Assessment of Lake Taharoa water level

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Contents

List of Tables

List of Figures

List of Appendices

Abbreviation

NRC	Northland Regional Council
NIWA	National Institute of Water & Atmospheric Research Ltd
ET	Evapotranspiration
DEM	Digital Elevation Model
VCSN	Virtual Climate Station Network
AWBM	Australian Water Balance Model
PET	Potential Evapotranspiration
PED	Potential Evapotranspiration Deficit

Executive Summary

In earlier months of 2022, Lake Taharoa experienced the lowest water level since 1995. During February 2021 – March 2022 period, lake level fluctuates over a range of generally less than 0.5m in response to rainfall and evaporation patterns. The lake has little surface inflows and outflows with very small volumes of water taken recorded. Lake Taharoa has a large surface area (approximately half of the lake catchment area) resulting in large amount of water lost to the atmosphere via evaporation process. Evaporative water loss has increased since 2003 as a consequence of dry weather while rainfall over the lake has decreased since 1986. The lake water imbalance is proved to be directly driven by the contrary patterns of lake rainfall and lake evaporation. This finding is based on a key assumption that human activity has little or no influence on the lake water level. In order to adequately quantify the change in lake water balance, further investigation is required to fully understand the potential impact of human activities on the change of lake level. This would involve recording/collecting data on water taken from the lake for any purposes, and data on land-use changes within the lake catchment and its vicinity.

Introduction

In April 2022, an investigation considering the key factor(s) influencing the variation of Lake Taharoa water level was initiated given the lake water level had been significantly low since February 2022. This short report provides a preliminary assessment of change in Lake Taharoa water level with respect to natural and human activities. Data and methods used for this desktop assessment is briefly described. Following a discussion provide some insight into the change in lake water level, and further recommendations for future work are also provided.

Background

Water levels across lakes fluctuate over time, influenced by both natural and human activities (Delclaux et al., 2007; Zhang et al., 2016). The key natural components are lake rainfall (i.e., rain over the lakes), lake evaporation (evaporation over the lakes), and lake inflow (runoff that enters the lakes from the surrounding land through tributaries and rivers). In some cases, lake outflow may occur through water leakage underground via infiltration. The main artificial component is surface water and groundwater taken from the lakes intentionally by human activities. It is therefore essential to monitor both natural and human influences to better understand lake water level changes. With sufficient data available application of lake water balance is essential in this regard.

Data

Rainfall, evapotranspiration (ET), lake water level, groundwater level data from nearby stations and virtual rainfall and ET data were used (Table 1 and Figure 1). Water taken by two consent holders is assembled for consumptive water estimation.

Northland DEM/LiDAR and Kai Iwi Lakes bathymetry were used for delineating the lake and its catchment boundary.

Table 1: Meteo-hydrological data used for the Lake Taharoa water level assessment.

Data type	Site name	Record	Authority	Note
Rainfall	Kai Iwi at Kai Iwi Lake Road	1986-1993	NRC	
	Kaihu at Kai Iwi Lakes (McLeod)	2015-2022	NRC	
	Northland VCSN 29092/30681	1972-2016	NIWA	
Evapotranspiration	Dargaville 2	1981-1988	NIWA	
	Dargaville EWS	1998-2002 2003-2022	MetService	Gaps between 1999-2000
	Northland VSCN 29092/30681	1972-2016	NIWA	
Groundwater	Lake Kai Iwi at Bore 2, 5, 6	2015-2022	NRC	
Lake water level	Lake Taharoa at Kai Iwi	2021-2022	NRC	
	Staff gauges	1995-2021	NRC	discrete data only

Note: rainfall, lake water level and groundwater level is directly measured at monitoring sites while ET is estimated from climatic variables obtained at climate monitoring sites using Penman method. Virtual data (VCSN) is modelled from rainfall and ET measured/ estimated at monitoring sites which represents in a grid/cell form with a single grid/cell covers an area of 5km x 5km.

