Preliminary Hydrogeological Assessment for Lake Rototuna

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1. Introduction

Water levels in Upper Rototuna Lake have been decreasing since 2005 (Figure 1). Prior to the onset of the decreasing trend, lake water level elevations generally fluctuated above 95 mRL. Decreasing lake water levels could result in the deterioration of the lake water quality and deleterious effects on lake ecosystems.

Northland Regional Council (NRC) has carried out a preliminary assessment of the probable causes of the decrease in lake water levels. As a part of the preliminary assessment, Gary Treadgold, from the NRC Dargaville office, took Pride Mangeya on a familiarisation tour of the Rototuna lakes. Pride also collated information on the Rototuna lakes from within the NRC and from other stakeholders. The aim of this report is to:

- Summarise the available land-use, climatic and hydrogeological information from the area surrounding the Rototuna lakes.
- Identify and assess the probable causes for the decreasing trend in Upper Rototuna Lake water levels.
- Provide a preliminary analysis of the changes in lake water quality associated with the decreasing lake waters.
- Provide recommendations on additional work to be carried out around the lakes to improve our understanding of the hydrogeological system.

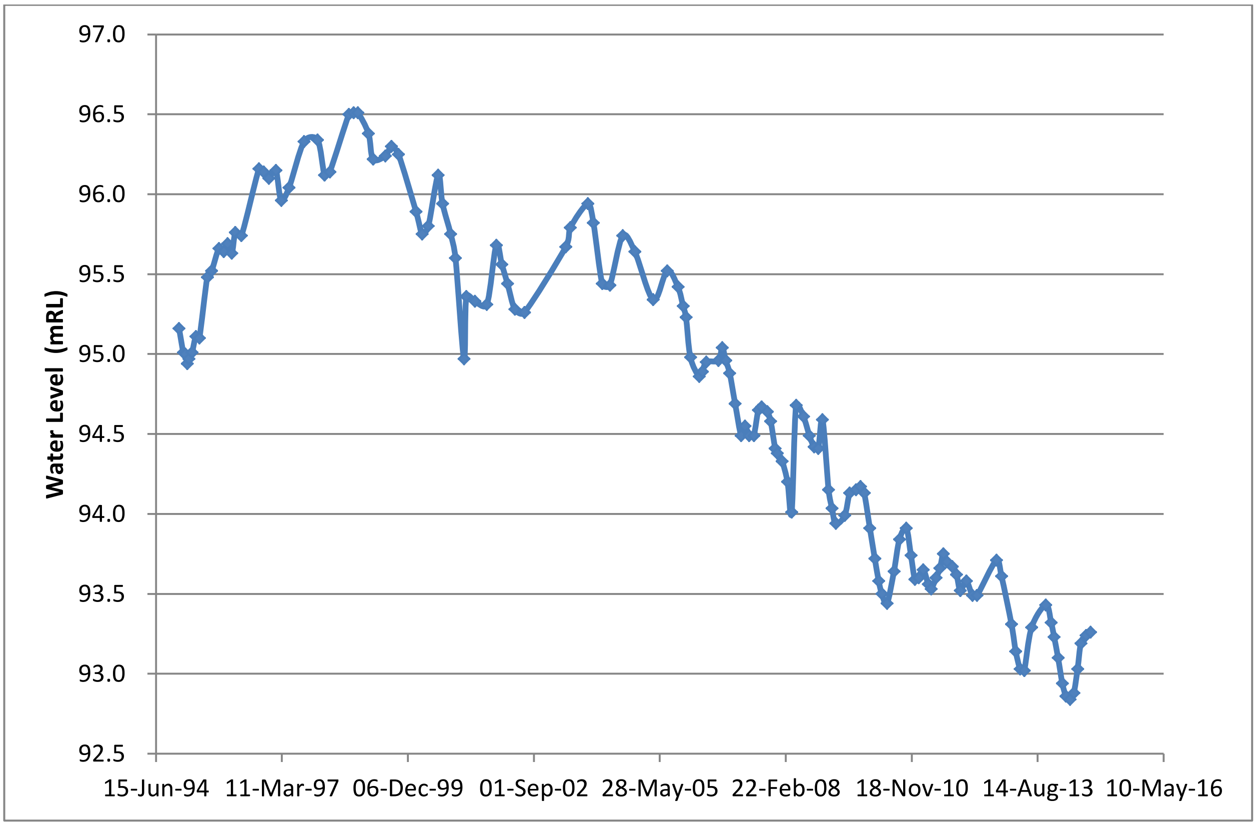

Figure 1. Upper Rototuna Lake Water Level Data from NRC monitoring records.

