Supplementary memo to Lakes *E.coli* memo dated 2/11/2017 – Water quality

Environmental Research Institute, University of Waikato

To: Greater Wellington Regional Council

From: Mathew Allan

CC: Natasha Tomic and John Bright

Date: 12/11/2017

Re: Lakes Wairarapa and Onoke water quality modelling

Purpose

To deliver a succinct memo regarding lake water quality changes in relation to baseline scenarios.

Glossary

TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Sediment
TLI	Trophic Level Index - indicates the health of a lake based on its degree of nutrient enrichment
Chl a	Chlorophyll a
cyano	Cyanobacteria
Macrophytes	Aquatic plants
Secchi depth	a measurement of water clarity whereby a black-and-white disk is lowered down from the lake surface until it disappears from view from the observer

Scenario Inputs that can influence changes

Catchment related scenarios are discussed in memos from other modelers and will not be covered in detail here. BAU, SILVER and GOLD scenarios were all ran using time periods is 2025, 2040 and 2080. The scenarios apply various mitigation options including retirement of land, pole planting, land treatment of wastewater, minimum flow rules, and on-farm mitigations.

This memo will only discuss results from 2080.

The Lake Wairarapa specific scenarios included the following:

Modelling shorthand naming conventions	Description
ALL_RUA_SILVER2080 ALL_RUA GOLD2080	All flows of the Ruamāhanga River entering Lake Wairarapa. No flow by-passing via the diversion.
MEDIAN_RUA_SILVER2025/2040/2080	Flows below median flow go into Lake Wairarapa, and flows above median flow are by-passed
Outlet_Close_SILVER2025/2040/2080, Outlet_Close_Rua_All_SILVER2025/2040/2080	Lake Onoke outlet closed January to March every year. Lake Onoke outlet closed Jan to Mar, all Ruamahanga flows diverted into Lake Wairarrapa before entering Onoke
1m_Inc_SILVER2025/2040/2080	Deepening both lakes by 1m

NOTE: Lake specific modelling scenarios were run in addition to catchment scenarios (see Table 1, Appendix).

Significant assumptions

Within lakes nutrient loading comes from external loads (catchment surface and groundwater flows) and internal loads (derived from diffusion and resuspension from nutrients stored in lake bed sediments). These nutrients derived from the lake sediments can comprise a significant proportion of the total load to the lake and therefore any modelling of lake ecology must consider these.

Therefore, any changes to nutrient concentrations derived from catchment modelling or from changes in flow regimes (Ruamāhanga division into Lake Wairarapa) were applied to sediment nutrient release rates based on a percentage reduction or increase of sediment nutrient release rates in relation to baseline conditions. This was in order to simulate how different catchment loads influence the release rates within the sediment. In reality, there is a lag time for sediments to reach equilibrium, usually between 10 and 15 years (Jeppesen et al 2005), but sometimes persisting for more than 20 years for internal loading of phosphorus (Søndergaard, Jensen & Jeppesen 2003).

DYRESM CAEDYM 1-D modelling is a simplification of reality whereby we assume the lake is fully mixed across the lake's surface, and only simulate variation over lake depth. This means we have multiple cells from the lake surface to the lake bottom. This allows models to run fast, and therefore run over long time periods, and be easily calibrated.

AED CAEDYM 3-D modelling is a close representation of reality where we can simulate and look at the lake from any prospective. This method divides the lake into cells across the lake surface and from the lake surface to the lake bottom. 3-D models require much more processing power, a much more difficult to calibrate, and take much longer to run. Therefore, these models will run over short time periods of three months in the summer of 2012 from January to the end of March.

Considering the large spatial variation of water quality and lakes Onoke and Wairarapa, 3-D modelling provides robust information on the scenarios that change the spatial variation of hydrodynamics and water quality inputs.

Result outputs for discussion

Reporting locations for 1-D

For 1-D modelling there are only two reporting points. The ideal Lake Wairarapa monitoring location for comparison to 1-D models is Lake Wairarapa Middle Site, due to its central location at the deepest point (2.6 m) within the lake (Fig 1). However monitoring data for this site is only available from January 2014. Therefore, for 1-D model calibration and validation data from Wairarapa Site 2 was adopted, as data was available from February 1994. This is also the second deepest monitoring site (2.2 m). While the model was calibrated for Site 2, our opinion is that model output data is valid for a reporting point at Lake Wairarapa Middle Site. Within Lake Onoke, data from the only long-term monitoring point within the lake (Site 1, 1.4 m depth) was used for calibration and validation, therefore model output could be used as a reporting point for Site 1 (Fig 2).

Reporting locations for 3-D

For 3-D lake modelling the reporting points included Lake Wairarapa Site 2, Middle, Alsops and Outlet (labelled DS barrage gates)(Fig. 1). For Lake Onoke sites included Site 1, Middle and Deepest, with the Middle and Deepest sites being additional to those requested by GWRC. The deepest point site is located to the south east of Lake Onoke at C. 6.8 m depth (Fig. 2).

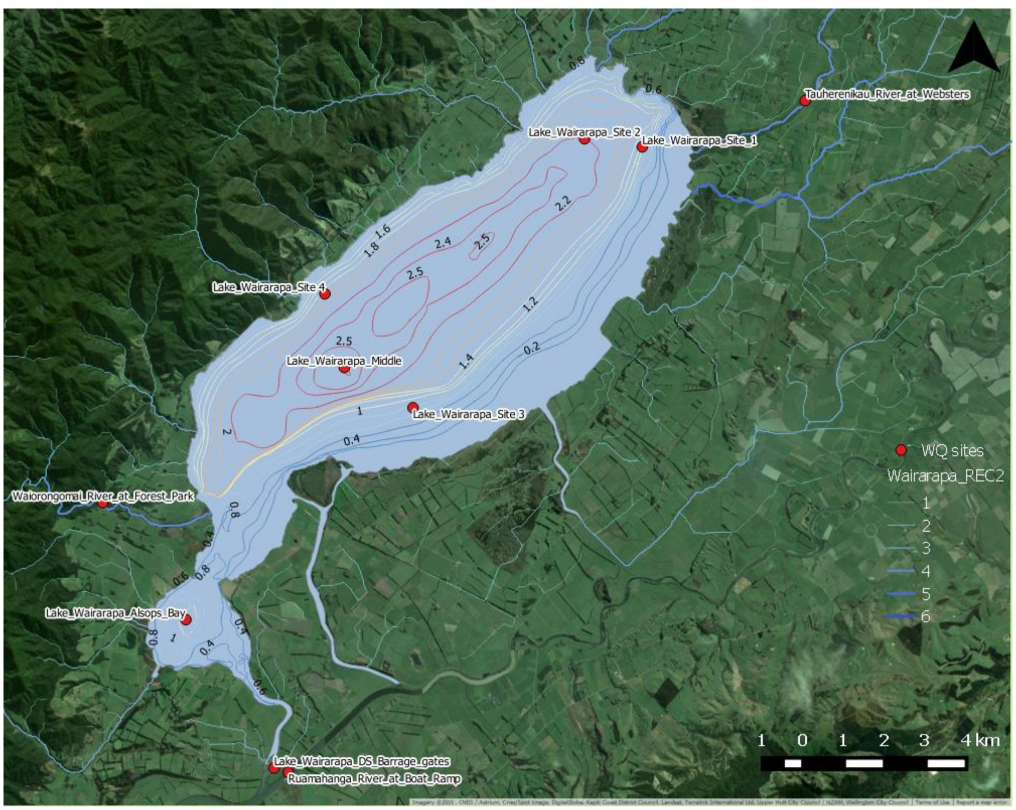

Figure 1. Lake Wairarapa study site with water quality (WQ) monitoring locations, River Environment Classification stream order (shades of blue), and bathymetric isobaths labelled by depth (m).

