Bay of Plenty
REGIONAL COUNCIL

MEMORANDUM

To: John Paterson
Sustainable farming Advisor

From: John McIntosh **Date:** 14 January 2013
Environmental Consultant

File Ref:

Subject: **Detainment structure in the Lake Okaro catchment**

1 Introduction

A detention bund structure is proposed for the Lake Okaro catchment upstream of the wetland. A structure with 16,000 m^3 capacity is proposed but one with less capacity could be built for a lower cost.

John Paterson has asked for the following analysis.

Your task would involve interpreting the NIWA performance reports on the constructed wetland, especially the nutrient bypass in storm events and the large SS build up currently occurring, and making some estimates on how much benefit to nutrient capture the proposed DB will create – such as:

- Some hydrological modelling of the history of storm events – we can use the Birchal Herd Home climate station data for this (e.g. see 2011 - 2012 rain fall graphs in earlier email below)
- Review NIWA reports of up to 40% nutrient bypass in storm events currently – what difference will the DB make to the current number and volume of by-pass events?
- What is the estimated P capture within the proposed structure itself?
- How much improvement in the P and N capture will the DB create in the existing constructed wetland?
- What improved to the lifespan of the existing constructed wetland? (i.e. relate to the 80 T of SS currently accumulating)
- Some comments on the 'Do nothing' consequences

2 Hydrology of the Catchment

Two tables describing the hydrology of the Okaro wetland from the NIWA report (Hudson and Nagels, 2011) are reproduced below. Table 3.3 provides the total bypass volume for each of three years of monitoring (2008, 2009, 2010).

Table 3-2: Annual hydrological balance for the constructed wetland.

Measurement point		Annual discharge (L x 10^6)		
		2008	2009	2010
Major stream	A	965.3	651.9	777.5
Pipe inflow to wetland	B	908.4	635.0	726.3
Minor stream inflow to wetland	D	132.7	120.7	130.2
Measured precipitation	P	23.1	15.4	29.9
Measured inflows	B+D+P	1064.3	771.2	886.4
Estimated evapotranspiration	E	18.4	18.4	18.4
Net precipitation	NP	4.7	-3.0	11.5
Measured wetland outflow (including net precipitation)	G	1101.3	878.02	1034.1
Additional outflow above inflow plus net precipitation	G-(B+D+P)	37.0	106.9	147.7
Difference between measured inflow and measured outflow as a percentage of inflow (%)	G-(B+D+P)/ (B+D+P)	3%	14%	17%

Table 3-3: Comparison of pipe inflow (B) and bypass flow (C) as proportion of total flow of major inflow stream (A).

Measurement point		Annual discharge (L x 10^6)		
		2008	2009	2010
Major inflow stream	A	965.3	651.9	777.5
Pipe inflow	B	908.4	635.0	726.3
Bypass flow	C	57.0	16.9	51.2
Bypass flow as a percentage of total flow in major inflow stream (%)	(A-C)/A	6%	3%	7%

The three years provide very different examples of the types of flow regimes that can occur in the catchment. In 2008 the total flow was highest but the bypass was of similar magnitude to 2010, which had much less flow. In 2009, the total flow was lowest and the volume of the bypass flow was only slightly greater than the volume of the proposed detention dam.

The rainfall in 2008 and 2010 was similar but in 2010 more summer rain fell and less drainage to the stream channel occurred.

In the table below, the largest rainfall events are collated with the peak flow at the wetland outlet to determine which events were most likely to result in a bypass flow.

	Month/event	Rainfall mm	Peak flow out L/s	Likely bypass
2008	April	80	110	
	April	46	186	**
	June	51	167	*
	June	24	85	
	June	34	92	
	July	45	150	*
	July	**48**	**210**	***
	August	**61**	**210**	***
	August	44	170	*
	August	33	165	*
	September	33	175	*
	October	25	118	
	October	35	135	
2009	February	43	105	
	June	31	68	
	June	6?	103	
	July	**81**	**155**	***
	August	7	95	
	August	18	90	
	August	19	120	
	September	26	110	
	September	10	55	
	October	22	160	*
	October	5	60	
2010	January	39	115	
	January	30	86	
	January	19	34	
	February	41	68	
	May	21	48	
	May	14	52	
	May	27	66	
	May	**91**	**250**	***
	June	38	95	
	June	27	78	
	June	25	62	
	June	14	62	
	June	13	63	
	July	12	24	
	August	30	90	
	August	29	120	
	August	10	120	
	August	**77**	**250**	***
	August	20	120	
	September	35	150	*
	September	25	140	
	September	10	80	
	September	14	78	
	September	5	50	
	September	12	62	