2. Land use

The land cover in the Upper Rototuna surface water catchment area consists mainly of pine forests and grassland. Forests and grassland areas cover 72% and 28% of the Upper Rototuna catchment respectively.

According to information obtained from Evergreen Forests Limited, planting and harvesting of pine trees has been occurring within the forestry area of the Upper Rototuna Catchment for over 40 years. Planting and harvesting of pine trees has resulted in varying historical land coverage patterns in the forestry areas. Imagery showing the land coverage within the forestry areas in 2003 and 2008 is provided in Figure A1 and Figure A2 of Appendix A. Table 1 presents a comparison of the landcover characteristics within the forestry properties of the Upper Rototuna catchment for 2003 and 2008. The area covered by mature pine trees increased by approximately 130% between 2003 and 2008. Figure A1 and Figure A2 of Appendix A also indicate that as the pine trees mature, the density of the tree canopy and hence the potential rainfall interception capacity also increases.

Table 1. Forestry Area Coverage for 2003 and 2008.

Forestry Property Land Cover	Area (m^2)	
	2003 (1)	2008 (2)
Mature Trees	689,700	1,563,300
Young Trees	306,800	-
Cleared (3)	566,800	-

Notes. (1) Calculated from air photos.
(2) Calculated from satellite imagery.
(3) Recently harvested area.

Satellite imagery from 2014 indicates that there has been no further tree harvesting within the Upper Rototuna Lake Catchment area since 2008.

3. Hydrogeology

3.1. Geological Setting

Lake Rototuna occurs within the young fixed parabolic dune deposits close to the boundary with the relatively older Awhitu Group dune sediments. The surfaces of the young parabolic dunes are fixed by vegetation but generally lack well developed soils. The Awhitu Group sediments consist of poorly moderately to poorly consolidated, large-scale cross-bedded dune sands with intercalated paleosols, lignite and carbonaceous mudstone (Edbrooke and Brook 2009).

3.2. Bore log Information

Limited geological information is available from driller's logs for Bore 209018 (Figure A3 of Appendix A) and Bore 208047 both drilled in the area surrounding Upper Rototuna Lake. The geological information available indicates the presence of homogenous sand formations from the ground surface to depths equal to or greater than 30 mbgl in both bores. The available geological information for the bores is as follows:

- Bore 208047 – The bore was drilled through and terminated within a 40 m thick sand formation.
- Bore 209018 - Geological information from the driller's log is presented in Table 2. A 30 m thick sand formation occurs from the surface to a depth of 30 mbgl. The sand formation

is underlain by a 0.2 m thick hard pan horizon. The continuity and lateral extent of the hard pan deposit is unknown. An alternating sequence of sands and mud was intercepted beneath the hard pan to a depth of 136.4 m.

Table 2. Geological Log for Bore 209018.

Bore Depth (mbgl) (1)		Geological Description (2)
From	To	
0	30	Various sands
30	30.2	Hard Pan
30.2	112.3	Various sands and muds
112.3	117.9	Orange Sand
117.9	118.9	Mud
118.9	133.5	Various muddy sands
133.5	136.4	Muds

Notes. (1) mbgl = metres below ground level.
(2) Geological descriptions are based on information obtained from the driller's log.

Bore 209018 is cased down to a depth of 127 mbgl and screened to 133.5 mbgl within the 'various muddy sands' formation. The static water level for the formation within the screened interval was 78.5 mbgl, indicating artesian groundwater conditions for the screened hydrogeological formation.

The hydraulic conditions in the geological formations above the screened zone are poorly understood. The driller's log for Bore 209018 does not provide information on groundwater inflow zones (if any) that were intercepted above the screened zone during the drilling of the bore.

3.3. Groundwater Spring and Seepage Zone Survey

A quick site walkover was undertaken to identify groundwater springs, seepages and ponded water at the ground surface on 31 October 2014. Heavy storms had occurred in the previous two days prior to the site visit. The following observations were made during the site walkover.

