Water Quality Monitoring Report for Lake Forsyth/Te Wairewa: January – December 2020

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1 Executive Summary

- This report briefly summarises the surface water quality monitoring of Lake Forsyth/Te Wairewa for the 2020 calendar year and provides an analysis of long-term trends.
- Conductivity, salinity, turbidity, nitrogen and phosphorus levels, as well as phytoplankton and cyanobacteria unit counts, all recorded statistically significant decreases since monitoring began. Trophic Level Index (TLI) also decreased over time, which is not surprising as this index is calculated from total nitrogen and total phosphorus (as well as chlorophyll a).
- There was no change in temperature over time. The guideline levels for temperature (19°C) were exceeded on two occasions during the 2020 monitoring year.
- The cyanobacteria biovolume alert and action levels were exceeded on nine and eight occasions, respectively. This number of exceedances is within the range recorded since monitoring began in 2008. As a result of these exceedances, health warnings were issued from 26 March–21 August 2020 and from 1 October–10 November 2020.
- The decrease in salinity is probably partially driving the change in phytoplankton composition from *Nodularia* spp., to *Dolichospermum* spp. and *Aphanizomenon* spp..
- These results show that water quality continues to improve within the lake, most likely due to the canal opening regime, although this cannot be concluded with certainty. Most notably, there has been a significant decrease in the TLI over time. However, the water quality is still poor at times, and additional lake and catchment management practices that improve water quality (e.g., planting) should therefore continue.

2 Introduction

In accordance with the requirements of Condition 11c (monitoring and reporting) of consent CRC134849 (to take and divert water from, and dam, Lake Forsyth/Wairewa), this report briefly summarises the surface water quality results of Lake Forsyth/Te Wairewa for the 2020 calendar year and provides an analysis of long term trends. The data used in this report was provided by Environment Canterbury (ECan).

3 Methods

Samples were taken at least monthly from the lake and analysed for conductivity, salinity, temperature, turbidity, Dissolved Inorganic Nitrogen (DIN), Dissolved Reactive Phosphorus (DRP), Trophic Level Index (TLI), phytoplankton unit counts, and cyanobacteria (a subset of phytoplankton) unit counts and biovolume. Unit counts and biovolumes were also assessed for particular species of potentially toxic cyanobacteria. Water quality parameters were analysed from when the monitoring began in 1993 until December 2020. Phytoplankton and cyanobacteria unit counts were assessed from 2004, and cyanobacteria biovolumes from 2008. Samples were typically collected from the ECan water level recorder site (hereafter referred to as 'Recorder'), with the exception of salinity, which was also recorded at two additional sites (Figure 1).

Percent change in parameters between the pre-canal opening regime (various dates for each parameter from 1993 – September 2009) and the post-canal opening regime (October 2009 – December 2020) are presented in this report. However, as there is (1) generally a larger dataset for the pre-canal opening regime compared to the post-canal opening regime, and (2) no way to account for other potential drivers of change, such as land use practices, extrapolation of these results to the opening regime should be carried out with caution.

Long-term data trends were analysed using Time Trends software (NIWA, 2014[1]). The Seasonal Kendall trend test was used to test the significance, magnitude and direction of trends, providing an average annual percent change. Water quality parameters were analysed as independent data. Total phytoplankton data, including the subsets of cyanobacteria and potentially toxic cyanobacteria, were analysed as dependant data. Long-term data trends for cyanobacteria biovolume were not analysed, due to the sampling methodology varying between state of environment monitoring and samples collected during blooms to assess human health risks.

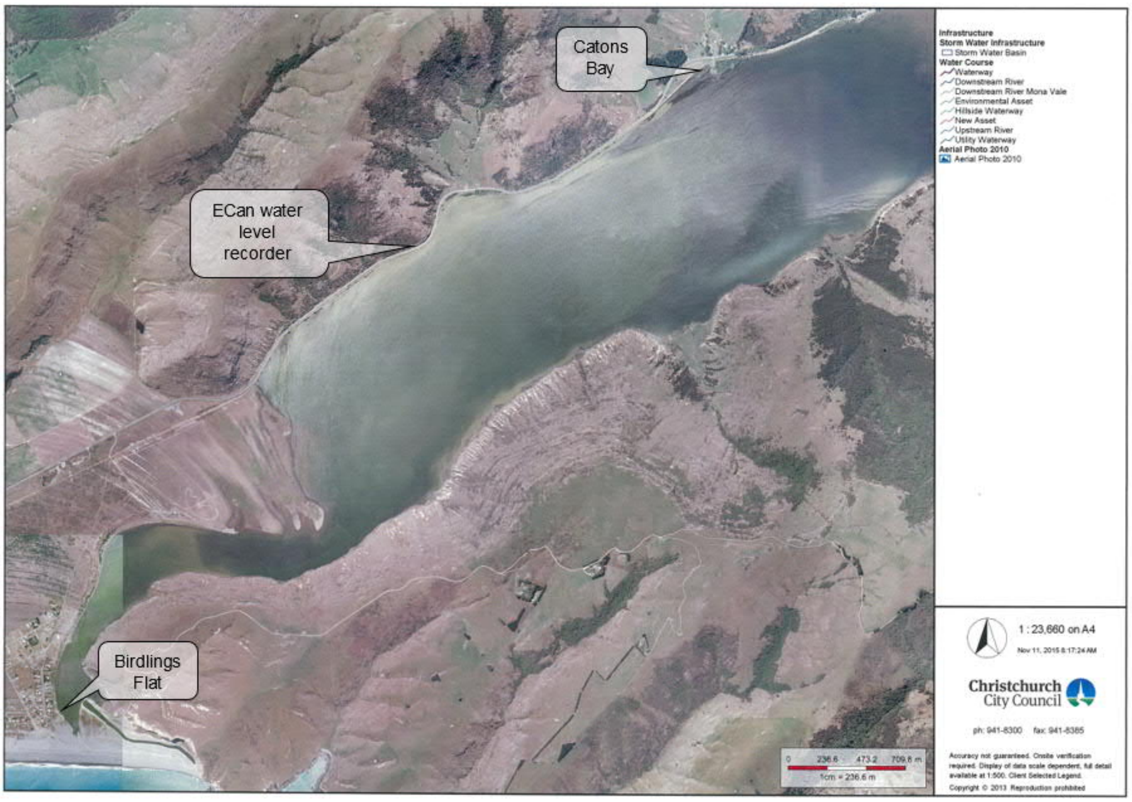

Figure 1. Water quality monitoring sites in Lake Forsyth/Te Wairewa.

4 Results

4.1 Water Quality measurements

Conductivity and salinity

- These two parameters are related to each other, so are presented together.
- A general decreasing trend was recorded over time for both parameters (Figures 2 – 3 in Appendix A).
- Following the implementation of the canal opening regime, median conductivity and salinity concentrations have decreased by nearly 80% (Table 1).
- There was a statistically significant decrease (5% per annum) in conductivity at the Recorder site since monitoring began in July 1993.
- There was a statistically significant decrease (7% per annum) in salinity at the Recorder site since monitoring began in November 1998. A significant decrease of 20% was

[1] NIWA, 2014. Trend and equivalence analysis. Software Version 6.3. NIWA. http://www.jowettconsulting.co.nz/home/time-1/Timetrends_setup.zip?attredirects=0.

recorded at the Catons Bay site and a 13% decrease at Birdlings Flat since monitoring began in December 2006.

Temperature

- Following the implementation of the canal opening regime, median temperature has increased by 18%.
- However, no statistically significant change over time was recorded for temperature since monitoring began in August 1993, with seasonal variations in levels as expected (Figure 4 in Appendix A).
- Frequent exceedances of the Land and Water Regional Plan guideline level (19°C; Environment Canterbury, 2015[2]) have occurred since monitoring began. Two of the 12 samples taken during the 2020 monitoring year exceeded this guideline.

Turbidity

- Following the implementation of the canal opening regime, median turbidity decreased by 9%.
- There was a statistically significant per annum decrease in turbidity of 2% since monitoring began in July 1993, with fewer large peaks in levels over time (Figure 5 in Appendix A).
- Compared to the rest of the 2020 data, there was a spike recorded in July (76 NTU), which was associated with some rain in the days prior to sampling (CCC rainfall recorder at Christchurch Akaroa Highway).

DIN

- Following the implementation of the canal opening regime, median DIN decreased by 63%.
- There was a statistically significant per annum decrease in DIN of 2% since monitoring began in July 1993 (Figure 6 in Appendix A).
- There were fewer peak concentrations after approximately September 2010.
- Compared to the rest of the 2020 data, slightly elevated levels were recorded in November.

DRP

- Following the implementation of the canal opening regime, median DRP decreased by 18%.
- There was a statistically significant decrease in DRP of 3% per annum since monitoring began in July 1993 (Figure 7 in Appendix A).
- There were fewer peak concentrations after approximately 2010.
- Compared to the rest of the 2020 data, a slightly elevated level was recorded in December.

