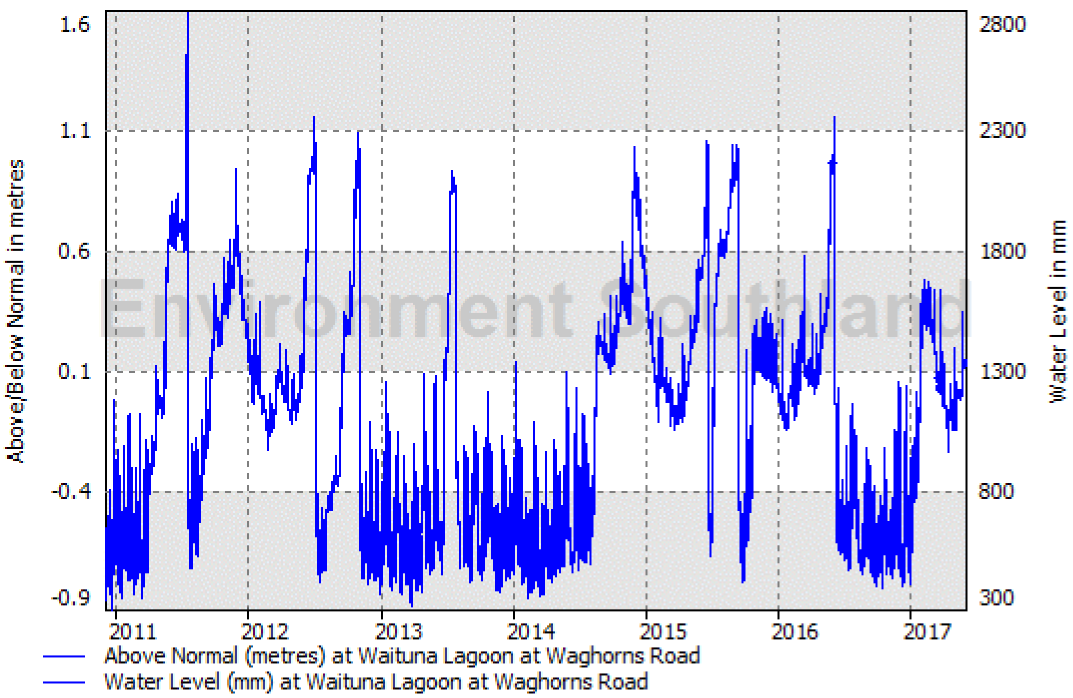

Figure 7. Water levels recorded at the mid-lagoon site from 2010 to 2017 showing the short duration of high water events (i.e. > 2.0 m), even when the lagoon wasn't opened (e.g., late 2011 and late 2014).

Effects of raising the trigger level on fringing wetlands

It is the SAG's view that the fringing wetland system would benefit from episodic inundation at levels >2.0m. For example, the inundation of low-lying rushland (Fig. 8) will promote the establishment of native wetland vegetation and promote habitat diversity. In support of this, a comparison of the vegetation changes between 1995 (Johnson/Partridge 1995) and 2012 (Wriggle 2012) shows that a number of species had shifted down-slope during this period (Bythell 2013). Both botanical ecologists Hugh Robertson and Brian Rance (DOC) concur with this finding and the utility of having a more flexible water regime, especially at higher water levels, to help rejuvenate valuable wetland ecology and reduce the abundance of non-native plant species. Consequently, the SAG recommends that increasing the trigger level to 2.5 m will provide for beneficial episodes of inundation and rejuvenation of valuable fringing wetland plant communities.