- There was no evidence of ponded water above ground surface in the Upper Rototuna Lake catchment area, which indicates high infiltration rates associated with the fixed parabolic dune sands in the Upper Rototuna Lake catchment area.
- There was no evidence of groundwater springs and seepages along the slopes around the Upper Lake Rototuna Lake, which suggests that the groundwater table around the Upper Rototuna Lake is generally deep (ie much lower than the ground surface elevation).
- Mr Bob Zimmerman indicated that a near constant water level occurs throughout the year in a shallow hand dug well located on his Property (Figure A3 of Appendix A).
- Groundwater seepage discharges were also observed to the north of the shallow hand dug well on Mr Zimmerman's property.

3.4. Conceptual Groundwater Flow Model

A simplified conceptual hydrogeological profile along Section Line A-A' through the Rototuna valley (Figure A3 of Appendix A) is presented in Figure A4 of Appendix A The conceptual model has a sand formation overlying an alternating mud-sand sequence. This geological layering is consistent with geological information from Bore 209018 (Table 2).

It is thought that infiltrating groundwater percolates vertically downwards through the unsaturated sand formation to the top of the alternating mud-sand sequence. Vertical flow from the unconfined sand formation to the underlying alternating mud-sand sequence is likely to be very low due to:

- Anisotropic hydraulic conductivity properties of the alternating mud-sand sequence. The vertical hydraulic conductivity (K_v) of the alternating mud-sand sequence is expected to be much smaller than the horizontal hydraulic conductivity (K_h).
- The hard pan beneath the base of the unconfined sand formation (Bore 209018) is expected to restrict vertical flow from the unconfined sand formation to the underlying alternating mud-sand sequence.

The overall effect of the restricted vertical groundwater flow through the base of the unconfined sand formation is that, in the area around the Upper Rototuna Lake, groundwater is likely to accumulate near the base of the unconfined sand formation resulting in saturated groundwater conditions (water table) occurring at the base of the formation (Figure A5 of Appendix A). The groundwater table is therefore expected to occur below the Upper Rototuna Lake bottom with localised groundwater mounding beneath the lake bottom due to groundwater seepage discharge from the lake. The deep groundwater table in the area around Upper Lake Rototuna could explain the lack of the groundwater discharges (springs and seepages) in the Upper Lake Rototuna Catchment area.

The groundwater flow system beneath the Upper Rototuna Lake is likely to be connected to the groundwater system beneath the Lower Rototuna Lake (Figure A5 of Appendix A).In the area to the east of Lower Lake Rototuna, the groundwater table is expected to occur above the lake level resulting in permanent groundwater discharge features such as springs, seeps and ponded surface water as observed on Mr Zimmerman's Property.

As observed from bore 209018, the mud layers within the alternating mud-sand sequence act as confining/semi-confining layers to the interbedded artesian sand formations.

4. Probable Causes for Water Level Decrease

The Probable causes for the decrease in water levels in Upper Lake Rotonuna since 2005 were identified from the assessment of available information and interviews with various stakeholders within the lake catchment. The following probable causes were identified:

- Changes in landuse patterns.
- Increased groundwater seepage losses from Upper Rototuna Lake to Lower Rototuna Lake caused by the breaching of the Lower Lake Rototuna natural embankment .
- Decreasing trends in rainfall patterns since 2005.

An assessment of each of these probable causes is provided in the following sections.

4.1. Changes in Landuse Patterns

Information presented in Section 2 clearly shows a change in land area coverage patterns within the forestry area between 2003 and 2008. The area covered by mature pine trees within the Upper Rototuna Catchment increased by more than 130% between 2003 and 2008.

Increasing the area covered by pine trees can reduce lake water levels by (i) increasing rainfall interception by the pine tree canopy (ii) increasing evapotranspiration.

Interception storage by canopy of mature pine trees can capture up to 30% of mean annual rainfall (Jacobs 2014). In addition, runoff to the lake that is generated in forest areas from throughflow that reaches the ground surface is likely to be less than runoff generated in grassland areas.

Evapotranspiration from pine forests can be a significant component of the water budget. Studies carried out in the pine forests in the Aupouri sand aquifer area indicate that evapotranspiration can be approximately 90% of average annual rainfall (HydroGeo Solutions 2000).

