Flows of water and nutrients to Lake Tarawera and connected lakes

A thesis

submitted in fulfilment

of the requirements for the degree

of

Master of Science (Research) in Earth Science

at

The University of Waikato

by

Nicola Jane Wilson

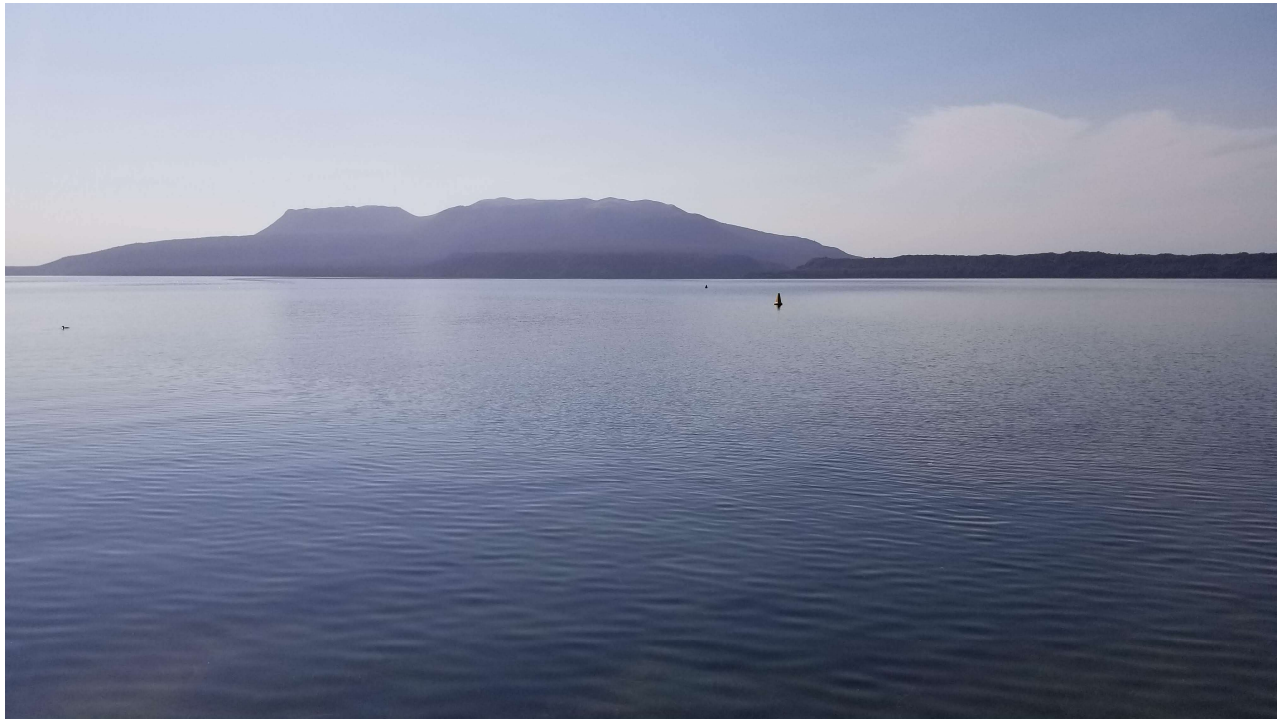
THE UNIVERSITY OF WAIKATO

Te Whare Wānanga o Waikato

2022

Thanks to my supervisors Troy Baisden and Dave Campell from Waikato University

Thanks BOPRC and Tarawera Ratepayers Society who helped fund this research



25 May 2022 presentation to Rotorua Lakes TAG

Objectives

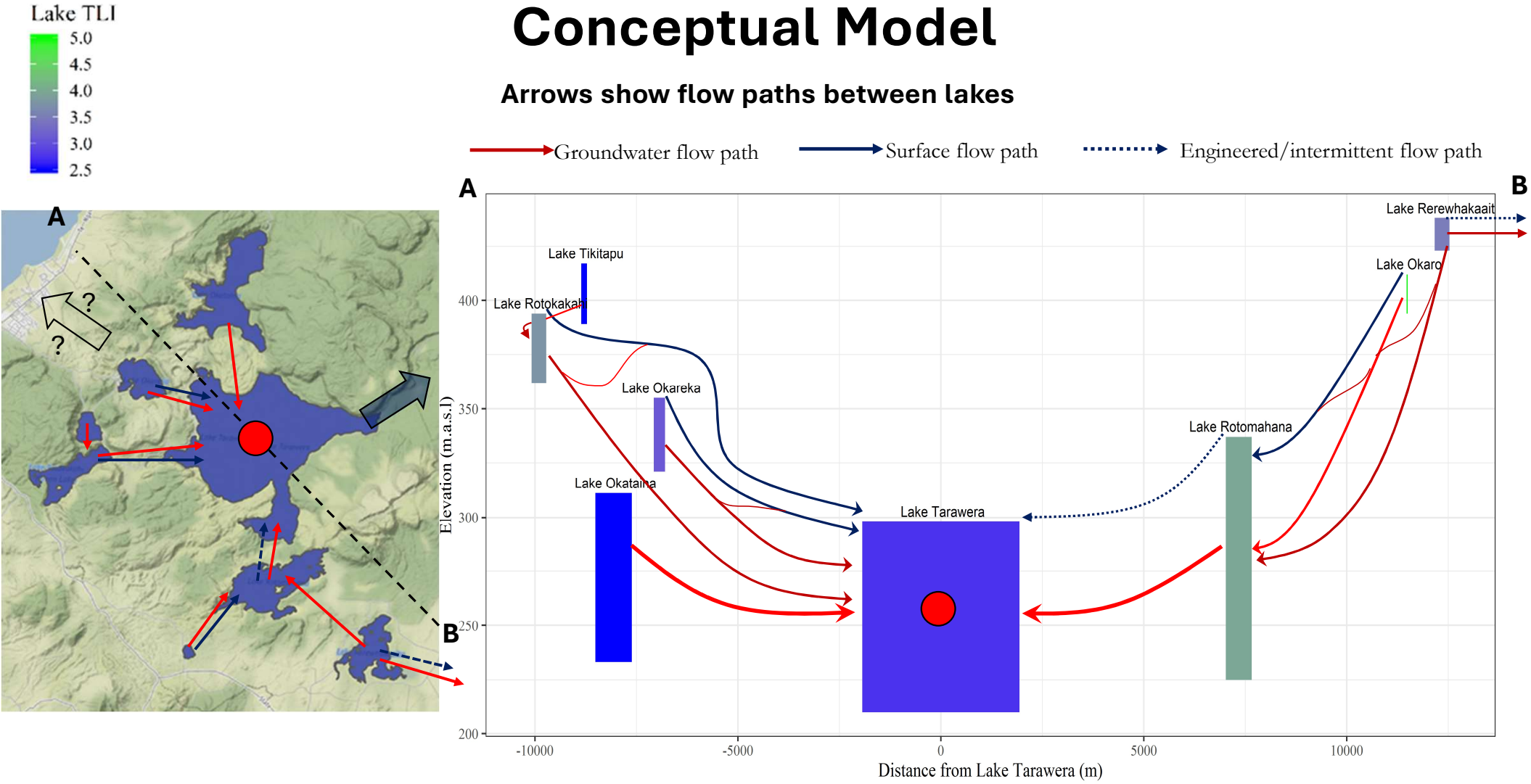
1) To improve understanding of groundwater flows in the Lake Tarawera catchment → Water isotopes
2) Describe flows and nutrient loads to Lake Tarawera and hydraulically connected lakes under different climate and land use scenarios → Water balance approach

“The Greater Tarawera Lakes”

- Seven lakes drain into Lake Tarawera via groundwater and/or surface water connections
- Most of outflow from the greater catchment is to the east via the Tarawera River
- Some outflow from the Rerewhakaaitu catchment towards the Waikato
- Possibility of some groundwater flow towards Lake Rotorua???

Conceptual Model

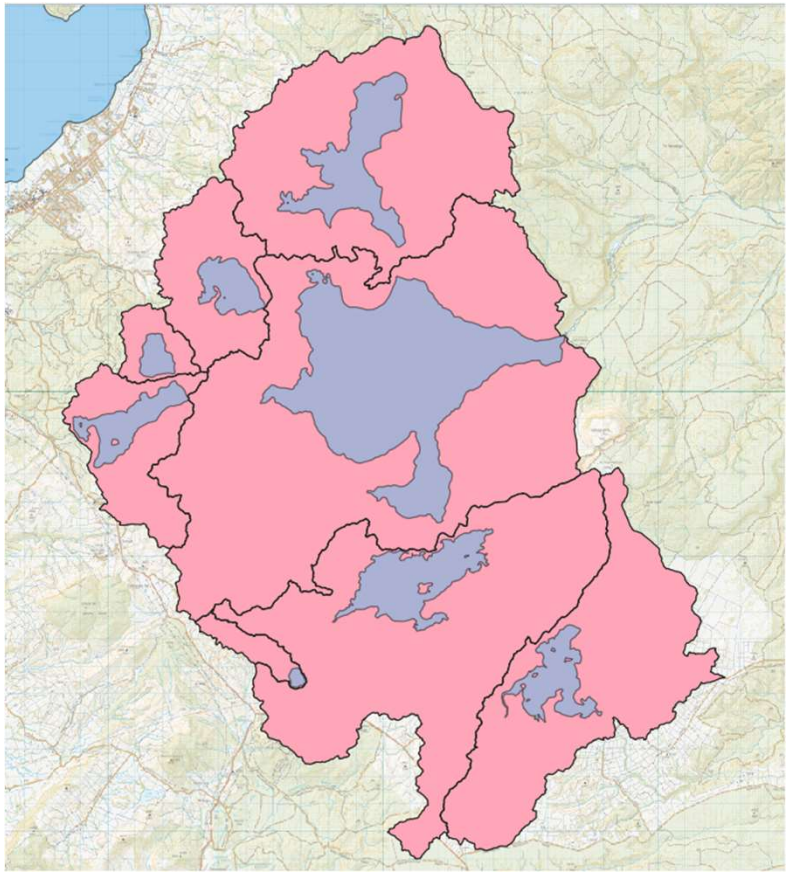
Arrows show flow paths between lakes



Conceptual model idea: Alastair MacCormick, slide credit: Chris McBride

Terminology

- Catchment vs local catchment
- Catchment equals local catchment for Lake Okaro, Okareka, Okataina, Rerewhakaaitu, and Tikitapu
- Catchment does not equal the local catchment for Lakes Rotokakahi, Rotomahana and Tarawera
- Greater Tarawera Lakes are all eight lakes