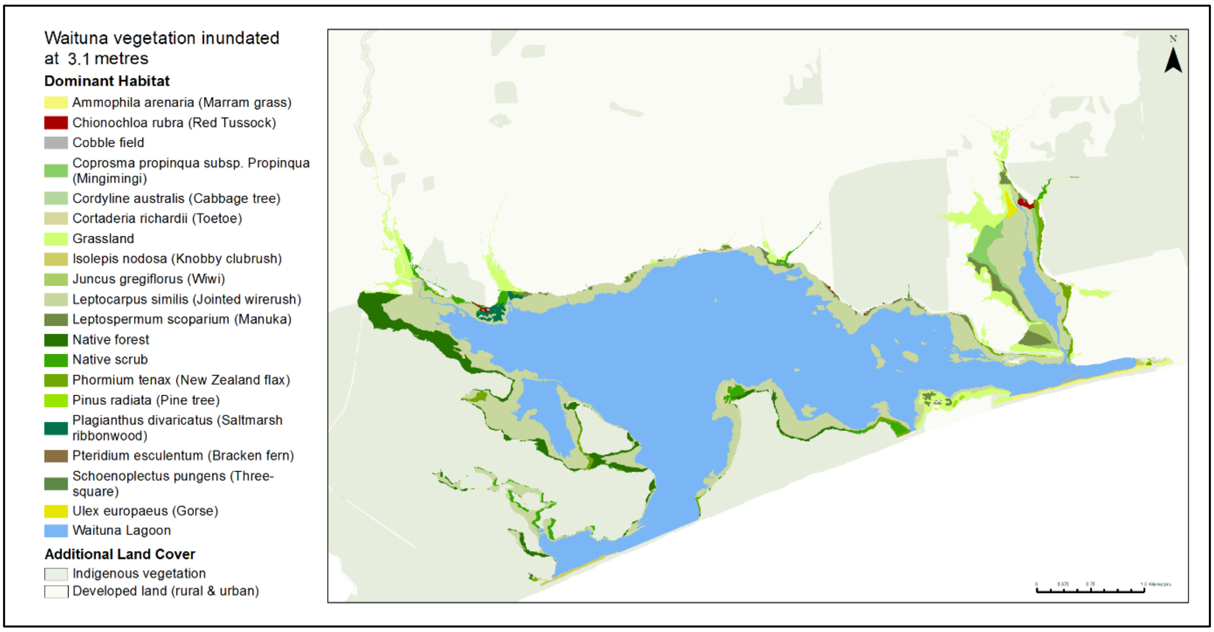

Figure 8. Fringing wetland habitats of Waituna Lagoon which would be flooded at a water level of 3.1 m a.s.l. Data are based on LIDAR surveys (Environment Southland) and a wetland vegetation survey (Wriggle 2012).

Summary

Summaries of trigger level considerations for Questions 1 and 2 were produced and these are shown in Table A1(Appendix 1).

The SAG concluded that raising the trigger level to 2.5 m was likely to benefit the submerged macrophyte community if the lagoon is not able to be closed. That is because in some seasons (spring-summer) prolonged opening events can have a detrimental effect of macrophyte growth and reproduction. A hydrological model used to hindcast hydrological inputs and outputs to the lagoon showed that raising the trigger level to 2.5 m would have avoided the occurrence of any spring-summer openings. Assumptions of the hydrological model are presented in Appendix 2. A simple macrophyte habitat model based on light penetration to the lagoon bed indicated that while the area of the lagoon bed receiving enough light for macrophyte growth would increase at higher lagoon levels, the proportion of the lake bed receiving adequate light would be reduced to 30% at the trigger level of 2.5 m. However, this effect would be minor because the periods of light increased limitation would be relatively short, and this stress could be mitigated with a comprehensive hydrological management plan.

The SAG also concluded that allowing the trigger level to rise to 2.5 m would benefit the fringing wetland plant community.

The models we used are simple models which illustrate some of the trade-offs and trends expected in relation to raising the trigger level. Some important knowledge gaps remain. Therefore, the SAGs recommendations (below) should be considered interim recommendations, and an adaptive management approach should be utilised when developing a long-term hydrological management plan for the lagoon, informed by good quality monitoring of the lagoons water quality, emergent and submerged plant communities, fish community and other important cultural and ecological values.

Recommendations

The SAG recommends raising the lagoon level trigger value to 2.5 m to avoid spring-summer openings, which can be detrimental to the ecology of the macrophytes and the health of the lagoon. This new trigger level will also improve the health of the fringing wetland plant community.

The SAG also notes, however, that regular opening of the lagoon during winter is still likely to be required as a strategy to mitigate water quality impacts. Opening events may also be required in the event of prolonged algal blooms.

Careful monitoring of the macrophytes, macroalgae, phytoplankton and the fringing wetland plant community should continue so that any unforeseen consequences of the increase in the trigger value can be considered in an adaptive management approach to managing the lagoon health.

