Lake Brunner water quality update: December 2021

1. Introduction

Lake Brunner is a large (41 km^2), deep lake (max. depth 109 m), inland from Greymouth on the West Coast. It has high water quality and is a popular recreational destination for people within and beyond the region. It is likely that intensive agriculture in the catchment has contributed to nutrient increases, which have been observed following the initiation of monitoring in the early 1990's.

Central lake monitoring supports a long and comprehensive data record. Data collected at Cashmere Bay and the tributaries has also been presented. This Lake Brunner water quality update is produced annually and is intended to replace earlier updates, although earlier reports may contain more detail on specific research projects conducted at the time.

The National Policy Statement for Freshwater Management (NPS-FM) 2014, (amended 2017), contains a National Objectives Framework (NOF) with a set of national bottom lines aimed at achieving healthy waterways. The NOF attribute states range from A to D. An attribute with a category (or state) of D is below the national bottom line (C for ammonia). For Lake Brunner, we can apply the NOF to total nitrogen (TN), total phosphorus (TP), ammonia, and chlorophyll *a* data. We can also apply it to *E. coli* bacterial data. The most recent five-year block of data is used to determine these attribute states.

It should be noted that sampling frequencies have varied over time, with quarterly or bi-monthly sampling the norm prior to 2009. Therefore, certain analyses have varying record lengths used depending of what historic data is available.

2. Lake processes and nutrient limitation

Lake Brunner is an oligotrophic (low nutrient) lake. The Redfield ratio of 16 parts nitrogen to one-part phosphorus is considered the approximate ratio required by lake phytoplankton and plants. If the ratio is higher, then growth will be limited by a lack of phosphorus. Algal productivity is considered to be limited by the availability of phosphorus, throughout the year, based on molar ratios of TN to TP, and NO_3^- (nitrate) to dissolved reactive phosphorus (DRP). These ratios were 81 and 68, respectively, for a 10 year average. The ratio of particulate nitrogen to particulate phosphorus was 15, suggesting that phosphorus limitation may not be as substantial as otherwise suggested by TN:TP or NO_3^-:DRP.

Of the various forms of total nitrogen in the lake, 2% was ammonia, and 53% was nitrate, thus 55% was dissolved inorganic nitrogen (DIN, ammonia plus nitrate). Dissolved organic nitrogen (DON) accounted for 36% of all dissolved nitrogen. This leaves 9% of particulate nitrogen. DON is the dominant form of dissolved nitrogen coming from forested catchments whereas nitrate is the dominant form leaving Lake Brunner's pasture catchments (Rutherford et al. 2008; Verburg 2009; Wilcock et al. 2013).

When a warm surface layer forms a barrier to mixing the lake is said to be stratified. The bottom section of the lake during stratification is called the hypolimnion and oxygen can't reach the hypolimnion from the epilimnion (surface layer) once the lake is stratified. The rate at which oxygen is depleted is strongest nearest the lake bottom as this is where aerobic decomposition of organic matter is occurring.

The lake has a long residence time (1.14 years), which enhances the retention of nutrients by the lake. The lake retains 50 to 55% of phosphorus transported in from the catchment by burial in the sediment, with 20% of nitrogen retained by burial or removed by denitrification (Verburg et al. 2013). Because of an enhanced capacity for storage of nutrients, especially of phosphorus, by burial in the sediment, lakes with long residence times are less sensitive to phosphorus loading and are more resilient than lakes that are flushed faster. But this is on the condition that primary productivity does not exceed a level that could result in anoxia (no oxygen) at the sediment/water interface on the bottom of the lake. This happens when enough organic matter decomposes on the lakebed, using up all available oxygen. With no oxygen, different chemical and biological processes occur, and phosphorus stored in the sediment can be released. This new phosphorus adds to the phosphorus already coming from tributaries. More phosphorus increases algal growth, leading to more decomposing organic matter, causing less oxygen etc. Thus begins a cycle which is very hard to stop, and lake water quality deteriorates.

Seasonality drives annual variation for many of the parameters measured in the lake. This is why we use statistical tests that accommodate for seasonal patterns within the data. Additional information on the processes occurring in Lake Brunner can be found in previous West Coast Surface Water Quality reports, which can be found on the Council website www.wcrc.govt.nz.

3. Water quality in the main lake

3.1. Dissolved oxygen depletion rates and minima in the central lake

Council monitor's vertical oxygen and temperature profiles monthly at the center of the lake. It has been assumed so far that oxygen levels at the bottom of the lake remain high enough to avoid significant release of phosphorus from the lakebed. Historically, when phosphorus inputs are contrasted against anticipated outputs, no obvious phosphorus recycling is apparent – we will look at this in more detail further on in this document.