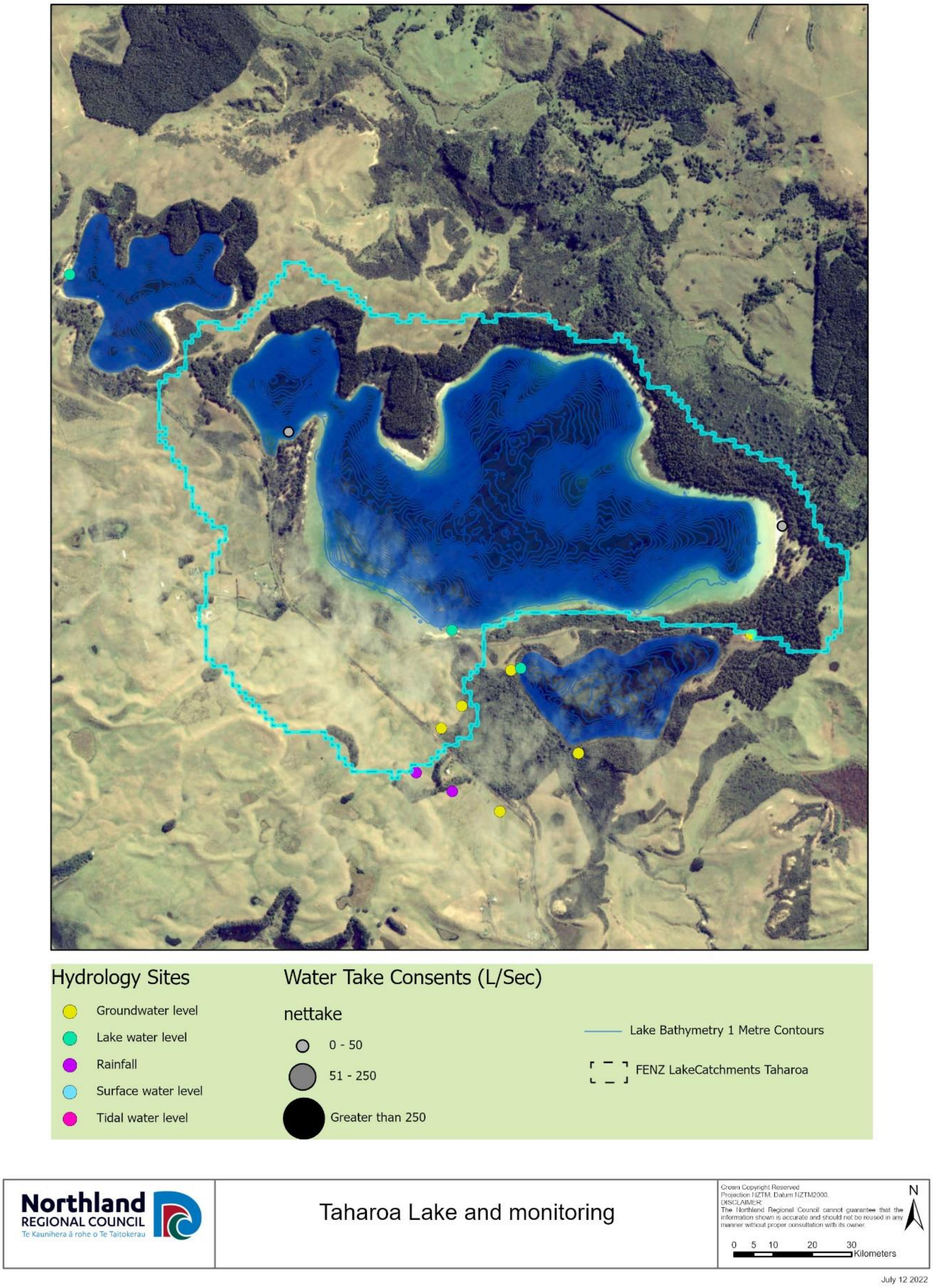

Figure 1: Lake Taharoa and its hydrological monitoring sites.

Methodology

A combination of methods were applied for the analysis comprising of statistical analyses and numerical modelling. Several assumptions were made due to limited data, the key assumptions included:

- the lake remains at its 80% of full capacity all year round,
- only two consent holders are taking water from the lakes,
- land-use within lake catchment and its surrounding has not changed over the past two decades.

a) Data analysis

In order to maximise the data length, data from different sources were used for data gap filling and extension where appropriate. Data was tested as below:

- Comparison between at-site and virtual rainfall, evapotranspiration (ET) was made.
- Rainfall and ET dataset were statistically tested for the magnitude of change over time.

b) Estimation of lake area and lake catchment area

The lake and its catchment boundary were delineated using REC-2 and bathymetry data available. The estimated lake surface area and catchment drainage area are approximately 2.06km^2 and 4.23km^2 respectively.

c) Estimation of lake rainfall and evaporation

Rain and evaporation over the lake was estimated using catchment rainfall, potential ET and lake surface area.

Note: There is no measurement of evaporation rate from the lake available.

d) Modelling of lake inflow

Australian Water Balance Model (AWBM) was used to simulate lake inflow from lake catchment rainfall, ET and catchment characteristics. The process of developing the model followed the following three steps:

- Parameters of the established AWBModel for other catchments in Northland with similar characteristics is used.
- The model takes rainfall, potential evapotranspiration (PET) and catchment area as inputs and runs with above parameters to simulate flows from the catchment into the lake (lake inflow).
- Lake inflow is then computed as daily rate (m^3/s) and monthly volume (mm/month).

e) Consumptive water takes (consented takes)

Annual volumes of the two consented takes were estimated from actual take rates and permitted take rates for the periods 2016-19 and 2019-22, respectively. The water use records were not available for the entire period, i.e., 2016 to 2022.

f) Lake water balance

A simple lake water balance equation was used to provide an indication of the key influencers of the lake volume change.

$$\frac{\Delta S}{\Delta t} = P_{lake} - E_{lake} + Q_{in} - Q_{out} + \varepsilon$$

Where: $\frac{\Delta S}{\Delta t}$ denote change in storage over time, P_{lake} is lake rainfall, E_{lake} is the lake evaporation, Q_{in} is lake inflow, Q_{out} is lake outflow and ε represents the uncertainties in the water balance arising from errors in the data, i.e., such as net ground water flux or minor abstractions which usually cannot be accounted for directly.

Results and Discussion

a) Variability of rainfall and evapotranspiration

The pattern of monthly rainfall and evapotranspiration (ET) in the area is consistent over time. However, the pattern of monthly ET is contradictory to that of rainfall (Figure 2 andFigure 3). Rainfall mainly concentrates in rainy season (May, June, July) while maximum evapotranspiration occurs in January.

The magnitude of monthly rainfall dramatically decreases while the monthly evapotranspiration significantly increases from 1990s to 2000s. Daily rainfall decreases by approximatively 20% between 1986 and 2022. Daily evapotranspiration increases by approximatively 26% between 1981 and 2022 (Table 2).

Data analysis also indicates that modelled rainfall and evapotranspiration (VCSN) is overestimated which far higher than the measurements (Figure 2 andFigure 3). Therefore, adjustment is made here based on annual evapotranspiration ratio.

Table 2: Daily rainfall statistics (mm).

Indicator(s)	Record	Mean	Median	Min	Max	SD	Trend
Rainfall	1986-1993	3.374	0.5	0	83	6.638	Decreasing
	2015-2022	2.678	0	0	59	5.859	Decreasing
Evapotranspiration (ET)	1981-1988	2.34	2.1	0	6.7	1.422	Decreasing
	1997-2002	2.723	2.4	0	7.3	1.674	Decreasing
	2003-2020	2.955	3	0	7.8	1.598	Increasing

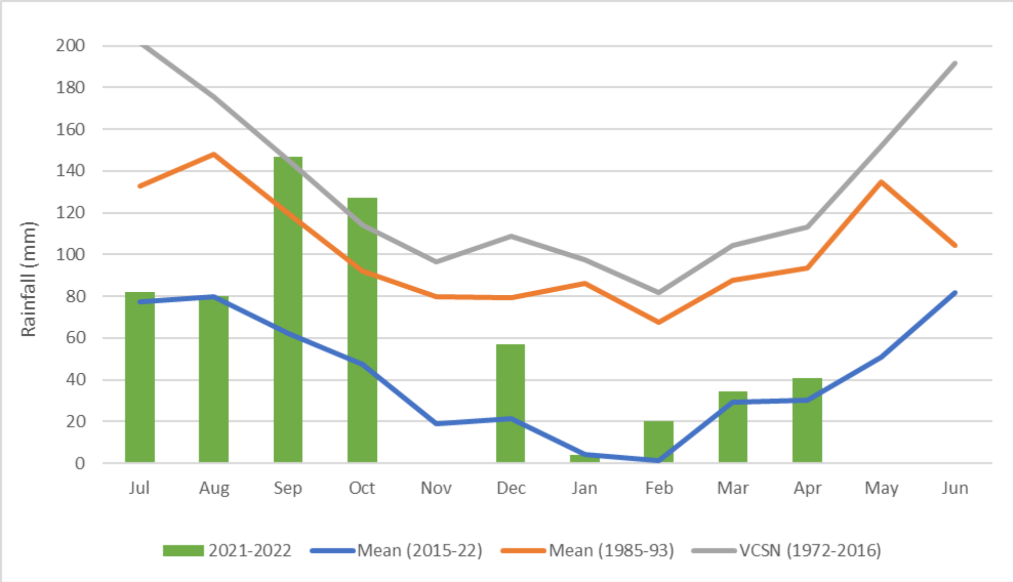

Figure 2: Monthly rainfall during water year 2021-22 monthly mean rainfall over different periods, 1985-93, 2015-22 and 1972-2016.