TLI

- This index is calculated using chlorophyll a, total nitrogen and total phosphorus.
- Following the implementation of the canal opening regime, median TLI decreased by 7%.
- A statistically significant decrease in TLI of 0.4% per annum was recorded since monitoring began in September 1999 (Figures 8a - 8c in Appendix A).
- Prior to the canal opening there was an increasing trend (Figure 8b); however, levels have been decreasing since the initiation of the canal opening (Figure 8c).

Phytoplankton and cyanobacteria unit counts

- Total phytoplankton counts recorded a statistically significant decrease of 6% per annum, since monitoring began in 2004 (Figure 9 in Appendix A).

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[2] Environment Canterbury, 2015. Canterbury Land and Water Regional Plan - Volume 1. February 2017. Environment Canterbury, Christchurch.

- Cyanobacteria counts recorded a statistically significant decrease of 15% per annum, since monitoring began in 2004 (Figure 9 in Appendix A).
- There was a reduction in peaks of concentration for both parameters since monitoring began. However, in September 2020 a notable spike in total phytoplankton was recorded, due to high counts of the diatom *Chaetoceros* sp. (Figure 9 in Appendix A).
- With respect to counts of potentially toxic cyanobacteria:
    - Following the implementation of the canal opening regime, median cyanobacteria counts decreased by 99.7%.
    - *Merismopedia* spp. counts were high when monitoring first began in 2004, but since 2011 counts have reduced to occasional numbers, with a significant per annum decrease of 362% since monitoring began (Figure 10 in Appendix A).
    - Large counts of *Nodularia* spp. were recorded when monitoring first commenced, but only occasional re-occurrences have been recorded since 2010 (Figure 10 in Appendix A). Low numbers of *Nodularia* spp. were occasionally recorded in 2020. The decline in *Nodularia* spp. is likely due to the decrease in lake salinity, as optimal growth occurs between 7–18 ppt[3]. With one exception, salinities in the lake have not exceeded 5 ppt since January 2010. Although a significant decrease was recorded since monitoring began, the percent change was zero, likely due to a small number of peaks recorded at the beginning of the dataset and predominantly no records thereafter.
    - *Dolichospermum* spp. and *Aphanizomenon* spp. have generally been present in low numbers, as was the case this monitoring year (Figure 10 in Appendix A). A significant increasing trend was recorded for both cyanobacteria; however, a zero percent change over time was recorded, due to a high proportion of zero abundance, particularly early in the dataset. It is probable that the increasing abundance of these two cyanobacteria is a result of lower salinity in the lake, with both species able to grow in freshwater[4]. Rosen *et al* (2018)[5] concluded that salinities greater than 7.5 ppt were not tolerated by *Dolichospermum circinale*.

Cyanobacteria biovolume

- A comparison of the pre and post canal opening regime is not provided for biovolume, as this metric is impacted by low samples taken pre-opening (19).
- With respect to individual species of potentially toxic cyanobacteria (Figure 11 in Appendix A):
    - During the 2020 monitoring year, *Nodularia* spp. was record in small volumes on many occasions.
    - *Merismopedia* sp. numbers were occasionally high when monitoring first began but are generally present year-round in low numbers, as was the case this monitoring year.
    - *Dolichospermum* spp. have generally been present in low volumes; however, spikes in concentrations are typically recorded a couple of times a year. No spikes were recorded in 2020.
    - Low numbers of *Aphanizomenon* spp. are typically recorded; however, small peaks of biovolume have occurred every spring/summer since December 2016, as was the case this year.

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[3] Mazur-Marzec, H., Żeglińska, L. & Pliński, M. 2005. The effect of salinity on the growth, toxin production, and morphology of *Nodularia spumigena* isolated from the Gulf of Gdańsk, southern Baltic Sea. Journal of Applied Phycology 17, 171–179.

[4] Halinen, K., Jokela, J., Fewer, D., Wahlsten, M., & Sivonen, K. 2007. Direct evidence for production of microcystins by Anabaena strains from the Baltic Sea. Applied Environmental Microbiology, 73(20), 6543–6550.

[5] Rosen, B., Loftin, K., Graham, J., Stahlhut, K., Riley, J., Johnston, B., and Senegal, S. 2018. Understanding the effect of salinity tolerance on cyanobacteria associated with a harmful algal bloom in Lake Okeechobee, Florida: U.S. Geological Survey Scientific Investigations Report 2018–5092, 32 p.

- Of the 22 samples taken in 2020, the biovolume alert guideline level for all potentially toxic cyanobacteria (0.5 mm^3/L) was exceeded on nine occasions and the action guideline level (1.8 mm^3/L) was exceeded on eight occasions (Ministry for the Environment and Ministry of Health, 2009[6]; Figure 12a in Appendix A). Over half of the alert and action exceedances were due to *Nodularia* spp.. This number of exceedances per annum is within the range previously recorded since monitoring began in 2008 (Figure 12b in Appendix A).
- Consequently, the Canterbury District Health Board advised the public to avoid contacting the water, and eating fish or shellfish from the lake, and recommended to keep livestock and pets away from the lake. These warnings were in place from 26 March–21 August 2020 and from 1 October–10 November 2020.

4.2 Lake Openings and Lake Water Quality

- It is difficult to identify relationships over one monitoring year between lake water quality, and the timing or duration of lake openings (Figure 13 in Appendix A), and any changes observed cannot be definitively concluded to be due to the lake openings. Changes may instead be due to other factors, such as land use practices. However, as shown in this report, since the canal opening was instigated in 2009, there have been significant improvements in water quality within the lake, most notably a decrease in conductivity, salinity and TLI. This was highlighted in the Commissioner's decision on the lake opening consent, based on the evidence presented by a number of experts (Collins et al, 2016)[7].
- Lake openings likely improve water quality by allowing water to flow out to sea and disallowing significant flows of salt water back into the lake, which previously occurred with the former mid-beach opening regime. This has resulted in a decrease in lake salinity.

4.3 Myriophyllum

- Flowerings of *Myriophyllum*, a native macrophyte, were noted in the consent hearing to be observed in the lake in 2014 and 2015 (Collins et al, 2016), anecdotally for the first time in many years. This species was noted to be indicative of a healthier lake environment, as they require good light penetration and a stable lake level.
- However, from 2017–2020 no flowering or emergent growths were observed (Adrian Meredith and Tina Bayer, 2018–2021, personal communication).

5 Conclusion

- Water quality continues to improve within the lake, most likely due to the canal opening regime. Most notably, there has been significant decrease in the TLI since canal openings were initiated.

[6] Ministry for the Environment and Ministry of Health. 2009. New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines. Prepared for the Ministry for the Environment and the Ministry of Health by SA Wood, DP Hamilton, WJ Paul, KA Safi and WM Williamson. Wellington: Ministry for the Environment.

[7] Collins, D., Cowie, B. & Langsbury, H. 2016. Decisions of hearings commissioners, in the matter of applications to the Christchurch City Council (RMA92021940 and RMA92030265), and the Canterbury Regional Council (CRC134837, CRC134839, CRC134864, CRC135060 and CRC 160434) made jointly by the Christchurch City Council and Wairewa Rūnanga Incorporated for consents to carry out activities associated with the artificial opening and closing of Te Roto o Wairewa/Lake Forsyth to the sea. Little River, Banks Peninsula, New Zealand.

- The decrease in salinity recorded is probably partially driving the change in phytoplankton composition from *Nodularia* spp., to *Dolichospermum* spp. and *Aphanizomenon* spp..

Table 1. Percent change of parameters at the Environment Canterbury Recorder Site at Te Wairewa/Lake Forsyth, before (various dates for each parameter from 1993 – September 2009) and after (October 2009 – December 2020) the implementation of the canal opening regime.

Parameter	Count (n)		Median		Percentage change
	Pre	Post	**Pre**	Post	
Conductivity (µS/cm)	587	171	920	200	-78%
Salinity (ppt)	496	243	5.2	1.1	-79%
Temperature °C	694	641	13	15.3	18%
Turbidity (NTU)	599	136	14	12.8	-9%
DIN (mg/L)	512	133	0.043	0.016	-63%
DRP (mg/L)	504	96	0.004	0.0033	-18%
TLI	121	134	5.99	5.59	-7%
Potentially toxic cyanobacteria - counts (unit/ml)	137	175	47500	120	-99.7%