In the lowest rainfall year of 2009, only one event could have triggered a bypass flow. A rainfall event with 81 mm in July 2009 must have generated the 16,900 m^3 bypass flow, calculated by Hudson & Nagels (2011). The flow at the wetland outlet is relatively low. Assuming that all measurements were being recorded accurately, the rainfall intensity (81 mm in about 15 hours) may have been such that the bypass flow dominated the flow to the wetland for the duration of the event.

In 2008, two rainfall events are very likely to have triggered bypass flows. Other events may have triggered some bypass flows. If we assume, that 57,000 m^3 of bypass flow was generated from the two main rainfall events, the volume of each can be estimated in proportion to the rainfall. The largest event would have generated a bypass flow of 32,000 m^3.

In 2010, it is likely that bypass occurred in two main events. If a flow of 51,200 m^3 is allocated in proportion to the rainfall that generated the events. The largest bypass event would have involved about 28,000 m^3 flowing directly to Lake Okaro.

3 Size of a detainment structure

The detainment structure will have to detain a maximum volume of 32,000 m^3.

If the piped discharge had an orifice weir allowing 180 L/s to flow down to the wetland intake and there was 16,000 m^3 capacity. Peak flow is 500 L/s (Appendix A, Table A-3. (Hudson & Nagels, 2011)). That is calculated from the largest bypass flow rate plus 180 L/s flow into the wetland and rounded up.

At peak flow the detention bund would be filling at 1800 m^3/hr.
With a discharge rate of 180 L/s, the bund would be discharging at about 650 m^3/hr.
The nett filling rate of the detention structure would be about 1150 m^3/hr.
At this rate the bund could fill for about 14 hours.
This matches the duration of most high rainfall events.
Over the 14 hours 9100 m^3 would be discharged to the wetland.
A total volume of 25,000 m^3 could be controlled if peak flow occurred for 14 hours.
As peak flow is unlikely to occur for that length of time it is likely that a greater volume could be controlled.

If the bund was full and the inflow dropped to the average flow of 30 L/s.
The nett discharge rate of the bund would be 540 m^3/hr.
The bund would take about 30 hours to empty.

4 Troubleshooting

Bypass flow occurred for 186 hours, 60 hours and 167 hours respectively for 2008, 2009 and 2010.
Bypass flow was 57,000 m^3, 16,900 m^3 and 51,200 m^3 for 2008, 2009 and 2010.

The duration of flood hydrographs is 2-5 days. The duration of high flows in the upstream channel is for period up to 60 hours. It is likely that a bypass flow of 32,000 m^3 would be an extreme event.

A bund of at least 16,000 m^3 would be needed to contain high flows in the Lake Okaro catchment.

5 Nutrient reduction with detention bund

Table 4-3: Efficacy of Total-N retention by the Lake Okaro wetland. LOADEST LAD technique used to estimate loads. Negative values indicate that the wetland was a net source of material.

Assessment point	TN load balance by year (kg)		
	2008	2009	2010
A load (kg)	1430.9	781.3	1014.6
B load (kg)	1326.9	760.2	927.9
C load (kg)	103.9	21	86.7
D load (kg)	116.8	115.5	322.1
Wetland inflow load (B+D) (kg)	1443.7	875.7	1250
Outflow load (G) (kg)	846.6	729.5	1100.6
Load retained by wetland (kg)	597.1	146.2	149.4
Reduction of inflow load by wetland (%)	41%	17%	12%

By directing the bypass flow through the wetland and using 2010 data from Table 4-3 (Hudson & Nagels, 2011),

86.7 kg of TN would be reduced by 12 %.
TN would be reduced by 10 kg (3% of AP target for wetland removal).

Table 4-5: Efficacy of TP retention by the Lake Okaro wetland. LOADEST LAD technique used to estimate loads for 2008 and 2009. 2010 loads estimated using regression technique [a]. Negative values indicate that the wetland was a net source of material.