Satellite imagery from 2014 and information received from the forestry company indicates that there has been no further tree harvesting within the Upper Rototuna Lake Catchment area since 2008.

It is, therefore, highly likely that the main cause for the decreasing trend in Upper Rototuna Lake water levels is due to:

- increased rainfall interception storage by the pine tree canopy.
- Increased evapotranspiration from the pine forest area.
- decreased runoff to the lake from the forest areas.

The trend of decreasing lake water levels is likely to continue until new steady state conditions are achieved in the catchment water balance, if no further forest harvesting is carried out.

4.2. Increase in Seepage losses due to Lower Lake Breach.

Jacobs (2014) have suggested that the decreasing trend in Upper Rototuna Lake water levels since 2005 is due to the breaching of the natural embankment structure for the Lower Rototuna Lake. The exact date when the breach occurred is unclear but various sources indicate that the breach occurred in the 1970's (Griffin 2014 and Gary Treadgold *personal communication*)

Griffin (2014) suggested that prior to the breach, water levels in the Lower Rototuna Lake were 4 m higher than current levels. The decrease in Lower Rototuna Lake water levels would have resulted in a decrease in groundwater seepage outflows from the Lower Rototuna Lake and a decrease in groundwater levels below the Lower Rototuna Lake.

The conceptual groundwater flow model (Section 3.4) indicates that there is a hydraulic connection between the groundwater system between the two lakes (Figure A5 of Appendix A). Therefore, lowering groundwater levels in the Lower Rototuna Lake would have had some effect on groundwater levels in the Upper Rototuna Lake. The relatively high hydraulic conductivity of the poorly consolidated and relatively well sorted sand formation would have resulted in a relatively quick response in Upper Rototuna Lake water levels to changes in Lower Rototuna Lake water levels.

Given that the breach in natural embankment occurred in the 1970's, it is highly unlikely that the main cause of the recent trend in decreasing water levels from 2005 in Upper Rototuna Lake would have been the breaching of the natural embankment for the Lower Rototuna Lake. Water level monitoring records for the Upper Rototuna Lake actually indicate that an increase in Upper Rototuna Lake occurred between 1995 and 1998 (Figure 1) after the lower dam breach had occurred.

4.3. Rainfall Pattern Changes

Rainfall records from the Pouto Point rainfall gauging station and the NIWA land station at Dargaville were used to assess whether the current decreasing trend in Upper Rototuna Lake water levels could be due to decreasing rainfall within the area. The Point Pont gauging station and the NIWA station at Dargaville are located approximately 21 km and 35 km from the site respectively. The median annual rainfall at Dargaville of 1,200 mm is very similar to the rainfall patterns at the Rototuna lakes (NIWA 2013). The median annual rainfall at Pouto Point is between 1,200 mm and 1,300 mm.

Graphs of monthly rainfall totals and Upper Rototuna Lake water levels (Figure 2 and Figure 3) do not indicate any relationship between the decreasing trend in lake water levels and rainfall.