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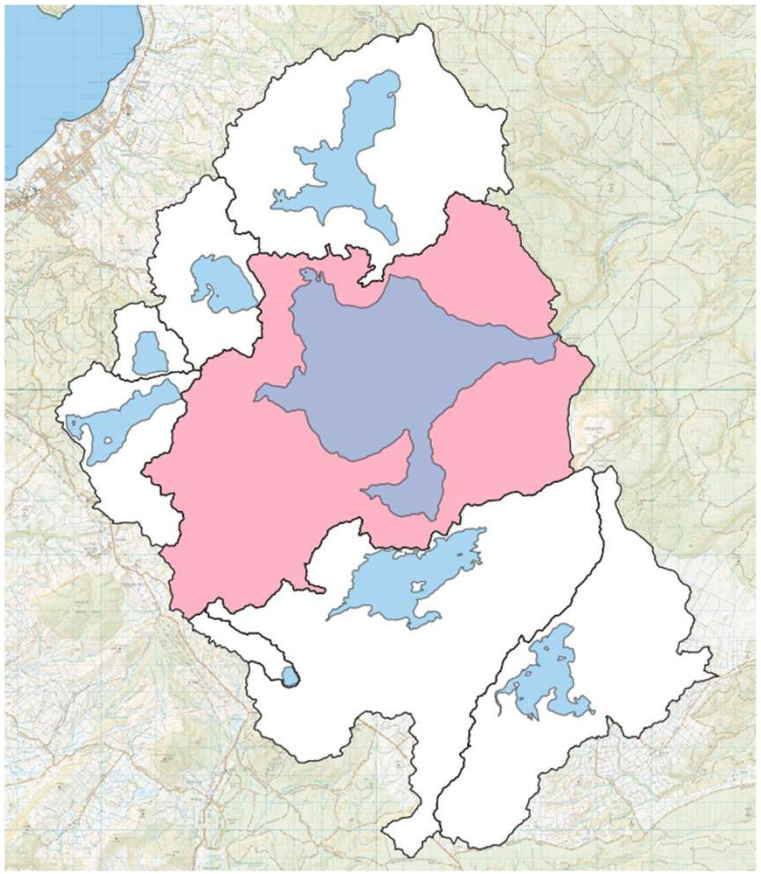
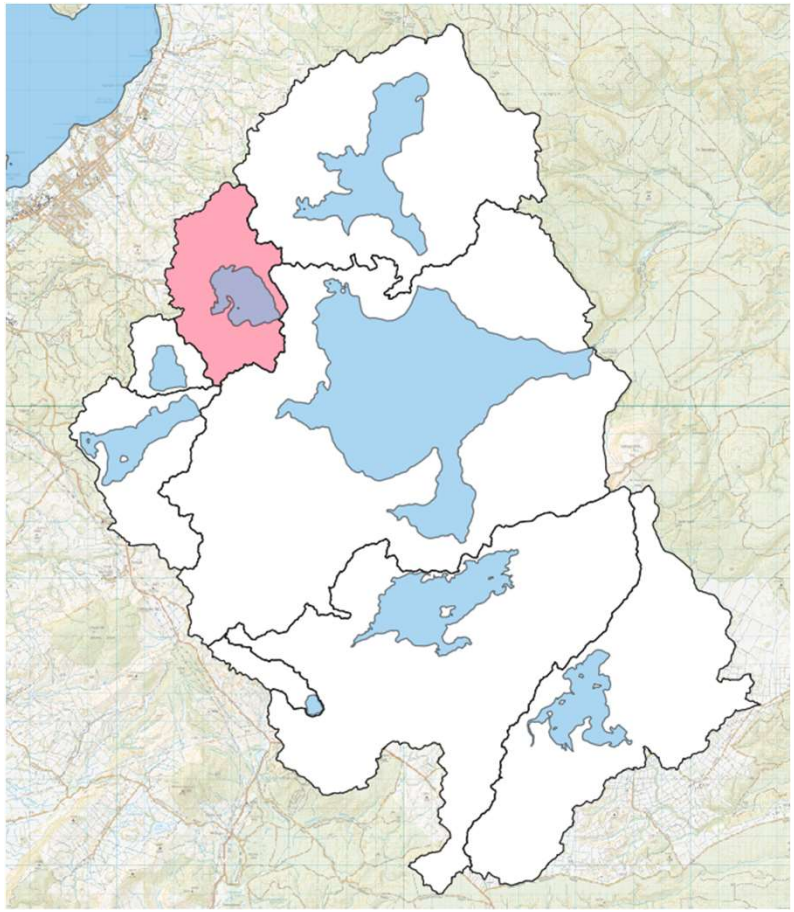


Lake Tarawera catchment

Lake Tarawera **local** catchment



Lake Ōkareka catchment

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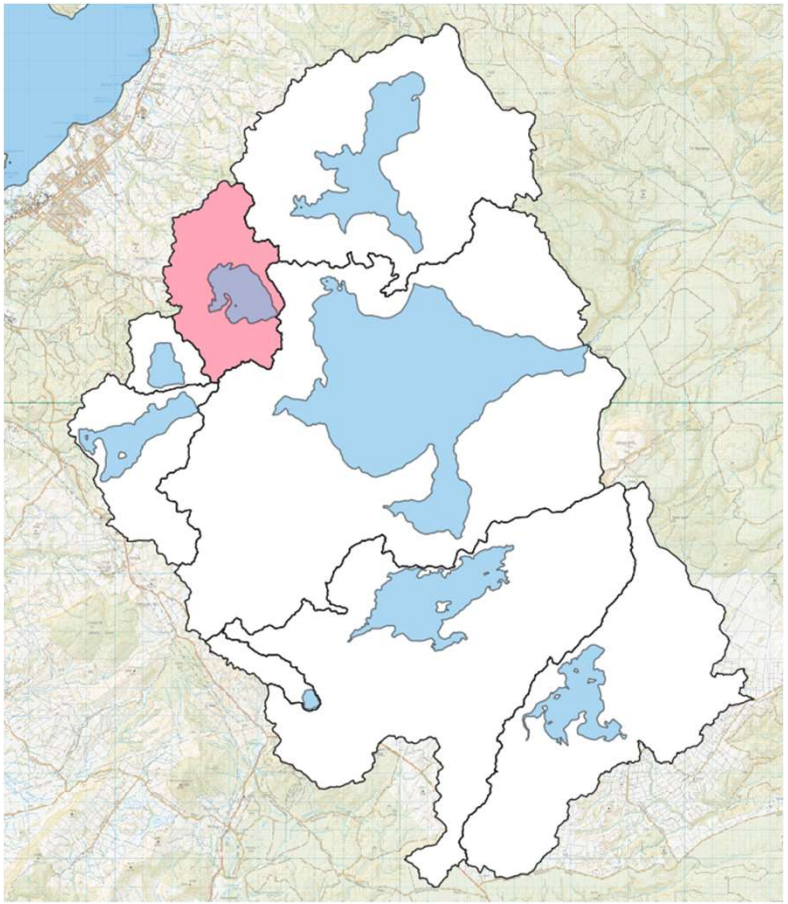


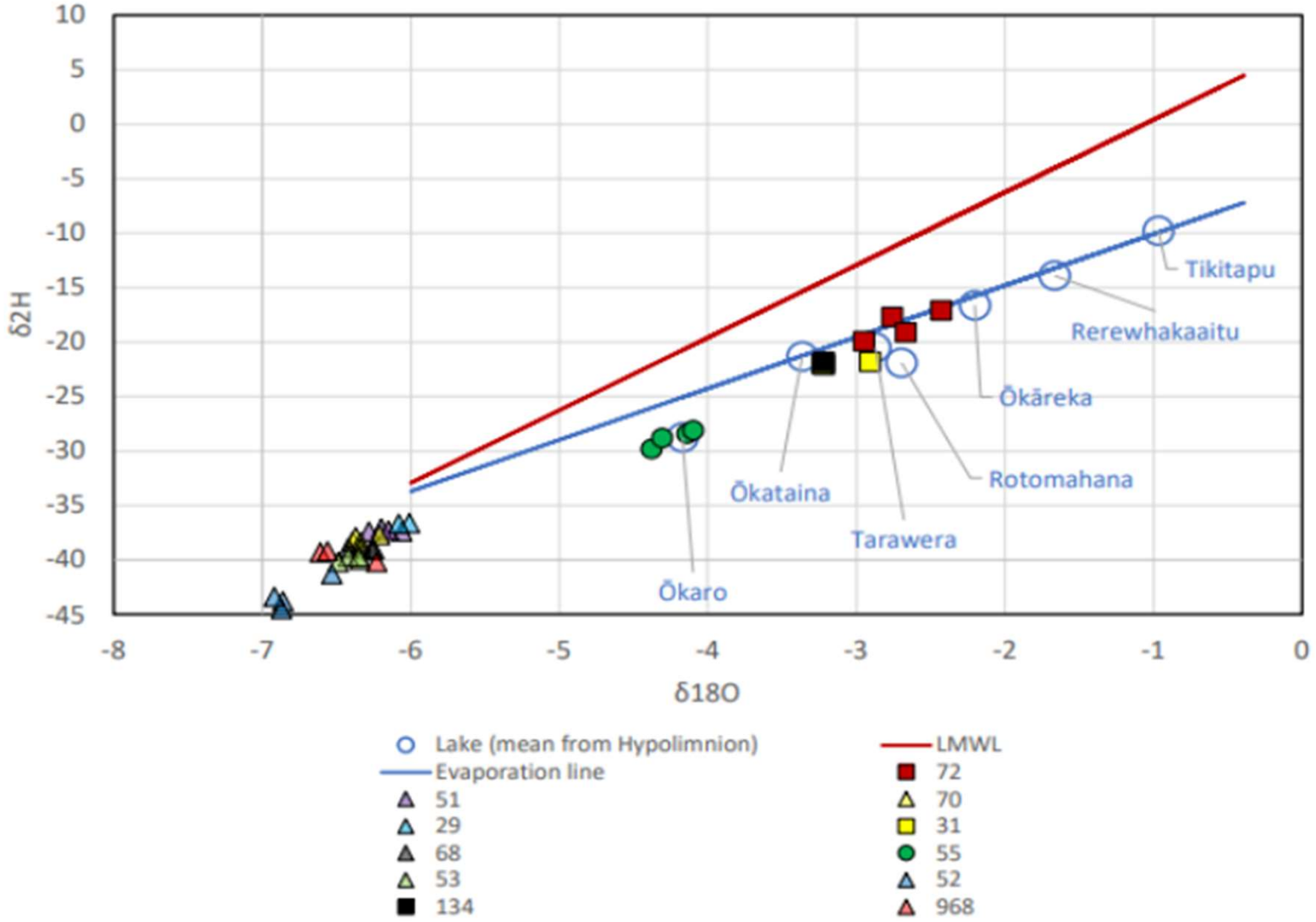
Lake Ōkareka **local** catchment

Understanding groundwater flow using isotopic analysis of water

Investigation of groundwater flow within and out of the Greater Tarawera Catchment using isotopes of water. Analysis of water from:

1. Groundwater within and outside of catchment
2. Surface water inflows to Lake Tarawera
3. Surface water outflow from Lake Tarawera (the Tarawera River upstream and downstream of the falls)
4. Surface water inflows to Lake Rotorua

Isotopic composition of groundwater in Greater Tarawera catchment



Mix Lake/Rainfall · Mix Lake/Rainfall (geothermal) · Rainfall · Uncertain

△ Groundwater ▽ Surface water inflow to Lake Tarawera

Water provenance determined via linear mixing models and visual analysis of biplots.