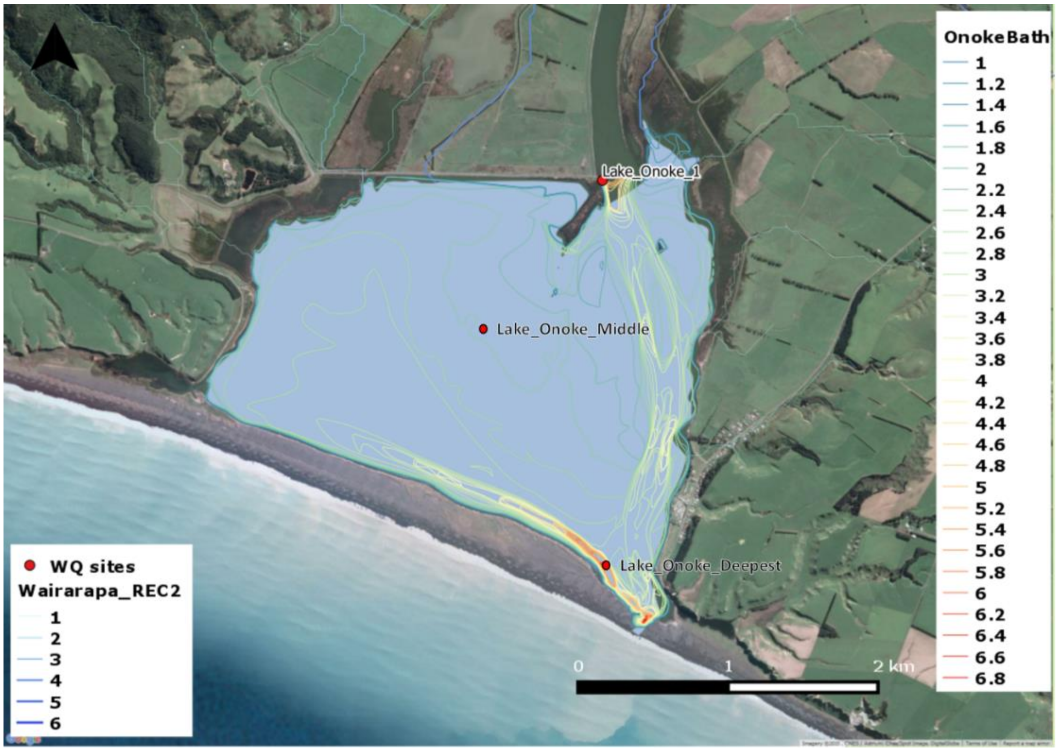

Figure 2. Lake Onoke study site with water quality (WQ) monitoring location shown (Lake_Onoke_1) with bathymetric isobaths (m) displayed in the legend.

Catchment load of TN and TP under BAU, GOLD and SILVER

Under the catchment land-use mitigation scenarios for GOLD and SILVER 2080 external load (from the catchment) for total nitrogen (TN) was reduced by approximately 10% for Lake Onoke and approximately 5% for Lake Wairarapa. External loads of total phosphorus (TP) were reduced by approximately 42% for lakes for Wairarapa and Onoke (Fig. 3 & 4).

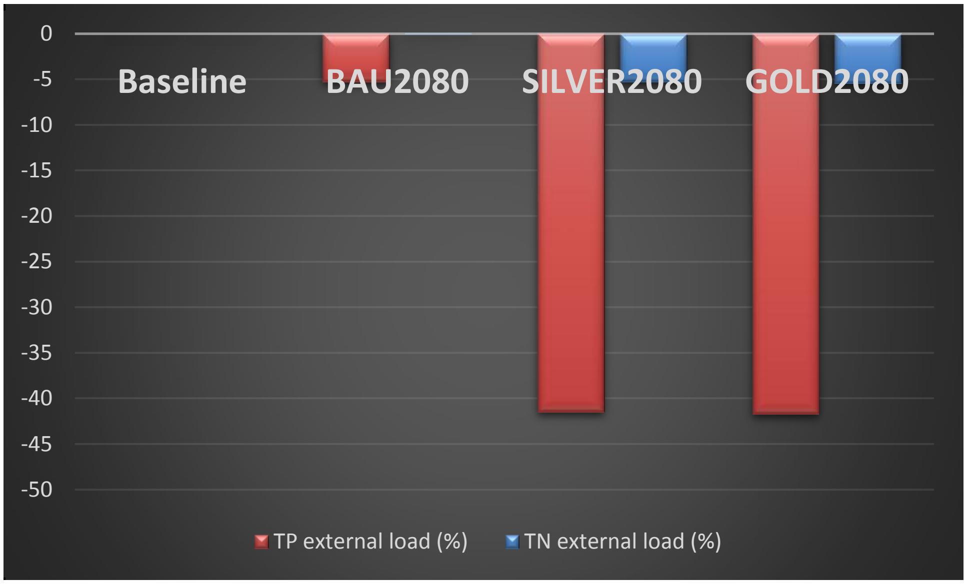

Figure 3. Reductions in catchment total nitrogen and total phosphorus load for Lake Wairarapa.

