Memo

From	**Dr Piet Verburg and Dr Chris Hickey, NIWA**
To	Paul Radich, Perry Group
CC	
Date	11 October 2017
Subject	**Te Awa Lakes Plan Change**

Te Awa Lakes Plan Change – Water Quality Technical Review

Perry Group requested NIWA to prepare a response to the request for Water quality information for the Te Awa Lakes by Streamlined Environmental. Below is the detailed request in the Water Quality Review by Streamlined Environmental, followed by our response.

Water Quality Information Requested *(as requested through the Water Quality Review by Streamlined Environmental*)

1. Provide an assessment of the likely trophic state of the lakes following implementation of the Stormwater Management Plan and covering the various stages of the proposed development. This assessment should be undertaken by a suitably qualified and experienced professional and, be carried out using established empirical relationships predicting phytoplankton (as chlorophyll *a*) as a function of nitrogen and phosphorus concentrations, retention time, and light climate.

   As a minimum, the assessment should be based on the following data:

a. Nitrogen and phosphorus concentrations measured in samples from bores (or piezometers) intercepting groundwater flowing into the current ponds (future lakes). Ideally such samples should be seasonal (summer, autumn, winter, spring) but a one-off sample from a number of sites located within the catchment of the proposed lake during late spring should at least capture likely nutrient concentrations in the lakes at the start of the summer period, when growth of phytoplankton could be an issue. Analysis of groundwater should include dissolved reactive phosphorus, total dissolved phosphorus, nitrate-nitrogen and ammonium-nitrogen as well as total N and P. Note, samples from the existing ponds would not be suitable since dissolved reactive phosphorus especially could be expected to adsorb to the suspended sediment within the pond. This may not be the case with shallow groundwater feeding the lakes and flowing through sands.
b. An estimate of the bathymetry of the future main lake (length, breadth, depth) and expected volume.
c. An estimate of inflow and outflow rates during the period December - April. The estimate should take into account the proposed extended detention, and drawdown of the main lake in summer to maintain water levels in the adventure lakes.
d. An estimate of the partition between surface flow and groundwater flows once the SMP is implemented.
e. An estimate of the average concentration of SS, TP, and TN reaching the lakes from surface flows once the SMP is implemented (post treatment).

Reason
The plan change assumes Te Awa Lakes will provide high visual amenity and be swimmable. However, the plan change documents provide insufficient information regarding the likely trophic state of the lakes. High nutrient levels in the lakes, for example, could result in algal blooms, including blooms of toxic algae. Besides being unsightly, these blooms can deprive the water of oxygen, kill fish and aquatic birds, affect domestic animals and humans and render the lakes unsuitable for contact recreation. Such outcomes will result in failure of the Plan Change to achieve its objectives and could result in an on-going financial burden associated with cleaning-up the lakes. It needs to be demonstrated that the lakes will be maintained in an appropriate trophic state throughout the year.

2. Provide data on *E coli* in samples of surface and groundwater entering the existing ponds.

Reason
To identify any faecal contamination in surface and groundwater water sources within the catchment of the lakes, and help confirm whether or not the lakes will be suitable for contact recreation.

Response:

Background to the assessment

A concept schematic for stormwater management for the site is shown in Appendix 1 (from CKL 2017). The majority of the water entering the two lakes will be derived from rainfall and the stormwater drainage network. The inflows to the “Adventure lake” within the Adventure Park will be solely sourced from capture of rainfall from roofs in sub-catchment 4 – so will have minimal nutrient inputs and negligible opportunity for faecal contaminants. Therefore we have not provided any further assessments relating to this lake.

The other “Recreational lake” receives stormwater flows from sub-catchments 1, 2 and 3 (areas 19.7 ha, 14.2 ha, 7.4 ha, respectively; totalling 41.3 ha. CKL (2017) Appendix 1). An assessment of water quality from these catchments provides the basis for this assessment. Stormwater flows from each of these catchments are routed through treatment wetlands (Northern and Southern, and the Eastern Detention Basin, Appendix 1), which provide the potential for treatment in addition to various other design option implemented in the catchments.

The stormwater flows from sub-catchment 6 do not flow to either of the lakes but will be routed to the Waikato River through a consented, but not operational, discharge at the north of the site.

There is potential for some groundwater flows to enter the Recreational lake or to be used as make-up water for maintaining Adventure or Recreational lake volumes. For this reason, we have included an assessment of average groundwater quality for use as inflow water to the lakes.