Conclusions:
Lake-to-lake groundwater connections between the lakes of the Greater Lake Tarawera catchment are not widespread and likely to be isolated to localised areas

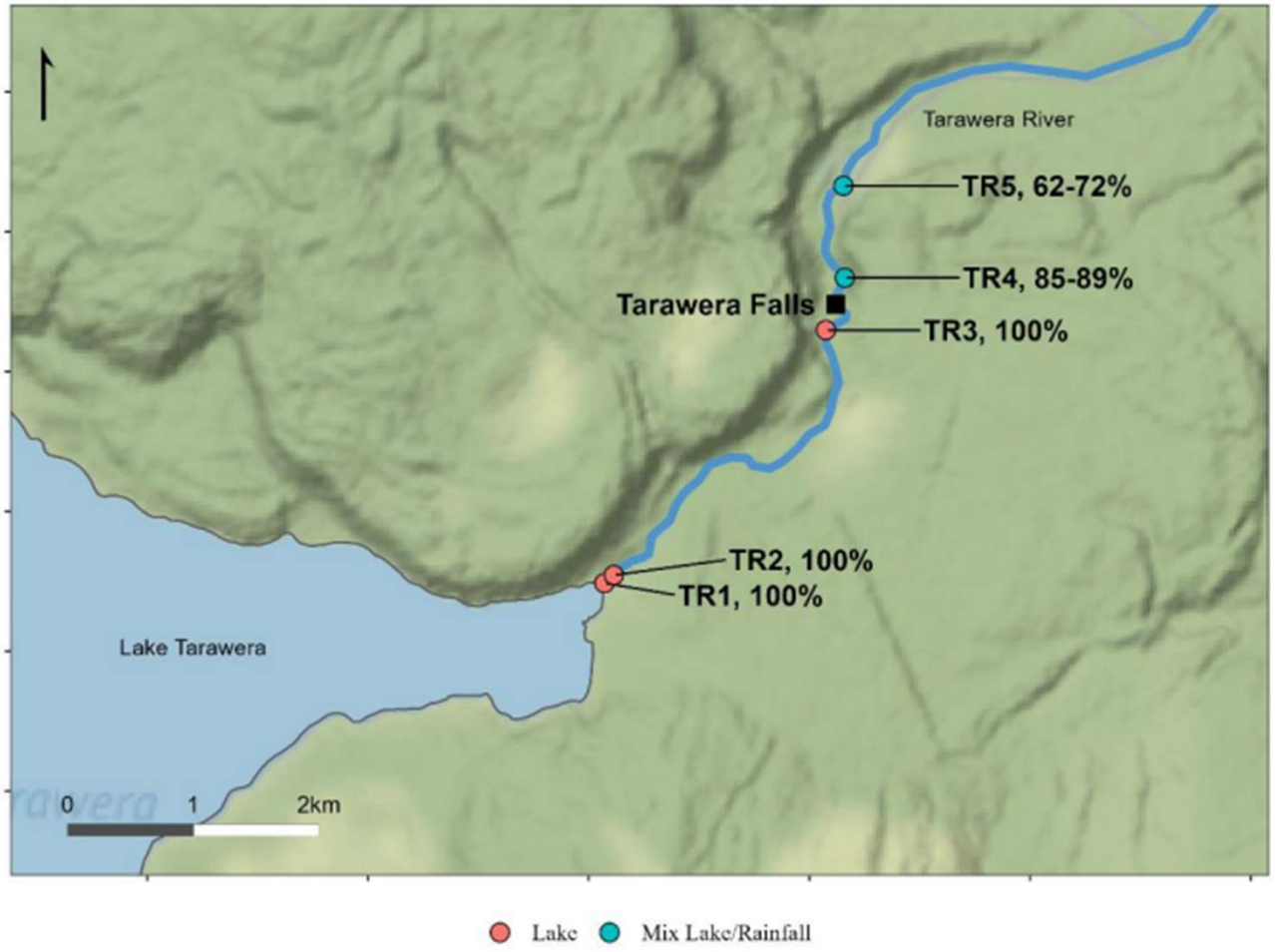
Groundwater flow out of the Greater Lake Tarawera catchment towards Lake Rotorua cannot be ruled out, although is not likely to comprise large part of the total groundwater outflow.

Outflow from the Lake Tarawera catchment

- Is there evidence of groundwater outflow from Lake Tarawera itself? → Yes, The isotopic composition of water from the deep bore at the outlet suggests so

- Are the flow gains observed in the Tarawera River downstream of the Tarawera Falls sourced from lake water from Lake Tarawera?

→ No, the isotopic composition of river water suggests it is rainfall-recharged groundwater, some of which has bypassed the lake



Source water contributions determined using a linear mixing model

Conclusions:

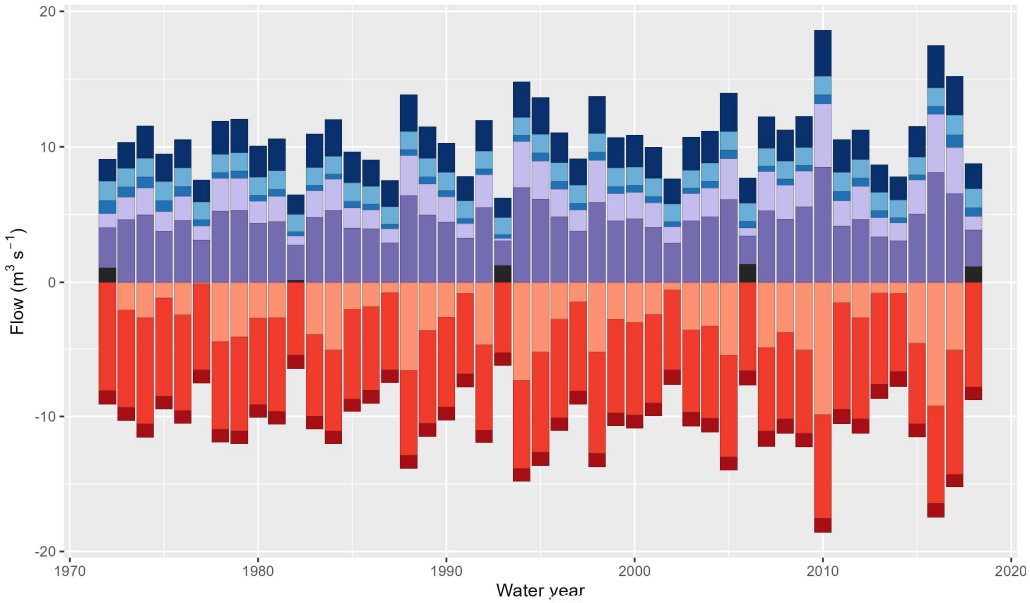
Gains in flow in the Tarawera River downstream of the Tarawera Falls are sourced from rainfall recharged groundwater, contrary to previous suggestions that they are sourced from lake water recharged groundwater. The magnitude of the gains indicates that some groundwater from the Tarawera catchment bypasses the lake.

Water Balance

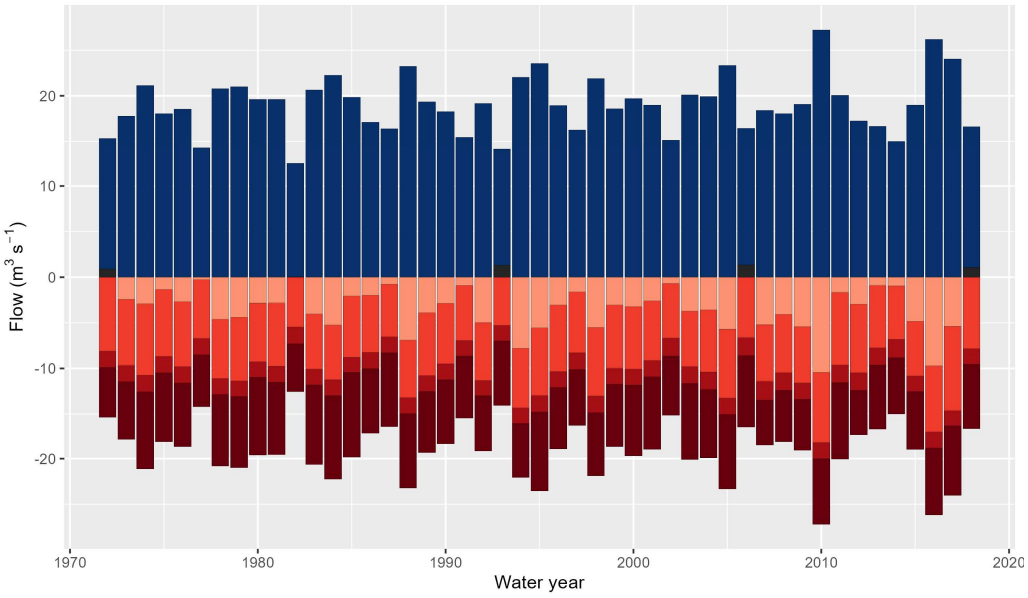
- Annual water balances calculated from 1972-2018 for each lake and catchment
- Variations observed year-year in the flow volumes and contributions of each source
- Different datasets and methods are used to assess uncertainties
- First study to account for land use, land cover and soil water stress in the calculation of evaporation