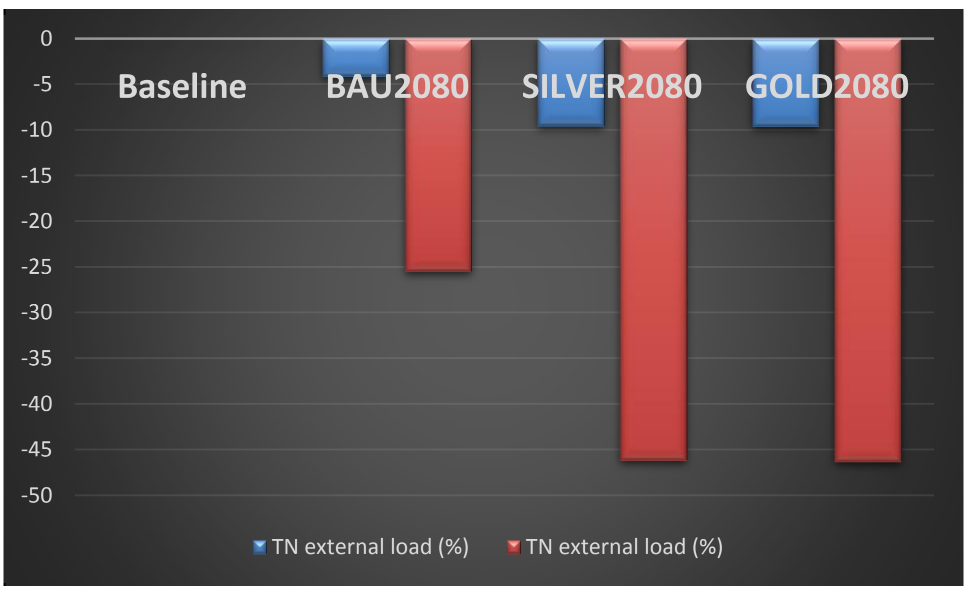

Figure 4. Percent reductions in catchment total nitrogen and total phosphorus load for Lake Onoke.

1-D Scenario results

Within Lake Wairarapa, 23 different scenarios were run (Appendix table 1) resulting in water quality variable changes from baseline between 60.4% reduction (chlorophyll (chl) *a* under the MEDIAN_RUA_SILVER_2080 scenario) and 330% increase (*E. coli* under the ALL_RUA_SILVER2025 scenario).

The lakes catchment scenarios GOLD and SILVER resulted in improved water quality, however for SILVER and GOLD scenarios increases in nitrate concentrations ranged from 0.6% (SILVER2025) to 17.2% (SILVER2080), primarily driven by lower phytoplankton nitrate uptake associated with greater phosphorous limitation. However under these two scenarios TN was still reduced by 13%.

Simulated changes in NOF bands are presented in Table 1 and Table 2.

1-D Catchment scenario lakes results

The BAU scenarios only marginally improved water quality, for example BAU2080 resulted in a 1.8% reduction in TP concentrations and a 2.0 % reduction in TN concentrations (Fig. 3). However, the SILVER and GOLD scenarios both had a significant influence on water quality, and as expected the largest improvement in water quality occurred on the 2080 scenarios. The GOLD2080 and SILVER2080 scenarios simulated very similar reductions in nutrient concentrations in both Onoke and Wairarapa, and increases in water clarity (Fig 3 and 4). For example in Wairarapa, SILVER2080 simulated a 13.3 % reduction in total phosphorus whereas as GOLD2080 simulated a 13.5% reduction. Generally, the largest changes in water quality parameters were seen in chl *a* concentrations, for example GOLD2080 saw a 41.0% reduction in chl *a* concentrations.

1-D 3-D lake scenario results water quality

The diversion of the Ruamāhanga River into Lake Wairarapa, combined with changes in catchment scenarios discussed above, brought about the greatest changes in water quality, both positive and negative. While the scenario generally improved water quality in Lake Wairarapa, scenarios where the entire flow was diverted increased *E. coli* concentrations by 321 %, due to high concentrations in the Ruamāhanga River. In addition, residence time reduced to 9.1 days compared to 38.1 days under baseline.

The diversion of Ruamāhanga River flows below median (SILVER2080 flows) saw the greatest improvement in water quality of all 1-D scenarios, due to increased flushing, lower inflow nutrient and total suspended solid concentrations (even though total loads increased), leading to shorter residence times (23.5 days compared to 38.1 days under baseline), reducing the impact of high internal loading and sediment resuspension.

However 3-D models showed an increase chl *a* concentration (due to less light limitation) under the Ruamahanga division scenarios. For any simulation that changes the hydrodynamics including lake depth increase, diversion, and the closure of lake mouth, the 3-D simulation results provide a more accurate representation of the system (see conclusions).

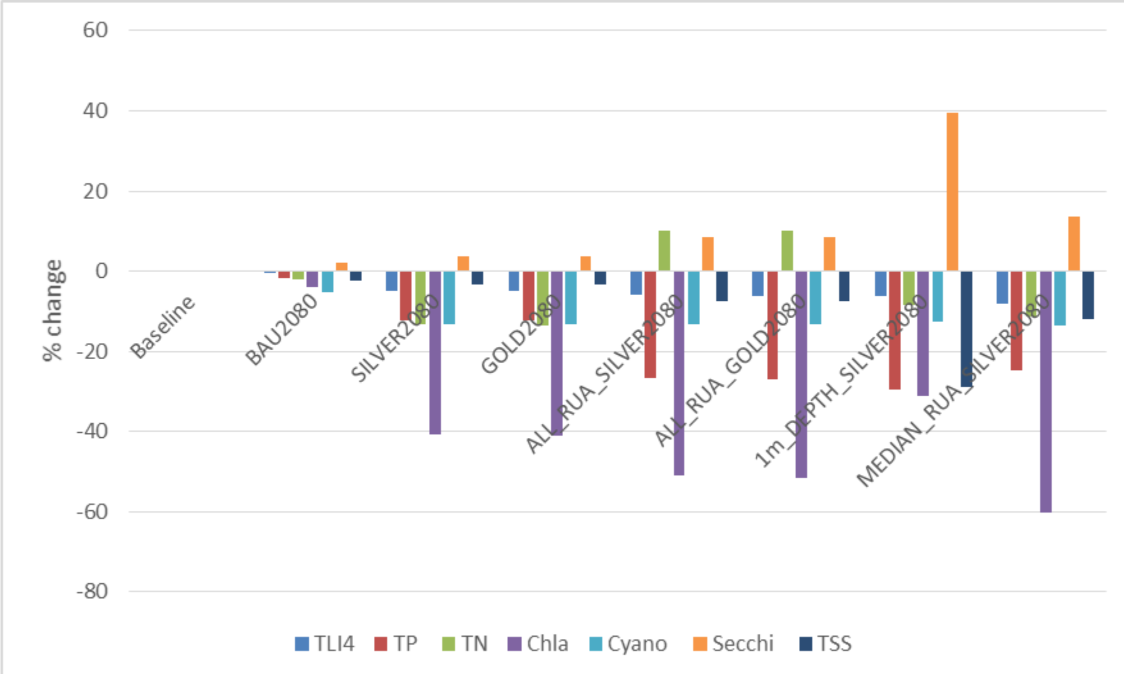

Figure 5. Lake Wairarapa 1-D simulation summary percentage change for 2080 (positive is increase, negative is decrease).