6 Appendix A: Graphs

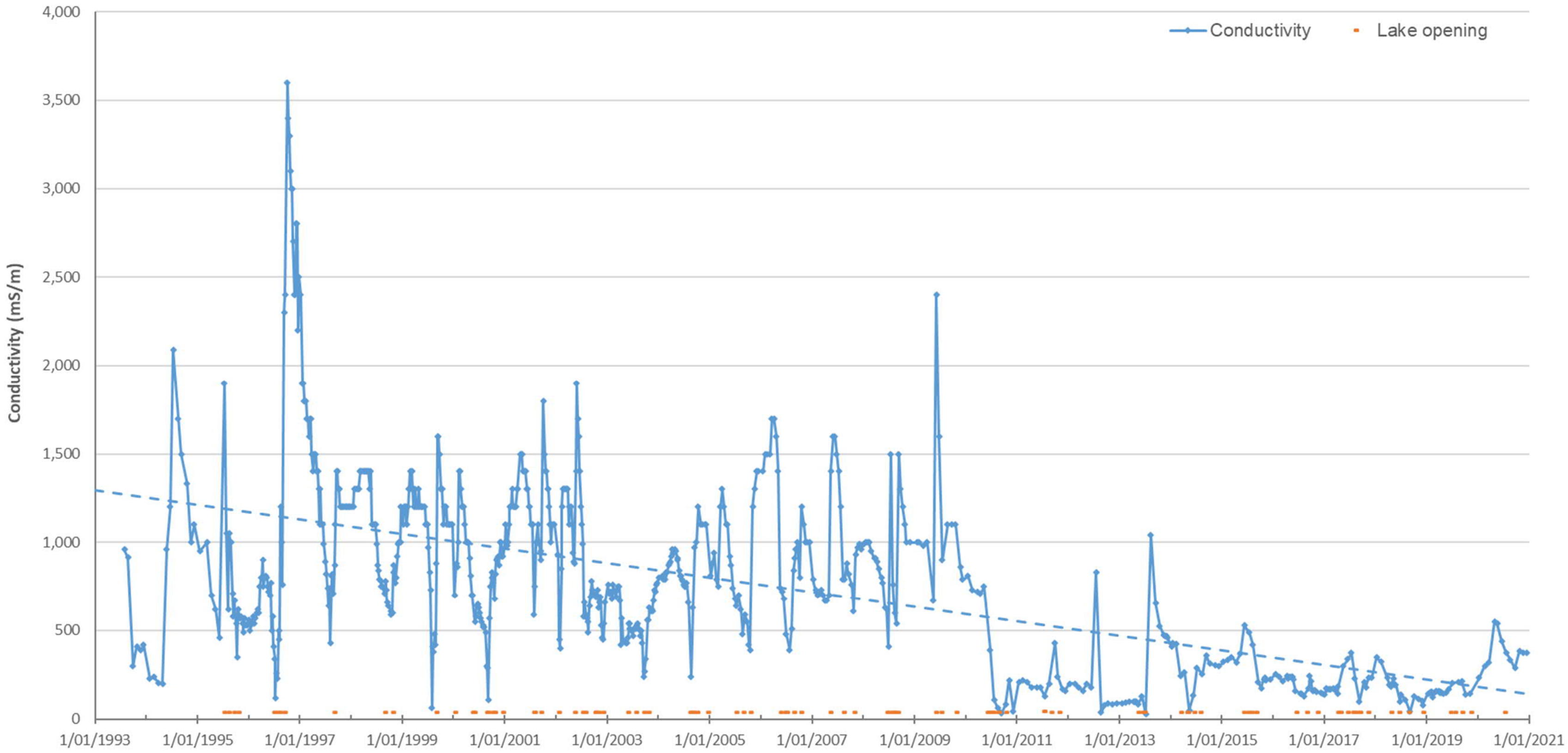

Figure 2. Conductivity of water at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the entire dataset (July 1993 - December 2020). The dashed line is a linear trendline.

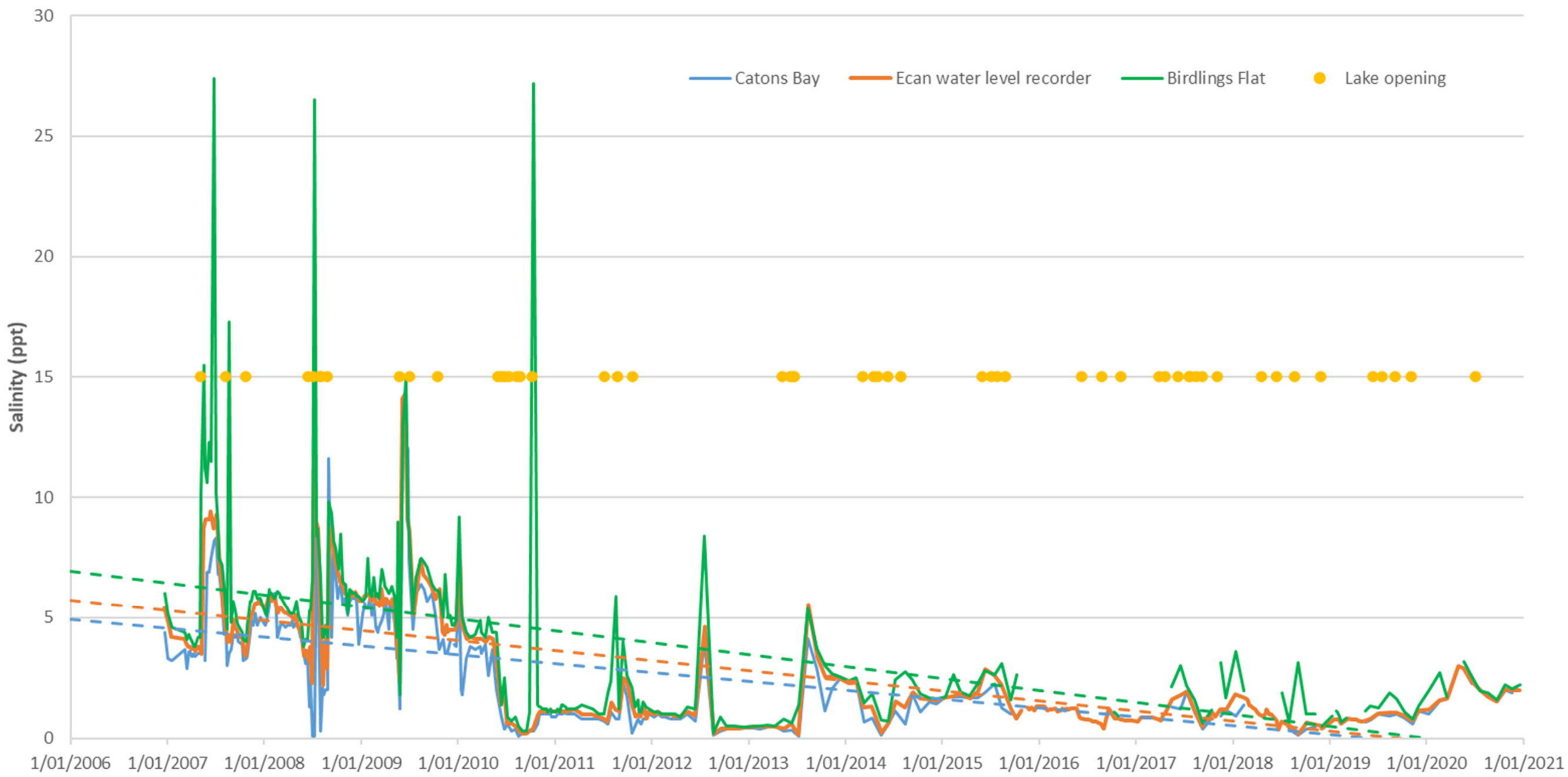

Figure 3. Salinity of water at Wairewa/Lake Forsyth at three sites (ECan Water Level Recorder, Catons Bay and Birdlings Flat) from the entire dataset (December 2006 - December 2020). The dashed lines are linear trendlines.