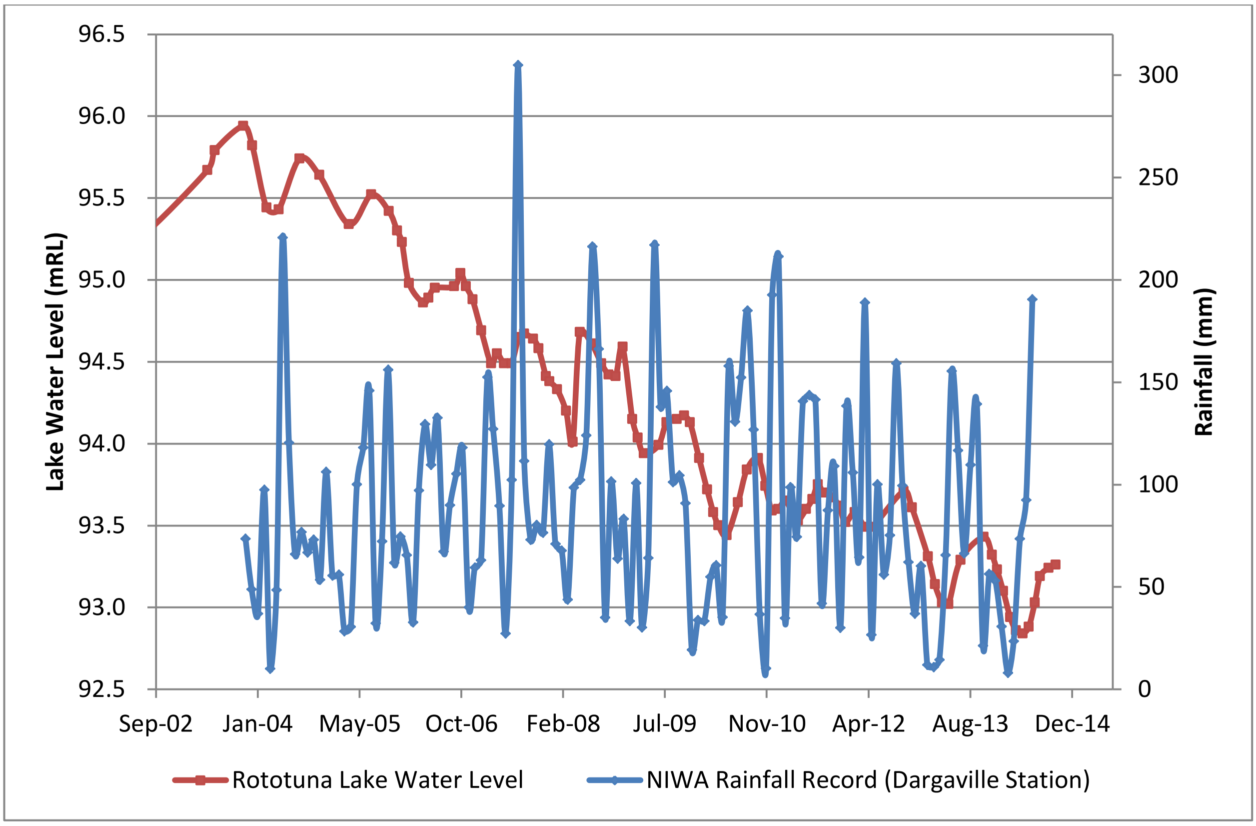

Figure 2. NIWA (Dargaville Station) Rainfall Record and Upper Rototuna Lake Water Levels.