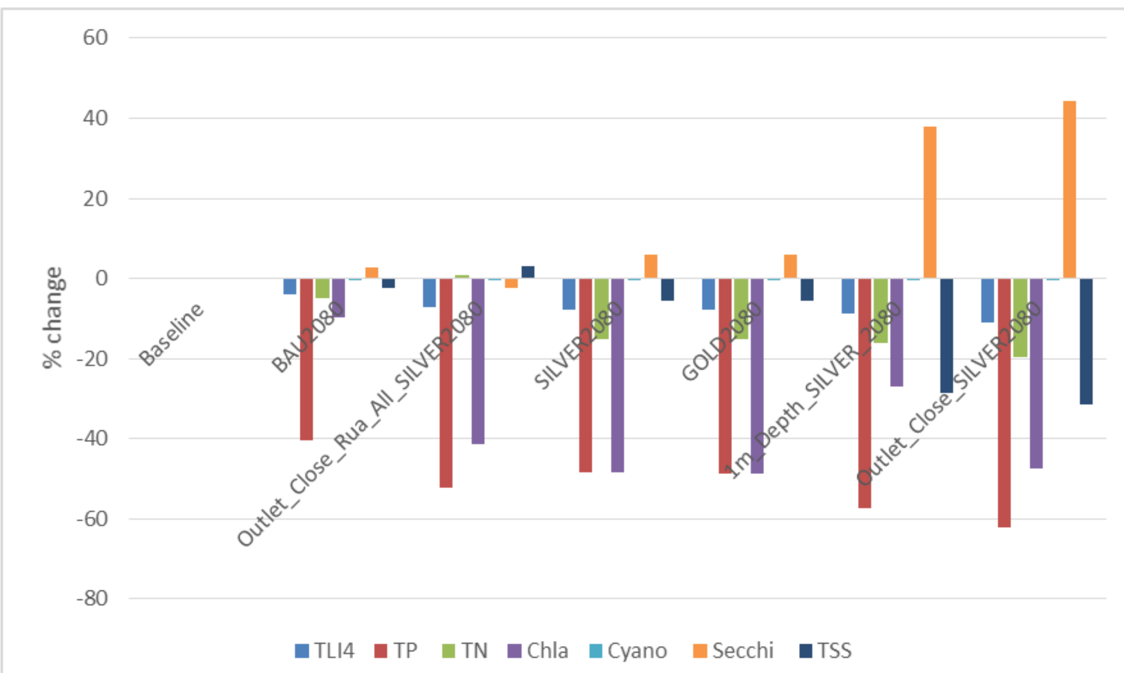

Figure 6. Lake Onoke 1-D simulation summary percentage change (positive is increase, negative is decrease) for 2080.

Total phosphorus 1-D

The reductions in catchment TP loads were reflected within lakes to differing extents within lakes Onoke and Wairarapa. The 42% reduction in external TP load resulted in a 12 and 49 % reduction for GOLD and SILVER 2080 within Wairarapa and Onoke respectively. The lower reduction in TP concentrations within Lake Wairarapa is due to the larger internal loading from the lake sediments, due to diffusion of phosphate and resuspension of suspended particles with bound phosphorus.

Total nitrogen - 1-D

The reductions in catchment TN loads were reflected within lakes to similar extents within lakes Onoke and Wairarapa. Catchment derived TN was reduced by 5% for Lake Wairarapa and 10% for Lake Onoke, which resulted in a 13 % and 15 % reduction for GOLD and SILVER 2080 within Wairarapa and Onoke respectively. Nitrogen internal loading from lake sediments is generally much less (as a proportion of total load from catchment and sediments) due to the fact that nitrogen bind strongly to sediments.

Phytoplankton – 1-D-3-D

Under the baseline scenario one-dimensional modelling simulated that the dominant phytoplankton in Lake Wairarapa and Onoke was green algae, with lesser concentrations of diatoms and cyanobacteria. Model simulations showed that cyanobacteria concentrations often peaked during late summer months but did not reach high concentrations (concentrations above 10 µg per litre). Recent GWRC field data indicates that diatoms, green algae and cyanobacteria are all present in the lake at certain times, but that diatoms and green algae are dominant. There was a recorded cyanobacteria algae bloom on the 9/5/2008 in Lake Wairarapa however since then none have been recorded (Perrie 2005). All simulations showed that green algae continue to dominate the phytoplankton assemblage.

Lake Wairarapa Phytoplankton

For catchment nutrient mitigation scenarios 1-D simulations all estimated reductions in phytoplankton concentration, caused mainly by a reduction in available nutrients, particularly more phosphorous limitation. Reductions under catchment scenarios were greatest under SILVER and GOLD 2080 with a 40% reduction. However, the greatest reduction in phytoplankton was simulated and Ruamāhanga below median flow division with a 60% reduction.

However 3-D simulations however showed a slight increase in chl *a* concentration under the same scenario, likely owing to less light limitation causing enhanced algal growth (Fig 7). The 1 m depth increase scenarios resulted in reduced phytoplankton concentrations within 1-D, however 3-D modelling showed significant increases. Again less light limitation due to less suspended sediment is the driving factor here. When comparing the 1 m depth increase scenarios (SILVER2080 flows) to the SILVER2080 scenario, 1-D simulations also showed an increase in median chl a concentration. Therefore under the same flow and nutrient conditions the 1 m depth increase within the 1-D model simulated increased chl *a* concentrations. Therefore when the effect of inflow is controlled for, both the 1-D and 3-D models simulated an increase in chl *a* concentrations. However this is not the case for the Ruamāhanga diversion scenarios, where 1-D modelling simulates decreased chl *a* concentrations and 3-D model simulated increased concentrations when compared to SILVER2080 and baseline.

All scenarios indicate higher chl *a* concentration in the south of the lake, particularly Western areas of Alsop's Bay. This is potentially due to less suspended sediment resuspension in this area, and more available light for phytoplankton growth.