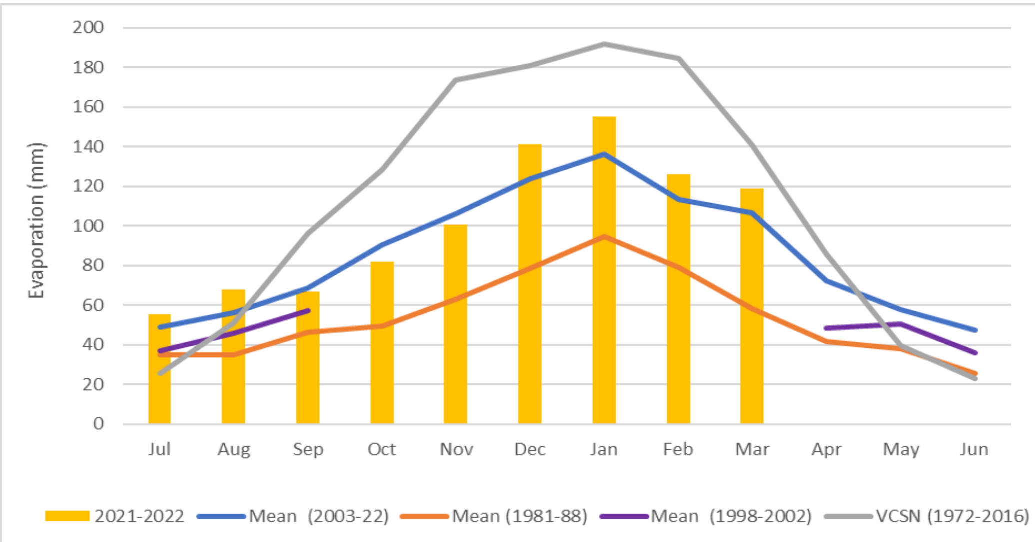

Figure 3: Monthly evapotranspiration during year 2021-22 and monthly mean evapotranspiration over different periods, 1981-88, 1998-2002 and 2003-22. Note, the 1998-2002 line is incomplete due to the gaps in dataset.

b) Estimation of lake inflow and outflows

Catchment runoff or lake inflow were computed for 2015-2022 period after being tested with different rainfall-evapotranspiration datasets between 1972 and 2022 (Appendix 1). Lake inflow corresponds well with catchment rainfall and evapotranspiration. Similar pattern of rainfall was found for the catchment inflow.

A prolonged drought which lasted from 2018 until 2020 significantly impacted on catchment runoff (Figure 4). Lake inflow of the current water year (2021-22) is below the multi-year average as a result of declining rainfall and increasing evapotranspiration (Figure 5).

Lake inflow is far greater than outflow (Figure 6). Lake outflow is estimated purely from two consent holders' takes. This does not consider water diverted from lake Taharoa to lake Kai Iwi and water losses to underground. Therefore, it is important to note that the estimated outflow volumes do not reflect the actual water volume flowing out of the lake.

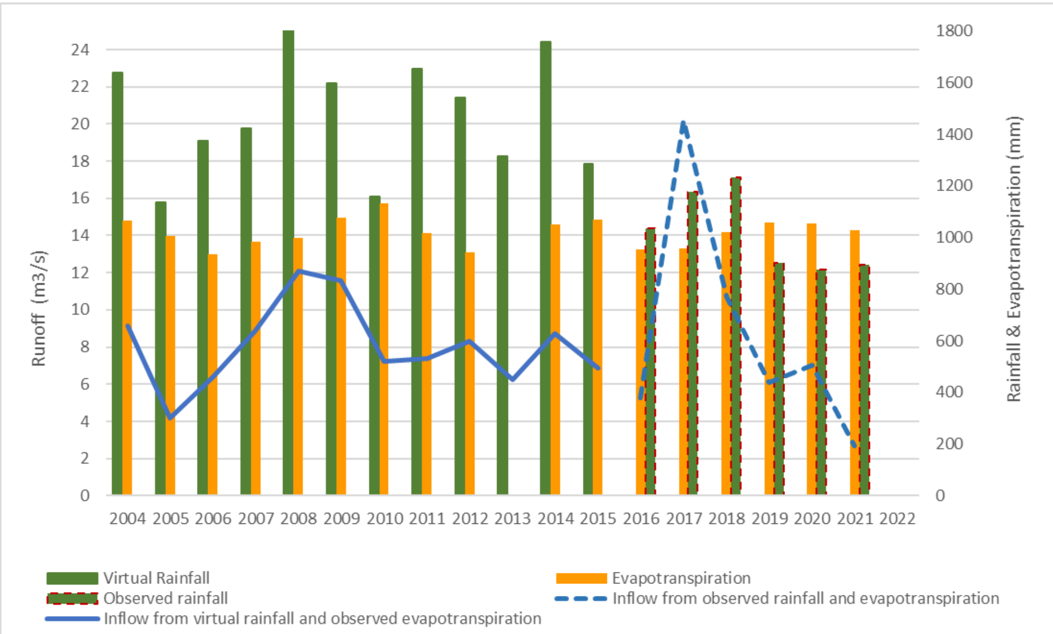

Figure 4: Annual rainfall, evapotranspiration, and runoff of lake catchment. Note, catchment runoff is lake inflow.