A comprehensive long-term hydrological management plan is needed for the lagoon. This should account for the effects of hydrological (including openings) management on the following indicators of lagoon health:

- Water column nutrient concentrations
- Algal/cyanobacteria blooms
- Light limitation or other stressors on macrophytes, especially *Ruppia* spp.
- *Ruppia* life history and related requirements for completion of its life cycle
- Fringing wetland health
- Fish migration
- Water fowl and wading birds (feeding and breeding habitats)
- Cultural values
- Recreational values

This study highlighted some knowledge gaps with regard to understanding how water level management affects the health of the lagoon. We recommend research be carried out on how water level management impacts on:

- the health of the fringing wetland,

- nutrient cycling and, especially across the sediment-water interface,
- turbidity of the lagoon.

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Appendix 1: Values and considerations taken into account in recommending raising the trigger level to 2.50 m.

Table A1. Summary of trigger level considerations in relation to Question 1 and 2 – "Is there an ideal maximum ecological water level".

Aim	Maximum	Discussion	Information needed
Preventing spring/summer openings during 'years of concern' to enable macrophyte regeneration	2.5m	Summer openings stress macrophytes and favor macroalgae. Ruppia benefits from closure and low salinity during the germination stage (spring)	No
Allowing the timing of opening events to benefit fish spawning and migration where possible	na	Issue for fish include timing of events and the maximum water level.	Relevant fish spawning and migration information
Managing a fluctuating water regime to support fringing wetlands – e.g. Oioi, turf plants	2.5m	LiDAR elevation models indicate that most wetland vegetation will be inundated when lagoon levels are ~2.3m. Irregular inundation at higher levels is positive for these systems. Also refer to the Blythell (2013) shoreline monitoring report.	Effects of water level management on fringing wetland plant communities
Providing a mechanism for excessive nutrients to be flushed to the ocean	>1.8m	Flushing of nutrients can occur above 1.8m when there is sufficient hydraulic gradient. The higher the water level the better the flushing when opened.	No
Providing a mechanism to disrupt a prolonged algal bloom	>1.5m	Ecological guidelines suggested that if needed an opening could occur at 1.5m to disrupt a prolonged algal bloom. A minimum height is needed for an effective opening, not a maximum.	No
Ensuring maximum water levels do not cause negative effects on aquatic/wetland plants (e.g. light limitation)	2.0m	Light limitation is likely to have an impact on submerged vegetation in deeper parts of the lagoon. D_{10} may be in order or 1.0-1.5m. Prolonged inundation (>20 days per annum) at higher water levels (e.g. >2.3m) may limit productivity. But because the gravel barrier is leaky – such prolonged events may be unlikely. Unknown potential positive effect of raised level on turbidity and light penetration.	Effects of water level on sediment resuspension and effects on light penetration and sedimentation onto macrophytes.
Recommendation based on these values	**2.5m**	**Note: a comprehensive water level management regime (plan) will be required to ensure the water level is optimised in any given year/event**	

Appendix 2: Assumptions of hydrological model (from Chris Jenkins, Environment Southland)

1. 39 years of record from the Waihopai River used for calibration. [Caveat: In the high event in 1994 where the Lagoon got to 3.25 MSL (Current Gauge board; 3.45 old board), there was more rainfall in the Waituna catchment than the Waihopai. The lagoon got to a maximum of 2.959 using the Waihopai data.]

2. The instant opening value of 2 MSL applied to the model does not reflect reality. Many times the lagoon rises above this, so the modelled days above 2.1 etc may not reflect reality.

3. The models use random closing criteria, so re-running these gives slightly different values each time. As some of the scenarios are very similar (Opening from 2.5 to 3 metres) there is little difference in the results as the lagoon didn't get above 2.5 metres in these models, so the summaries are almost the same.

4. The Lagoon actually got up to 2.8 MSL in July 2011. This was not reflected in the modelled results. With the winter opening criteria of 2 metres, this event would have been opened six days before the peak, so this is why the model results show lower peaks than what has resulted from past management.

5. Given these assumptions there is still some uncertaintly in the model outputs and this should be taken into consideration when using the model to develop a water level management plan.