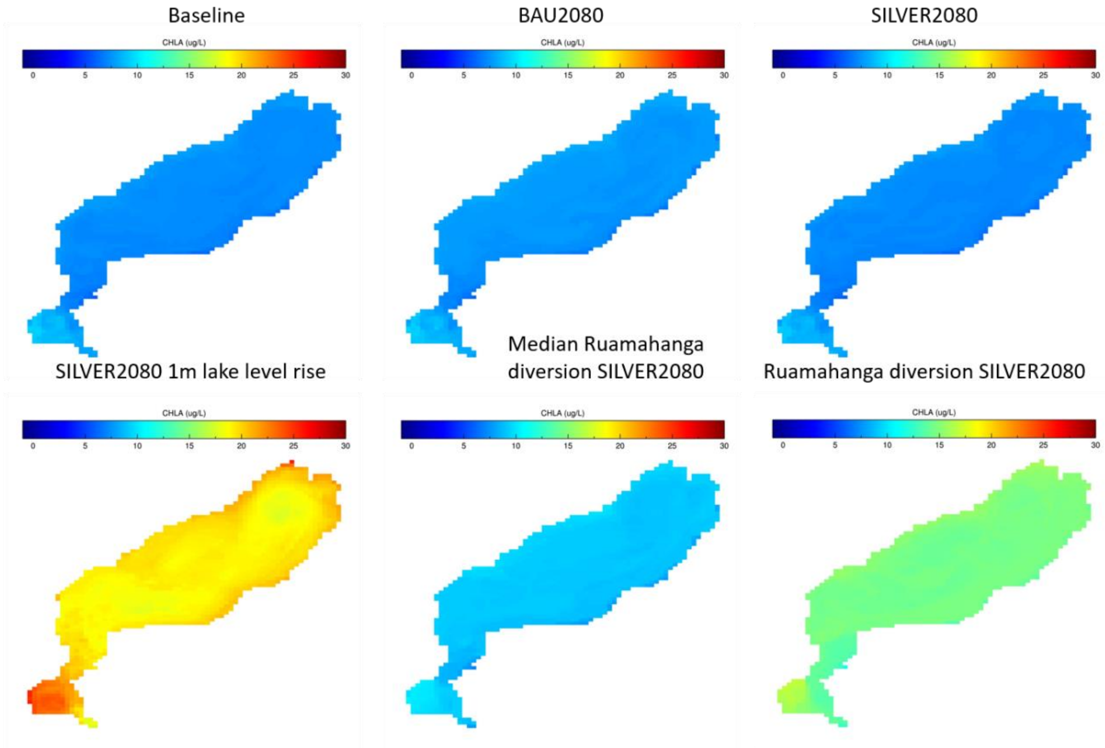

Figure 7. Simulated total chlorophyll *a* concentrations in Lake Wairarapa using three-dimensional models.

Lake Onoke Phytoplankton

For the 1-D model, reductions under catchment scenarios were greatest under SILVER and GOLD 2080 with a 49% reduction in phytoplankton concentration. Lake level 1 m increase (1m_Inc_SILVER2025) simulated a lesser 27% decrease in chl *a* concentrations for the same inflow loads, likely due to enhanced algal growth from more like availability caused by less sediment resuspension owing to the deeper depth. However, 3-D models also indicated the possibility of higher algal growth compared to baseline under 1 m lake level increase in western Lake Onoke. Aligned with 1-D modelling, 3-D modelling also showed a reduction in chl *a* concentrations at all sites under the outlet close scenario (Fig. 8). Within Lake Onoke the outlet close scenario simulated higher TSS concentrations which likely limited algal growth due to increased light limitation. However when the scenario is combined with the Ruamāhanga diversion through Lake Wairarapa there was simulated increased chl *a* concentration near Ruamāhanga inlet, likely derived from high chl *a* concentrations in Lake Wairarapa being entrained into Lake Onoke.

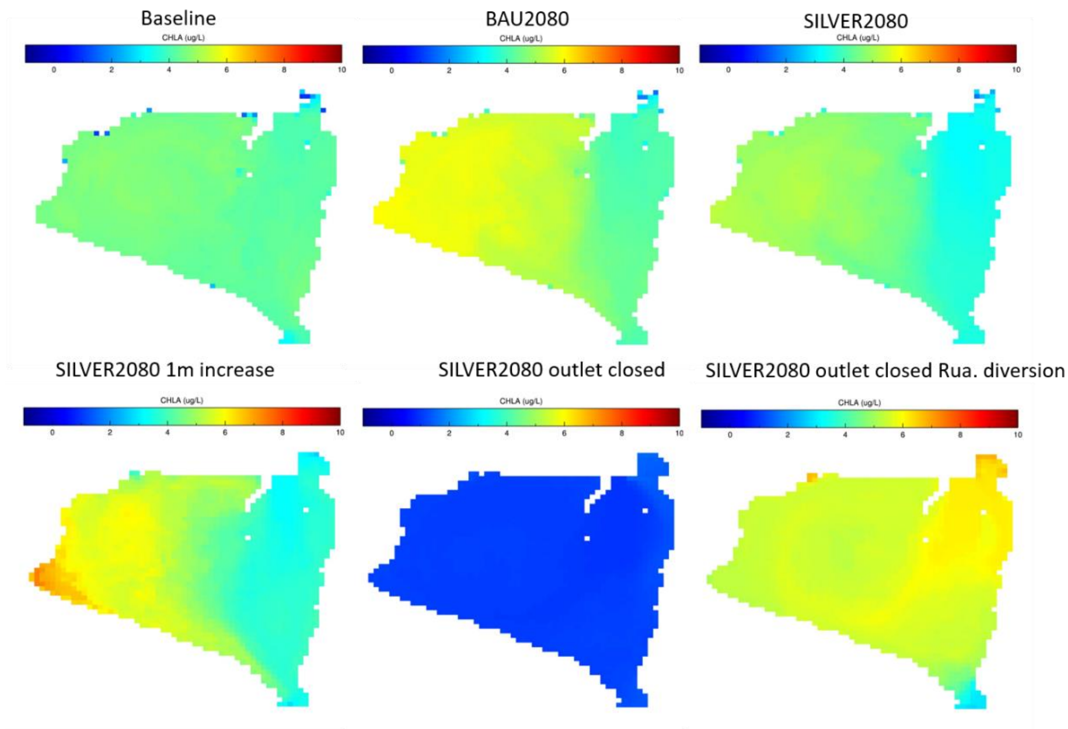

Figure 8. Simulated total chlorophyll *a* concentrations in Lake Onoke using three-dimensional models.

Total suspended sediments – 1-D and 3-D

While the external load of sediments reaching Lake Wairarapa was reduced by 29% under SILVER and GOLD, this only resulted in 3% reduction in median total suspended solids (TSS) within the lake. This is due to the dominant influence of resuspension from lake sediments due to currents and waves. A 43% reduction in TSS entering Lake Onoke under GOLD and SILVER 2080 resulted in a 5% reduction in median TSS concentrations within the lake. Again this is due to the dominant influence of sediment resuspension, combined with TSS entering from Lake Wairarapa. In addition most suspended sediment entering lakes is quickly deposited, especially silt and sand fractions.

Three-dimensional simulation outputs of TSS concentrations in Late Wairarapa all show a similar pattern of spatial variation with high concentrations associated with eastern areas of the lake and lower concentrations in Alsop's Bay (Fig 9). The obvious changes in TSS concentration came as a result of the 1 m lake level increase with large reductions in median TSS. This is due to the decreased influence of wind and waves on suspended sediment resuspension. When all flows were diverted from the Ruamāhanga River there was an increased in simulated TSS in Alsop's Bay, likely derived from pulses of large inflow concentrations of suspended sediment.

