MEMORANDUM

To: TAG for 02/08/2013

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Copy To: Andy Bruere

Date: 05/08/2013

Subject: **Proposed detainment bund in lower Lake Ōkaro catchment**

Summary

An evaluation was carried out of the capacity of a proposed detainment bund to be located above the Lake Okaro constructed wetland, to retain sediment and phosphorus from the upstream catchment. The detainment bund would mitigate flow and reduce overflow discharges to the wetland bypass channel, which from 2008 to 2010 occurred c. 1.6% of the time and represented c. 3 to 7% of the annual discharge immediately above the wetland (Hudson and Nagels 2011). The detainment bund would serve multiple purposes; retaining sediment and P on farmland immediately behind the bund, restricting peak flows to the wetland and reducing occurrences of bypass diversions, and protecting the wetland and lake from deleterious effects of additional sediment and phosphorus. The latter nutrient in particular appears to have an important control on cyanobacterial (blue-green algae) blooms in the lake. Reducing catchment-derived phosphorus loads to the lake is essential to help alleviate cyanobacterial blooms, meet the Trophic Level Index and to reduce the frequency of and reliance on alum dosing in future.

Introduction

Lake Ōkaro is the smallest and most productive of the publicly managed Rotorua/Te Arawa Lakes. It has a catchment area of 359 ha divided among six landowners with a predominantly pastoral land use (95.7%; Lake Ōkaro Action Plan 2006). Over the past decade, the Trophic Level Index (TLI) of Lake Ōkaro has been approximately 5.5 (supertrophic). In 2006 the Lake Ōkaro Action Plan was established by Bay of Plenty Regional Council (BoPRC), Rotorua District Council and Te Arawa Maori Trust Board, specifying a combination of best land management practices, and in-lake and in-catchment restoration actions with the common goal of achieving a reduction in the 3-year TLI target to 5.0. The farming community has also been engaged, forming the Ōkaro Community Restoration Group and undertaking a Sustainable Farming Funded project (SFF Project Number 09/164 from 2009 – 2012) to improve practices with yearly farm performance monitoring using the Overseer nutrient budget model. Despite these efforts and continuing implementation of catchment and lake restoration measures the lake has not, as yet, achieved this water quality target. Specifically, it has still been subject to major blooms of cyanobacteria, commonly in spring but in some cases persisting through summer and into winter.

Total depletion of inorganic nitrogen during the growth phase of several recent summer cyanobacteria blooms and previous observations of heterocysts (the N-fixing structure of cyanobacteria filaments) (Paul 2006) suggests that N-fixation may be important in the bloom dynamics and that this group of cyanobacteria may be at a competitive advantage under these conditions of low concentrations of inorganic nitrogen (Figure 1; note summer 2011, 2012 and 2013). Therefore, the management of phosphorus load to Lake Ōkaro is likely to be a critical tool to control phytoplankton populations and blooms, and ultimately the TLI. Effective management of both internal and external nutrient loads is considered essential in order to effect improvements in lake water quality. Internal loads, which are highly important in Lake Ōkaro due to persistent hypoxia/anoxia of bottom waters (Scholes 2009) and elevated pH in surface waters and lake margins (Max Gibbs, pers. comm.) for much of the year, are being addressed by BoPRC using chemical flocculants (Alum) and adsorbent sediment capping agents (Aqual P).

The present memorandum concerns in-catchment measures to control external nutrient loads to Lake Ōkaro , particularly phosphorus. A constructed wetland intercepts the two surface inflows to the lake in order attenuate nutrients through a variety of processes including sedimentation of P-enriched topsoil, P adsorption, incorporation into plant biomass, and denitrification (Hudson et al., 2009). Preliminary assessments of the wetland’s efficacy have been encouraging (Hudson and Nagels, 2011). However, the design of the wetland necessitates that under high rainfall much of the discharge to the wetland is diverted and enters the lake directly through an overflow channel. It is during these conditions when suspended sediment and particulate phosphorus concentrations are highest in the wetland. Therefore, these periods of bypass flow can be considered a ‘missed opportunity’ to intercept the external P load. Here we evaluate a proposal to build a ‘detainment bund’ (DB) in the lower Ōkaro catchment, in order to retain sediments and P on land, and to better regulate the flow of water from the catchment through the wetland during periods of high flow.