Water Balances 1972 - 2018

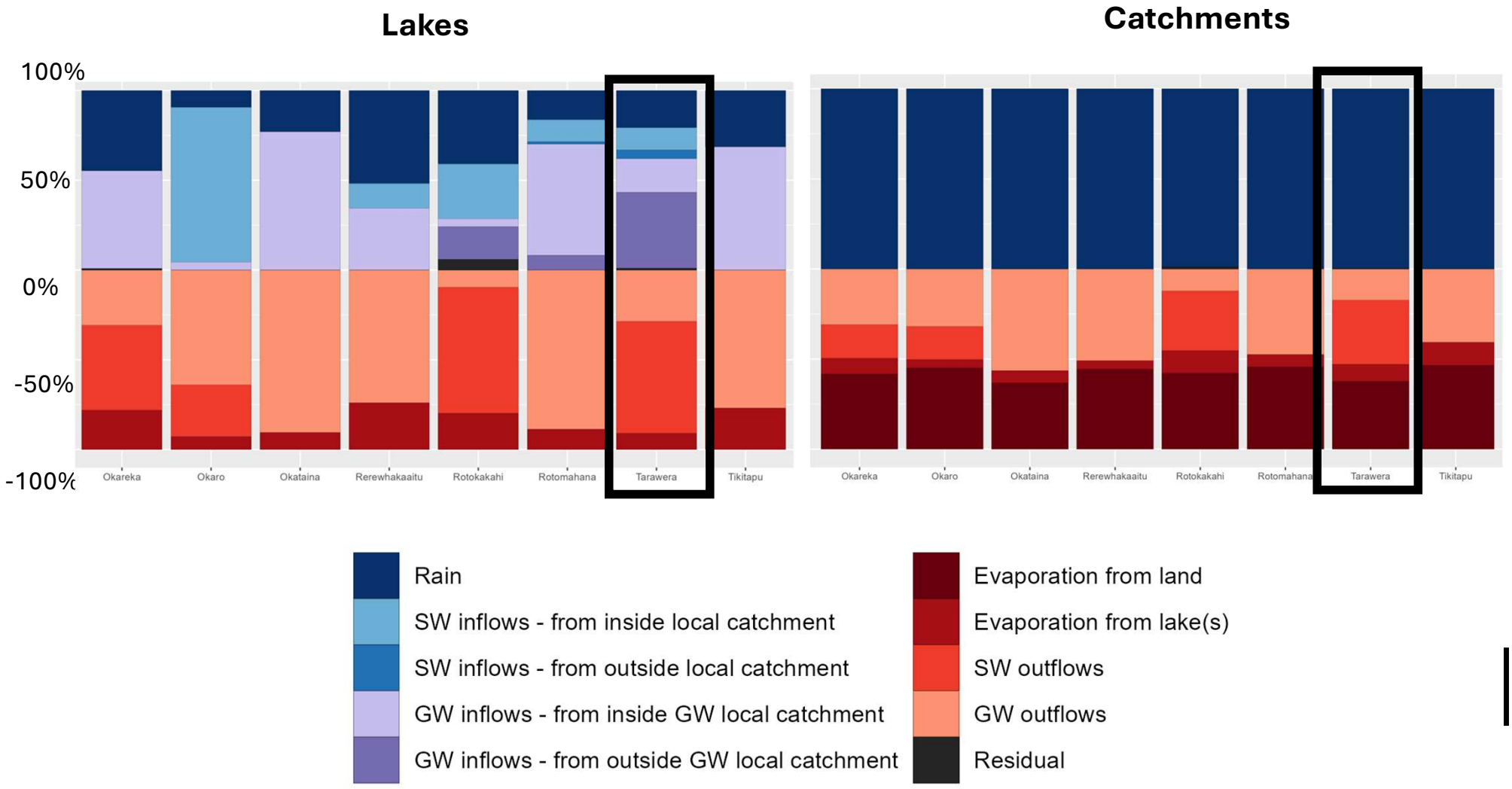
Lake Tarawera



Tarawera Catchment



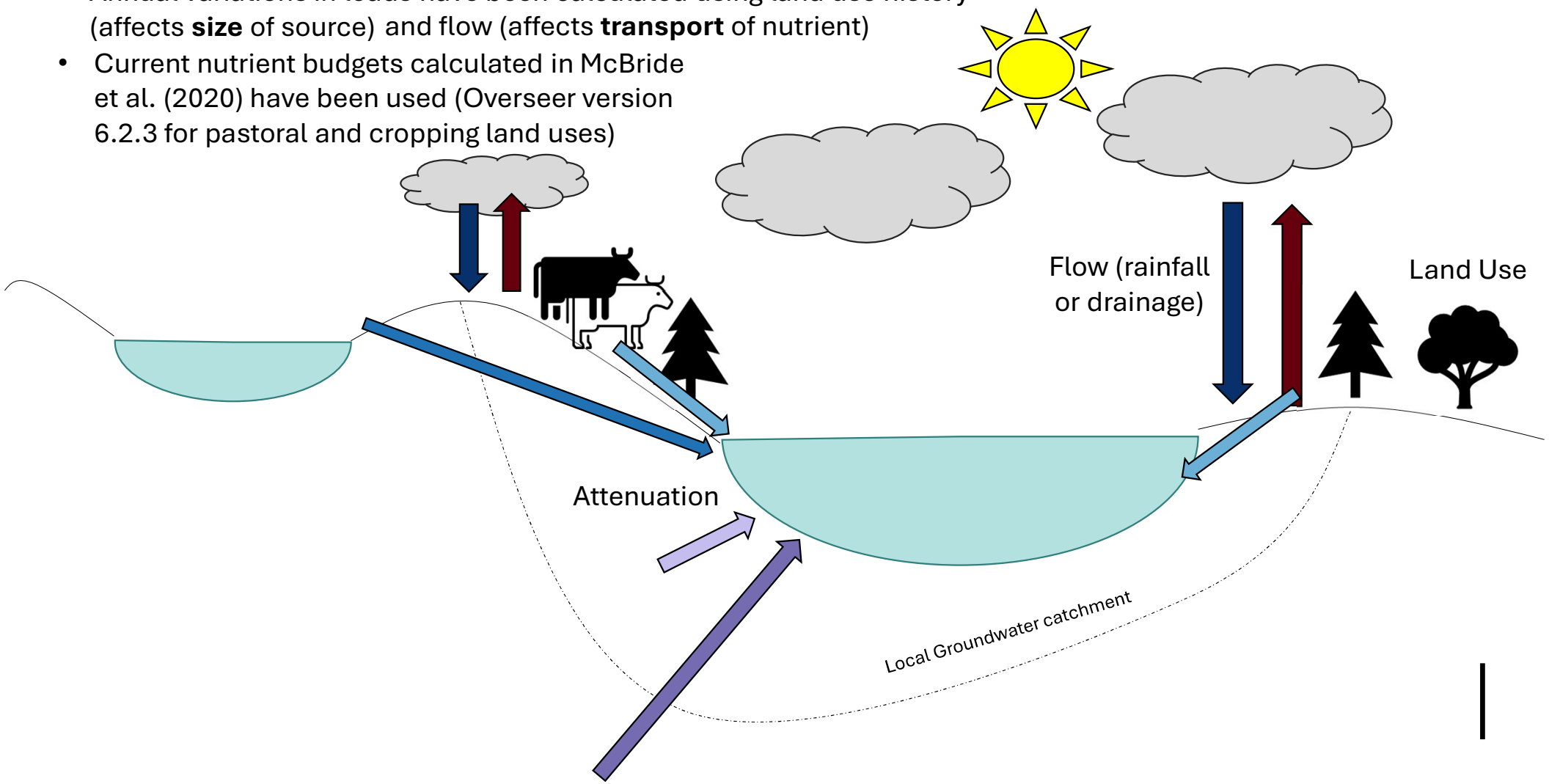
Average Contributions to Flow

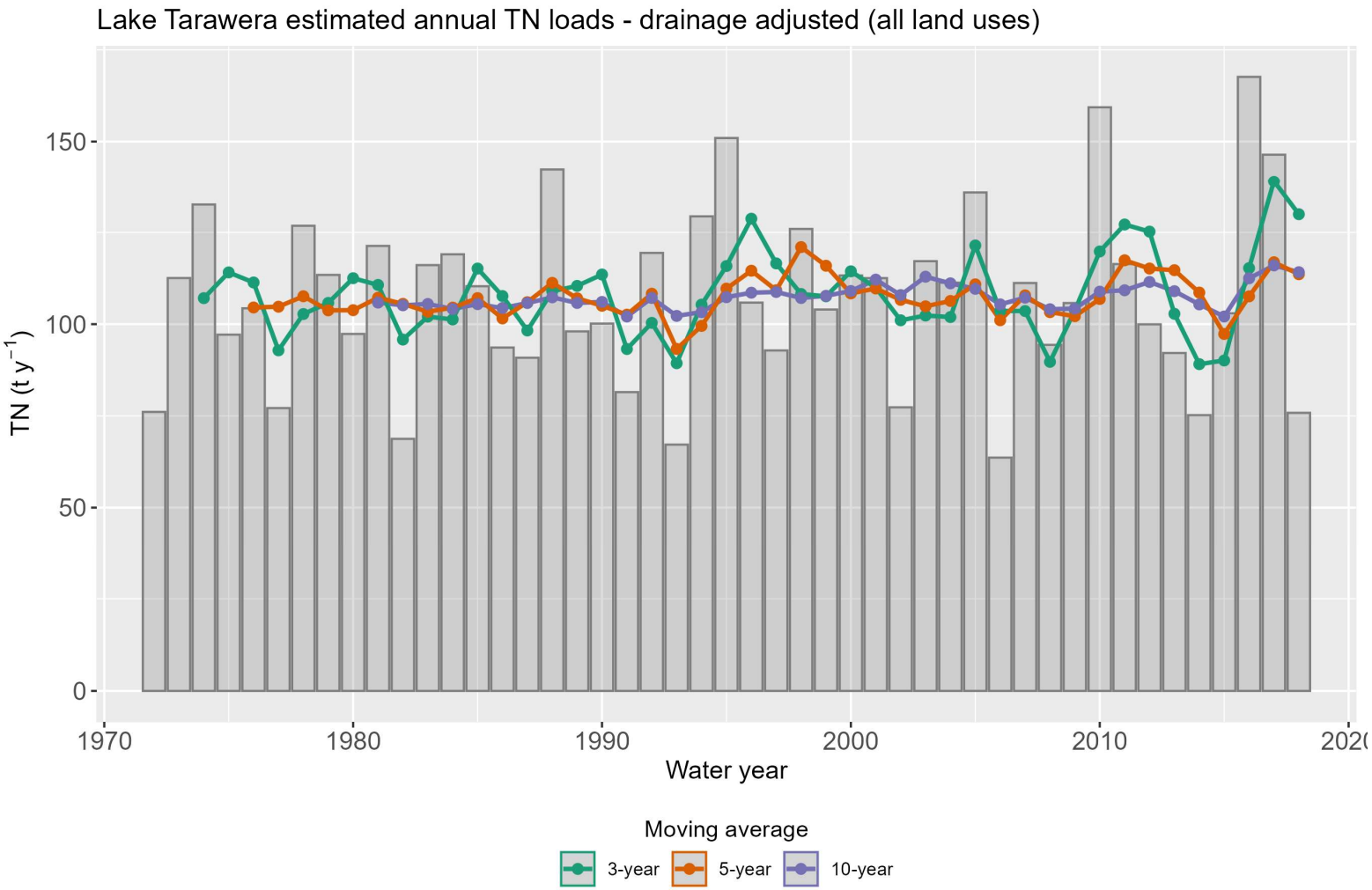


Nutrient Loads

- Nutrient loads to each lake from 1972-2018 have been estimated for TN and TP
- The magnitude of nutrient loads to the lakes depends on the **size** of the nutrient source and the **transport** of nutrients
- Hypothetical scenarios modelled for comparison – agriculture vs. native forest
- Different datasets and methods are used to assess overall uncertainties