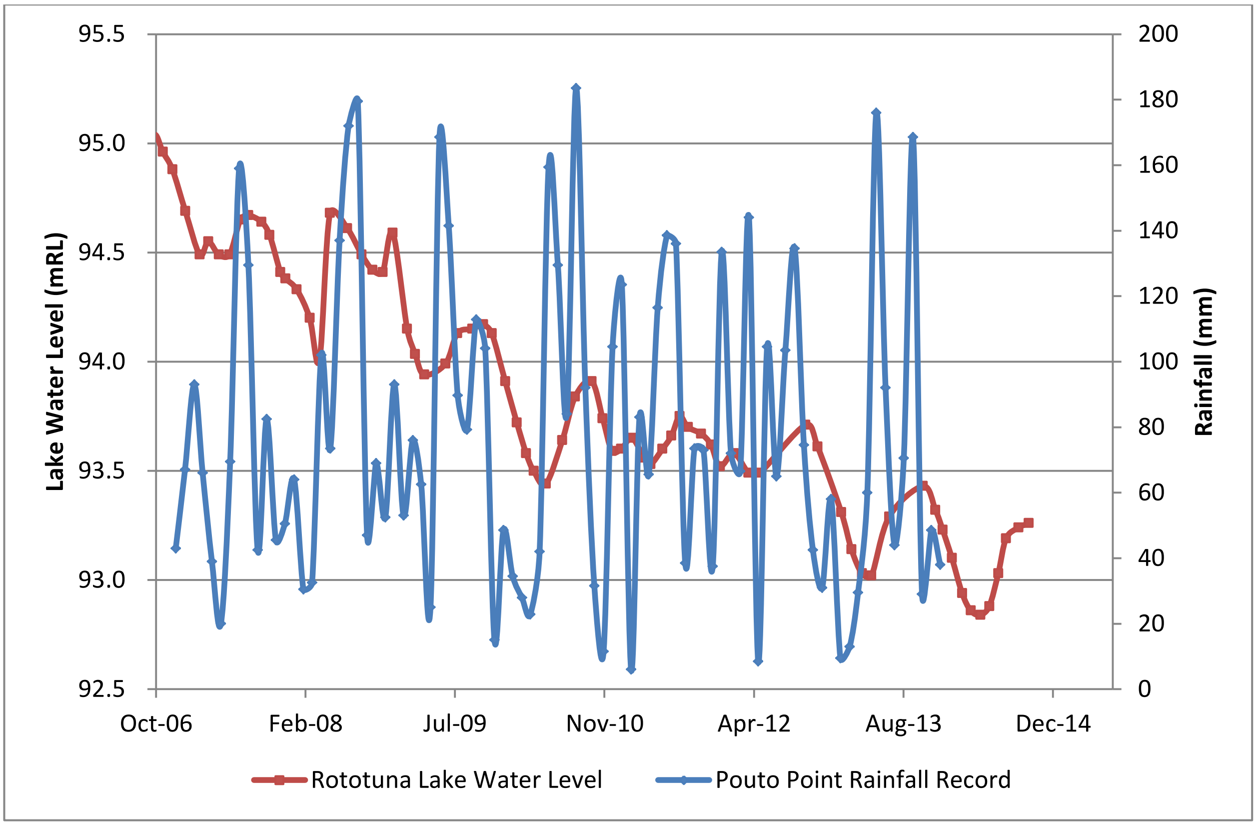

Figure 3. Pouto Point Rainfall Record and Upper Rototuna Lake Water Levels.

5. Lake Water Quality

NRC has been monitoring the concentrations of a number of chemical parameters including dissolved organic nitrogen (DON), dissolved organic phosphorous (DOP), chlorophyll a, conductivity, dissolved inorganic nitrogen, dissolved oxygen, pH, ammonium, nitrate, and suspended solids in the Upper Rototuna Lake since 1990. With the exception of dissolved organic nitrogen (DON) and dissolved organic phosphorous (DOP) there have been no clear trends observed in concentrations of the monitored chemical parameters.

Dissolved organic nitrogen (DON) concentrations in the Upper Rototuna Lake have been on an increasing trend since 2005 from a peak concentration of approximately 0.5 g/m3 in 2005 to a peak concentration of approximately 0.7 g/m3 recorded in June 2014 (Figure 4). The increasing DON concentrations coincide with decreasing lake water levels.

Peak dissolved organic phosphate (DOP) concentrations measured in Upper Rototuna Lake measured in 2012 and 2014 have been much higher than peak concentrations measured in the preceding years (Figure 5).

The increasing nitrogen and phosphorous concentrations are most likely caused by a concentration effect due to a reduction in lake water volume. Increasing dissolved nitrogen and phosphorous concentrations are associated with deteriorating lake health (Jacobs 2014 and Waiora Northland Water 2014).