Wetland construction and performance

The Ōkaro wetland covers an area of 2.3 ha, and services two inflowing streams – a larger stream to the north and a smaller stream to the south – which drain the majority of the Lake Ōkaro catchment. The wetland is located near the lake shore and was completed in 2005 at a cost of approximately $600,000 (Hamill et al. 2010). A weir at the major (north) inflow has an inlet which allows a maximum discharge of 184 L s^{-1} to the wetland, and any surplus flow (>184 L s^{-1}) is diverted away from the wetland and transported directly to the lake (Hudson and Nagels 2011). Nutrient reduction targets for the wetland as specified in the Lake Ōkaro Action Plan (2006) were 350 and 16 kg of total nitrogen and total phosphorus, respectively. NIWA was contracted by BoPRC to evaluate discharge and nutrient loads to, and nutrient load reduction by, the wetland over the period 2008 – 2010. The wetland was estimated to attenuate annually between 41 and 12% (597 and 149 kg) of incoming total N, and 60 and 12% (303 and 31 kg) of total P; generally exceeding targets set prior to its construction.

From 2008 to 2010, bypass (direct-to-lake) flow was present during 1.6% of flow records, and was estimated to account for between 3 and 7% of annual discharge from the major inflow (Hudson and Nagels 2011). This flow comprised between 6.8 and 34.7 kg (2.8 and 6.7%) of total phosphorus load and between 2.8 and 6.4% of suspended sediment load to the lake annually.

NOTE: Bypass flow was derived (rather than directly gauged), and the earlier iteration of this report (Hudson et al. 2009) specified that for 2008 the bypass was active 2.3% of the time, accounting for a full 34.5% of discharge. There will be some uncertainty in these figures, and bypass flow (and hence bypass nutrient load) may be higher than reported by Hudson and Nagels (2011). It may be useful to directly gauge the bypass flow in order to accurately assess the discharge quantity and frequency of operation.