Trends in oxygen depletion rates are calculated annually (Figure 1). If rates are increasing it could indicate increasing eutrophication. Depletion rates have varied over the last 10 years, which may be the result of variable climatic regimes. The data to date does not indicate that depletion rates are increasing - if anything they are decreasing, but there is no obvious trend (Figure 1).

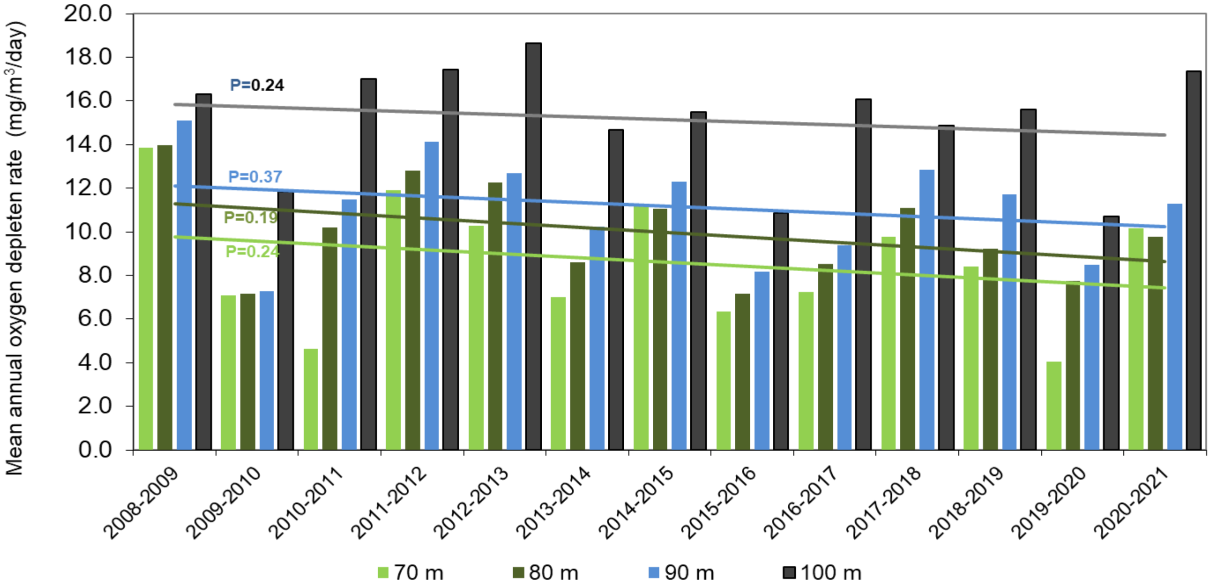


Figure 1 Hypolimnetic oxygen depletion rates in Lake Brunner 2008 to 2021. The P values represent the level of significance of the trend in depletion rates over time, as determined by the Mann-Kendall trend test. The '100 m' depth measurements are those measured from the very bottom of the lake, with the actual distance from the surface typically varying by +/- 1 m, and occasionally by +/- 2 m. Other readings are measured consistently from the surface.

Higher algal productivity is considered to increase oxygen depletion rates, as dead phytoplankton sinks to the lake bottom, consuming oxygen as it decomposes. Water temperature, nutrient availability, and sunlight have a role in driving algal growth – the first two are measured by the Council.

There was no obvious relationship between oxygen depletion rates and chlorophyll *a*, therefore algal abundance may not be an important driver of oxygen consumption rates (Figure 2).

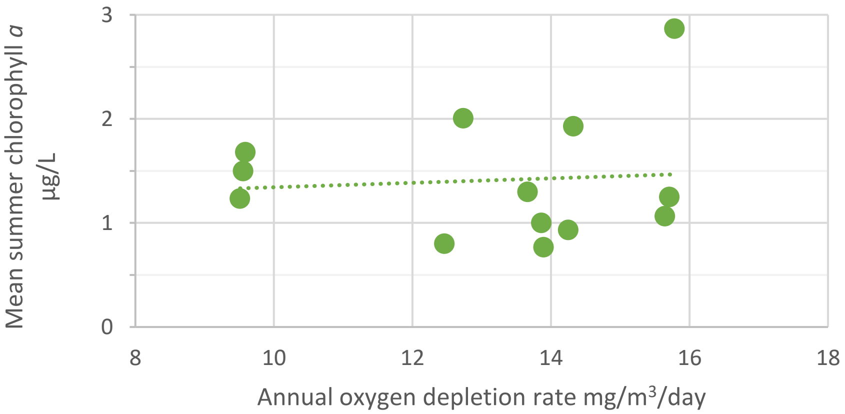


Figure 2 Mean summer chlorophyll a, measured at the surface (1-25 m tube sample) vs. annual lakebed (95 m) depletion rate of the following year.