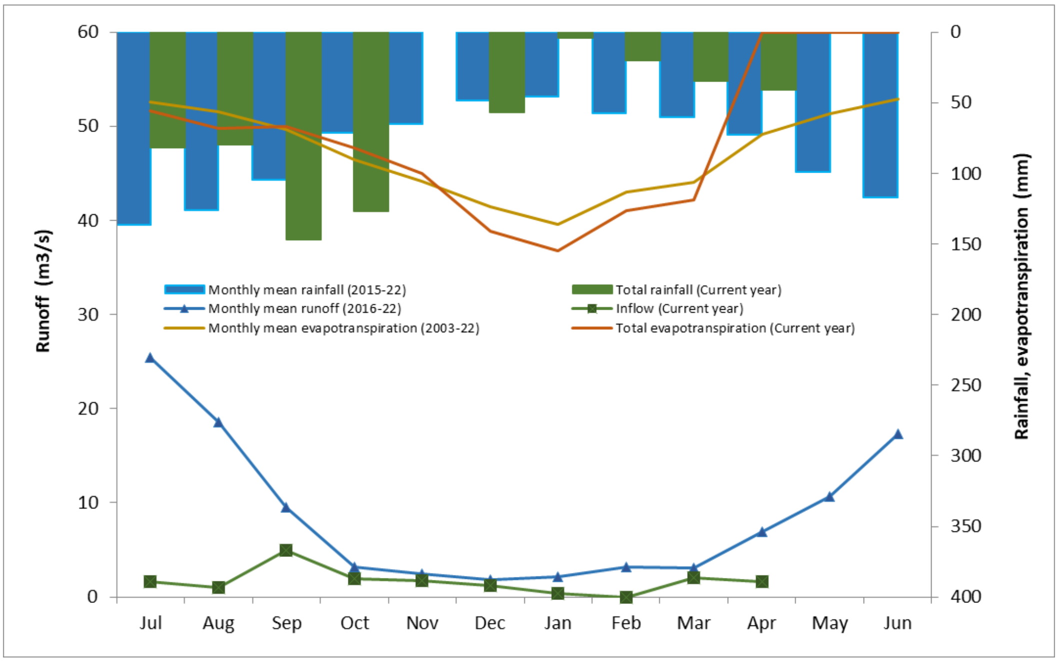

Figure 5: Monthly distribution of catchment rainfall, evapotranspiration, and runoff for different periods: 2015-2022, 2016-2022, 2003-2022. Note, catchment runoff is lake inflow.

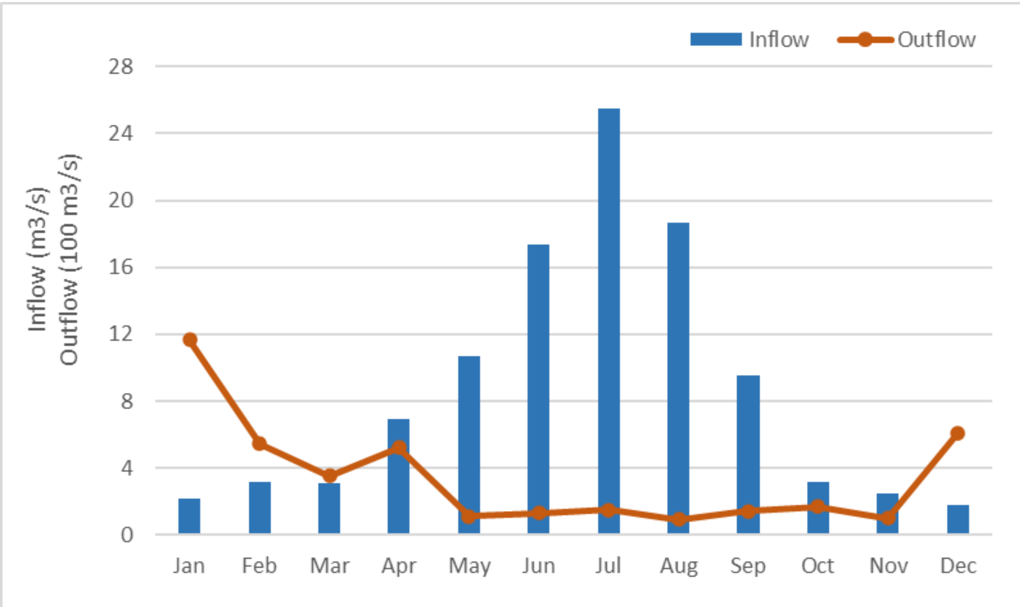

Figure 6: Monthly lake inflow and outflow over 2015-2022 period.

c) Lake water level and its drivers

The Lake Taharoa experienced an abrupt decrease in water level since February 2022. The current lake water level is likely to be lowest on record (Figure 7). This reflects the imbalance between the sources (rainfall, inflow) and the losses (evaporation, outflow) of the lake.

Direct lake rainfall is quantified by catchment rainfall and lake area. Direct lake evaporation is calculated by potential evapotranspiration (PET) and lake area. Variability of lake rainfall and evaporation is similar to that of the catchment. This means there is an increase in lake evaporation as well as a decrease in lake rainfall in recent years. This directly impacted the lake Taharoa water level.

Lake outflow is minor compared to lake inflow. However, lake inflow decreases dramatically post-2017 and reaches its lowest in 2021-22 water year (Figure 8). Amount of rainfall and evaporation are significantly higher than both inflow and outflow combined (Figure 4 – Figure 8).

Loss to underground is not detected for all Kai Iwi lakes (verbal communication with Northland Regional Council groundwater scientist). Variability of groundwater level is prevailed by rainfall while lake water level is influenced by compensation between rainfall and evaporation (Figure 9).

It is obvious that lake rainfall and lake evaporation play an essential role in regulating the water balance of the lake (Figure 10). However, this is indicative only because lake outflow does not consider all water takes including permitted takes (which do not require a consent under the Regional Plan).

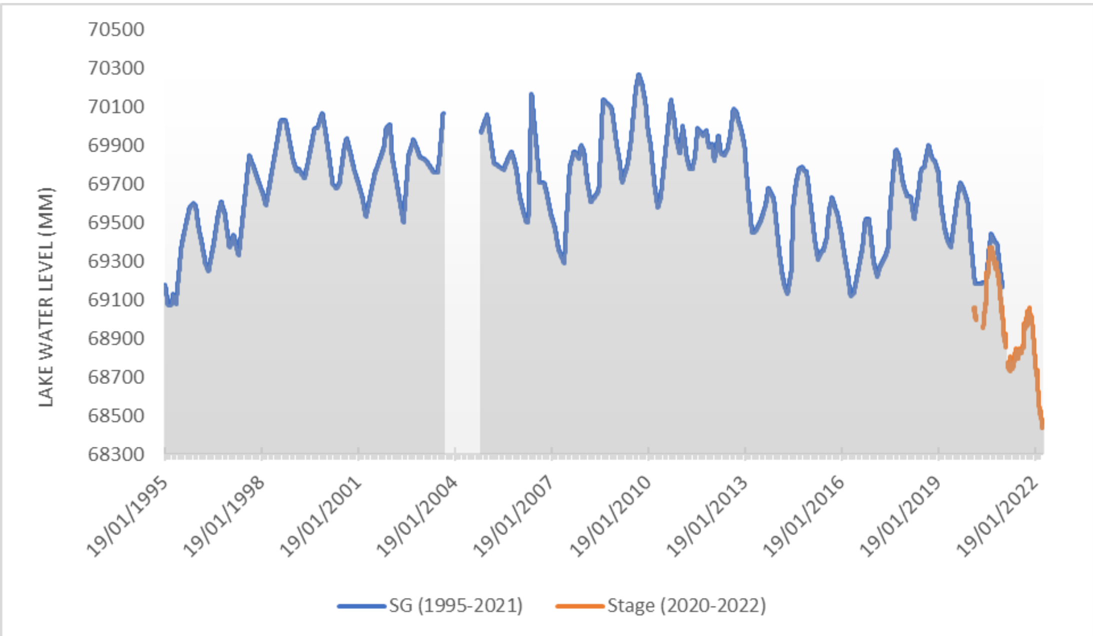

Figure 7: Lake Taharoa water level: staff gauging (SG) and automatic recording (Stage) during 1995-2022 period.