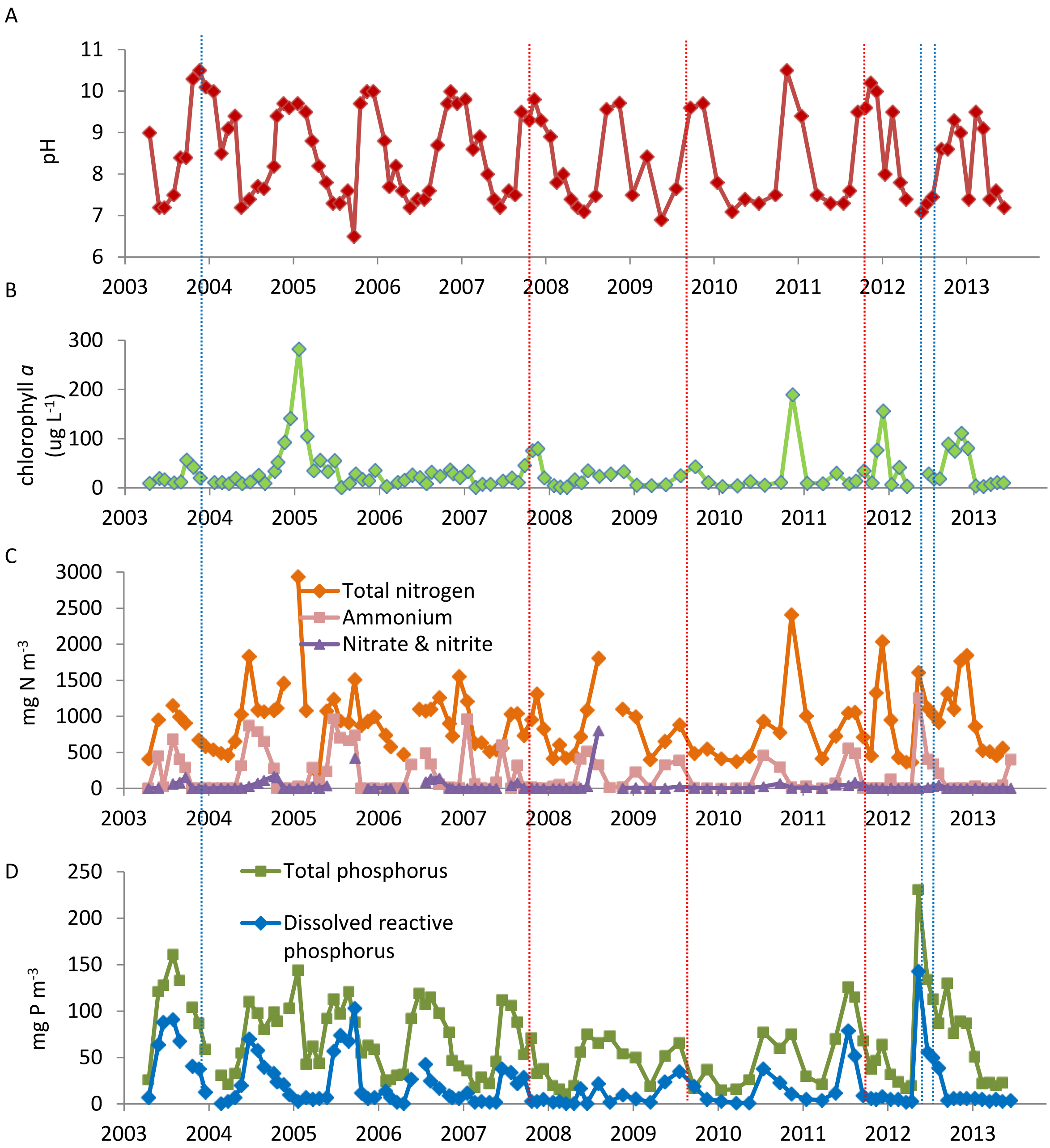

Figure 1: Time-series plots of Lake Ōkaro surface (integrated 0 to 4 m) concentrations for A) pH, B) chlorophyll *a*, C) nitrogen and D) phosphorus. Blue dashed line represents lake dosing with Alum, and dashed red line represents dosing with Aqual P.

Design of proposed detainment bund

Detainment bunds (DBs) are a relatively new mitigation tool specifically designed to temporarily pond ephemeral water discharges behind an earth bund during intense rainfall and runoff events. This can allow for the removal by sedimentation and/or adsorption of sediment and nutrients from typically P-enriched ephemeral waters (Clarke et al. 2013). A DB typically has a ‘choked riser’ outlet that allows a restricted amount of surface water to flow through the bund, and an open top to the riser near the crest elevation of the bund to drain excess ponded water if required. Detainment bunds are designed to be of minimum impact to land owners/operators. In order to minimise impacts on pasture quality, water should not generally pool behind the bund for longer than three days (Clarke 2013). However, the potentially flooded area of the bund proposed is mostly existing retired riparian plantings, therefore longer durations of inundation are a lesser concern.

An existing farm dam in the upper Ōkaro catchment, 1.5km upstream from the wetland intake wier, was adapted for storm water detainment with a choked riser outlet in March 2009, (photo below). This adds c. 600mm of potential height above the normal pond level providing potential for 15,300m3 of storm event storage. Flow at its outlet has been observed to be consistently low (c. 5 L s^{-1}; John Paterson, pers. comm.).

Figure 2: Adapted outlet riser, installed at the exisiting farm dam in the upper Ōkaro catchment. Photo supplied by John Paterson, BoPRC.

BoPRC proposes to build a second detainment bund in the lower Ōkaro catchment, approximately 300 m upstream of the wetland inlet weir on the northern (major) inflow. The bund would service a total catchment area of approximately 180 ha, of which ~70 ha are already intercepted by the upper detainment structure. This leaves a remaining catchment of ~110 ha serviced by the proposed bund (Figure 3).