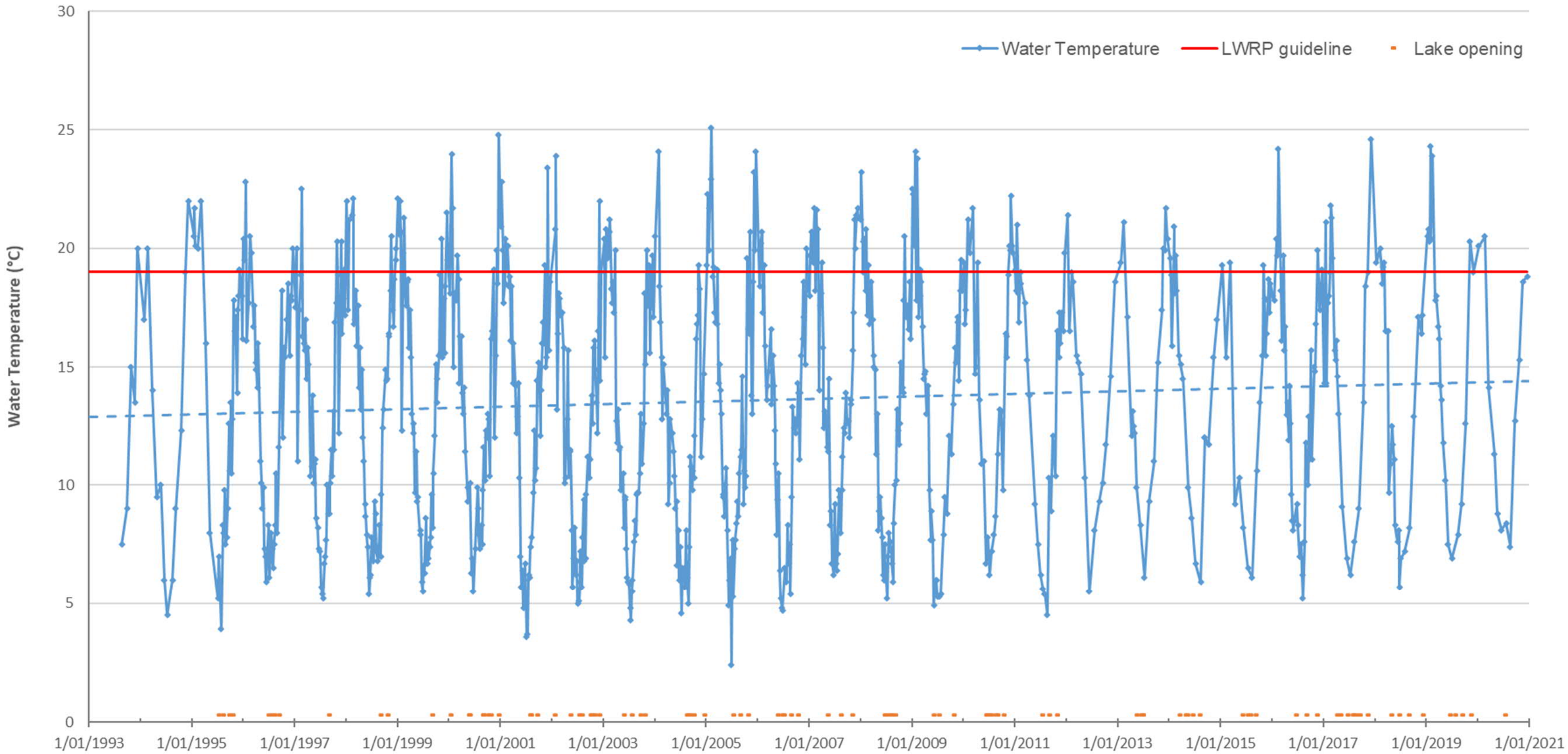

Figure 4. Water Temperature at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the entire dataset (August 1993 - December 2020). The dashed line is a linear trendline. Red line = Land and Water Regional Plan (LWRP) guideline for coastal lakes (19°C).

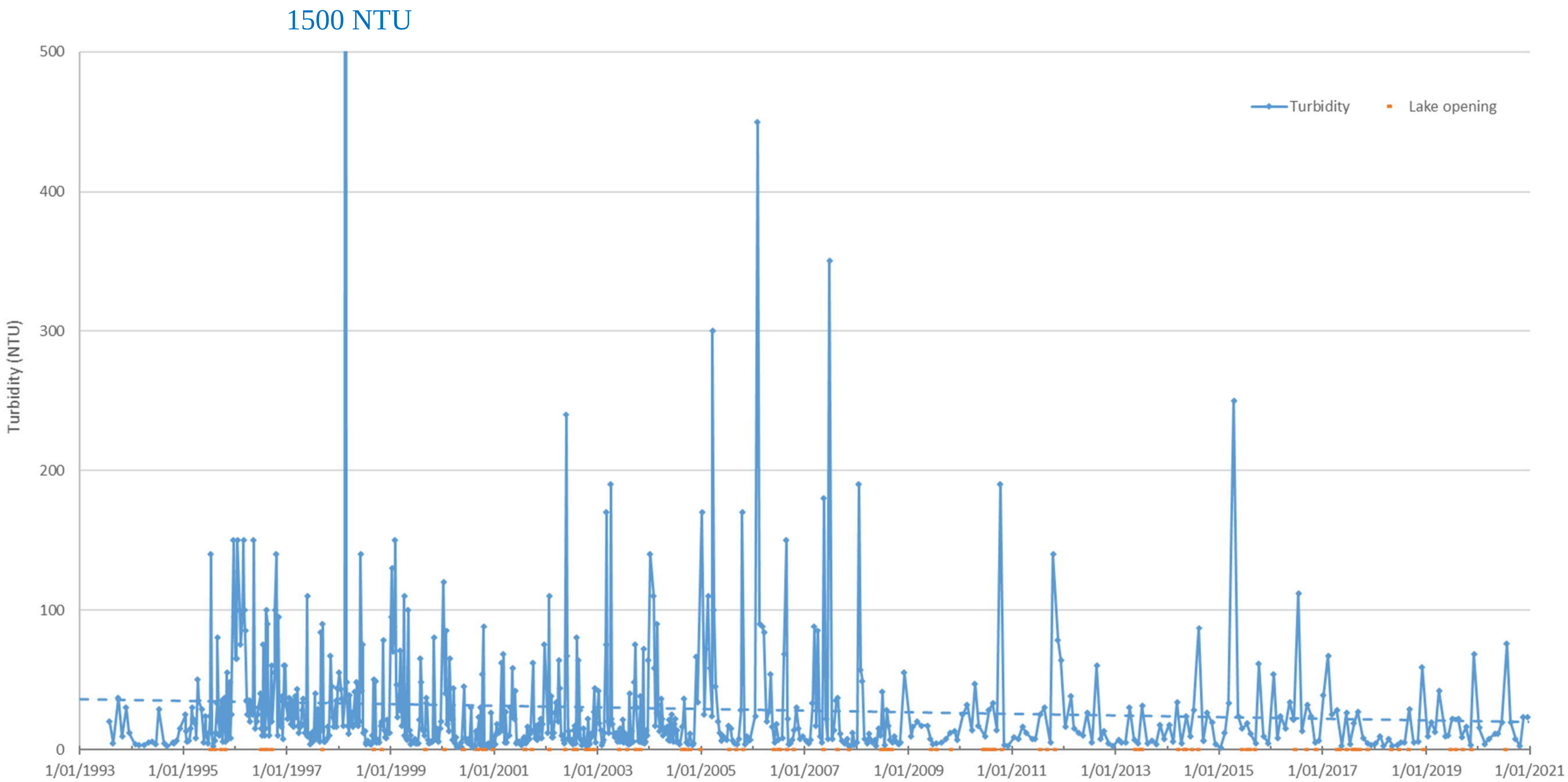

Figure 5. Turbidity of water at Wairewa/Lake Forsyth at the water level recording site for the entire dataset (July 1993 - December 2020). The dashed line is a linear trendline. One data point is substantially higher than the other data points and is therefore off the scale of the graph – number above the graph detail the concentration.

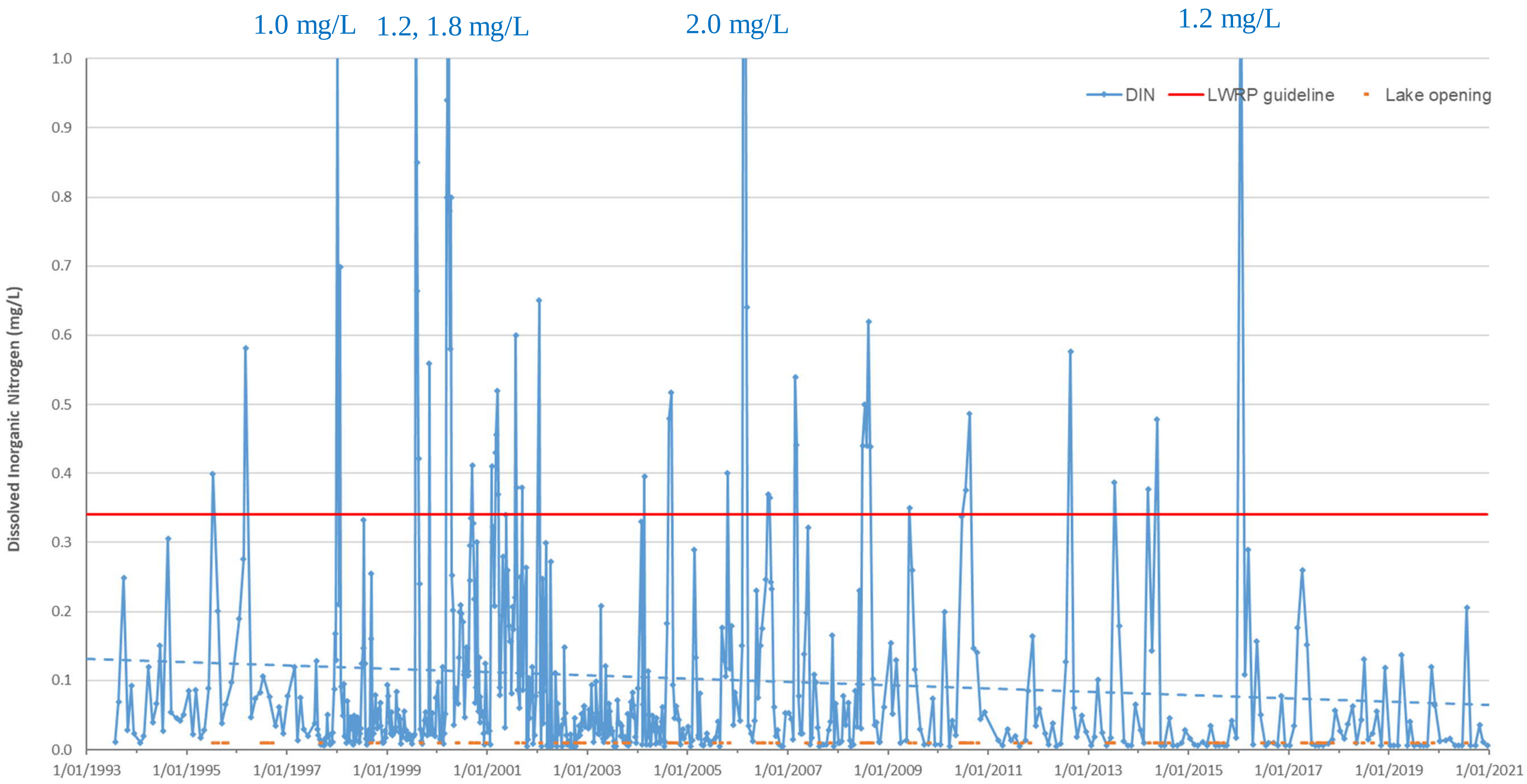

Figure 6. DIN at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the entire dataset (July 1993 – December 2020). The dashed line is a linear trendline. Five data points are substantially higher than the other data points and are therefore off the scale of the graph – the numbers above the graph detail their concentrations.