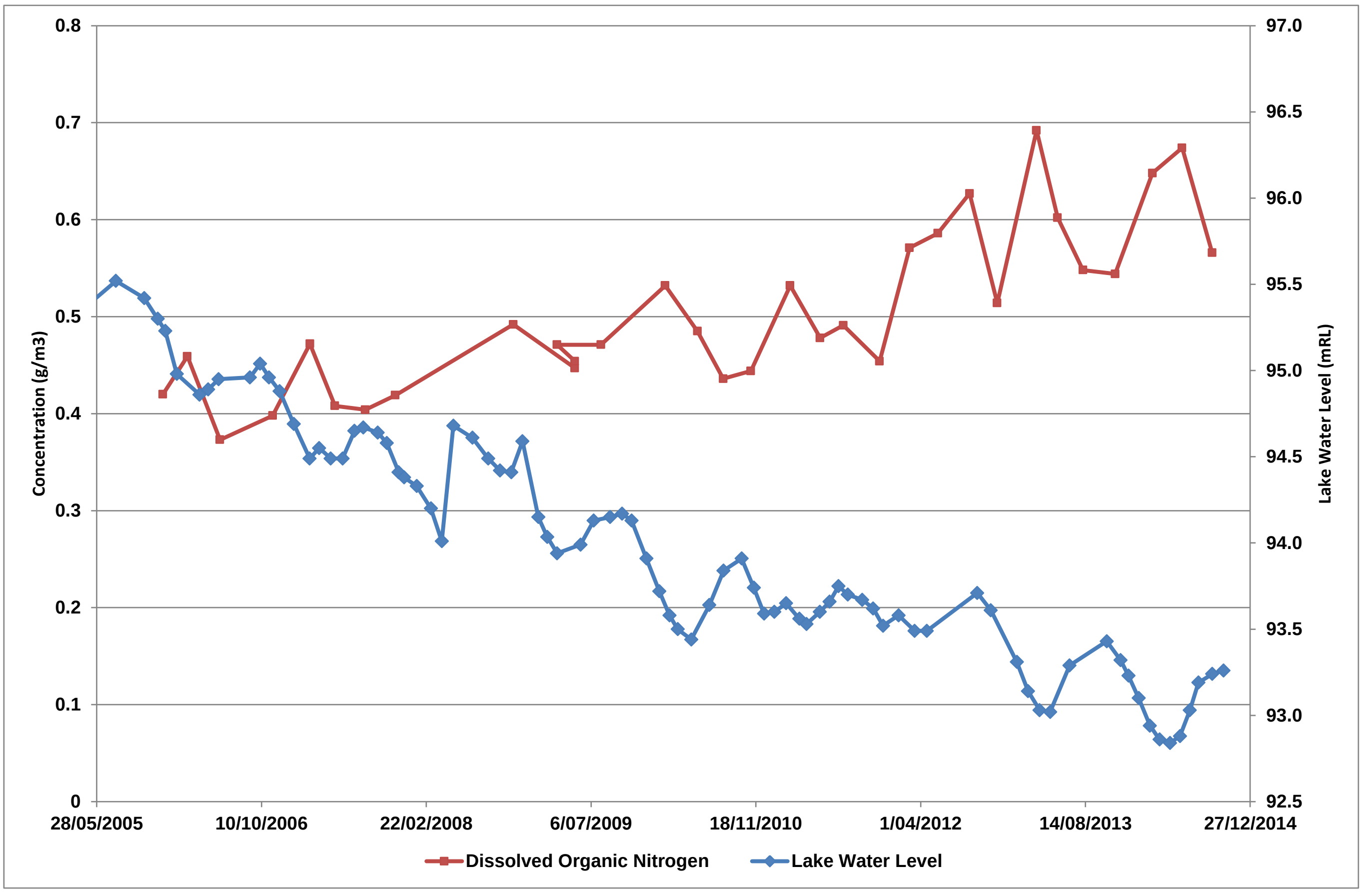

Figure 4. Dissolved Organic Nitrogen Concentrations in Upper Rototuna Lake.