General comments: Nutrients

We consider that total phosphorus and total nitrogen are the most important water quality variables measured in lake monitoring. We note that Streamlined Environmental in their Water Quality Review of the Te Awa Plan Change suggest (on page 4) that "the nitrogen and phosphorus in lakes relating to excessive phytoplankton is measured in terms of the dissolved inorganic fractions (e.g. dissolved reactive phosphorus, nitrate, ammonia). Therefore, the central question that hasn't been addressed, is "What are the dissolved inorganic phosphorus and nitrogen concentrations in the lakes likely to be?"". We do not agree. Total nutrients, not dissolved nutrients, are used to calculate the Trophic Lake Index (TLI), in State of the Environment reporting of lake monitoring by councils and MfE. Lastly, concentrations of total nutrients, usually total phosphorus, are used to predict annual mean and annual maximum phytoplankton biomass, where photosynthetic pigment chlorophyll *a* is used as a proxy for phytoplankton biomass. In the same paragraph, the Streamlined review continues by discussing the national bottom lines for concentrations for phosphorus and nitrogen in lakes given in the National Policy Statement for Freshwater Management 2014 (NPS). However, the national bottom lines for concentrations for phosphorus and nitrogen are those of total nutrients, not dissolved concentrations. The latter are often a minor component of total nutrient concentrations in lakes. In this assessment we concentrate on total phosphorus and total nitrogen.

To estimate the average trophic state of the Te Awa lakes with commonly used empirical relationships (OECD 1982; Verburg et al. 2017), a number of data are required: Total nutrient inputs, annual mean lake inflow from the catchment and lake outflow rate, lake surface area and lake volume. Nutrient inputs can be derived from expected concentrations in the inflow, times the total inflow rate. The goal is to estimate future phytoplankton concentrations, ideally both annual means and annual maxima. Phytoplankton concentrations are usually driven by availability of phosphorus, not by nitrogen. However, phytoplankton concentrations can also be estimated using empirical relationships with nitrogen concentrations in the inflows.

Concentrations of nutrients and *E. coli* in groundwater

The Streamlined review calls for information of nutrient concentrations in groundwater, suggesting that from these concentrations expected phytoplankton concentrations in the lake can be derived. Information of nutrient concentrations in groundwater on the site are in Table 1, and we consider them in this assessment. However, the Recreational lake is expected to be lined or lined in part. The lake will be principally fed by surface flow from its catchment, although there is potential for some groundwater inflow we have not considered that in our estimates of water quality.

Table 1. Summary of results of measurements of nutrient concentrations in four boreholes on 14 September 2017, and *E. coli* counts from eight sites, including the four boreholes, on the same date. For the calculation of averages, samples below detection are assumed to have a concentration half the detection limit. Analysis carried out by Hill laboratories. (CKL 2017).

Sample type	unit	Average	Standard deviation
Dissolved Phosphorus (DP)	g/m^3	0.03	0.02
Total Nitrogen (TN)	g/m^3	3.08	3.77
Total Ammoniacal-N (NH_4-N)	g/m^3	0.34	0.53
Nitrite-N (NO_2-N)	g/m^3	0.03	0.03
Nitrate-N + Nitrite-N (NNN)	g/m^3	0.12	0.14
Total Kjeldahl Nitrogen (TKN)	g/m^3	2.97	3.80
Dissolved Reactive Phosphorus (DRP)	g/m^3	0.02	0.01
N dissolved organic % of TN	%	55	43
Escherichia coli	MPN / 100mL	47.50	59.51

Data of total phosphorus from boreholes were not available[1]. We suggest that total phosphorus should be measured, and with appropriate methods that allow low detection limits (≤0.01 g m^{-3}; 0.001 g m^{-3} is achievable). Dissolved phosphorus was below detection in 3 out of 4 samples. However, the detection limit was high (ranging from 0.02 to 0.10 g m^{-3}). The variation was large for each of the sample types, with the standard deviation exceeding the averages for most variables (Table 1). *E. coli* counts ranged from 2 to 159 per 100 ml. If we can assume particulate phosphorus to be negligible, and therefore that dissolved phosphorus is close to total phosphorus, it appears that the TN:TP ratio in groundwater is likely to be high, ranging from about 20 to 200, and an average possibly >100 (the ratio of the averages of TN and dissolved P in Table 1 is 123). This is high compared with TN:TP ratios in lakes monitored by Councils, the average and median TN:TP ratios are around 25, ranging from 4 to about 150 (Verburg et al. 2010). Nitrogen in groundwater on the site appears to have a large organic component (calculated as TKN – NH_4 – NO_3 – NO_2), ranging from 4 to 96 % of TN (average 55%). The average concentration of nitrite was one quarter of that of nitrate, but nitrite was higher than nitrate in 3 of the 4 samples.