While no increase in the oxygen depletion rate is reassuring, oxygen minima, measured at the lakebed, have in recent years been lower (Figure 3) The lowest oxygen reading on record occurred in 2021 (4.18 mg/L), with the second lowest recorded in 2019 (4.2 mg/L). This was consistent in shallower layers of the hypolimnion (Figure 3), which largely mimicked patterns observed at the lakebed. While not exceptional these years had higher than average depletion rates, particularly in 2021 (Figure 1). These were 15.6 mg/m^3/day in 2019 and 17.4 mg/m^3/day in 2021 - the average for 2009-2021 was 15.1 mg/m^3/day.

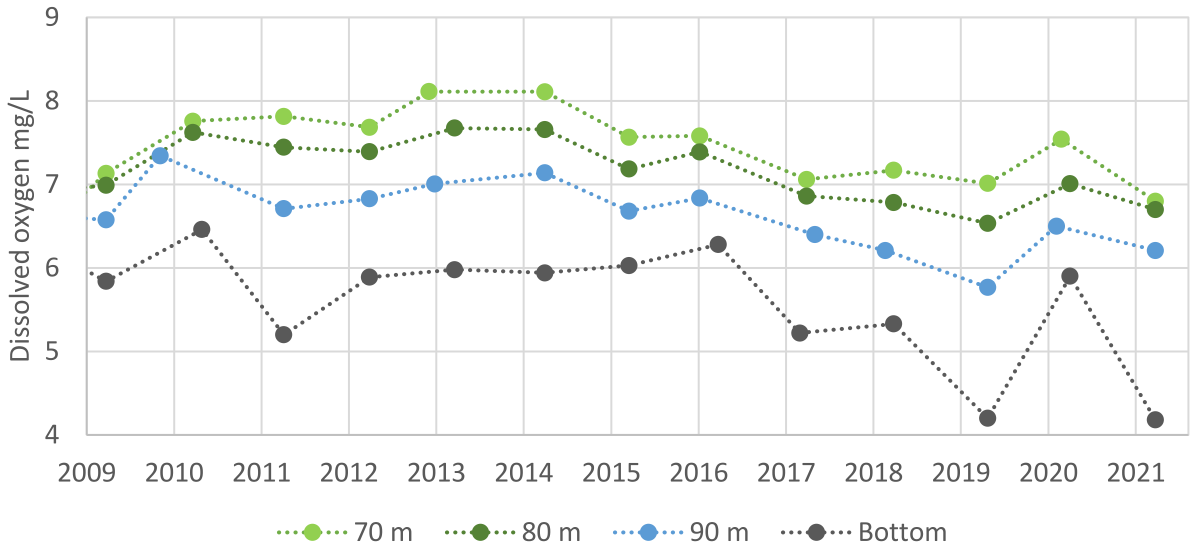


Figure 3 Minimum dissolved oxygen levels measured in autumn/winter prior to mixing, from 2009 to 2021. Measurements for 70 m, 80 m, 90 m depths are taken from the same time as those selected for the lake bottom (~ 100 m depth). Sampling is conducted at the central lake site.

Traditionally our focus has been on oxygen minima and depletion rates to indicate the risk of lakebed anoxia, but it is worth examining patterns in temperature and oxygen from other angles. We can examine durations of temperature stratification to see whether they are influencing oxygen minima. De-stratification normally occurs between June and July, and very occasionally later (July-August). There was no evidence to indicate that destratification is occurring later (Figure 4). But the number of days per annum that oxygen declined increased, albeit with a degree of variability among years (Figure 5). There was also a loose negative relationship with these durations and annual DO minima (R=0.36, linear regression) (Figure 5).

We examined the relationship between mean summer and annual (July to June) surface temperature versus end of year (July) dissolved oxygen minima (Figure 6). Annual and summer mean temperatures were reasonably close among years (R=0.8, linear regression). Warm surface temperatures were more likely to coincide with lower hypolimnetic oxygen, but this relationship was inconsistent (R=0.1, linear regression).