Within Lake in Onoke 3-D simulation outputs of TSS showed higher concentrations within western lake areas under catchment scenarios (related to the clockwise lake circulation pattern found here), however lake outlet closed scenarios simulated generally higher TSS concentrations, especially near the Ruamāhanga inflow location (Fig. 10). This is most likely associated with less flushing under the scenarios, however when the Ruamāhanga was first diverted through Lake Wairarapa, the large increase in TSS is likely derived from higher TSS derived from resuspension in Lake Wairarapa. Under the outlet closed scenario with no Ruamāhanga division, there is lower flushing, causing higher TSS concentrations. One-dimensional modelling also showed higher TSS concentrations in Lake Onoke under the outlet closed scenario with all Ruamāhanga diversion. And under non-diversion simulations showed reduction TSS concentrations (in contrast to the 3-D model which showed an increase).

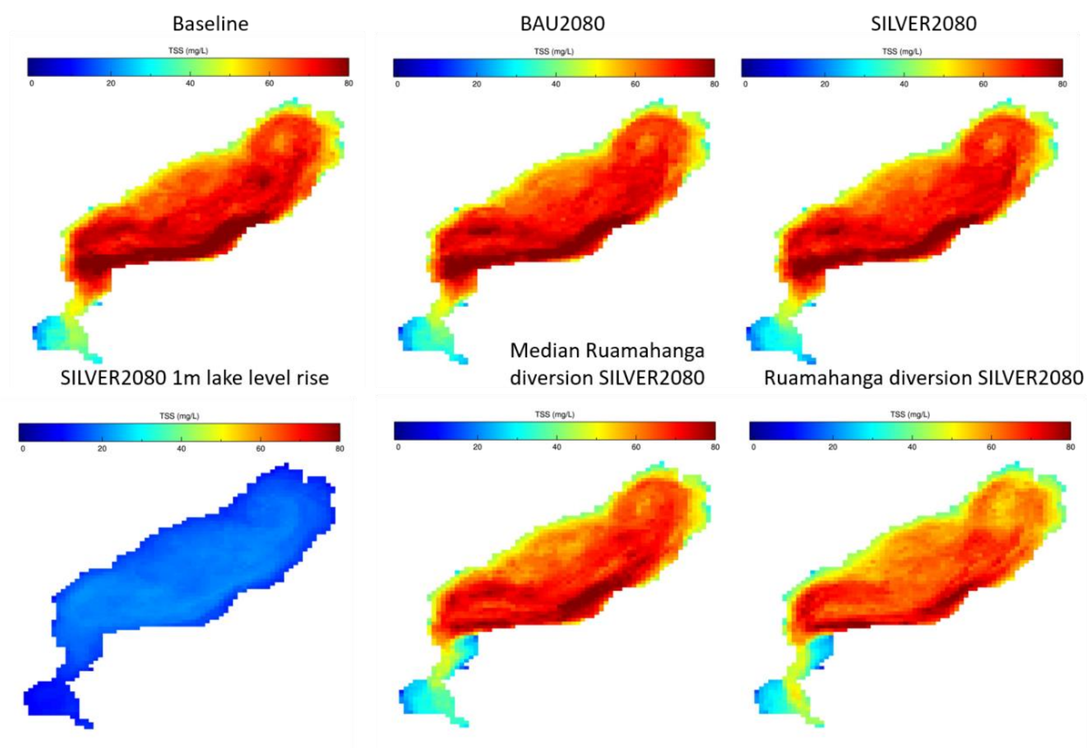

Figure 9. Simulated total suspended solids concentrations in late Wairarapa using three-dimensional models.

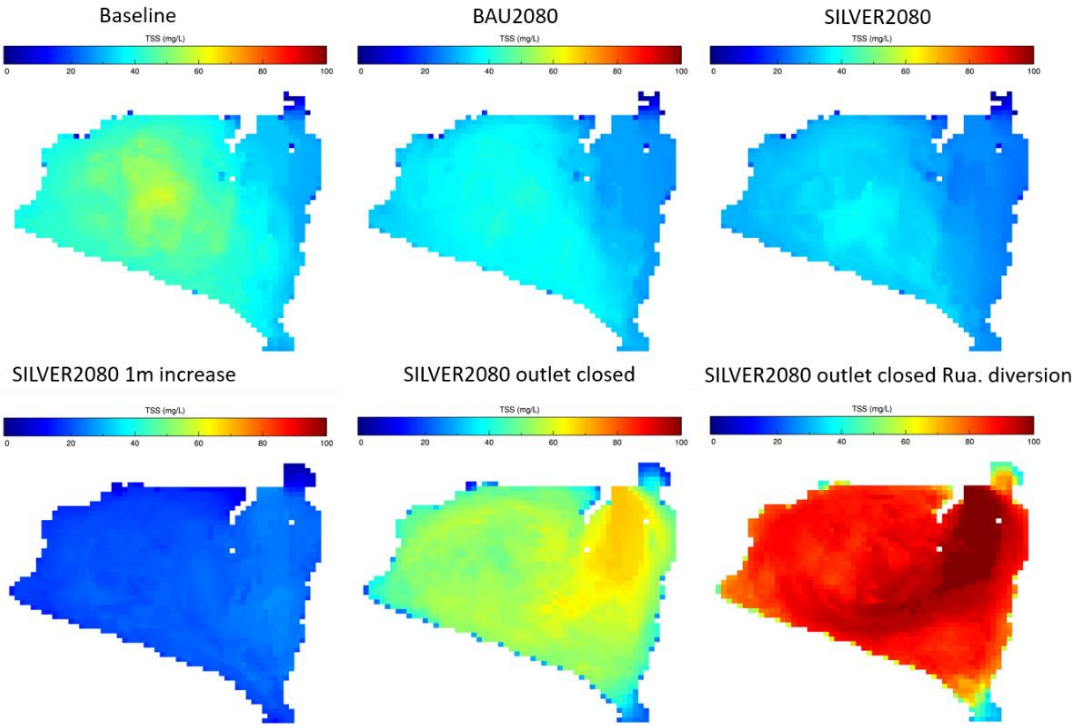

Figure 10. Simulated total suspended solids concentration in Lake Onoke using three-dimensional models.

Macrophytes

For Lake Wairarapa, 1-D modelling shows that under the 1 m depth increase scenario, macrophytes could re-establish within the lake to greater than 40% coverage, dramatically increasing the water quality within the lake, reducing TLI to 4.4. This represents a regime shift in the lake to an alternative stable state, which none of the other scenarios showed the potential to achieve. The silver and gold 2080 scenarios simulated that macrophytes could recover to 10% coverage.

One-dimensional modelling simulated that under the current conditions macrophytes cannot re-establish in Lake Onoke

Table 1. Summary of one-dimensional simulation results for water quality variables in Onoke and Wairarapa, colour-coded for NOF bands.