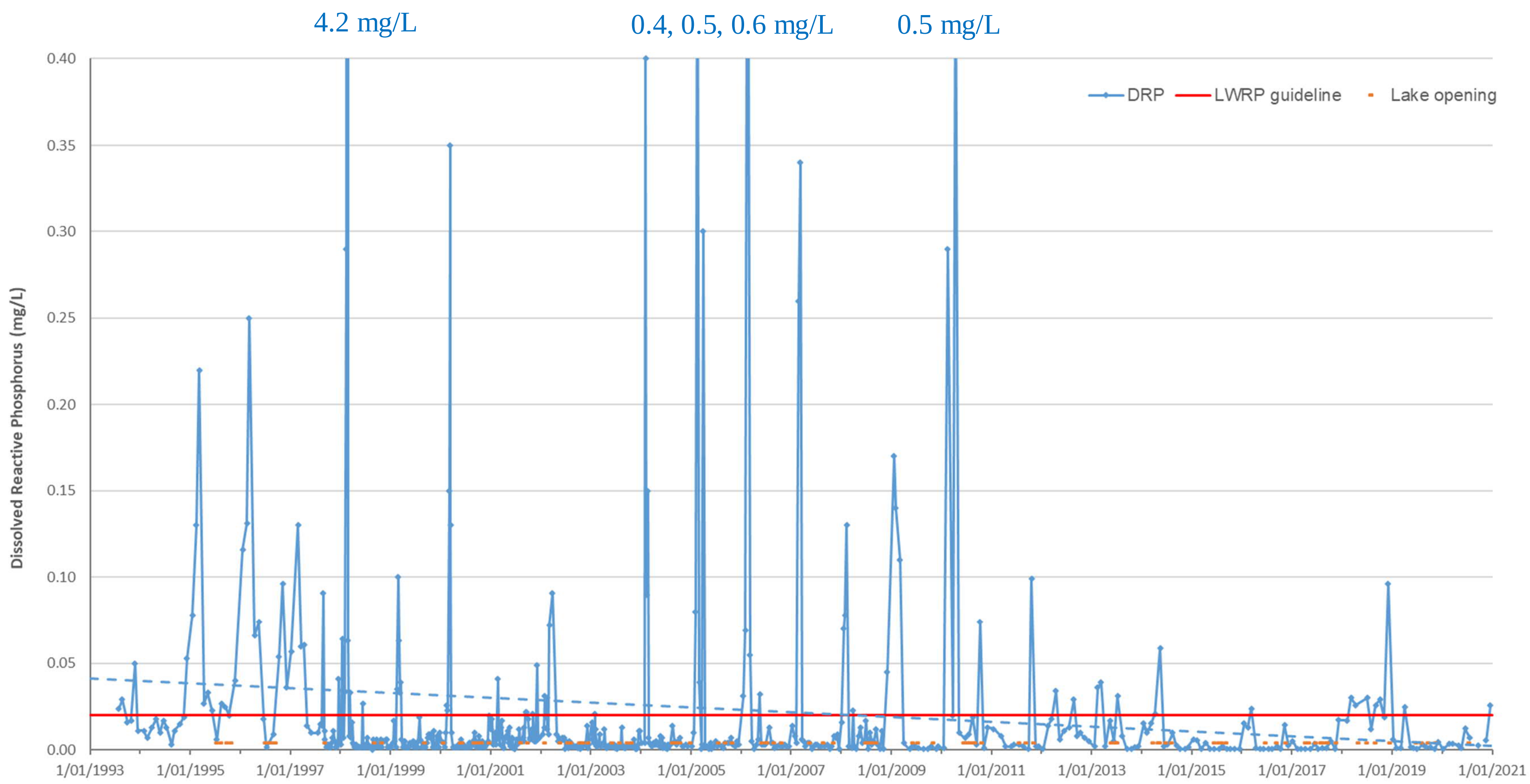

Figure 7. Total phosphorus at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the entire dataset (July 1993 – December 2020). The dashed line is a linear trendline. Five data points are substantially higher than the other data points and are therefore off the scale of the graph – the numbers above the graph detail their concentrations.

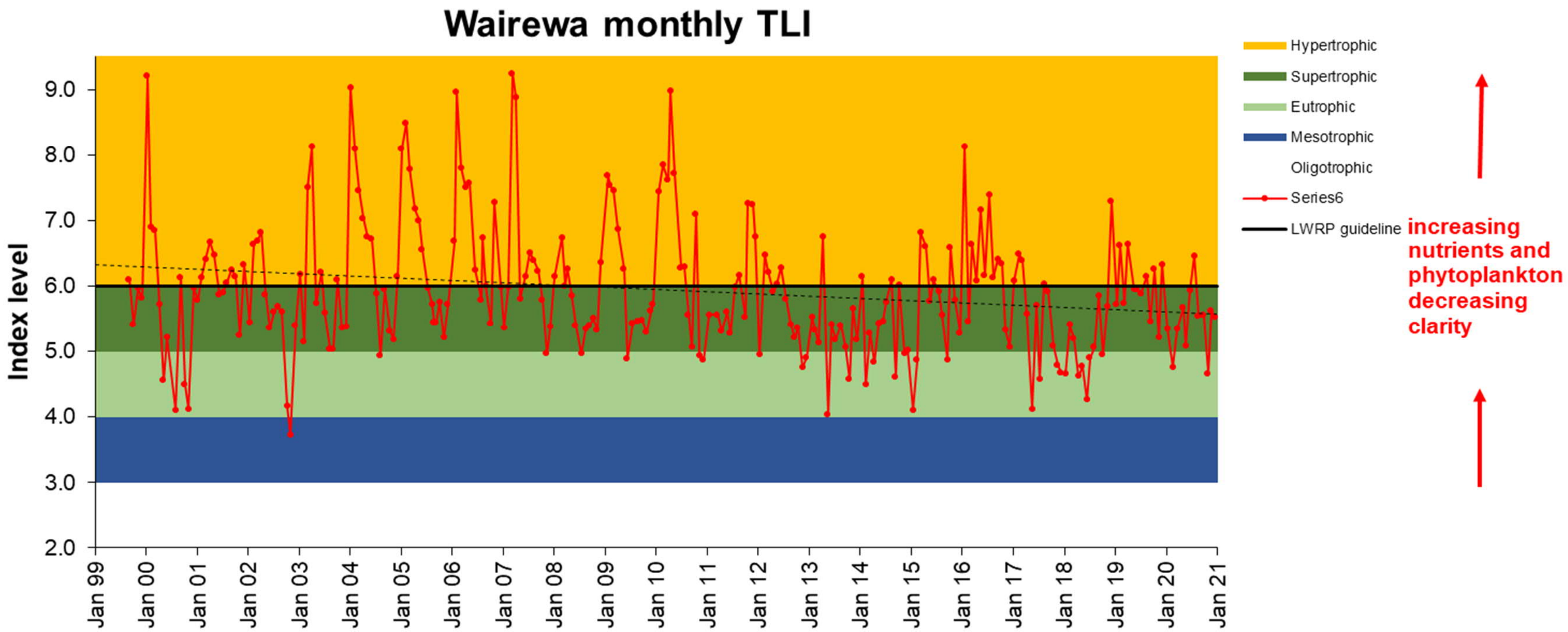

Figure 8a. Trophic Level Index (TLI) at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the entire dataset (September 1999 – December 2020). The dashed line is a linear trendline. Solid black line = Land and Water Regional Plan (LWRP) guideline for coastal lakes (6). Graph modified from ECan versions.