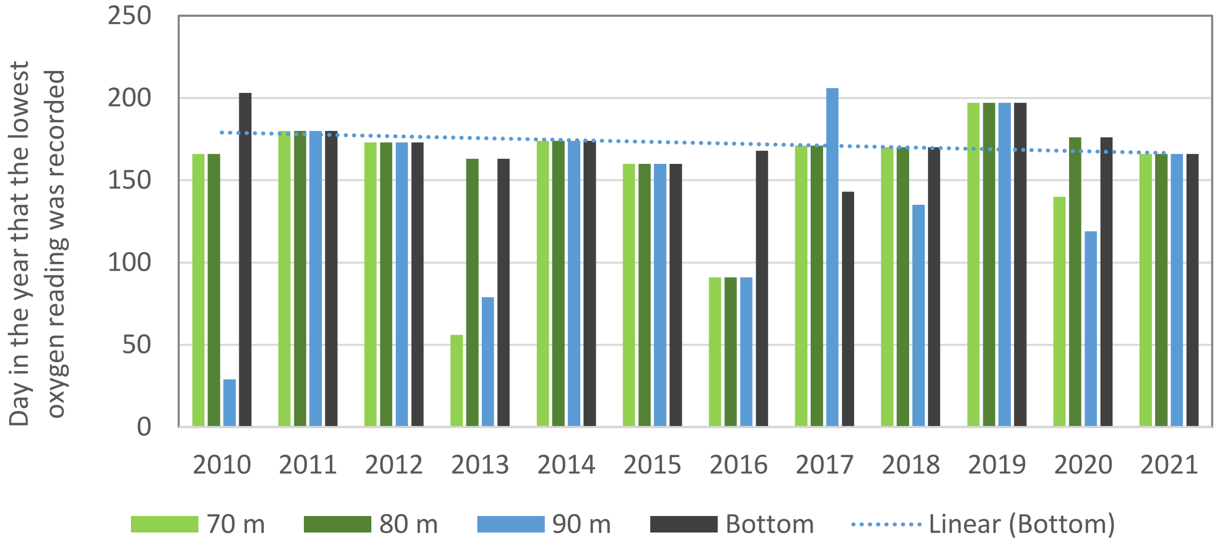


Figure 4 The day (Julian) in which the lowest dissolved oxygen levels were measured prior to mixing, each year, from 2009 to 2021. Measurements for 70 m, 80 m, 90 m, and ~ 100 m depths are taken from the point of lowest dissolved oxygen for each depth. Sampling is conducted at the central lake site.

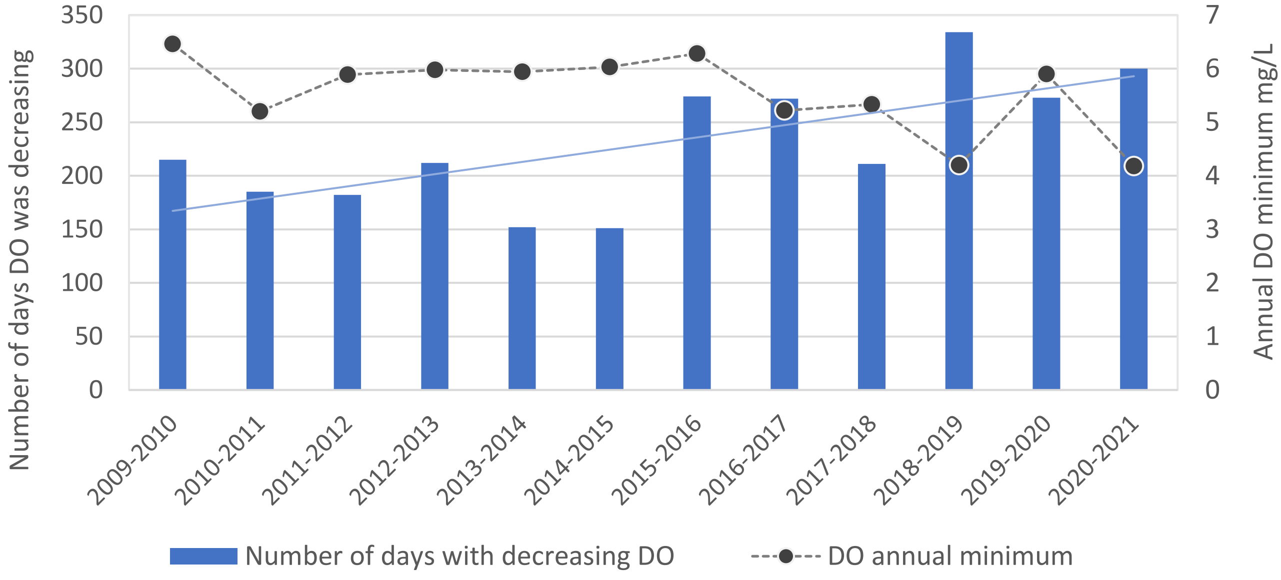


Figure 5 The number of days for which dissolved oxygen was decreasing each year, from 2009 to 2021. Measurements were made at the lakebed at the lake centre. The year has been taken from August to July to encompass one stratification cycle.