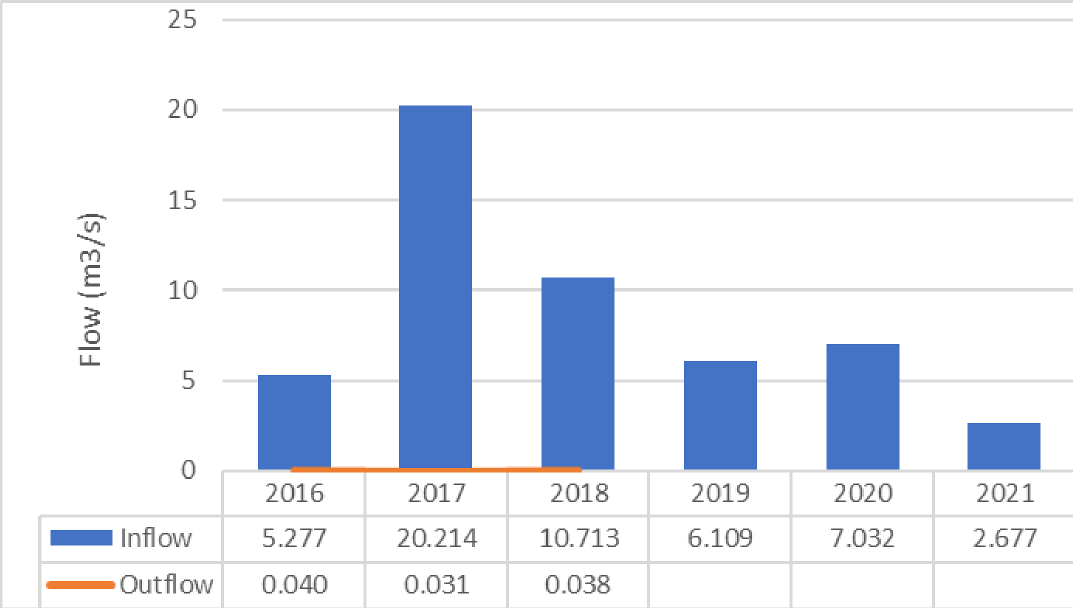

Figure 8: Lake inflow and outflow

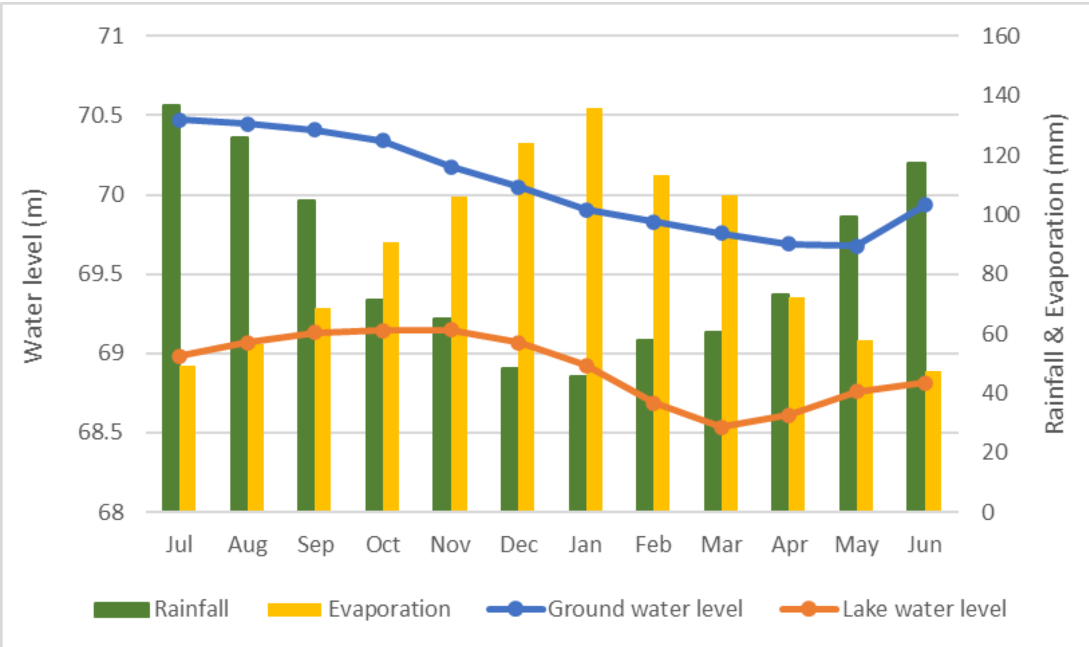

Figure 9: Groundwater and lake water level in response to rainfall and evapo/transpiration during the monitoring periods as per Table 1.