- Annual variations in loads have been calculated using land use history (affects **size** of source) and flow (affects **transport** of nutrient)
- Current nutrient budgets calculated in McBride et al. (2020) have been used (Overseer version 6.2.3 for pastoral and cropping land uses)




Lake Tarawera estimated annual TN loads - drainage adjusted (all land uses)
150
100
50
0
TN (t y^{-1})
1970
1980
1990
2000
2010
Water year
Moving average
3-year
5-year
10-year

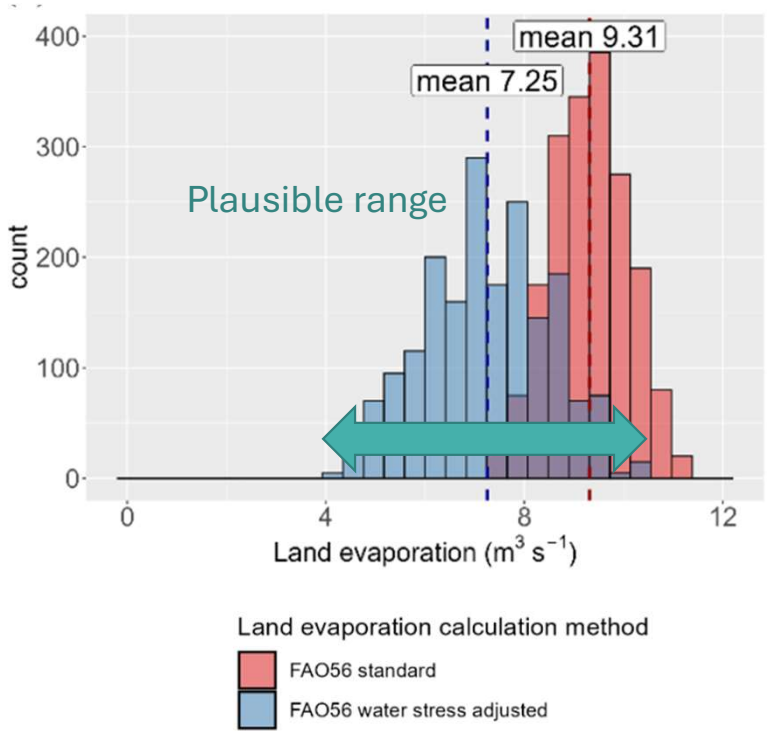
Interannual variability and uncertainty

- Water balance and nutrient load calculations were automated to run using every combination of datasets and methods considered in the study
- Results assessed as probability distribution
- I used the 95% confidence interval of the distribution to describe my results as a range
- Automation undertaken with R programming language

Interannual variability and uncertainty

- Bracketing approach used to describe uncertainties
- The outer limits of what's possible within a range of uncertainty most important
- Accounting for seasonal water stress decreases land evaporation by an average of 204 mm/y

Land evaporation – Lake Tarawera Catchment



Lake Tarawera Flows – Mean, median and 95% confidence interval of distribution from water balance

	Mean	Median	95% CI lower limit	95% CI upper limit
Inflows ($m^3 s^{-1}$)				
Rainfall	2.264	2.277	1.453	3.134
SW in (total)	1.870	1.828	1.582	2.391
SW in (from inside local catchment)[1]	1.336	1.331	1.274	1.398
SW in (from outside local catchment)[1]	0.534	0.497	0.308	0.948
GW in (total)	6.770	6.632	2.300	12.570
GW in (from inside local catchment)[1]	2.029	1.955	0.313	4.277
GW in (from outside local catchment)[1]	4.741	4.678	1.961	8.244

	Mean	Median	95% CI lower limit	95% CI upper limit
Outflows ($m^3 s^{-1}$)				
Lake evaporation	0.989	0.972	0.918	1.122
SW out	6.775	6.673	5.460	8.092
GW out	3.275	2.958	0.000	9.331
Water out of GT catchments[2]	-	-	-	-
Totals ($m^3 s^{-1}$)				
Inflow total	10.904	10.834	5.511	17.646
Outflow total	11.039	10.835	6.462	17.645

Lake Tarawera nutrient loads: land use scenarios

Summary statistics (t y^{-1})

	Nitrogen			Phosphorus		
	TN all native	TN current	TN all agriculture	TP all native	TP current	TP all agriculture
Mean	79.70	106.89	262.17	7.41	10.65	24.87
Median	79.65	106.82	262.08	7.40	10.65	24.84
95% CI lower limit	61.03	77.19	169.81	6.00	7.88	16.08
95% CI upper limit	97.45	135.08	350.09	9.00	13.79	34.80
Minimum	52.41	63.53	127.25	5.45	6.78	12.60
Maximum	117.95	167.63	451.48	10.14	16.08	42.02
Uncertainty and variability	± 48%	± 57%	± 72%	± 37%	± 51%	± 69%

Conclusions

- Lake-to-lake groundwater connections likely to be isolated to localised areas
- Flow gains observed in the Tarawera River downstream of the Tarawera Falls are sourced from rainfall-recharged groundwater
- Flows and nutrient loads to the lake are variable year to year
- Groundwater inflows to Lake Tarawera 62% of the total (70% of these from outside of the local catchment)
- Evaporation has a considerable influence on the water balance, accounting for seasonal water stress decreases evaporation by an average of 204 mm y-1

		Groundwater receiving lake							
		Ōkareka	Ōkaro	Ōkataina	Rerewhakaaitu	Rotokakahi	Rotomahana	Tarawera	Tikitapu
Groundwater exporting lake	Ōkareka		-	Possible	-	-	-	Occuring	-
	Ōkaro	-		-	-	-	Likely	Possible	-
	Ōkataina	-	-		-	-	-	Likely	-
	Rerewhakaaitu	-	-	-		-	Occuring	Possible	-
	Rotokakahi	Unlikely	-	-	-		-	Not occuring	-
	Rotomahana	-	-	-	-	-		Occuring	-
	Tarawera	-	-	-	-	-	-		-
	Tikitapu	Possible	-	Unlikely	-	Likely	-	Possible	

Dark shading indicates confirmed connections

Light shading or no shading indicates unconfirmed connections

Further research recommendations

- Model loads under different land use scenarios
- Investigation of unconfirmed lake-to-lake groundwater connections – well installation and testing
- More isotopic analysis and other geochemical analysis to understand groundwater flow pathways
- Refine lake evaporation estimates using buoy data
- Sampling of Tarawera River under different flow regimes
- Detailed studies to quantify interactions between groundwater and lake water
- Resampling of deep bore at Tarawera outlet
- Relationship between lake level and groundwater outflow

Acknowledgements

- My supervisors - Troy Baisden and Dave Campbell, University of Waikato
- BOP Regional Council and Tarawera Ratepayers Association for funding
- NIWA for providing rainfall and PET datasets

Demonstration of web app....

https://nickiwilson.shinyapps.io/TaraweraMsc/

nickiwilson.shinyapps.io/TaraweraMsc/

Paused

Apps | New Tab | Love Our Lakes | Ro... | R - Data Services -... | PAK'nSAVE | Online... | (+) WaikatoEnviroD... | Environmental data... | Spatial References | He-Mapuna-te-Tam... | Spatial Data Scienc... | r-spatial

Greater Tarawera Lakes - Water and Nutrient Flows

Tarawera Catchments Web Tool

Information and Help

Select datasets and methods for calculations:

Choose Options

Click to Run Calculations

View catchment flow and nutrient loads:

- All catchments - annual averages
- Okareka
- Okaro
- Okataina
- Rerewhakaaitu
- Rotokakahi
- Rotomahana

Instructions

This interactive web tool calculates water balances and nutrient loads for the Greater Tarawera Lakes and their catchments based on user input selections. This is useful for visualising, exploring, and communicating uncertainties in the estimates of water flow and nutrient loads.

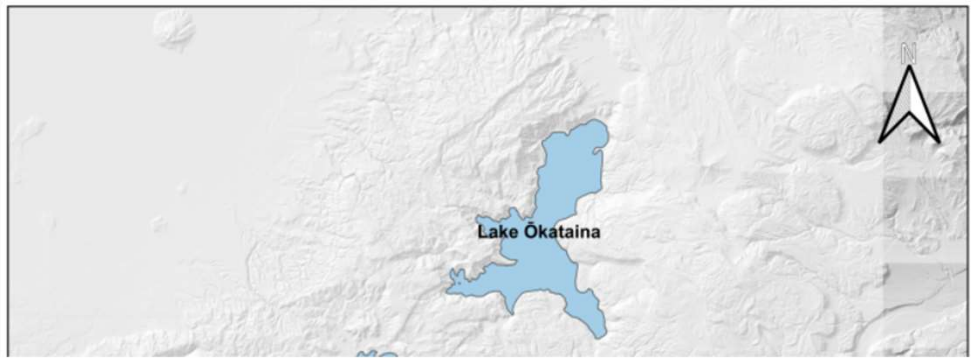
To explore the data:

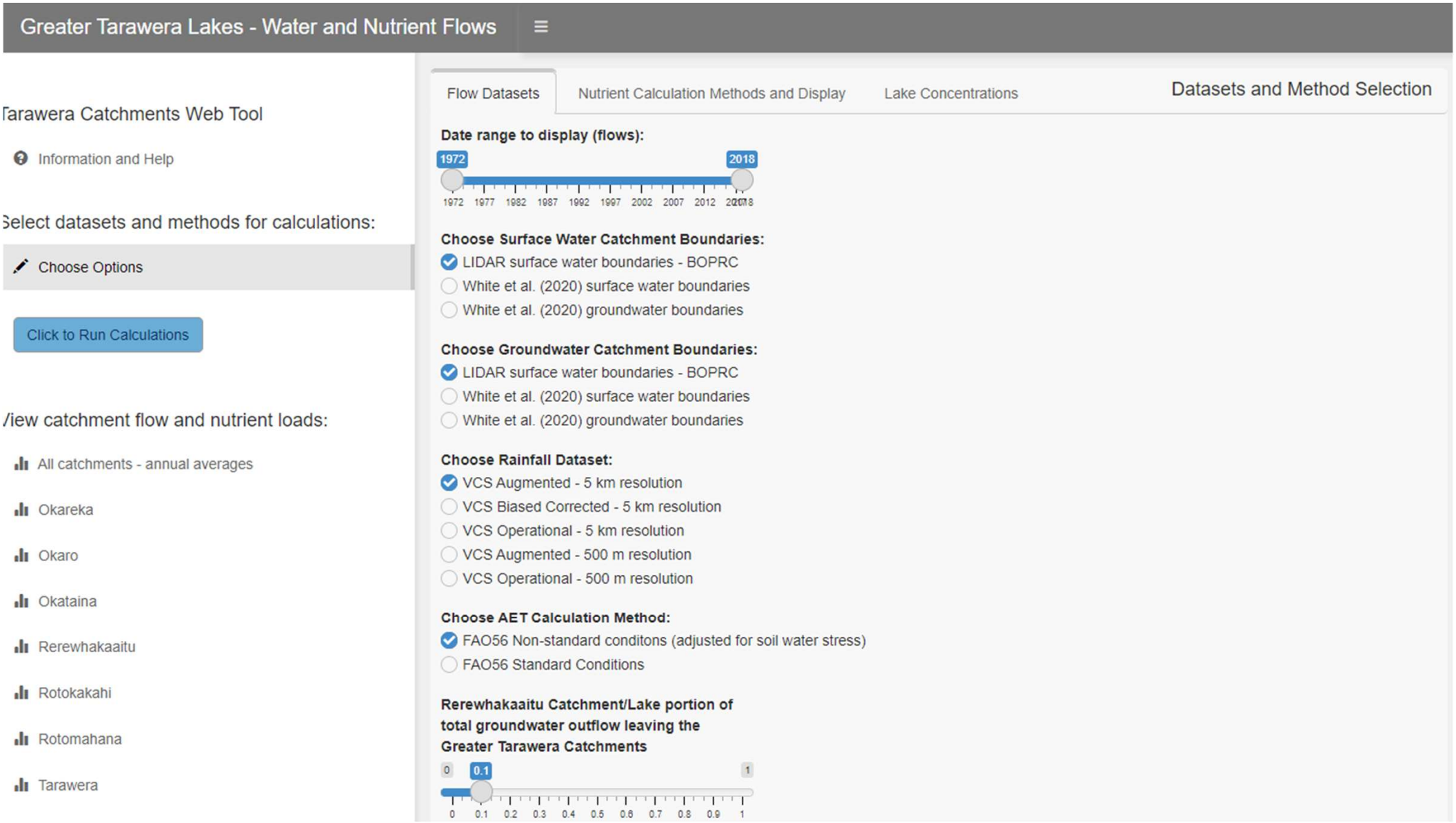
1. Click on 'Choose Options' to select the datasets and display methods to use in the calculations. Options can then be selected using the four tabs: 'flow datasets', 'groundwater routing options', 'nutrient calculation methods and display', and 'lake concentrations'.
2. Click on the 'Click to Run Calculations' button to run the calculations. This may take approximately 20 seconds.
3. Outputs can then be viewed by selecting the viewing options (and subsequent tabs displayed on the side bar).

For further information contact Nicola Wilson at nicola_wilson@outlook.co.nz

Background

Lake Tarawera is a large, deep lake located within the Taupo Volcanic zone, 12 km south-east of Rotorua. It occupies a surface area of 41.44 km^2, and has mean and maximum depths of 50 m and 88 m respectively. Seven smaller lakes within the 'Greater Tarawera Lakes' catchment (Ōkareka, Ōkaro, Ōkataina, Rerewhakaaitu, Rotokakahi, Rotomahana and Tikitapu) contribute flows to Lake Tarawera via groundwater and/or surface water. The quantity and quality of flows from these connected lakes is important in assessing hydrological inputs to Lake Tarawera.

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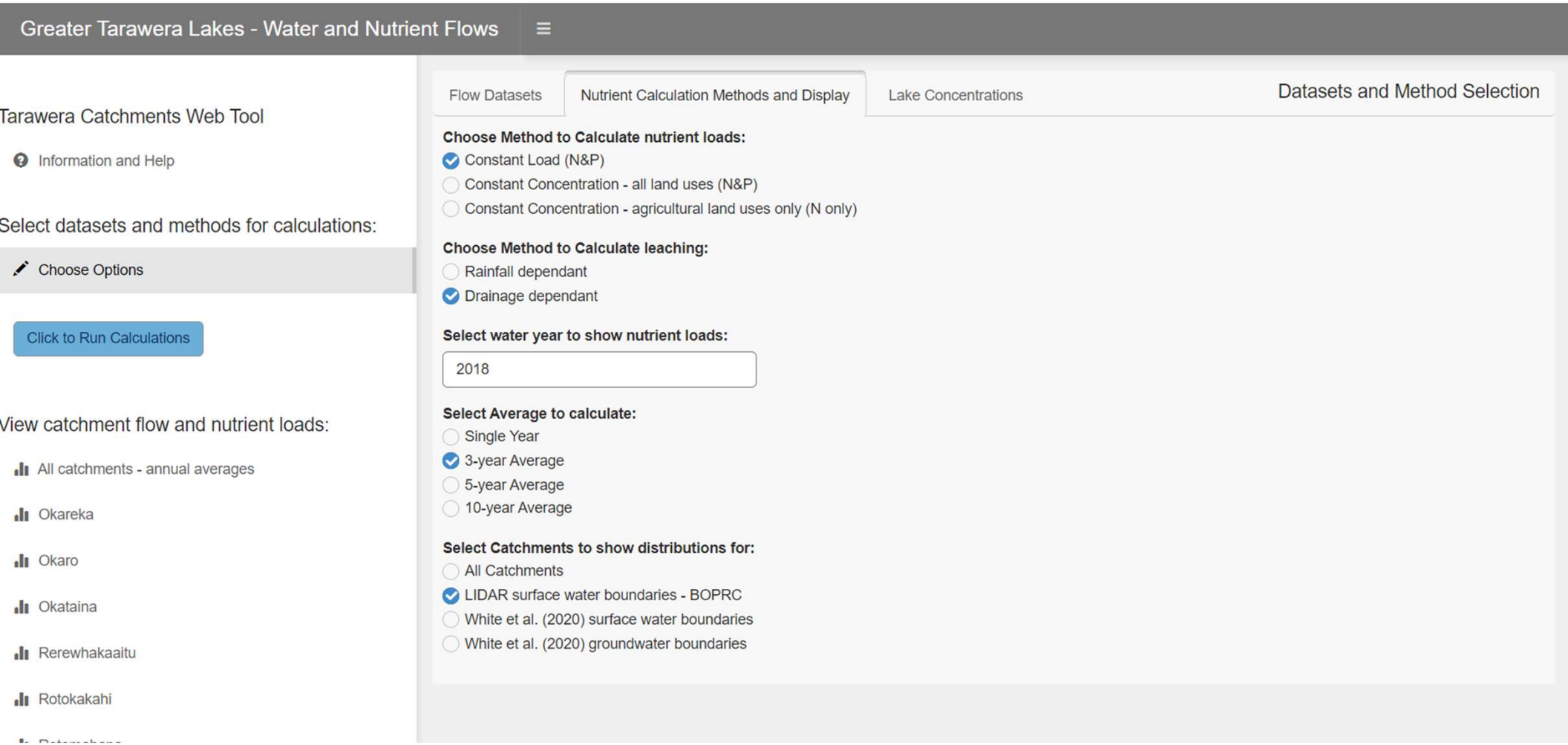
Information and Help
Select datasets and methods for calculations:
Choose Options
Click to Run Calculations
View catchment flow and nutrient loads:
All catchments - annual averages
Okareka
Okaro
Okataina
Rerewhakaaitu
Rotokakahi
Rotomahana
Tarawera
Flow Datasets
Nutrient Calculation Methods and Display
Lake Concentrations
Datasets and Method Selection
Date range to display (flows):
1972
2018
1972 1977 1982 1987 1992 1997 2002 2007 2012
Choose Surface Water Catchment Boundaries:
LIDAR surface water boundaries - BOPRC
White et al. (2020) surface water boundaries
White et al. (2020) groundwater boundaries
Choose Groundwater Catchment Boundaries:
LIDAR surface water boundaries - BOPRC
White et al. (2020) surface water boundaries
White et al. (2020) groundwater boundaries
Choose Rainfall Dataset:
VCS Augmented - 5 km resolution
VCS Biased Corrected - 5 km resolution
VCS Operational - 5 km resolution
VCS Augmented - 500 m resolution
VCS Operational - 500 m resolution
Choose AET Calculation Method:
FAO56 Non-standard conditons (adjusted for soil water stress)
FAO56 Standard Conditions
Rerewhakaaitu Catchment/Lake portion of total groundwater outflow leaving the Greater Tarawera Catchments
0
0.1
1
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1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Rotokakahi
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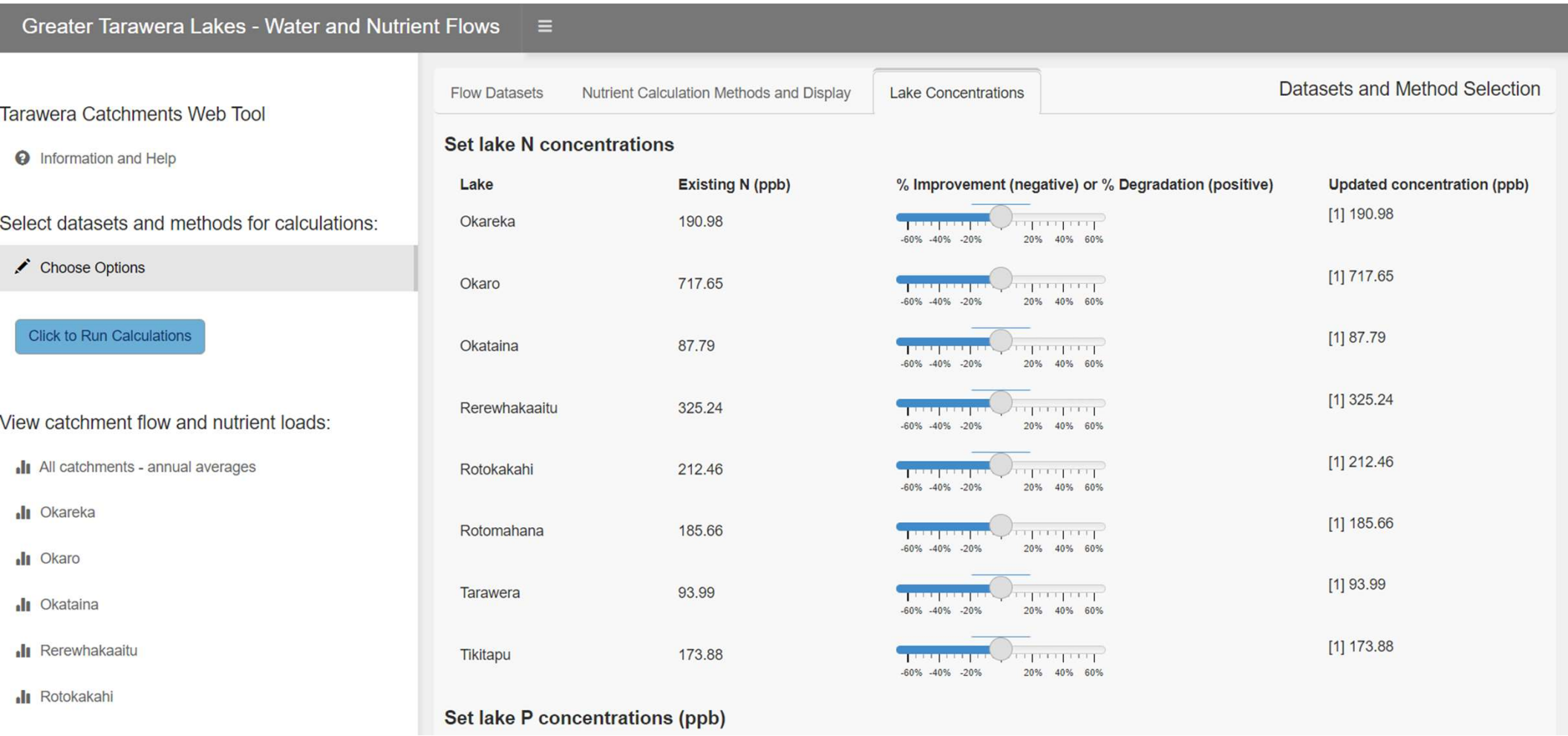
Lake Concentrations
Datasets and Method Selection
Choose Method to Calculate nutrient loads:
Constant Load (N&P)
Constant Concentration - all land uses (N&P)
Constant Concentration - agricultural land uses only (N only)
Choose Method to Calculate leaching:
Rainfall dependant
Drainage dependant
Select water year to show nutrient loads:
2018
Select Average to calculate:
Single Year
3-year Average
5-year Average
10-year Average
Select Catchments to show distributions for:
All Catchments
LIDAR surface water boundaries - BOPRC
White et al. (2020) surface water boundaries
White et al. (2020) groundwater boundaries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Datasets and Method Selection
Set lake N concentrations
Lake
Existing N (ppb)
% Improvement (negative) or % Degradation (positive)
Updated concentration (ppb)
Okareka 190.98 [1] 190.98
Okaro 717.65 [1] 717.65
Okataina 87.79 [1] 87.79
Rerewhakaaitu 325.24 [1] 325.24
Rotokakahi 212.46 [1] 212.46
Rotomahana 185.66 [1] 185.66
Tarawera 93.99 [1] 93.99
Tikitapu 173.88 [1] 173.88
-60% -40% -20% 20% 40% 60%
Set lake P concentrations (ppb)