Lake Wairarapa	Modelling dataNo NOF band	Modelling dataNOF band	BAU	SILVER	GOLD	SILVER + 1 m deth	Silver + Onoke outlet closed	Silver + Onoke outlet closed + all flows of Ruamāhanga into Lake	Silver + all flows of Ruamāhanga into Lake Wairarapa	Silver + non-flood flows of Ruamāhanga into Lake Wairarapa
E. coli										
Phytoplankton		C	C	B	B	C			B	B
Total nitrogen		B	B	B	B	B			C	B
Total phosphorus		D	D	D	D	D			D	D
Trophic Level Index -TLI	5.6		5.5	5.3	5.3	5.2			5.2	5.1
Total suspended sediment	65		64	63	63	46			60	58
Ammonia toxicity		A	A	A	A	A			A	A
Cyanobacteria (planktonic)	A		A	A	A	A			A	A
Macrophytes (% cover)	0.027		3.93E-08	11	11	44			17	1.40E-05
Lake Onoke										
E. coli										
Phytoplankton		C	C	B	B	C	B	B		
Total nitrogen		B	B	B	B	B	B	B		
Total phosphorus		D	D	C	C	C	C	C		
TLI	5.4		5.2	5.0	5.0	4.9	4.8	5.0		
Total suspended sediment	32		31	30	30	23	22	33		
Ammonia toxicity		A	A	A	A	A	A	A		
Cyanobacteria (planktonic)	A		A	A	A	A	A	A		
Macrophytes (% cover)	0.030		0.0321501	0.0321057	0.032106	0.0373972	0.00646906	0.0128636		

Table 2. Summary of three-dimensional simulation results for water quality variables in Onoke and Wairarapa, colour-coded for NOF bands.

Attribute	Modelling data		BAU		Silver		Gold		Silver + 1m additional depth		Silver + Onoke outlet closed		Silver + Onoke outlet closed + all flows of Ruamāhanga into		Silver + all flows of Ruamāhanga into Lake Wairarapa		Silver + non-flood flows of Ruamāhanga into Lake Wairarapa	
	No NOF band	NOF band																
Lake Wairarapa Middle																		
Phytoplankton		C	–	C	–	C	–	C	↓	D					↓	D	–	C
Total nitrogen		B	–	B	–	B	–	B	–	B					–	B	–	B
Total phosphorus		D	–	D	–	D	–	D	↑	C					–	D	↑	C
Trophic Level Index -TLI	5.49		–	5.49	–	5.31	–	5.32	–	5.17					–	5.56	–	5.24
Total suspended sediment	71		1418	70	1417	70	1429	71	344	21					1357	68	1481	73
Ammonia toxicity		A	–	A	–	A	–	A	–	A					–	A	–	A
Lake Onoke Middle																		
Phytoplankton		B	↓	C	–	B	–	B	↓	C	↑	A	↓	C				
Total nitrogen		C	↑	B	↑	B	↑	B	↑	B	↑	B	–	C				
Total phosphorus		B	–	B	–	B	–	B	–	B	↑	A	–	B				
TLI	4.64		–	4.63	–	4.45	–	4.45	–	4.51	↑	3.98	–	5.00				
Total suspended sediment	59		-30	41	-36	37	-36	38	-65	21	-9	53	56	92				
Ammonia toxicity		A	–	A	–	A	–	A	–	A	–	A	–	A				

Summary

- For the Ruamāhanga division scenarios there were conflicting results between 1D and 3-D models. One-dimensional models simulated a decrease in chl *a* concentration, and 3-D models simulated and increase. The basic principle of modelling states that the model should be no more complicated than necessary to provide the needed information with acceptable accuracy. Considering the large spatial variation of water quality and lakes Onoke and Wairarapa, 3-D modelling results provide a more accurate representation of the changes in the spatial variation of hydrodynamics and water quality inputs. Therefore, the result of the 3-D models that diversion scenarios can potentially increase chl *a* concentrations is acceptable. However the below median Ruamāhanga can division scenarios only estimated a small increase in chl *a* concentrations, and within the error terms of chl a estimation, this may not prove to be significant.

- SILVER2080 and GOLD2080 catchment scenarios were not significantly different in lakes Wairarapa and Onoke.

- High internal loading of phosphorous from sediments in Lake Wairarapa results in reduction of effectiveness of mitigations compared to Lake Onoke. Catchment scenarios had a greater influence on Lake Onoke trophic status when compared to Wairarapa, due to the shorter residence time and lower internal load relative to external load (from the sediments) in Onoke.

- High sediment resuspension from the bottom sediments in Lake Wairarapa results in continued low clarity under all scenarios (except macrophyte re-establishment under a 1 m increase, with best water clarity achieved in the 1 m depth increase scenario (0.15 m Secchi, compared to 0.1 m under Baseline). Secchi depth is a measurement of water clarity whereby a black-and-white disk is lowered down from the lake surface until it disappears from view from the observer. The depth with the disc disappears from view is termed the Secchi depth. For significant macrophyte re-establishment Secchi depth would need to reach 0.5 m (Jeppesen et al 2005). The 3-D modelling showed potential for this to be achieved with lake level manipulation.

- Within Lake Wairarapa, a 1 m increase in lake depth combined with SILVER2080 catchment scenario increased **95th percentile** chl *a* concentrations when compared to the SILVER2080 scenario. This was caused by less light limitation due to less sediment resuspension from the lake bottom. However, the net effect increased water clarity and the potential for macrophyte re-establishment. These conclusions also apply for the 1 m increase scenario in Lake Onoke.

- For Lake Wairarapa, 1-D modelling shows that under the 1 m depth increase scenario, macrophytes could re-establish within the lake to greater than 40% coverage, dramatically increasing the water quality within the lake, reducing TLI to 4.4. This represents a regime shift in the lake to an alternative stable state, which none of the other scenarios showed the potential to achieve. However the macrophyte simulations have limited capacity to simulate the complex factors that would allow potential re-establishment. Therefore it is possible that the 1 m depth level increase is not the only scenario that would allow potential macrophyte re-establishment. The SILVER and GOLD 2080 scenarios simulated that macropytes could recover to 10% coverage. One potential management option would be to temporarily increase the lake depth, allowing macropyte re-establishment and a regime shift within the lake. The macrophyte scenarios clearly show that if external load was reduced, and water levels increased macrophyte re-establishment presents the best opportunity for water quality improvement and Lake Wairarapa.

- While 'the summer outlet closed scenario' generally brought about the greatest improvement in water quality in Onoke, there could be an increased risk of Cyanobacterial blooms. As long as the residence time remains under 20 days this risk would be very low. However under drought conditions and low-flow, the residence time could increase. Under this scenario, when Ruamāhanga waters were diverted through Lake Wairarapa, there was a 63.2% reduction in *E.coli* within Onoke, owing to higher mortality and settling within Lake Wairarapa, related to the longer residence time involved in taking the Lake Wairarapa flow path. In addition the lack of flushing under the scenario increased TSS concentrations, thereby limiting phytoplankton growth. Under low flow conditions and at times when TSS input from Lake Wairarapa was low, conditions would favor more algal growth.