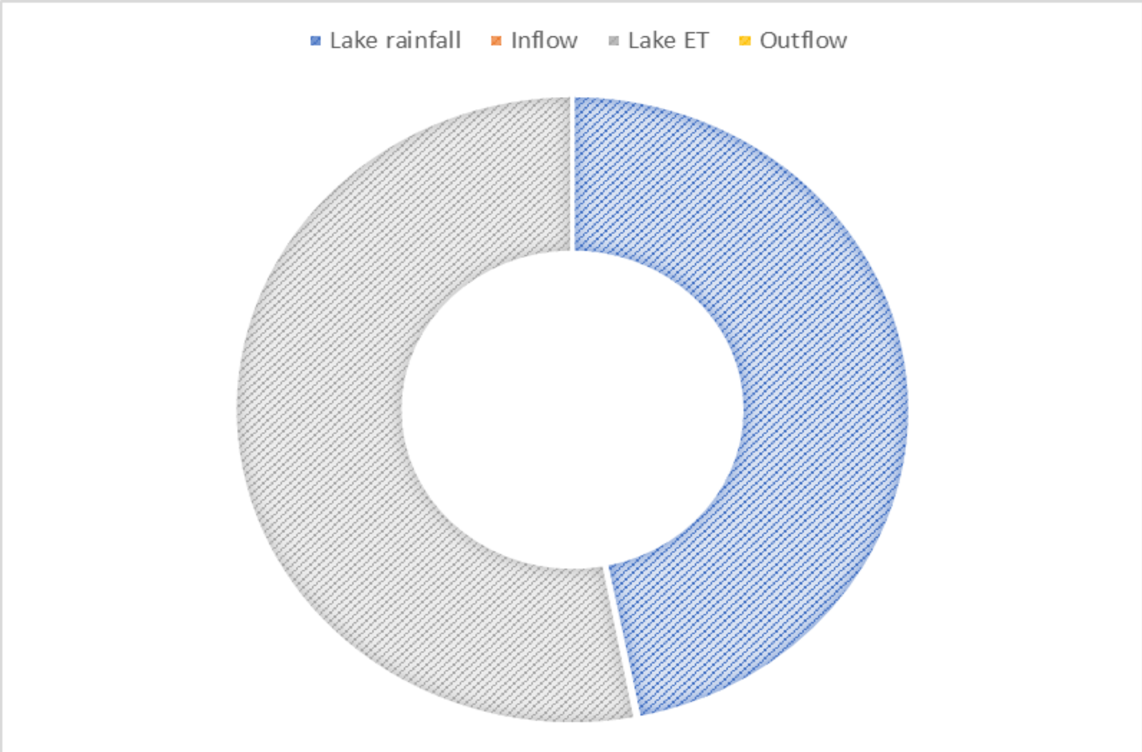

Figure 10: Indication of Lake Taharoa water balance based on lake rainfall, lake evaporation, lake inflow and outflow.

Limitations and Recommendations

a) Limitations

Even though this assessment emphasises that rainfall and evaporation seem to be the main influences on the lake water level fluctuation, several assumptions were made which present limitations to the estimation.

1. Uncertainties are associated with the following datasets: gaps in rainfall, evapotranspiration data, short water level data range and water use/take data.
2. Data only available for the two consented takes from the lake, no data was available for permitted takes and/or non-registered takes.
3. No flow data available from the drain between lake Kai Iwi and lake Taharoa.

b) Recommendations

To overcome the above limitations, recommended future steps include:

1. Assess the impact of the upcoming land-use change, i.e., 268 ha of new pine forest (Appendix 2) in the vicinity of the lakes to be planted between June and August 2022.
2. Quantifying of all water takes from the lake,
3. Establishing lake Area-Volume-Level relationship,
4. Developing a full lake water balance model.

   The outcomes of developing a water balance model for the lakes, are to:

   - predict excess/deficit water and corresponding depth-volume relationship for each lake,
   - predict variations in lake level,
   - predict exchange between lake components such as surface-groundwater, and
   - improve understanding of drivers of change in lake water level for the Kai Iwi lakes.

5. Considering the impact of climate change as Poutō peninsular is projected to be one of the most vulnerable to drought in the future (Appendix 3).

6. The study only focused on lake Taharoa, there is a need to undertake a similar assessment on the two other lakes, i.e., lake Waikare and lake Kai Iwi.

References

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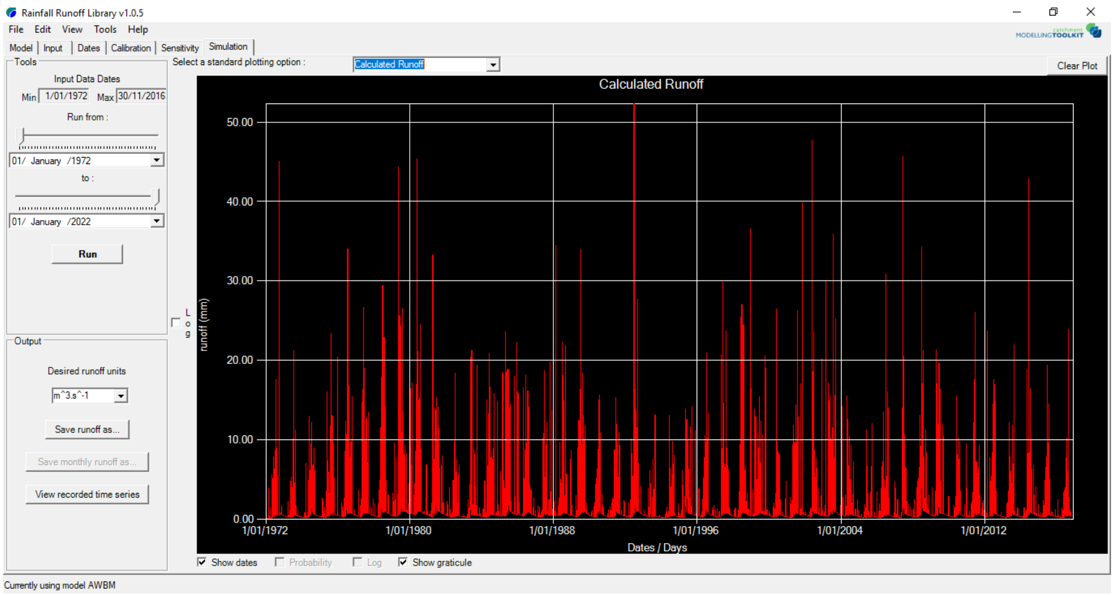
Zhang et al. (2016). Analysis of Poyang Lake water balance and its indication of river–lake interaction. SpringerPlus, 5:1555.

Appendices

Appendix 1: Inflow simulation using Australia Water balance model: (a) daily flow, (b) accumulated flow.