Hydrology

The Recreational lake volume is derived from the expected lake surface area of 4.26 ha (communicated by Bronwyn Rhynd, CKL), and a suggested mean depth of 3 m. The volume would be 127743 m^3. Expected annual inflow and outflow rates are given in Table 2.

The average given stormwater inflow to wetlands and Recreational lake is 847 m^3 day^{-1} (Table 2) and the expected Recreational lake outflow 705 m^3 day^{-1}. Thus, the Recreational lake residence time would be 181 days. This number was used in the estimation of trophic state of the lake.

[1] Analysis of total phosphorus has been requested from Hill Laboratories.

Table 2. Flows to and from the lakes on an annual basis (communicated by Bronwyn Rhynd, CKL).

Month	Annual
Daily Average Inflow to Lake (m^3)	847
Mean Daily Average Outflow from Lake (m^3)	705
Min Daily Average Outflow from Lake (m^3)	682
Weekly Average Inflow to Lake (m^3)	5932
Mean Weekly Average Outflow from Lake (m^3)	4935
Min Weekly Average Outflow from Lake (m^3)	4776

Inputs of nutrients to the Recreational lake

The estimates of nutrient inputs to the lake are based on our projection of what we think nutrient runoff will be, based on the catchment size and on our work in on Hamilton City stormwater. The specific yield data from Hickey et al. (2001) for Flagstaff was utilised for the catchment area of 41.3 ha (CKL 2017). Surface flows will be directed through a wetland which will attenuate the nutrient loads in the surface flows into each lake. The efficiency needed for the nutrient removal by the wetland is found by back-calculation from target concentrations in the lakes. The target concentrations of nutrients and chlorophyll *a* are based on the boundaries between National Objective Framework attribute states A, B and C (Table 3), listed in the National Policy Statement for Freshwater Management 2014 (NPS). The NPS provides annual median and maximum limits for various attributes for lake ecosystem health.

Nutrient concentrations in surface water which will flow into the lake are unknown. Therefore, the concentrations must be estimated from information gained elsewhere. Three sub-catchments drain to the main lake (sub-catchments 1, 2 and 3, Appendix 1; pers. comm. Bronwyn Rhynd, CKL). Total area of the catchment of the main lake is 41.3 ha (CKL 2017). Specific yield data of sediment, nutrients and *E. coli* were derived from Hickey et al. (2001), based on data for the Flagstaff catchment. The Flagstaff catchment at the time of the study was described as: "*a newly-developed residential area with low imperviousness and traffic density, modern infrastructure but likely higher proportion of bare ground than would be seen in a mature residential catchment*." It would be similar to Te Awa Lakes. The hydraulic specific yield for this catchment was 0.36, which is not incorporated into our calculations of the concentrations of sediment, nutrients and *E. coli* in the inflow to the Recreational lake. Instead the expected average inflow rate (Table 2) was used to calculate the loads in the inflow to the main lake. The expected amounts of sediment, nutrients and *E. coli*, and their concentrations in the inflow to the main lake, are given in Table 3.

Table 3. Estimated loads and concentrations of sediment, nutrients and *E. coli*, for the inflow to the Recreational lake.

	Specific catchment yield	Catchment yield	Annual average inflow concentration		
	(kg ha^{-1} yr^{-1})	(kg yr^{-1})	(kg m^{-3})	(g m^{-3} = ppm)	(mg m^{-3} = ppb)
SS	360	14869	0.0481	48.1	
TP	0.79	32.6	0.0001	0.11	106
TN	3.2	132.2	0.0004	0.43	427
	(cfu ha^{-1} yr^{-1})	(cfu yr^{-1})	(cfu m^{-3})	(cfu 100 mL^{-1})	
E. coli	5.71E+10	2.36E+12	7628116	763	

Modelling of nutrient concentrations and phytoplankton biomass in the lake

The inflow will be led through a wetland to attenuate the nutrient load, before it enters the main lake. Because the size of the wetland and its efficiency in removing nutrients are unknown, it is not possible to estimate directly the final loads entering the lake, and the concentrations of nutrients and algal biomass in the lake. Instead, we estimate the proportion of the nutrient load that the wetland must remove, in order to achieve concentrations of nutrients and chlorophyll *a* in the lake to fit within the boundaries between the NPS National Objective Framework attribute states A, B and C (Table 4).