Greater Tarawera Lakes - Water and Nutrient Flows

Tarawera Catchments Web Tool

Information and Help

Select datasets and methods for calculations:

Choose Options

Click to Run Calculations

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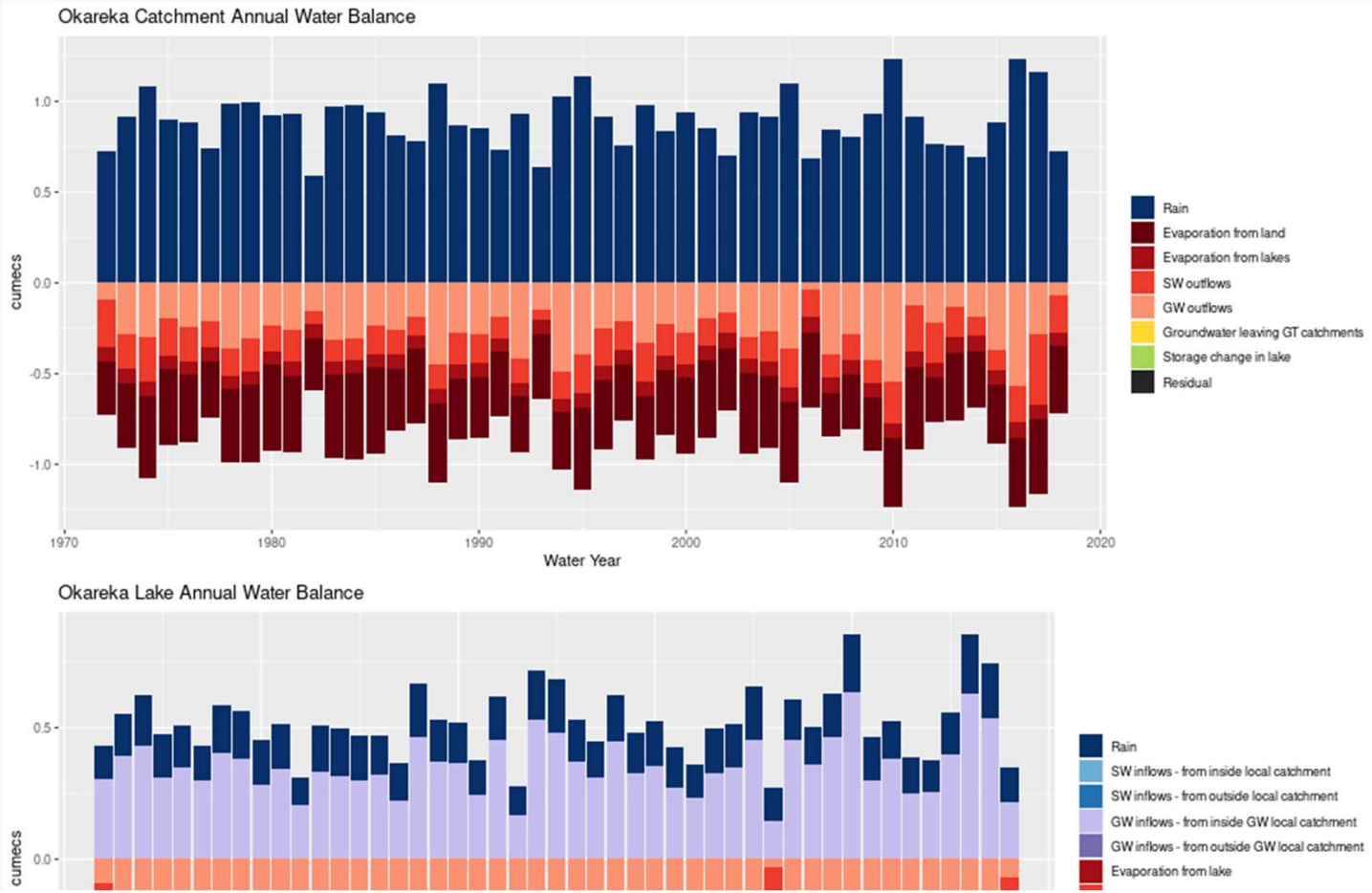
- Rotomahana
- Tarawera

Annual Flows | Annual Nutrient Variations | Nutrient Distributions | Nutrient Distributions - land use scenarios

Lake Okareka and Catchment



Greater Tarawera Lakes - Water and Nutrient Flows

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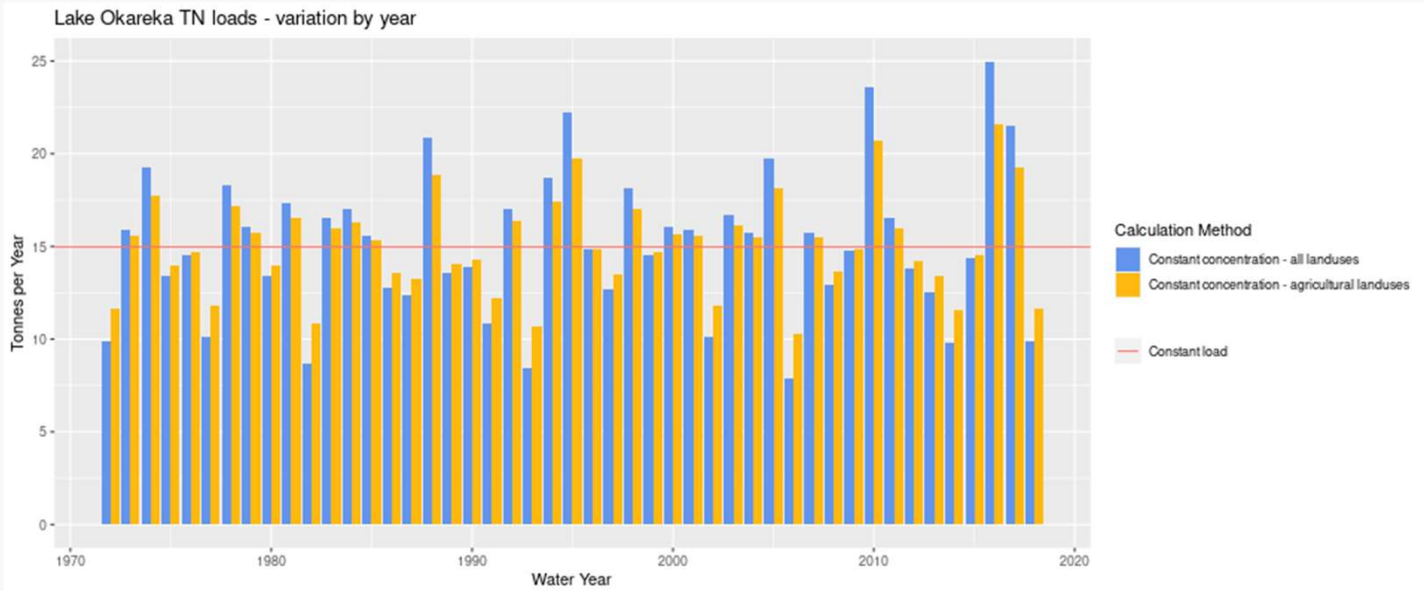
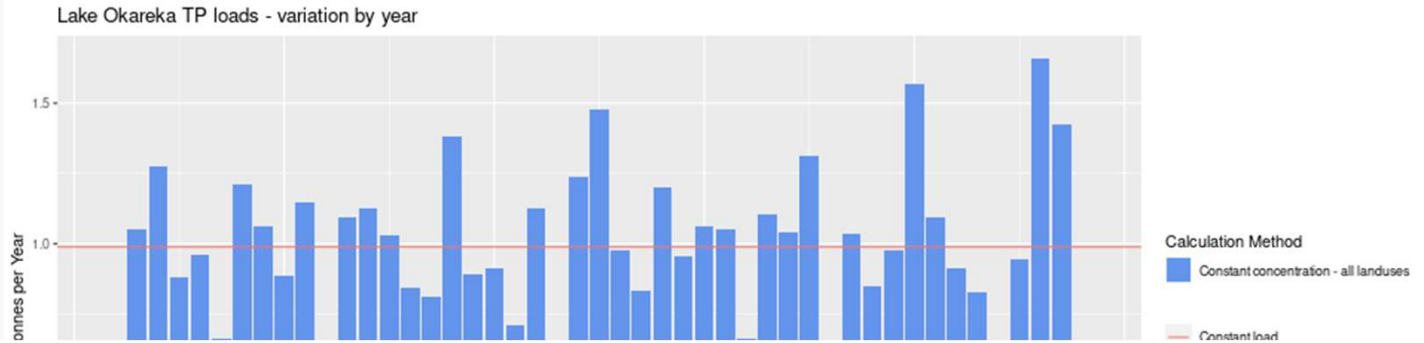
Annual Flows | Annual Nutrient Variations | Nutrient Distributions | Nutrient Distributions - land use scenarios