A



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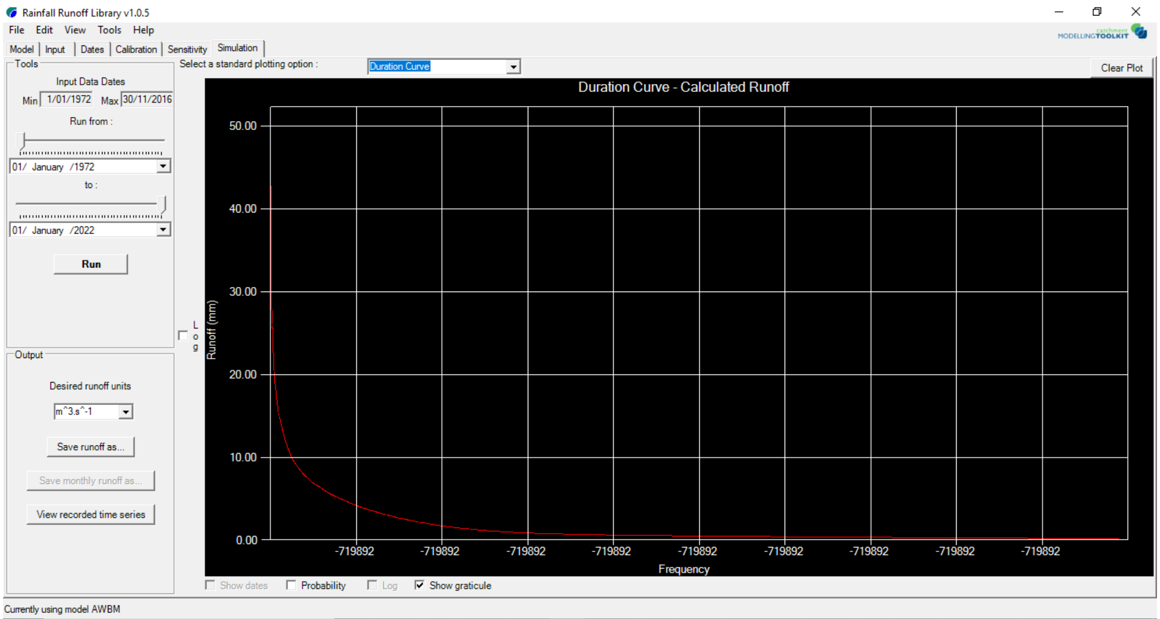
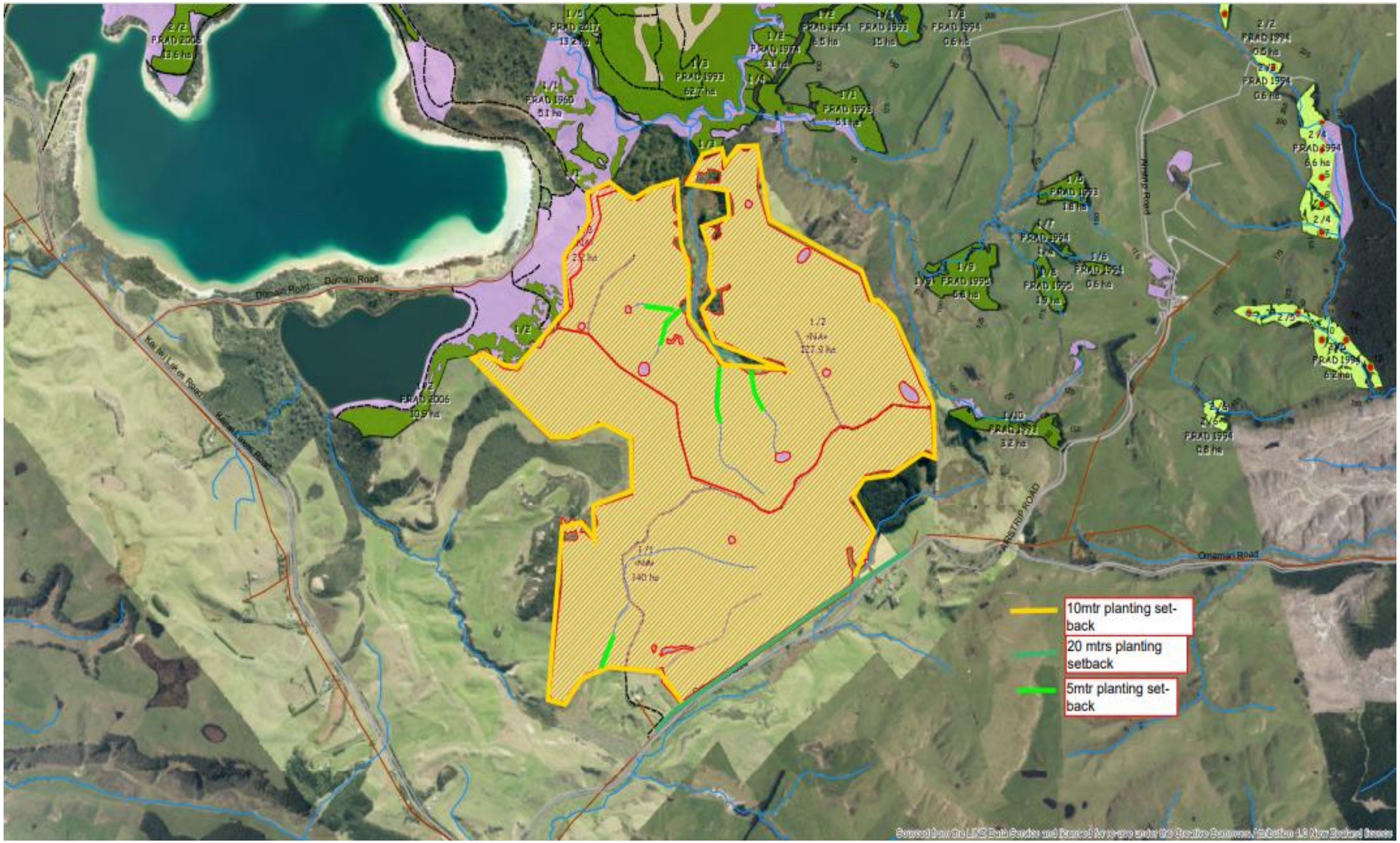
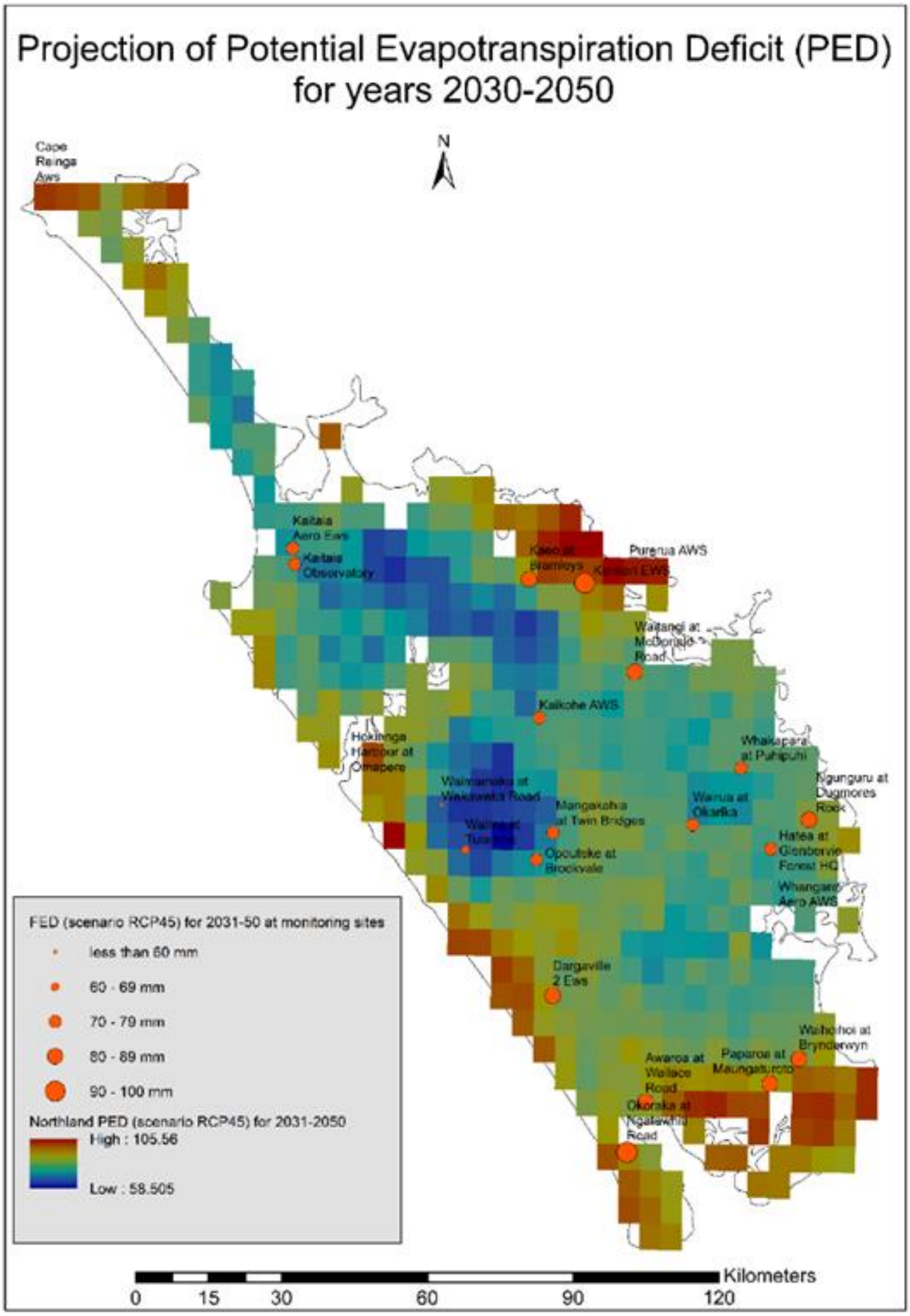