In the empirical relationships (OECD 1982; Verburg et al. 2017) used to estimate the concentrations of nutrients and phytoplankton in the lake, the nutrient concentrations are reduced relative to those in the inflow as a function of residence time (the ratio of volume : outflow). With longer residence times nutrients are increasingly attenuated, either by sequestration in the sediment or, in the case of nitrogen, by denitrification and loss to the atmosphere. We do not agree with the statement by Streamlined Environmental in their Water Quality Review that increased retention time must result in increased phytoplankton biomass (OECD 1982; Verburg et al. 2017). However, if sedimentation does not occur as predicted by conventional modelling, then increasing the flow through the lake and thereby reducing the residence time may improve water quality and reduce phytoplankton biomass. This may be the case when the sediments on the lake bottom are saturated with organic matter and bottom water is low in dissolved oxygen concentrations as a result of decomposition and oxygen consumption.

Table 4. National Objective Framework attribute states A, B and C and the national bottom line for chlorophyll *a*, TP and TN, from the National Policy Statement for Freshwater Management 2014 (NPS). The boundaries of the attribute states for nitrogen are those for polymictic lakes, in view of the planned shallowness of the lake. Units are mg m^{-3}.

Attribute states	Chlorophyll *a*	TP	TN
	Annual median	Annual median	Annual median
A	≤2	≤10	≤300
B	>2 and ≤5	>10 and ≤20	>300 and ≤500
C	>5 and ≤12	>20 and ≤50	>500 and ≤800
National Bottom Line	12	50	800
	Annual maximum		
A	≤10		
B	>10 and ≤25		
C	>25 and ≤60		
National Bottom Line	60		

Our estimation of concentrations of nutrients and phytoplankton in the lake does not take into account the potential for internal loading from the sediment to occur, an effect which cannot realistically be predicted and modelled. Internal loading from the sediment can occur when dissolved oxygen concentrations become low in the bottom water, resulting in a flux of dissolved phosphorus from the sediment to the water column, and raising the average concentration of phosphorus (Verburg et al. 2017). If this occurs, there are options available such as aeration and dosing with alum.

Light climate is taken into account in the empirical equations.

Predicted nutrient concentrations and phytoplankton biomass in the lake

The results of the modelling of concentrations of nutrients and phytoplankton in the lake are in Table 5.

Table 5. Estimated annual mean nutrient concentrations in the inflow, predicted annual mean concentrations of nutrients and chlorophyll *a* in the lake (mg m^{-3}), and the Trophic Lake Index (TLI; Verburg et al. 2010), with and without attenuation of nutrient loads by constructed wetlands. The predicted annual maximum chlorophyll *a* in the lake is shown as well.

	Nutrient load reduction (%)		
	0%	64%	87%
Inflow TP	105	38	14
Inflow TN	427	154	56
TP	46	20	9
TN	397	179	81
Chlorophyll *a*	9.6	4.3	1.9
Maximum chlorophyll *a*	29.1	11.7	4.7
TLI	4.7	3.7	2.7

The annual mean phosphorus concentration in the lake is expected to be reduced by more than half compared with the inflow, as a result of sedimentation. The annual mean nitrogen concentration in the lake is expected to be reduced by less than 10%, by sedimentation and by denitrification. **Without attenuation within a wetland of the phosphorus and nitrogen loads into the lake, the concentrations of nutrients and chlorophyll *a* are expected to be better than the National Bottom Line.** However, the predicted concentration of TP is close to the National Bottom Line.

Without attenuation within a wetland of the phosphorus and nitrogen loads into the lake the TLI is expected to be 4.7 (with chlorophyll *a* as predicted from the TP loads), suggesting the lake will be **eutrophic**, with chance of occasional algal blooms. Because of the relatively low concentration of nitrogen and low TN:TP ratio in the inflow (TN : TP = 4, Table 3) the concentration of TP is what determines how well the lake scores overall on the scale of attribute states. **Without attenuation of the phosphorus load, the lake will fall into TP attribute state C.** A >64% reduction in TP inputs is needed to change the expected TP attribute band from C to B, and an >85% reduction in TP inputs is needed to change the expected TP attribute band to A. **Without attenuation of the nitrogen load, the lake will fall into TN attribute state B.** A >31% reduction is needed in TN inputs to change the expected TN attribute band from B to A. **Without attenuation of the phosphorus load, as a result of the chlorophyll *a* concentration predicted from TP the lake will fall into chlorophyll attribute state C**. A >57% reduction is needed in TP inputs to change the expected chlorophyll attribute band from C to B, and an >87% reduction is needed in TP inputs to change the expected chlorophyll attribute band to A. The results for the annual maximum chlorophyll *a* concentration predicted from TP are different. A >16% reduction is needed in TP inputs to change the expected annual maximum chlorophyll attribute band from C to B, and a >70% reduction is needed in TP inputs to change the expected annual maximum chlorophyll attribute band to A.