Lake Okareka and Catchment





Greater Tarawera Lakes - Water and Nutrient Flows

Tarawera Catchments Web Tool

Information and Help

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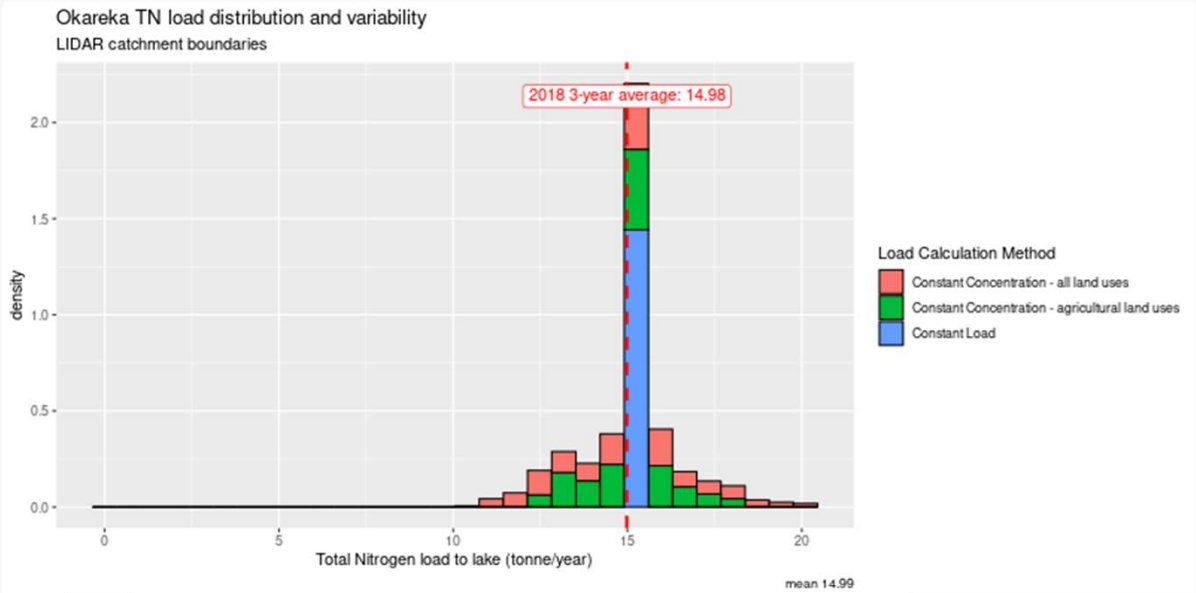
Annual Flows | Annual Nutrient Variations | Nutrient Distributions | Nutrient Distributions - land use scenarios

Lake Okareka and Catchment

Nitrogen



Show 10 entries Search:

	TN load statistics	Current Land Uses (T/Yr)
1	Mean	14.99
2	Median	14.98
3	Standard deviation	1.38

Greater Tarawera Lakes - Water and Nutrient Flows

Tarawera Catchments Web Tool

Information and Help

Select datasets and methods for calculations:

Choose Options

Click to Run Calculations

View catchment flow and nutrient loads:

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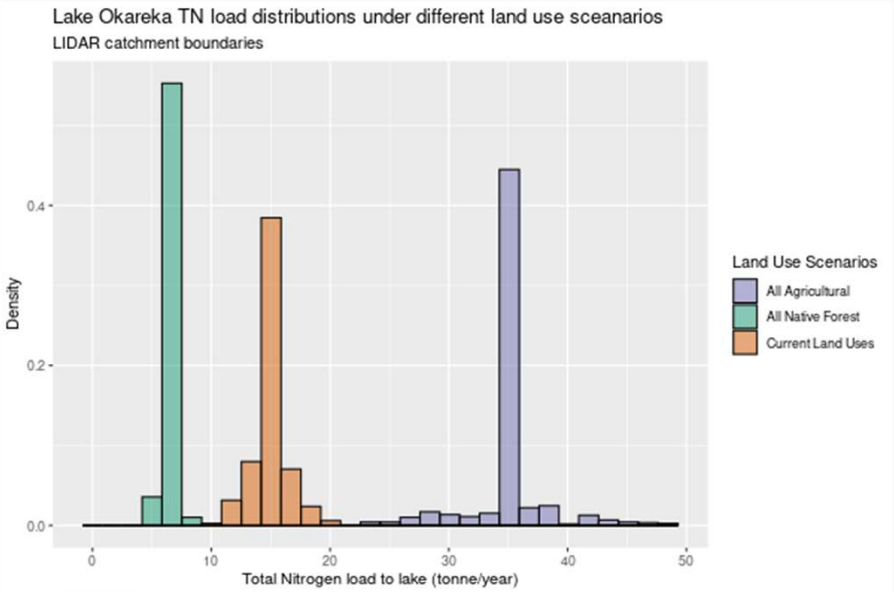
Annual Flows | Annual Nutrient Variations | Nutrient Distributions | Nutrient Distributions - land use scenarios

Lake Okareka and Catchment

Nitrogen



Show 10 entries

Search:

	TN load statistics	Current Land Uses (T/Yr)	All Agricultural (T/Yr)	All Native Forest (T/Yr)
1	Mean	14.99	34.91	6.49
2	Median	14.98	34.89	6.48
3	Standard deviation	1.38	3.06	0.34

Greater Tarawera Lakes - Water and Nutrient Flows

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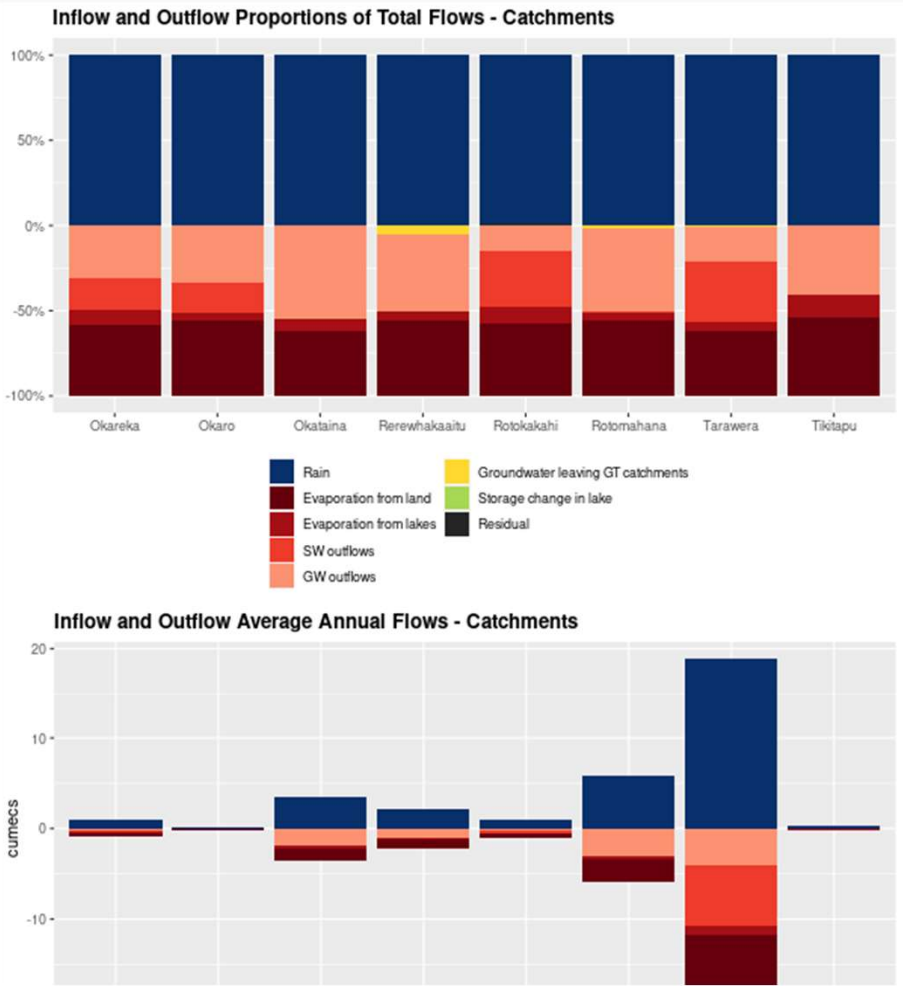
Catchment Flows | Lake Flows | Nutrients

Average Annuals



Information and Help

Select datasets and methods for calculations:

Choose Options

Click to Run Calculations

View catchment flow and nutrient loads:

All catchments - annual averages

Okareka

Okaro

Okataina

Rerewhakaaitu

Rotokakahi

Rotomahana

Tarawera

Tikitapu

View nutrient load breakdown by land use:

Nutrient load breakdown