A conservative 'rule of thumb', derived through the Rotorua P-Project's experiences of building DBs in the Lake Rotorua catchment (16 now constructed), is that an agricultural detainment bund should have 120 m^3 of storage capacity for every 1 ha of catchment area serviced (John Paterson, pers. comm.). The proposed structure would have a crest overflow outlet at 2.9 m, and a total storage capacity of 16,000 m^3, giving it a storage ratio of ~147 m^3/catchment ha (excluding the upper catchment already intercepted by the existing detainment pond). The proposed design has been independently assessed for its capacity to buffer storm flow events and cope with a 100-year flood event, and found to be satisfactory (McKercher 2013).

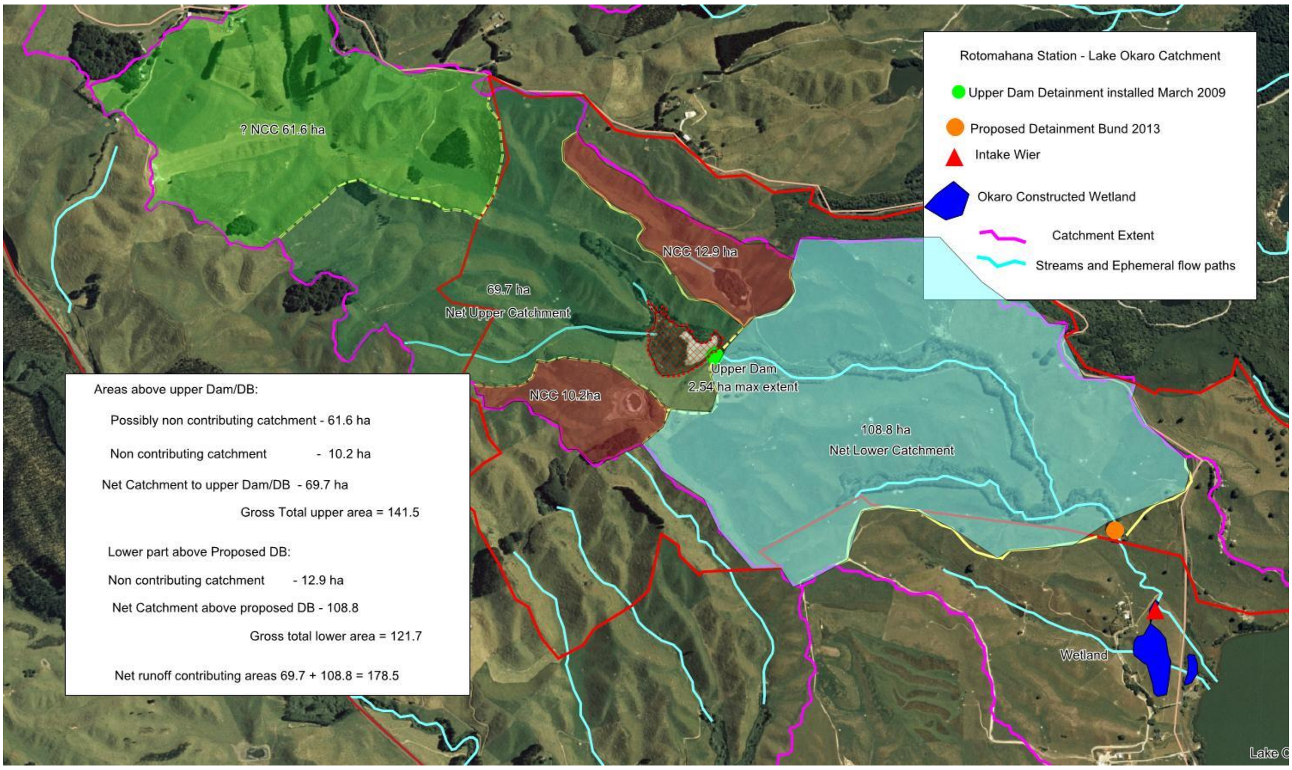

Figure 3: Aerial photograph showing catchment boundaries for the existing and proposed detainment structures. Figure supplied by John Paterson, BoPRC.