Therefore, overall, a >64% reduction is needed in nutrient inputs to change the expected attribute band from C to B, and a >87% reduction is needed in nutrient inputs to change the expected attribute band to A. However, if ground water will flow into the lake, its high TN:TP ratio (>100) will result in a relatively greater effect of nitrogen, compared with phosphorus, on which attribute band the lake will fall into.

If both the TP and TN loads are reduced by 64%, the expected TLI (based on transformed values of TN, TP and chlorophyll *a* concentrations) will be 3.67 (Table 5), suggesting the lake will be mesotrophic. If both the TP and TN loads are reduced by 87%, the expected TLI will be 2.67, suggesting the lake will be oligotrophic, in general a desirable state for lakes. If there is no difference in the reductions in TP and TN concentrations during its passage through the wetland, the expected TN:TP ratio in the lake will be 9. The TN:TP ratio in the lake will be enhanced compared with TN:TP = 4 in the inflow to the wetland and in the flow that exits the wetland, as a result of greater attenuation of phosphorus expected within the lake, compared with nitrogen. Naturally, if the attenuation within the wetland differs between phosphorus and nitrogen, as is likely, the expected TN:TP ratio in the lake will be different as well.

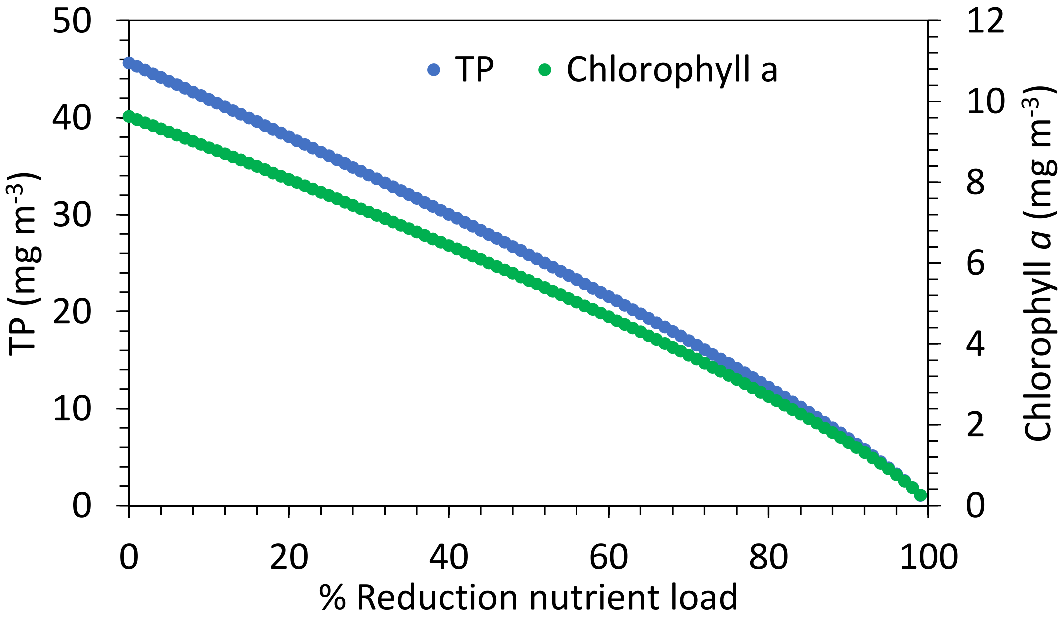

Figure 1. Reductions in expected concentrations of TP and chlorophyll *a* in the lake, as a result of the % reduction of the nutrient load entering the lake.

A reduction in the nutrient load of 64% results in reductions of the concentrations of nutrients and chlorophyll *a* in the lake of about 55%. A reduction in the nutrient load of 87% results in reductions of the concentrations of nutrients and chlorophyll *a* in the lake of about 80% (Table 5; Fig. 1).

A 50% increase in the lake volume, either by increasing the lake surface area, its depth, or by a combination of both, would result in a residence time of 272 days, and slightly smaller nutrient input reductions by the wetland would be needed to bring down phosphorus and chlorophyll *a* concentrations sufficiently to change the expected attribute band from C to B (>61%), or to change the expected attribute band to A (>86%).