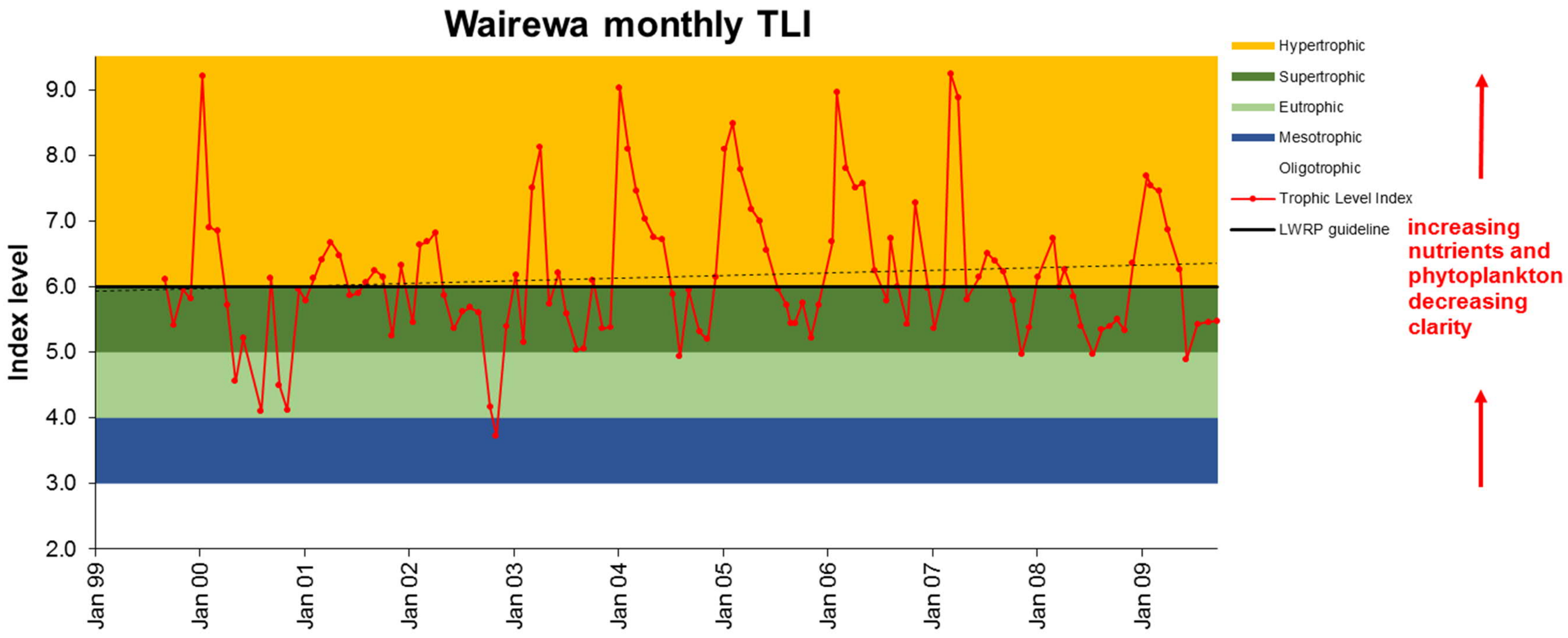

Figure 8b. Trophic Level Index (TLI) at Wairewa/Lake Forsyth at the ECan Water Level Recorder site prior to the construction of the canal opening (September 1999 –September 2009). The dashed line is a linear trendline. Solid black line = Land and Water Regional Plan (LWRP) guideline for coastal lakes (6). Graph modified from ECan versions.

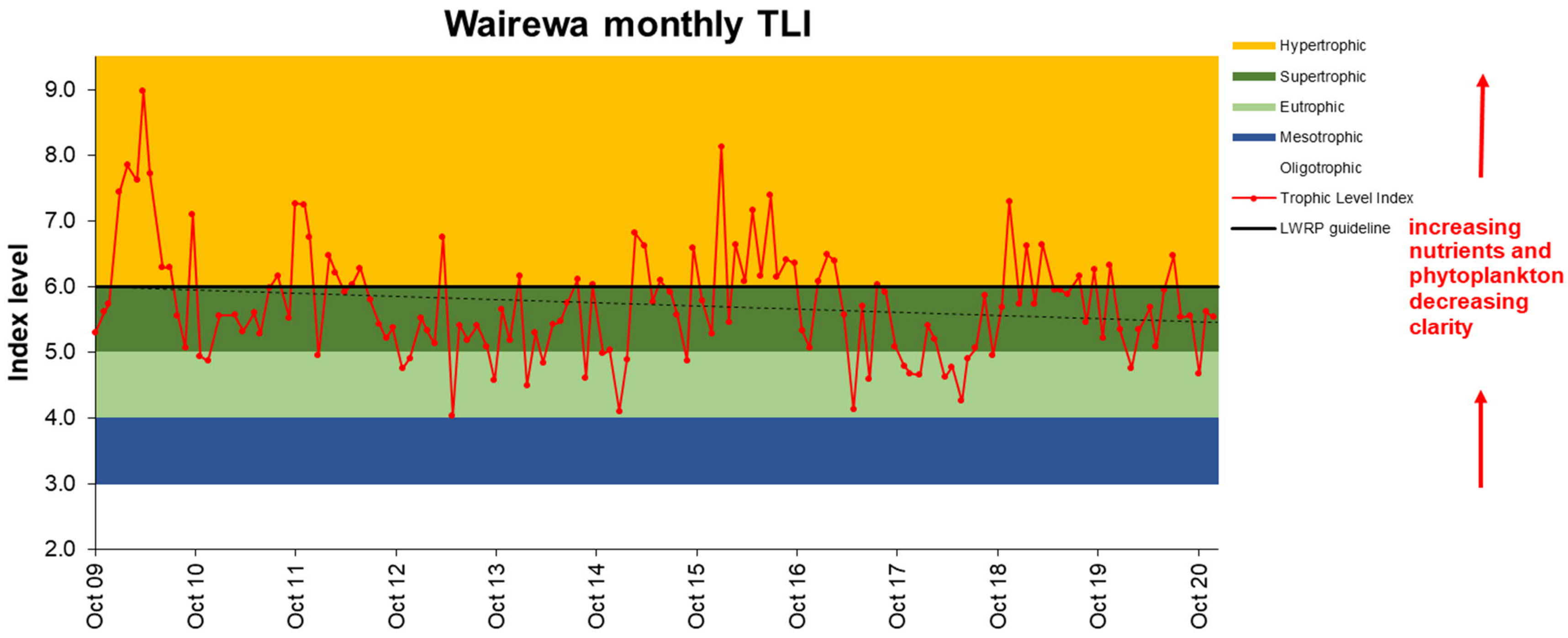

Figure 8c. Trophic Level Index (TLI) at Wairewa/Lake Forsyth at the ECan Water Level Recorder site after the construction of the canal opening (October 2009– December 2020). The dashed line is a linear trendline. Solid black line = Land and Water Regional Plan (LWRP) guideline for coastal lakes (6). Graph modified from ECan versions.

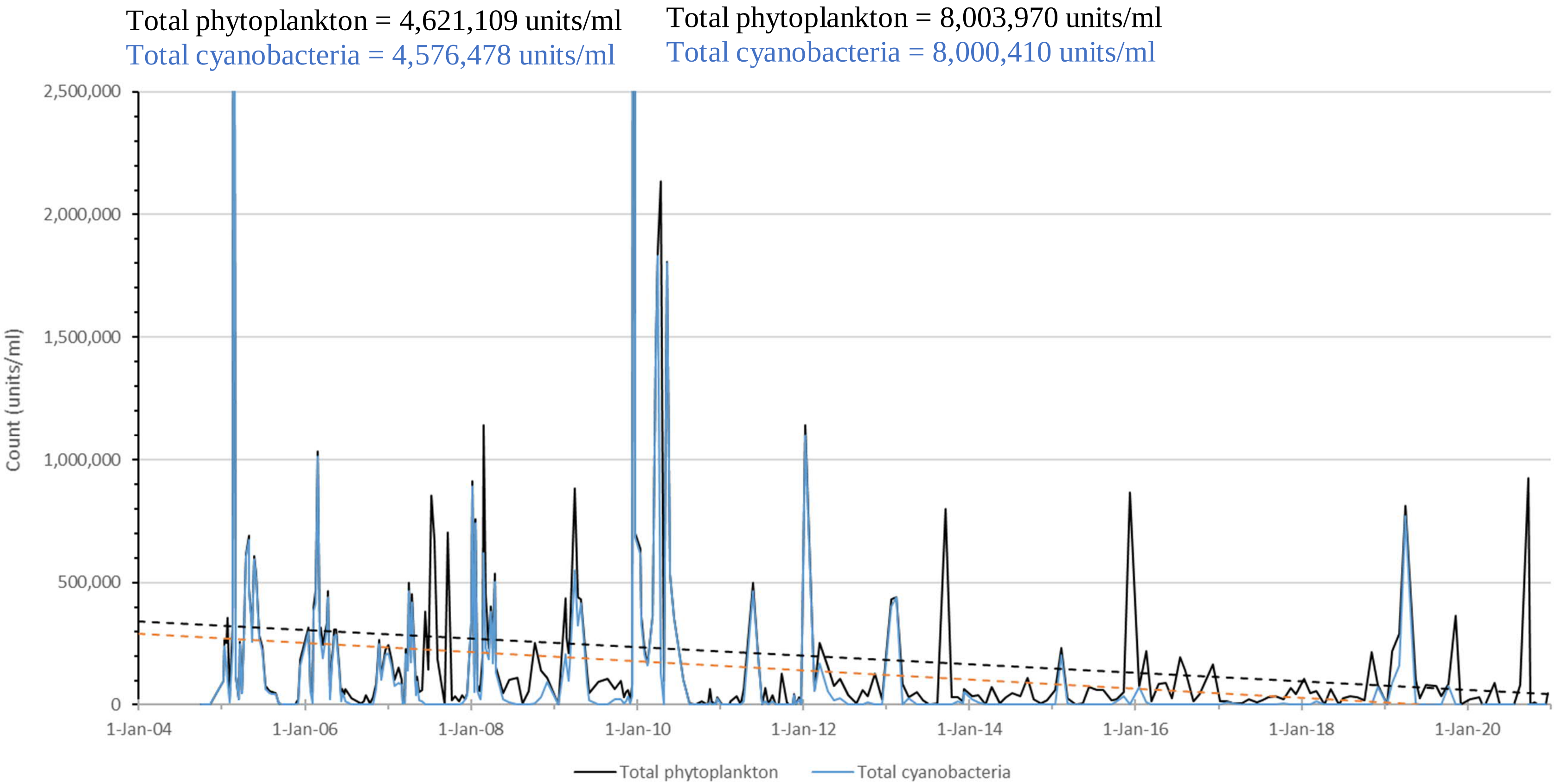

Figure 9. Total phytoplankton and cyanobacteria counts at Wairewa/Lake Forsyth at the ECan Water Level Recorder site from September 2004 to December 2020. The dashed lines are linear trendlines. Two data points are significantly higher than the other data points and are therefore off the scale of the graph – the numbers above the graph detail their concentrations.