Modelling flow redistribution by the proposed detainment bund

We used a c. 3.5 y record of flow for the northern stream, which was collected and provided by NIWA, in order to construct a simple hydrological model of the proposed DB. Although the proposed site is slightly upstream of the flow measurement site, we adopted a conservative approach and assumed that the DB would intercept the entire flow as measured at the wetland inlet.

Detainment bund volume was modelled on an hourly timestep, as:

$$DB_{t+1} = DB_t + (Q*3600) - (Q_{crit}*3600)$$

where:

- DB — is the volume pooled behind the bund in m^3, with the condition that $0 < DB < 16000\ m^3$
- Q — is the measured flow of the stream in $m^3\ s^{-1}$
- 3600 — is seconds, corresponding to the time step
- Q_{crit} — is the choked outlet capacity of the bund riser in $m^3\ s^{-1}$

We used the above equation to test $Q_{crit} = 0.184\ m^3\ s^{-1}$, a value corresponding to the current inlet capacity of the wetland (Hudson and Nagels 2011); i.e. if bund pooling durations were acceptable at $Q_{crit} = 0.184\ m^3\ s^{-1}$ then the bypass channel would never be needed and total stream discharge could be passed through the wetland year-round. We tested a further scenario of $Q_{crit} = 0.1\ m^3\ s^{-1}$, in order to restrict flow to the wetland and increase overall bund storage, as recommended by McIntosh (2013; Memo to BOPRC). For each hour timestep, water retained by the bund was considered to be the smallest of either total stream discharge, or total bund volume (i.e. any water that was not removed from the bund via outlet flow subsequent to the removal of all stored water from previous timesteps). Water that would be stored for longer than 12 hours was calculated as total stream discharge at each timestep if the bund volume at the timestep was greater than 12 hours of outlet flow (i.e. if bund volume > $12 * Q_{crit} * 3600$).