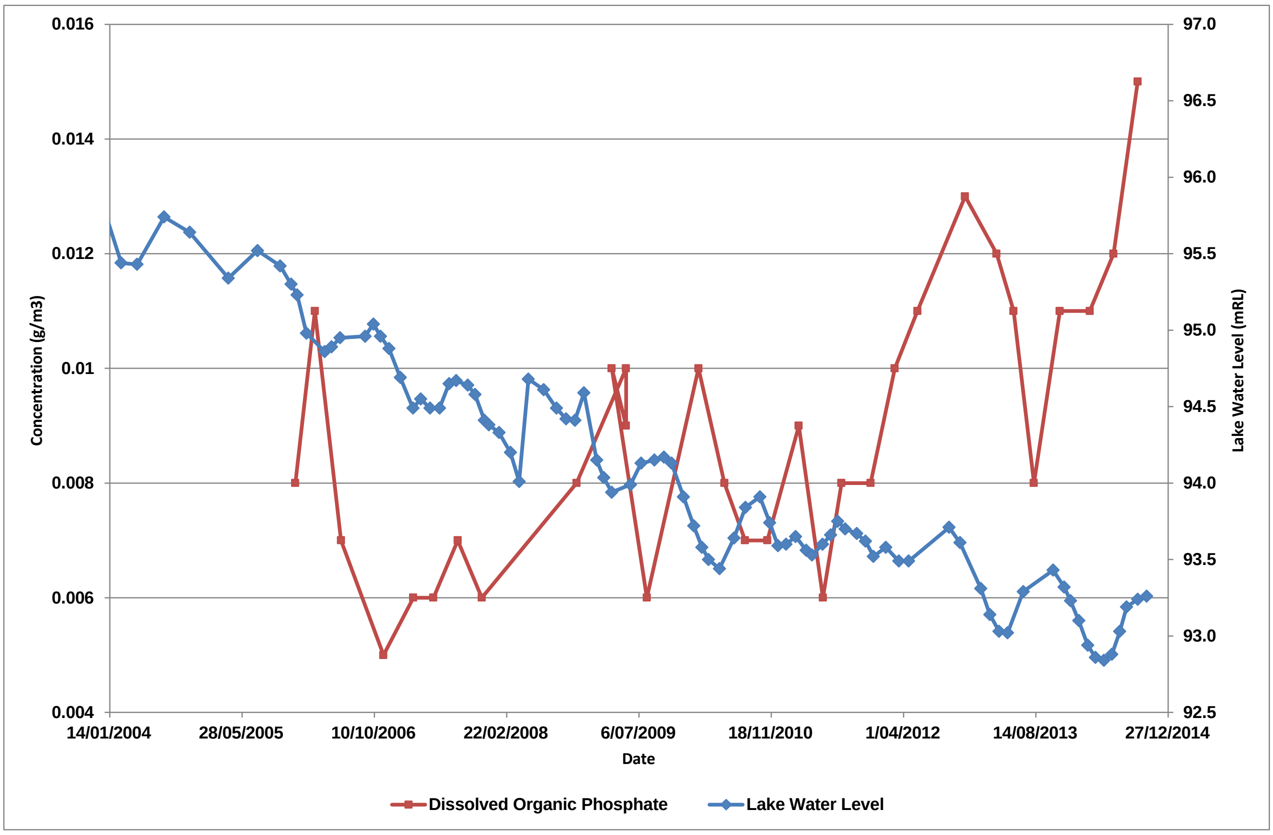

Figure 5. Dissolved Organic Phosphorous Concentrations in Upper Rototuna Lake.

6. Conclusions

1. The main cause for the decreasing trend in Upper Rototuna Lake water levels from 2005 onwards is likely to be the increase in the area covered by mature pine trees within the Upper Rototuna Lake Catchment.
2. The breaching of the Lower Rototuna Lake natural embankment in the 1970's could have caused a decrease in Upper Rototuna Lake water levels shortly after the breach event. However, based on our conceptual understanding of the groundwater flow system and the timing of the lake embankment breach , it seems highly unlikely that the decreasing trend in lake levels from 2005 onwards was caused by the embankment breach.
3. Upper Rototuna Lake water quality monitoring data shows an overall increasing trend in dissolved organic nitrogen (DON) occurring concurrently with the decrease in lake water levels. Increasing DON concentrations are normally linked to a deterioration in lake ecosystem health.

7. Recommendations

1. It is recommended that NRC obtains more accurate information on historical activities (harvesting and planting) in the forestry areas within the Upper Rototuna catchment. More accurate historical information on forest planting and harvesting can be used to improve any further assessments of the effect of land use on lake water levels.
2. When accurate information on historical activities within the forestry areas has been obtained, it is recommended that NRC carry out an assessment of the effect of different catchment landuse management scenarios on Upper Rototuna Lake Water Levels. NRC can use the existing GoldSIM model developed by Jacobs for NRC to carry out this

assessment. Results of this assessment can be used to inform management decisions on land-use within the Upper Rototuna Lake Catchment.

3. It is recommended that NRC carry out a detailed topographic survey of the area around both lakes.
4. It is recommended that NRC drill three bores around the Rototuna Lakes to improve the understanding of the geological formations, groundwater levels and groundwater flow directions. The conceptual hydrogeological model that has been developed for the area (Section 3.4) is based on limited groundwater information from only two bores. It is recommended that one bore is drilled adjacent to the Upper Rotototuna Lake; one bore is drilled in the region between the two lakes and one bore is drilled adjacent to the Lower Rototuna Lake. It is recommended that piezometers are constructed are in the bores. The specific piezometer design can be decided depending on the hydrogeological conditions encountered during the drilling.
5. It is recommended that NRC obtains information on the exact date when the breach in the Lower Rototuna Lake occurred.
6. It is recommended that NRC establish a rainfall measuring station in the Upper Rototuna Lake catchment to improve the understanding of the relationship between rainfall and lake water levels.

8. References

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NIWA, 2013: The Climate and weather of Northland. Third Edition. Prepared by P.R. Chappell.

Waiora Northkand Water, 2014:Northland Lakes State and Trends. Report Prepared for the Environmental Management committee.

APPENDIX A

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