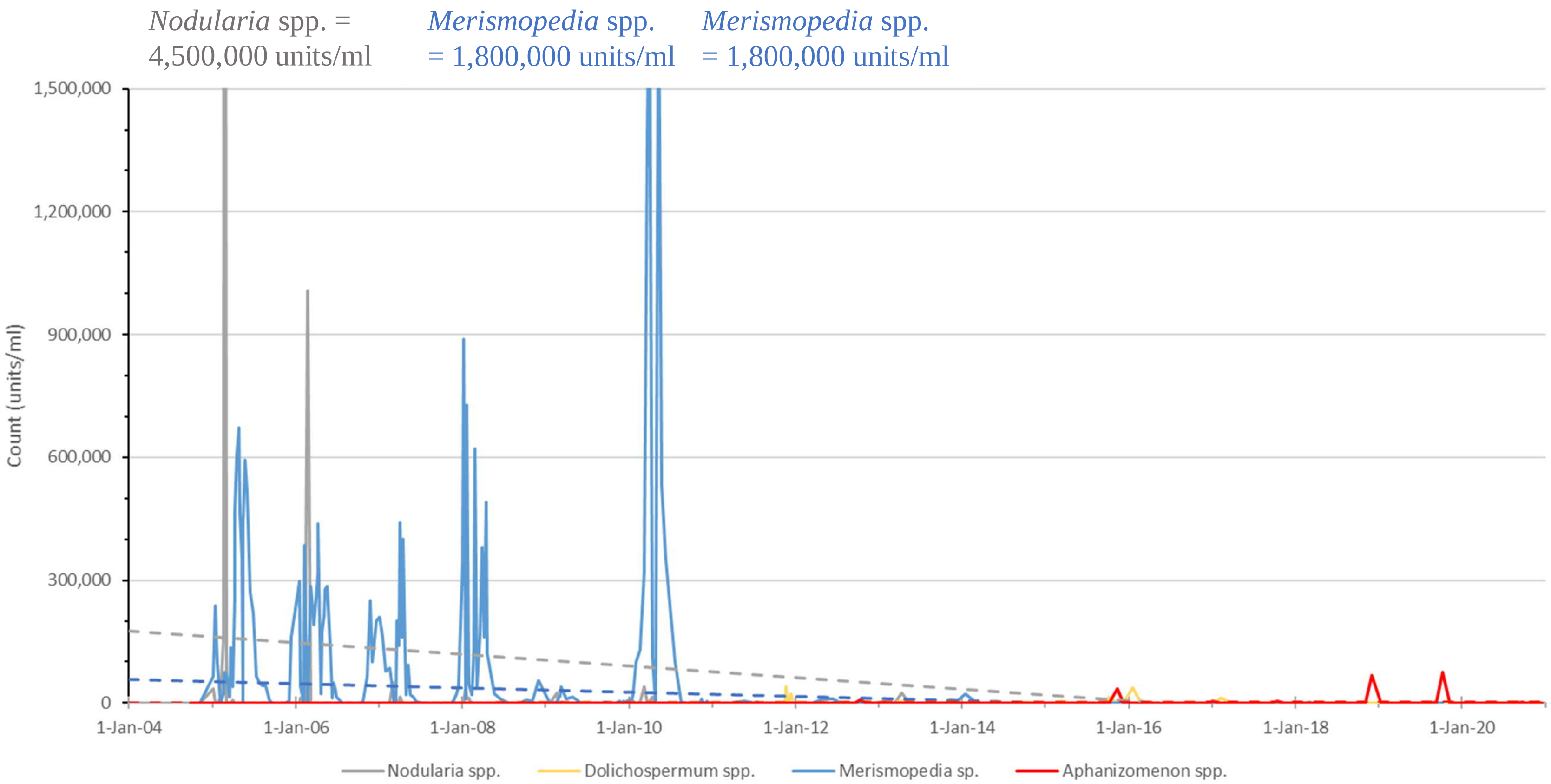

Figure 10. Counts at Wairewa/Lake Forsyth at the ECan Water Level Recorder site for the potentially toxic cyanobacteria *Nodularia* spp., *Dolichospermum* spp., *Merismopedia* spp. and *Aphanizomenon* spp. from September 2004 to December 2020. The dashed lines are linear trendlines. Three data points are significantly higher than the other data points and are therefore off the scale of the graph – the numbers above the graph detail their concentrations.

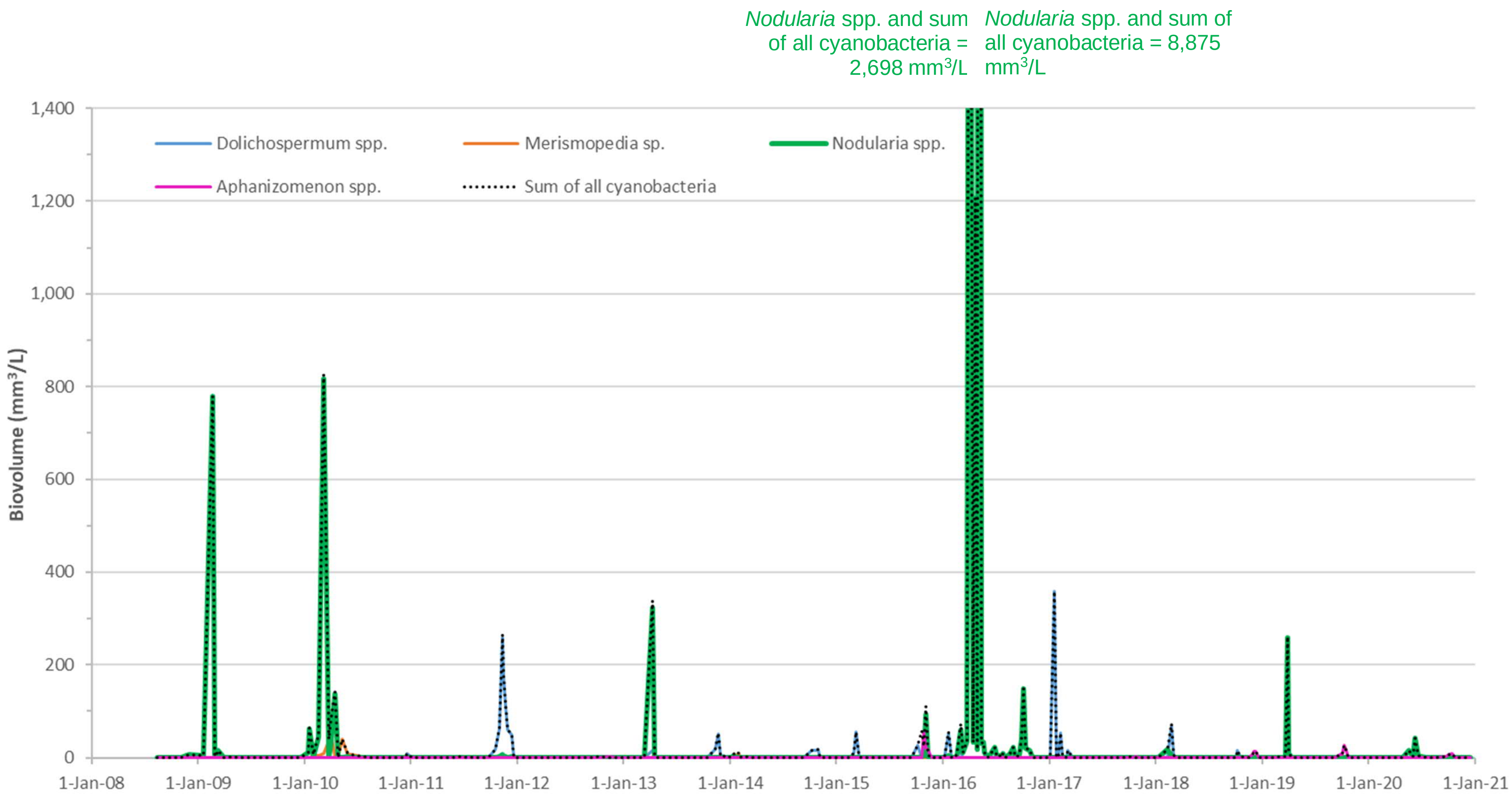

Figure 11. Biovolumes of potentially toxic cyanobacteria *Nodularia* spp., *Dolichospermum* spp., *Merismopedia* spp., *Aphanizomenon* spp. and the sum of all cyanobacteria at Wairewa/Lake Forsyth at the ECan Water Level Recorder site from August 2008 – December 2020. Two data points are significantly higher than the other data points and are therefore off the scale of the graph – the numbers above the graph detail their concentrations.