- Water quality in Lake Onoke is susceptible to changes in water quality in Lake Wairarapa, particularly in relation to chl *a* and TSS. High lake bed sediment resuspension events in Lake Wairarapa are transported to Lake Onoke. Modelling shows chl *a* in Onoke is partially derived from Lake Wairarapa. The very low residence time in Onoke (0.5 days) does not allow for significant phytoplankton growth. However, 3-D simulations show longer residence times in the western lake, and higher phytoplankton concentrations.

- The Ruamāhanga division scenarios present and innovative management option. When wind speeds are high in Lake Wairarapa, high sediment resuspension occurs. Under these conditions, the lake could be flushed with Ruamāhanga flows, thereby exporting suspended sediment, and any bound phosphorous and suspended organic matter. This would be an effective strategy to potentially reduce internal nutrient and sediment loading from the lake bed, and mitigate the very high sedimentation rate. However, under this scenario there would be high TSS transport into Lake Onoke. Provided the mouth is open much of this flow would be exported to the ocean. However, the effects on local seabed benthic communities may need to be considered.

- While 3-D modelling showed Ruamāhanga diversion have the potential to increase phytoplankton growth in Lake Wairarapa, this would be negated if macrophytes could re-establish within the lake

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Appendix

Table 1. Scenarios and assumptions.

Management option	Modelling inputs	Notes	Shorthand associated naming conventions
BASELINE	**Calibrated catchment model**	**All flows and concentrations based off a 22 year flow simulation from 1/7/1992 to 30/6/2014 (applies to all scenarios)**	**BASELINE**
BAU	Steep slope retirement/planting, stock exclusion from waterways, wastewater discharging partially to land, Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP), Tier 1 immediately.		**BAU2025/2040/2080**
SILVER	Steep slope retirement/planting, stock exclusion from waterways, riparian planting, wastewater discharging only to land, Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP), Tier 1 immediately Tier 2 mitigations by 2040 Tier 3 mitigations by 2080		**SILVER2025/2040/2080**

GOLD	Steep slope retirement/planting, stock exclusion from waterways, riparian planting, wastewater discharging only to land, Minimum flows and allocation amounts based on limits set in Proposed Natural Resources Plan (PNRP), Tier 1 mitigations immediately (as BAU), Tier 2 mitigations by 2025, Tier 3 mitigations by 2040		**GOLD2025/2040/2080**
All flows of the Ruamahanga River entering Lake Wairarapa. No flow by-passing via the diversion.	Gold scenario inflows (river flows and concentrations)	DYCD 057 Replaced with 200. GOLD2080 Flows, ELCD 057 Replaced with 200. GOLD2080 Flows	**ALL_RUA_GOLD2025/2040/2080**
As above.	Silver scenario inflows (river flows and concentrations)		**ALL_RUA_SILVER2025/2040/2080**
Flows below median flow go into Lake Wairarapa, and flows above median flow are by-passed.	Silver scenario contaminant concentrations inflows	DYCD 057 Replaced with 200. Silver2080 Flows. Flows below median of 78.10 m3 s-1	**MEDIAN_RUA_SILVER2025/2040/2080**
Lake Onoke outlet closed January to March every year.	Silver scenario contaminant concentrations inflows.	This includes a separate sub-scenario with the Ruamāhanga River diverted back into Lake Wairarapa	**Outlet_Close_SILVER2025/2040/2080** **Outlet_Close_Rua_All_SILVER2025/2040/2080**

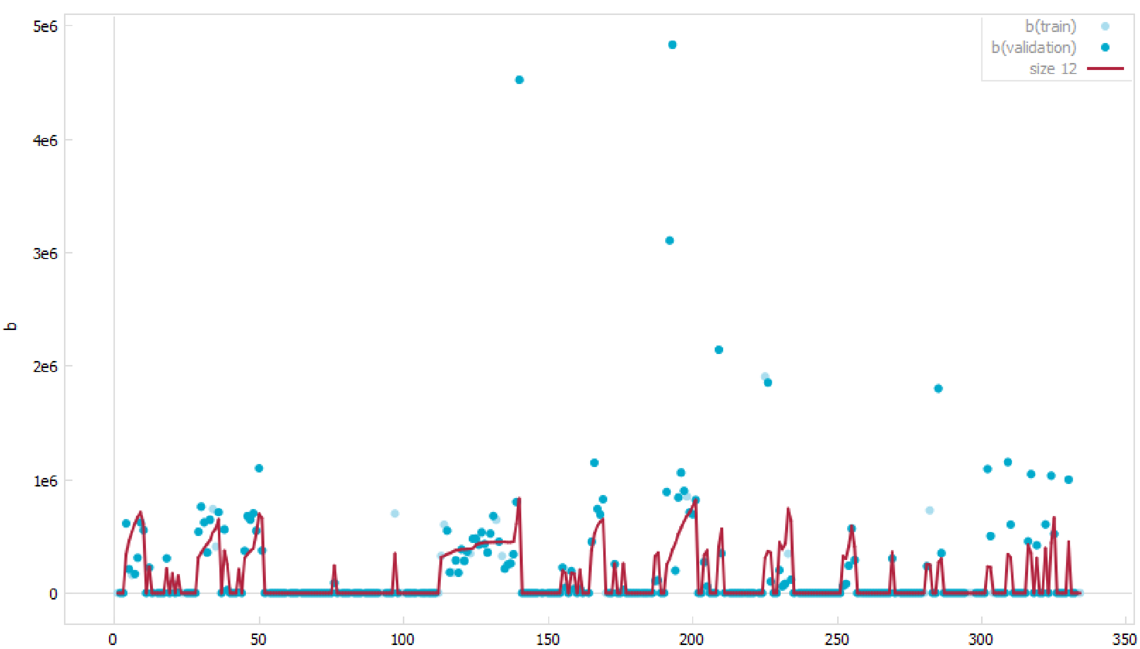
		(used onoke_all_zero_200 folder), New water balance with no ocean inflow Jan-March and high water level (95 percentile).	
Deepening both lakes by 1m.	Extra depth created by operating at a higher level. Silver scenario inputs	Operate at 1m higher level	**1m_Inc_SILVER2025/2040/2080**

Barrage inflow

There is uncertainty in deriving barrage inflow into Lake Wairarapa. The flow at the barrage gates has been monitored since August 2012, using a side-looking Acoustic Doppler Current Profiler (ADCP) (Thompson and Mzila 2015), however estimations for backflow into Lake Wairarapa were needed for the entire simulation period. A statistical model was using a symbolic regression model trained over the monitored barrage flow period. This model used Onoke water levels and Lake Wairarapa outflow as inputs:

Barrage inflow = (324.89*Onoke water level - 3018618.30)/exp(*barrage outflow*)

for simulations *barrage outflow* was determined using a water balance. Correlation Coefficient = 0.58, mean absolute error=122125.75 m3/day. Note that this method underestimated large barrage inflows (Appendix Fig. 1).



Appendix Figure 1. Barrett inflow estimations (redline) compared to in situ measurements (blue dots).