Assessment point	Total P load balance by year (kg)		
	2008	2009	2010
A load (kg)	519	242.4	262 [a]
B load (kg)	484.3	235.6	233.9 [a]
C load (kg)	34.7	6.8	17.3 [a]
D load (kg)	20	15.5	15.7 [a]
Wetland inflow load (B+D) (kg)	504.4	251.3	249.5 [a]
Outflow load (G) (kg)	201.8	194.5	219 [a]
Load retained by wetland (kg)	302.6	56.8	30.5 [a]
Reduction of inflow load by wetland (%)	60%	23%	12%

17.3 kg of TP would be reduced by 12 %.
TP would be reduced by 2 kg (12.5% of AP target for wetland removal).

Table 4-6: Efficacy of SS retention by the Lake Okaro wetland. LOADEST LAD technique used to estimate loads.

Assessment point	Suspended solids load balance by year (kg)		
	2008	2009	2010
A load (kg)	135885.8	124203.4	84434.8
B load (kg)	127759.4	120654.5	77994.4
C load (kg)	8126.4	3549	6440.4
D load (kg)	4255	5870.7	3637
Wetland inflow load (B+D) (kg)	132014.4	126525.3	81631.3
Outflow load (G) (kg)	16846.8	14574.2	23414.8
Load retained by wetland (kg)	115167.6	111951.1	58216.5
Reduction of inflow load by wetland (%)	87%	88%	71%

6440.4 kg of suspended solids would be reduced by 71 %.
Suspended solids would be reduced by 4572 kg.

Dylan has found that the TP concentration of solids he has detained is about 1500 mg/kg (dry wt). For 4572 kg of solids the phosphorus retained would be 6.7 kg *cf* 2 kg for wetland.

Additional benefit could be gained by retention of nutrients in the bunded area.

If suspended solids dropped by 20% with detention for 1 day, from Table 4.6, 16890 kg would be removed per year in the bund. This is based on a comparison of Dylan's plotted data.

Using the wetland nitrogen and phosphorus removal rate in comparison to solids removed, 37 kg of TN and 7.4 kg TP would be removed. Using Dylan's analysis of the phosphorus content of settled solids (1500 mg/kg), 26 kg P/yr would be removed. The difference may be that in the wetland environment, some of the phosphorus is transformed to a mobile form and is transmitted through the wetland.

A possible total removal would be 47 kg TN and 9.4 kg TP per year with nutrient removal by settlement of solids in the bund and from wetland treatment of the additional water passing through the wetland.

6 J Paterson bullet points

- Some hydrological modelling of the history of storm events – we can use the Birchal Herd Home climate station data for this (e.g. see 2011 - 2012 rain fall graphs in earlier email below) This has been carried out above.
- Review NIWA reports of up to 40% nutrient bypass in storm events currently – what difference will the DB make to the current number and volume of by-pass events? The report (Hudson & Nagels, 2011) completely turns this around. The nutrient bypass is quite low. The reassessment of the hydrology from the 2009 NIWA report has made a dramatic difference. I discussed this with Chris Tanner and he confirmed the lower bypass flow and lower nutrient bypass.
- What is the estimated P capture within the proposed structure itself? Using Dylan's data with 1 day detention and 1500 mg/kg total phosphorus in solids, 26 kg P/yr could be settled out. Lake Okaro solids will have a higher P content due to having more Rotomahana ash so the P capture could be higher still.
- How much improvement in the P and N capture will the DB create in the existing constructed wetland? I calculated that above and it worked out as 10 kg TN/yr and 2 kg TP/yr. Chris said that there is evidence that moderating the flow through a wetland improves performance and he was sending me information to that effect. If the pipe for the detainment bund could be throttled back to less than 180 L/s then that scenario would come into play ie you could spread the time period that the stream flow was admitted to the wetland even further.
- What improved to the lifespan of the existing constructed wetland? (i.e. relate to the 80 T of SS currently accumulating) It is probably an advantage to dredge solid accumulations in the wetland if phosphorus exchange occurs between settled solids and the overlying water. Perhaps some dredging points could be established where solids would then tend to accumulate. I talked to Chris about lowering the level of the wetland between high flow events to create storage. This could be done through the 'plug' with a 'U' bend outlet at a fixed height. Blockages would be an issue.
- Some comments on the 'Do nothing' consequences. The nutrient bypass now seems to be less significant than the 2009 report implied. The lesser volume of the bypass flow as estimated in the

2011 report makes the 16,000 m^3 bund perfect for controlling flows into the wetland. There may be greater value in moderating the flow of the stream being admitted to the wetland during and immediately after storm events and getting a better nutrient removal efficiency in the wetland. Suppose it was possible to throttle the bund back to 100 L/s (from current 180L/s) by more restriction on the DB's 'choke' outlet and allow greater residency time in the wetland for the stream during high flow times. This increased residency / treatment time could be a more valuable attribute of the proposed Detainment Bund than its ability to moderate the bypass flow. It may be possible to get the % nutrient removal back to 40% from the 2010 12%. I consider that there are valuable options to exercise if the bund is constructed to the maximum 16,000 m^3 capacity. I do not favour the 'do nothing' option for that reason.