It is unknown to us at this point to what extent summer drawdown of the main lake would occur to maintain water levels in the Adventure lake (1c of request for information), and this was not taken into account. In addition, the empirical equations available in the literature do not apply well to predictions on seasonal time scales. The predicted concentrations are annual means and annual maxima. We would recommend that the use of treated groundwaters (filtered and UV-sterilised) should be considered for use as top-up water for the Adventure lake, rather than the transfer of water held in the Recreational lake. This recommendation is largely based on the likelihood that faecal microorganisms are likely to be higher in the Recreational lake. We note that the groundwater nutrient sampling occurred only once (n = 4, Table 1) and additional sampling in different seasons may produce different results.

The predicted concentrations of nutrients and algal biomass in the Recreational lake without substantial nutrient reduction in a constructed wetland suggest that the lake is likely to experience algal blooms. Toxic cyanobacterial blooms may occur in view of the low TN : TP ratio (9) in the lake, which is a result of the low TN : TP ratio (4) estimated in the surface flow from the lake catchment. If the wetland removes proportionally more nitrogen than phosphorus this situation may be exacerbated. However, the way to approach the management of the lakes and protection of their trophic state most likely to succeed, is through ongoing monitoring and undertaking rapid mitigation actions if the lake deteriorates. There are several techniques available to ensure appropriate and satisfactory trophic lake conditions, even when ongoing nutrient inputs are so high that without management the lakes would be highly eutrophic and noxious algal blooms likely to occur. Included in the tool box are the addition of alum to reduce availability of phosphorus by locking it in the sediment, and polyacrylamide applications to settle sediment and reduce turbidity. Construction of wetlands of sufficient size and appropriate design will also help to attenuate nutrient inputs, in particular nitrogen.

The Recreational lake is in an area with a history of agricultural land use (orchard and pasture) and fertilizer applications for many years will have contributed to a legacy load of nutrients in the soil and groundwater. Therefore, it is to be expected that a new lake in this area may have to overcome eutrophication issues. Other lakes nearby, north of Hamilton (lakes Waikare, Whangape, Waahi), are shallow lakes that are near the top of the most eutrophic lakes in the country. Te Awa Lakes will be a great opportunity to show that with the right management, lakes in this region can have a healthy ecosystem, with a water quality maintained to a standard where they are acceptable for contact recreation. It may boost the political will to improve the existing lakes in the region as well. However, because of the smaller lake areas, healthy lake ecosystems and water quality conditions acceptable for contact recreation will be much easier to achieve in the Te Awa lakes.

Suspended sediment

The existing lakes on the site are highly turbid because of sand-mining activities on the site. As such, their current water quality does not provide a useful indication of future lake water quality.

We have used the specific yield coefficient for the stormwater run-off from the Flagstaff catchment to provide an annual suspended sediment (SS) concentration estimate of 48 g/m^3 for the Te Awa catchments (Table 3).

Water quality guidelines for clarity are 1.6 m measured with a black disk (MfE 1994), which provides the basis for estimating the level of treatment efficacy required for SS removal. Relationships between water clarity, turbidity and SS are available for New Zealand rivers (Davies-Colley and Close 1990) and for rivers affected by placer mining disturbance (Davies-Colley et al. 1992). We consider that the latter provides a suitable basis for estimating clarity effects from stormwater run-off. We have used a 1.6 m visual clarity as the basis of this indicative analysis.

A SS concentration of 48 g/m^3 corresponds to a visual clarity of about 0.18 m (see Appendix 2). Assuming a target clarity of 1.6 m, this relates to a 2 g/m^3 SS concentration (Appendix 2), indicating a 96% reduction in SS is required.

We consider that this analysis of SS reduction requirement is likely to be conservative since it is based on fine colloidal clays that generated the clarity reductions used for this assessment.

A high efficiency of treatment for SS removal will also be required for maximum concentration during storm events, as maximum concentrations may adversely affect lake clarity. The Flagstaff catchment study found that the maximum SS concentration was 2.4x higher than the event median concentrations.

Faecal microorganisms

Management of faecal microorganisms for human health risks in freshwaters is based on *E. coli* measurements. The MoH standards for bathing waters normally provide the basis for managing recreational waters for swimming. Recently, MfE has produced standards for swimming targets as part of the NOF framework for freshwaters in the NPS. These NOF standards are intended for long-term monitoring (5 year averaging) of freshwaters.