Appendix 2: Map of planned new plantation pine forest.



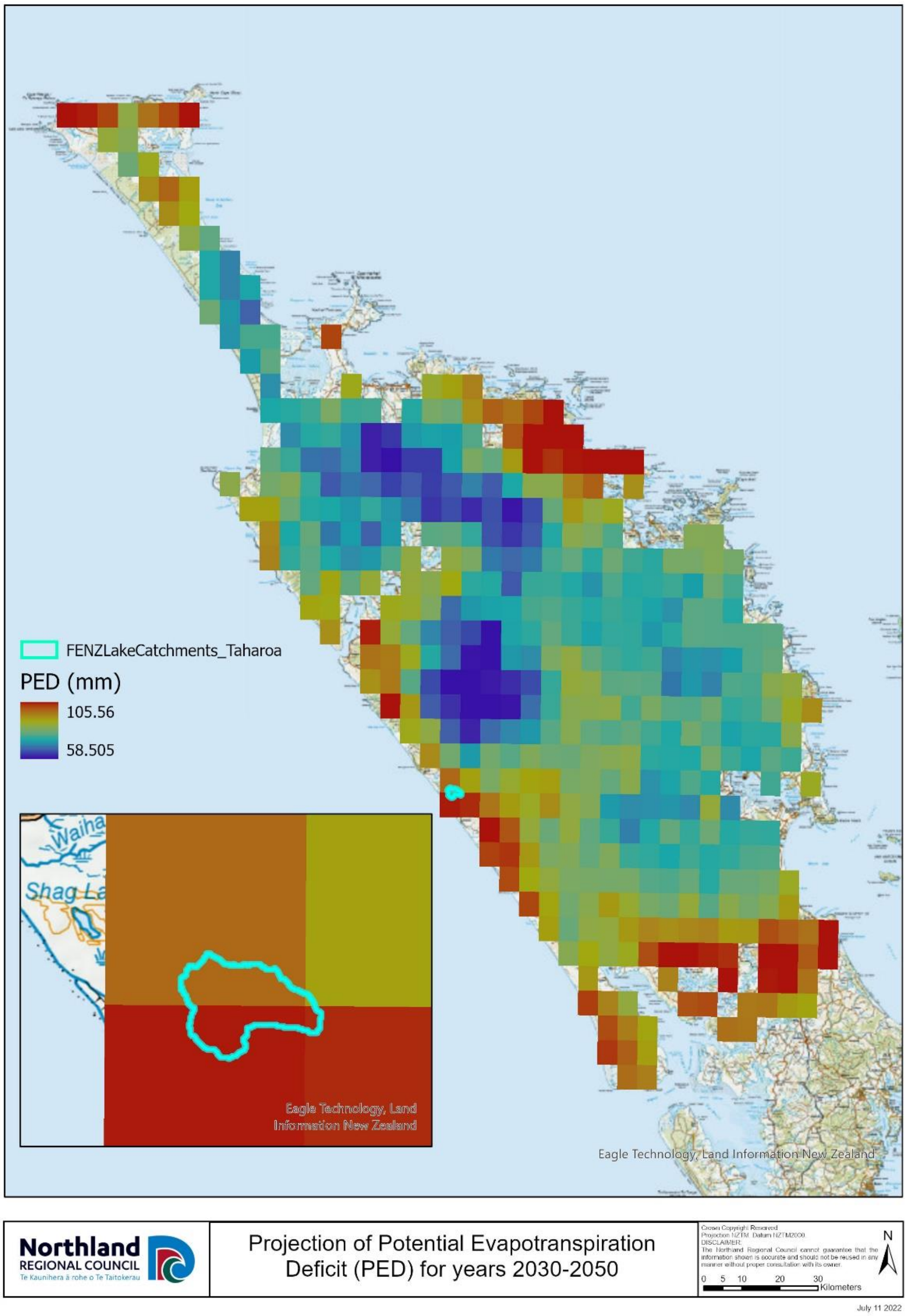
Appendix 3: Future projection of Potential Evapotranspiration Deficit (PED) for Northland.

A. Projected PED at monitoring sites and regionwide:



Note: PED is the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year. PED (mm), can be thought of as amount of rainfall needed in order to keep pastures growing at optimum levels (NIWA, 2016).

B. Projected PED in lake Taharoa area and regionwide:



Note: PED is the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year. PED (mm) can be thought of as amount of rainfall needed in order to keep pastures growing at optimum levels (NIWA, 2016).

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