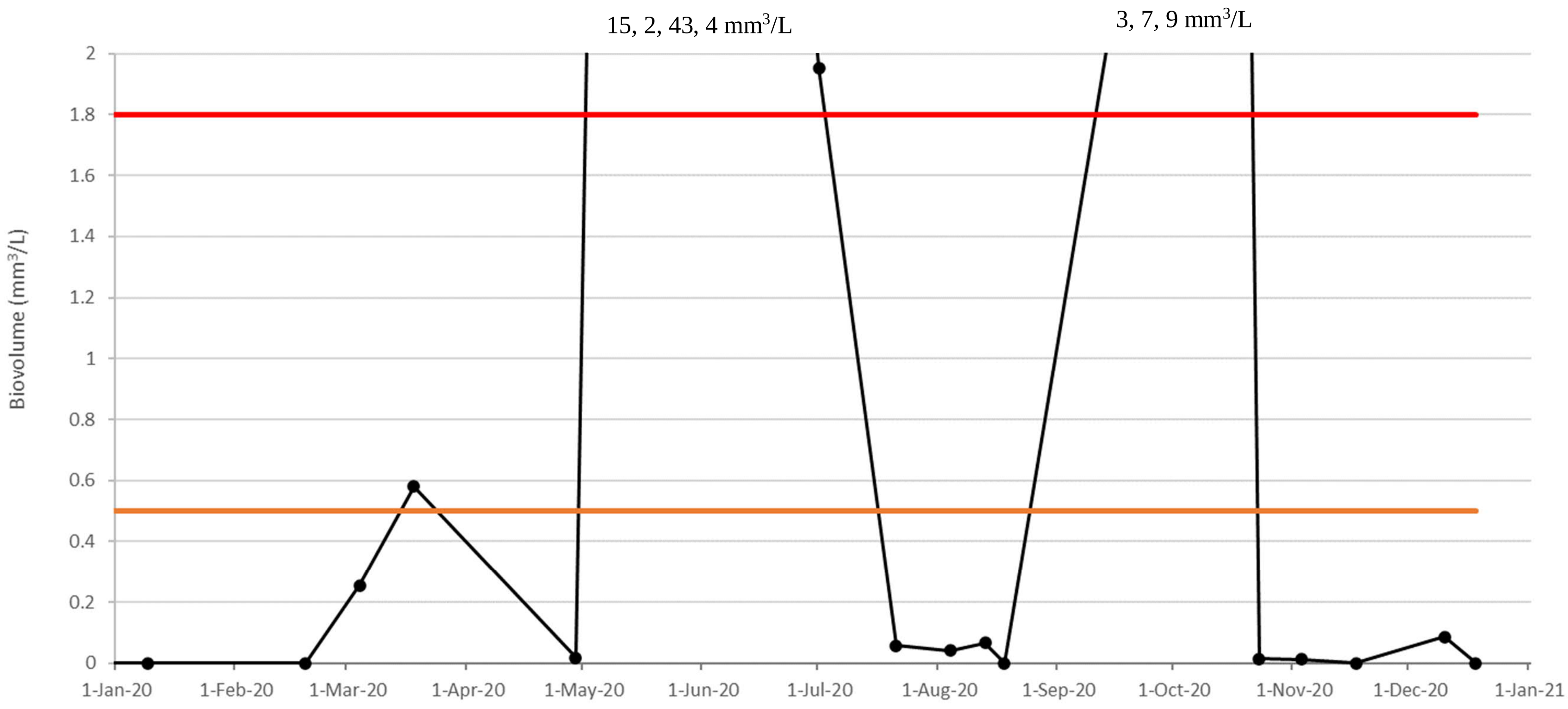

Figure 12a. Biovolume of the sum of all potentially toxic cyanobacteria (*Nodularia* spp., *Dolichospermum* spp., *Merismopedia* spp., and *Aphanizomenon* spp.) at the ECan Water Level Recorder monitoring site in 2020. Orange line = alert guideline level of 0.5 mm^3/L; red line = action guideline level of 1.8 mm^3/L (Ministry for the Environment and Ministry of Health, 2009).

Figure 12b. Number of samples of potentially toxic cyanobacteria (*Nodularia* spp., *Dolichospermum* spp., *Merismopedia* spp., and *Aphanizomenon* spp.) that exceeded either the alert (0.5 mm^3/L) or action (1.8 mm^3/L) level at the ECan Water Level Recorder site from 2008- 2020 (Ministry for the Environment and Ministry of Health, 2009).

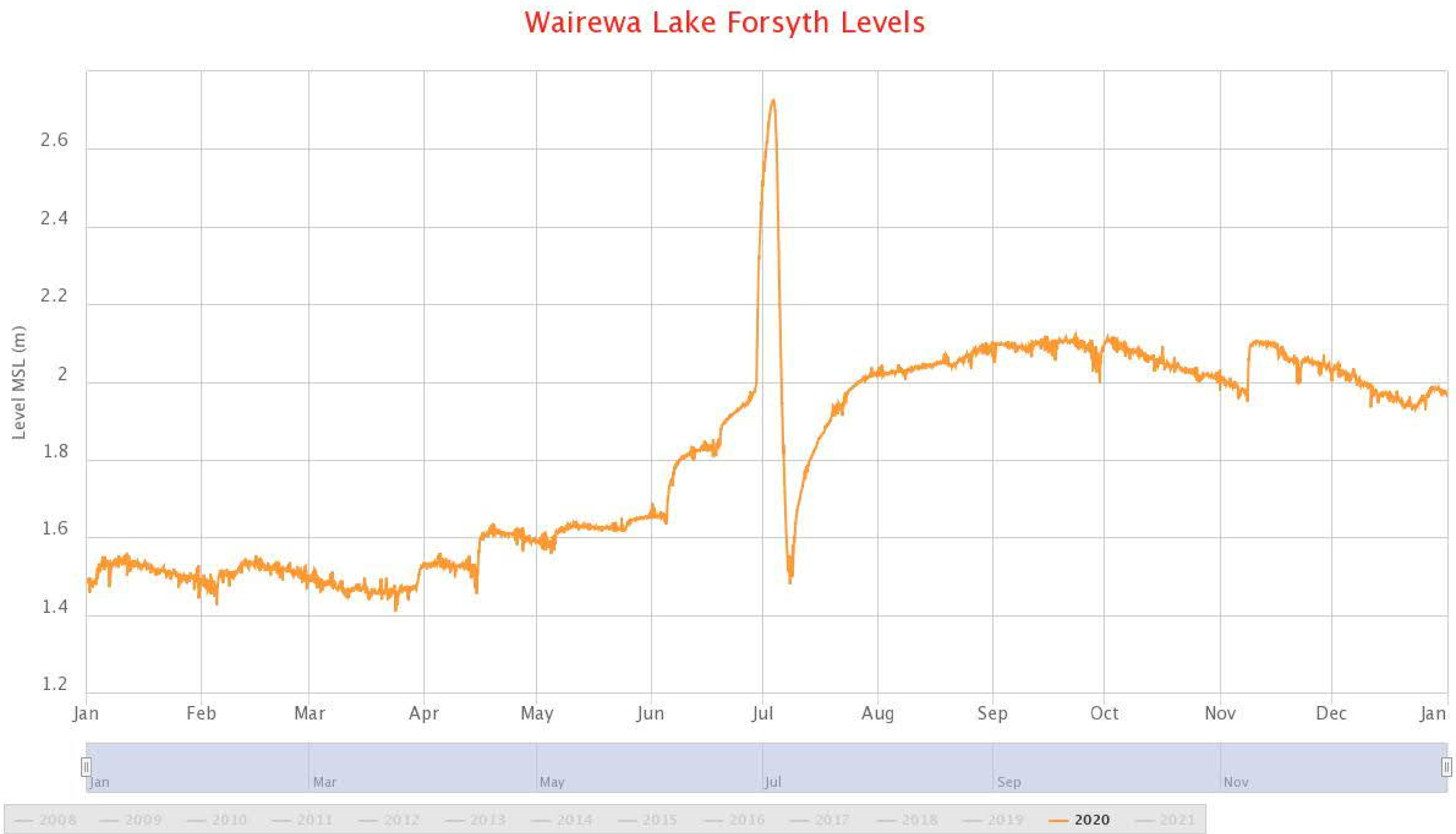

Figure 13. Water level in Lake Forsyth/Te Wairewa in 2020. The sharp drop in water level indicates when the lake was opened.