We have used the Flagstaff catchment data to calculate an annual average flow concentration of 763 cfu *E. coli* 100 mL^{-1} for the Te Awa catchments (Table 3). The MfE standards for "Human health for recreation" have median concentration of ≤130 cfu *E. coli* 100 mL^{-1} for all lake attribute states (Appendix 3). This indicates that an average treatment efficiency of 83% reduction in *E. coli* will be required for the Recreational lake.

Lakes of different attribute state are classified based on the 95^{th} percentile of the *E. coli* 100 mL^{-1} (Appendix 3). No information is available to estimate the 95^{th} percentile *E. coli* concentration in the Te Awa catchments, however, the maximum *E. coli* measured in the Flagstaff study was 5.4x greater than the median. Based on that factor a 75% reduction in *E. coli* would be required at all times in order to achieve a B grade lake, which is suitable for contact recreation.

Discussion of treatment options

Design depth for the Recreational lake. It must be kept in mind that if the lakes are shallow, in the order of 3 m, then weed beds are more likely to develop. These will create a potential nuisance in recreational lakes and increase the likelihood of exotic invasive macrophyte problems which are common in the Waikato Region. A depth of at least 10 m would be required to minimize submerged macrophyte growths. In addition, lake shore slopes should not be too steep, which would enhance erosion.

Nutrient removal. Additional treatment options are available to remove phosphorus from the stormwater inflows or for whole lake treatments. The whole lake chemical treatments using alum or Aqual-P™ (an aluminised zeolite) are usually undertaken if high rates of internal release of phosphorus is occurring from sediments during periods of summer deoxygenation periods as a positive feedback effect of eutrophication (Hickey and Gibbs 2009; Gibbs and Hickey 2012). Whole lake treatments for phosphorus management to limit cyanobacterial blooms has been successfully undertaken on Lake Okaro (Gibbs and Hickey 2017). Aeration of the lake during summer can also prevent phosphorus release from sediments. Continuous dosing of alum to high-phosphorus streams discharging to Lake Rotorua has reduced phosphorus loads and contributed to improved water clarity in the lake in recent years (Gibbs et al. 2016; Gibbs and Hickey 2017). Continuous alum dosing is used internationally to reduce phosphorus loads to lakes in order to prevent algal blooms.

Sediment removal. Effective sediment removal from stormwater is required to maintain high clarity lake waters suitable for recreational use. Treatment of the existing lake waters present on the site would also be likely to be required to reduce SS concentrations. Maintenance of water quality in the Recreational lake will also require minimising internal sediment sources from bank erosion and wind-driven resuspension of bed sediments.

A range of approaches may be used to remove sediments from waters. These include treatment with alum and polyaluminium chloride (PAC) as commonly used for reducing sediment run-off from road construction. More recently, cationic and anionic polyacrylamides have also been used for SS management in freshwaters. The high efficacy of polyacrylamides to achieve very low SS concentrations, together with the low toxicity of some formulations, makes them attractive for potential use in SS management in turbid freshwater environments (Gibbs and Hickey 2017). However, to our knowledge polyacrylamides have yet to be used for SS management in New Zealand lakes.

Conclusions

Predictions of treatment efficiencies for nutrients, suspended solids and faecal indicator bacteria (*E. coli*) were undertaken for the proposed Te Awa lakes.

The "Adventure lake" receives all its water from roof supply so was not included in this assessment.

The predicted water quality for the "Recreational lake" was based on stormwater flows derived from three sub-catchments and water quality estimated from contaminant yields measured for a Hamilton catchment (Flagstaff) and adjusted to the catchment area for the Recreational lake. These data were used to estimate the future lake water quality and the requirements for stormwater run-off treatment in addition to those operating in the Flagstaff catchment (runoff coefficient 0.36).

The future Recreational lake based on an average depth of 3 m would be predicted to be eutrophic without additional catchment treatment for nutrients.

The required level of water quality treatments to achieve different attribute states prescribed by MfE (2014) were:

Nutrients

Reduction of **total phosphorus**: Attribute State A, >85%; **B, >64%.**

Reduction of total nitrogen: Attribute State A, >31%.

Reduction of chlorophyll *a* concentration as predicted from **TP**: Attribute State **A, >87%;** B, >57%.

Suspended sediments

The minimum clarity standard for bathing is 1.6 m (black disk) clarity. An average of **94% reduction in SS** is required to achieve an average clarity of 1.6 m in the Recreational lake.

Faecal microorganisms

An **average** treatment efficiency of **83% reduction in *E. coli*** will be required for the Recreational lake. An estimated **75% reduction in *E. coli*** would be required at all times in order to achieve a **B grade** lake.