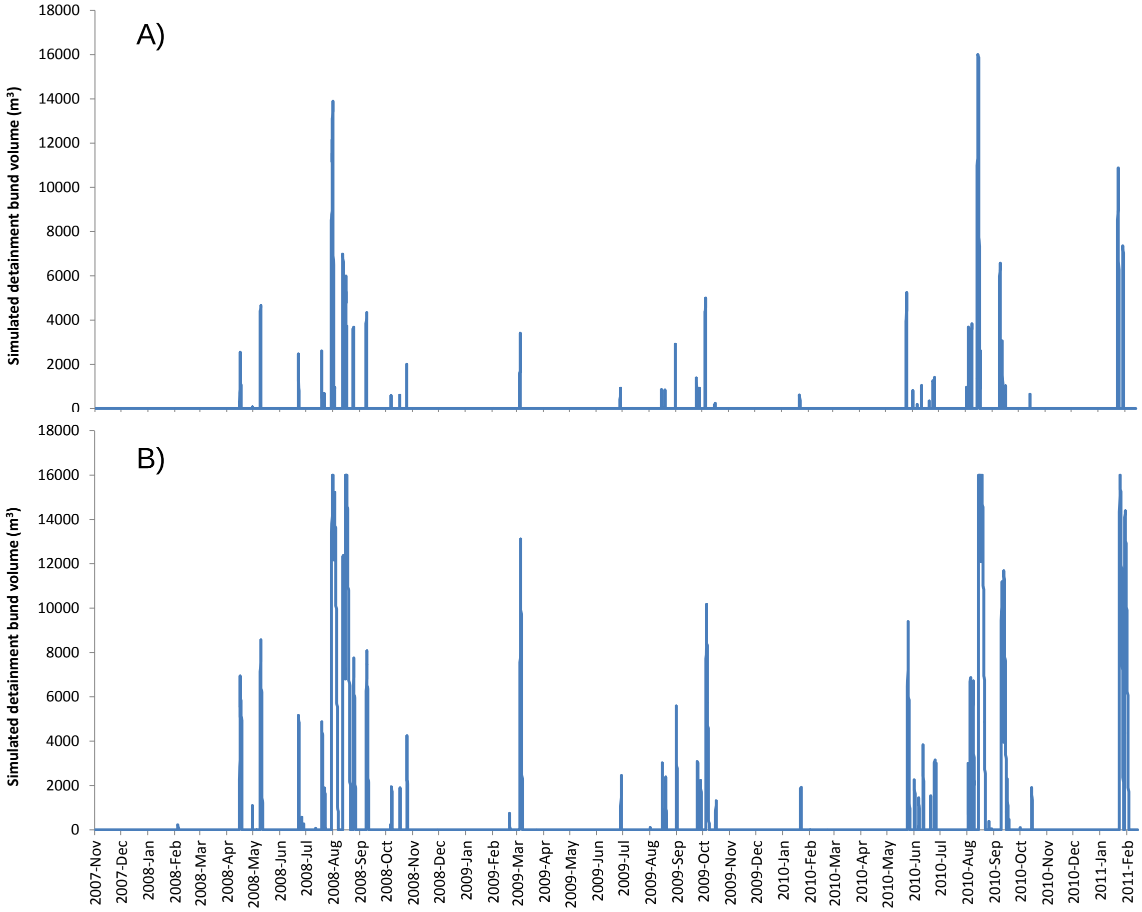

Figure 4: Simulated detainment bund volume over a c. 3.5 year period of flow from the northern stream in Lake Ōkaro's catchment, using a choked outlet allowance of A) $0.184\ m^3\ s^{-1}$, and B) $0.1\ m^3\ s^{-1}$.

Table 1: Summary statistics for simulated detainment bund filling dynamics under two scenarios of choke outlet capacity, corresponding to the current wetland inlet capacity (0.184 $m^3 s^{-1}$) and the capacity of 0.1 $m^3 s^{-1}$ recommended by McIntosh (2013; Memo to BoPRC).

(Nov 2007 to Feb 2011)	**0.184 $m^3 s^{-1}$**	**0.1 $m^3 s^{-1}$**
Total stream discharge (m^3)	2649296	2649296
Water retained by bund > 1 h (m^3)	499404	794281
Water retained by bund > 1 h (% total discharge)	18.9	30.0
Water retained by bund > 12 h (m^3)	84740	489266
Water retained by bund > 12 h (% total discharge)	3.2	18.5
Bund bypass overflow (m^3)	949	43366
Bund bypass overflow (% total discharge)	0.0	1.6
Bund inundation events >12h	21	37
Bund inundation events >72h	2	9

Results of scenario simulations are presented in Table 1. Simulation of the proposed bund with Q_{crit} = 0.184 $m^3 s^{-1}$ over November 2007 to February 2011, resulted in 21 events when water pooled in the bund for at least 12 h. On only one occasion did water reach the crest outlet (DB volume > 16,000 m^3). Under this scenario, for all but a few hours over 3.5 years the entire discharge of the north stream could be discharged to the wetland via its inlet. Pooling behind the bund lasted marginally longer than three days on two occasions, although it is likely that soil inundation and the upstream location of the proposed bund may reduce slightly the volume and duration of pooling. The detainment bund intercepted 18.9% of all stream discharge over the simulation period, with negligible bypass overflow.

Restricting the bund outlet (and hence the wetland inflow) to Q_{crit} = 0.1 $m^3 s^{-1}$, resulted in more water retention by the bund and many more sustained pooling events, with 37 greater than 12 h, nine greater than 3 days, and four where the 16,000 m^3 storage capacity was reached and thus the upper outlet (i.e. wetland bypass flow) would need to be used. Under this scenario, a greater proportion of total discharge (30%) was intercepted by the bund, however, bypass overflow was utilised more often (1.6% of total discharge). Therefore, at this reduced outlet capacity the bund would retain more water for longer, reduce the maximum flow rate through the wetland at all times (i.e. distribute wetland flow more evenly at sub-monthly timescales), and slightly reduce total discharge through the wetland on an annual basis. The benefits and drawbacks of these effects will need to be carefully considered when finalising the bund design, however, the increased frequency of sustained pooling events under the restricted outlet flow suggests much greater potential for retention of sediments and P on land.