7 Conclusion

The bund needs to have at least 16,000 m^3 capacity to effectively detain the extreme event where 32,000 m^3 is likely to bypass the wetland. The bund's outlet choke should be set to admit a maximum flow of 100 L/s. The design should incorporate an option to increase the bunds outlet choke to 180m L/s if over flow occurs too often.

Spreading flood peaks as they pass through the wetland allows greater nutrient removal (Chris Tanner personal comment).

Additional actions that would add value are installing dredging points for an annual or bi-annual removal of solids from the wetland, the bund and the area at the wetland intake. A low flow outlet through the plug to lower the level of the wetland to a fixed level between flood events to create storage would also enhance the treatment efficiency.

Maintenance checks of the inlet pipe to the wetland should be carried out to ensure that no blockage has occurred.

The option of retiring pasture to forest would result in a lower rate of nitrogen leaching but the fertility of the Rotomahana Mud soils is very high and sediment entrainment in runoff waters from plantations will still carry a large phosphorus load. The key to controlling this load is detainment of flood flows to settle out solids.

Appendix A Annual summary statistics for flows

Table A-1: Summary statistics for 2008 calendar year. Data summarised as hourly average values.

Statistic		Measured flow at location (L/s)			
	Major inflow (A)	Pipe inflow (B)	Bypass flow (C)	Minor inflow (D)	Wetland outflow (G)
No. of Cases	8784	8784	186	8784	8784
Minimum	8	8	0.25	0	12
Maximum	496.3	184	312.3	118.5	519.5
Median	22.3	22.3	77.1	3	27
Arithmetic Mean	30.5	28.7	85	4.2	34.8
Standard Error of Arithmetic Mean	0.4	0.3	4.5	0.1	0.3
Mode	10	10		2	15
Standard Deviation	39.7	28.1	61.6	4.9	31.2
Percentiles	0	0	0	0	0
1	9	9	0.5	0	13
5	9.5	9.5	3.1	1	14
10	10	10	10	1.8	15
20	13	13	25.9	2	17
25	14.8	14.8	38	2	19
30	16	16	46.8	2	20
40	19	19	58	3	23.5
50	22.3	22.3	77.1	3	27
60	25.5	25.5	94.9	4	30.2
70	29	29	114.7	5	34.3
75	31.8	31.8	125.5	5	38
80	34.8	34.8	133.5	5	41
90	45	45	164.4	7	56.3
95	64.8	64.8	199.9	8.5	88.3
99	266.9	184	265.2	21.3	171.1

Table A-3: Summary statistics for 2010 calendar year. Data summarised as hourly average values.

Statistic	Measured flow at location (L/s)				
	Major inflow (A)	Pipe inflow (B)	Bypass flow (C)	Minor inflow (D)	Wetland outflow (G)
No. of Cases	8760	8760	167	8220	8760
Minimum	1	1	0.5	0	10
Maximum	513	184	329	73.3	915.5
Median	15	15	77.5	3	26
Arithmetic Mean	24.7	23	85.2	4.1	32.8
Standard Error of Arithmetic Mean	0.4	0.3	4.9	0	0.3
Mode	8	8		2	15
Standard Deviation	38.2	27	63.2	3.4	29.6
Percentiles	0	0	0	0	0
1	8	8	1.2	1	11.5
5	8	8	4.7	2	12.5
10	8	8	10.8	2	14.3
20	9	9	26.7	2	15.8
25	9	9	35.3	2	17.5
30	10	10	42.2	3	19.3
40	12	12	62.9	3	22.5
50	15	15	77.5	3	26
60	20	20	87.9	4	29.8
70	23	23	103.5	4	35.3
75	26	26	120.5	5	37.3
80	29	29	131	5	41.1
90	39	39	174.7	6	55.3
95	53.6	53.6	200.5	8	75.1
99	260.1	184	304.6	18.8	140.7