All treatment assumptions are based on stormwater inputs from the designated sub-catchments with no inflows from groundwater.

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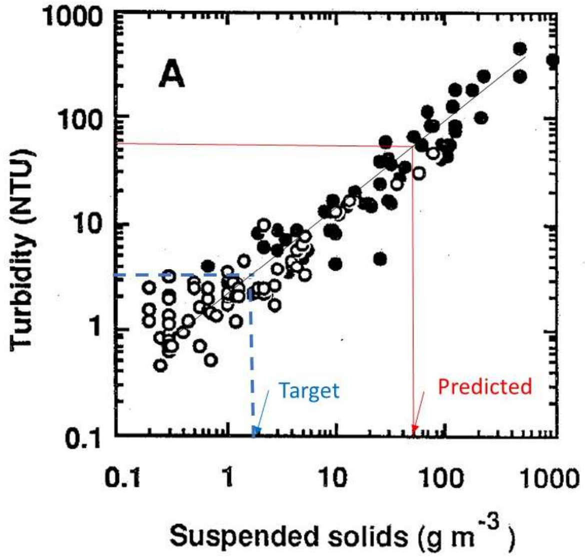
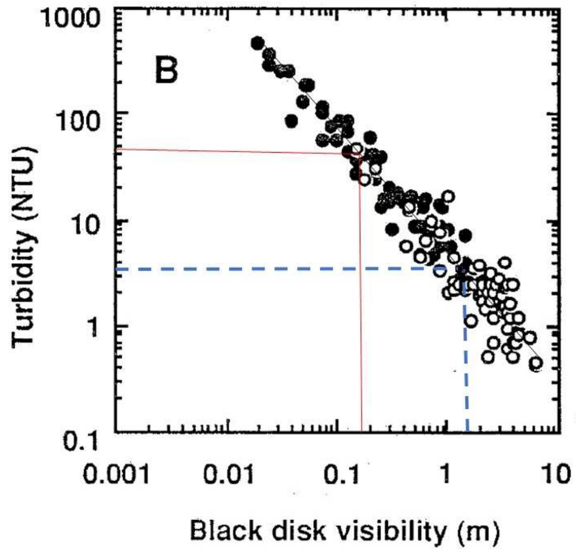
Appendix 1: Concept plan for stormwater development showing location of sub-catchments (CKL 2017).

Appendix 2: Suspended solids and clarity relationships

Appendix 2: Suspended solids and clarity relationships

Development of indicative water clarity (black disk) relationship with suspended solids. Relationships are from Davies-Colley et al. (1992) for fine suspended solids in West Coast streams.
"Predicted" (red) is median suspended solids concentration (48 g/m^3) and "Target" (blue dashed lines) is a visual clarity of 1.6 m (from MfE 1990).





Appendix 3: National freshwater standards for recreation (swimming) from MfE (2014)

Value	Human health for recreation				
Freshwater Body Type	Lakes and rivers				
Attribute	*Escherichia coli (E. coli)*				
Attribute Unit	*E. coli*/100 mL (number of *E. coli* per hundred millilitres)				
Attribute State[1 2]	**Numeric Attribute State**				**Narrative Attribute State**
	% exceedances over 540 cfu/100 mL	% exceedences over 260 cfu/100 mL	Median concentration (cfu/100 mL)	95th percentile of *E. coli*/100 mL	Description of risk of Campylobacter infection (based on *E. coli* indicator)
A (Blue)	<5%	<20%	≤130	≤540	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 1%*
B (Green)	5-10%	20-30%	≤130	≤1000	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 2%*
C (Yellow)	10-20%	20-34%	≤130	≤1200	For at least half the time, the estimated risk is <1 in 1000 (0.1% risk) The predicted average infection risk is 3%*
D (Orange)	20-30%	>34%	>130	>1200	20-30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >3%*

E **(Red)**	>30%	>50%	>260	>1200	For more than 30% of the time the estimated risk is ≥50 in 1000 (>5% risk) The predicted average infection risk is >7%*

* The predicted average infection risk is the overall average infection to swimmers based on a random exposure on a random day, ignoring any possibility of not swimming during high flows or when a surveillance advisory is in place (assuming that the *E. coli* concentration follows a lognormal distribution). Actual risk will generally be less if a person does not swim during high flows.

[1] Attribute state should be determined by using a minimum of 60 samples over a maximum of 5 years, collected on a regular basis regardless of weather and flow conditions. However, where a sample has been missed due to adverse weather or error, attribute state may be determined using samples over a longer timeframe.

[2] Attribute state must be determined by satisfying all numeric attribute states.