The years 2008 and 2010 were considered to be wet with high flows (Hudson and Nagels 2011), therefore the proposed bund storage capacity could be considered appropriate for the catchment it would service, based on the flow data available. The simplicity of this model and uncertainty in the stream gauge volumes (see note on page 3) suggest that interpreting the above simulations should be carried out with caution.

Nutrient and sediment retention by detainment bund

According to loads estimated by Hudson and Nagels (2011), up to 35 kg of total P and 8 t of sediment could be intercepted by the detainment bund (assuming bund outlet maximum of 0.184 $m^3 s^{-1}$). Clarke (2013) observed reduction in suspended sediments of up to 73% over 43 h, and particulate P reduction of up to 36% over 20 h in detainment bunds within the Lake Rotorua catchment. This suggests that the proposed bund could act as a pre-wetland filter, retaining P-rich sediment on farmland and reducing nuisance build-up of sediments in the wetland (Paterson 2013), as well as smoothing inflow to the wetland and reducing storm bypasses of water that would otherwise effectively be untreated before entering the lake. Ōkaro soils are mud-derived and naturally high in P as a result of erosion processes following the 1886 eruption of Mt Tarawera (Paterson, pers. comm.), therefore, P retention by the proposed DB could be even more efficient than the examples from the Lake Rotorua catchment given above.

Conclusion

Detainment bunds are a promising tool for retaining nutrients and sediments on land, preventing their transport to sensitive receiving environments. The constructed wetland in the Lake Ōkaro catchment has been found to be extremely effective for the reduction of external loads of soluble and particulate nutrients to the lake. Hudson and Nagels (2011) noted that P loads leaving the wetland were relatively consistent from 2008 to 2010, despite much higher incoming flows and loads in 2008. This suggests it is possible that using a DB to increase the overall water volume and P load through the wetland, could increase its nutrient removal efficiency.

Uncertainty in the actual volume and frequency of the current wetland bypass overflow means the volume of water intercepted by the proposed bund could, in fact, be somewhat higher. Therefore, we consider it important to directly measure the bypass flow to the lake for some period. Measurements through several heavy rain events could be used to validate the present estimations derived from total stream flow. These measurements would have important implications for the potential impact of the DB on nutrient load and flow to the wetland, and also on the storage and outlet capacities required of the bund itself. If more water was observed than was simulated in the scenario above, this could be easily accommodated by increasing the size of the choked outlet on the DB, although it would at times exceed the wetland capacity and require greater use of the bypass flow.

Based on the most recently available flow and load estimates for the Ōkaro catchment and wetland complex, a relatively small proportion of flow and P load (up to 7 and 6.7% respectively) would be intercepted behind the proposed bund using an outlet of 184 L s^{-1}. Nevertheless, in retaining a residual ~7% of the P load, the estimated cost of the proposed bund (c. $80,000; Paterson 2013) would not be wholly disproportionate to the wetland that presently treats the other 93% (c. $600,000; Hamill et al. 2010). Restricting the outlet capacity of the bund would allow it to intercept more water and retain it for longer, potentially retaining greater amounts of nutrients and sediment and increasing its efficacy. Therefore, the proposed detainment bund should be considered as a potential tool for improvement of water quality in Lake Ōkaro.

Request to TAG:

Given the need to manage external P loads to Ōkaro as effectively as possible, and in consideration of the points raised above, please comment on a suggested strategy:

- **Measure directly the wetland bypass flow through several rainfall events over coming months.**
- **Use these measurements to validate current estimations of bypass flow in order to better determine ideal choked bund outlet flow capacity, in order to optimise performance of the present bund design.**
- **Commission construction of the bund, based on the refined design.**

Acknowledgements

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