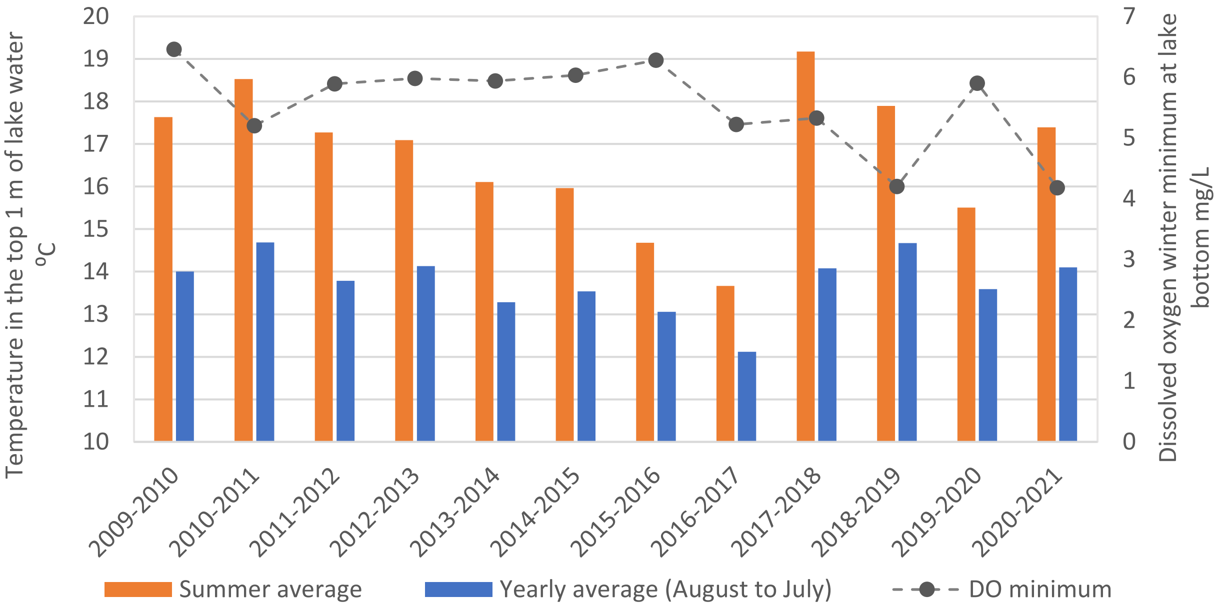


Figure 6 Summer (Dec-Feb) and annual mean temperature, from 2009 to 2021, compared to annual lakebed dissolved oxygen minima. The year has been taken from July to June to encompass one stratification cycle.

3.2. Season specific patterns in nutrients - central lake

Various forms of phosphorus are assessed in the center of the lake including total, dissolved reactive, dissolved organic, and particulate forms. Samples have been collected monthly via the 0-25 m deep composite sample, while deeper samples are collected at a range of depths in June, April, and October. The deepest sample was collected at 95 m, which is close to the bottom of the lake. We have looked to see if phosphorus has increased over time as a result of sediment release, resulting from lower lakebed oxygen.

Samples collected at a depth of 95 m are closest to the sediment/water interface. The months of April and October have the longest 95 m sampling record. Both of which showed weak increasing trends for dissolved reactive phosphorus (Figure 7). Similar patterns might have been expected in June, when oxygen depletion will have occurred for the longest period, but this was not evident, and not helped by the shorter sampling record. It should be acknowledged that these are relatively small, variable datasets, and these trends have not been validated statistically.

Surface composite samples (0-25 m) at the lake center are collected on a monthly basis. De-stratification can occur in July or August, so August (shortly after mixing) is the most reliable period to evaluate uniform phosphorus levels. Total and dissolved reactive phosphorus, in the month of August only, increased over the sampling period (

Figure 8). The strength of this August trend has not been evaluated statistically, but analysis of the full dataset, that includes every month from 2001-2019, indicated conflicting phosphorus trends, with increasing DRP, but decreasing particulate phosphorus (PP) and TP (Table 1). While statistically significant, the magnitude of change was small for DRP and TP, which may be a result of the low concentrations, which were close to lab detection limits.

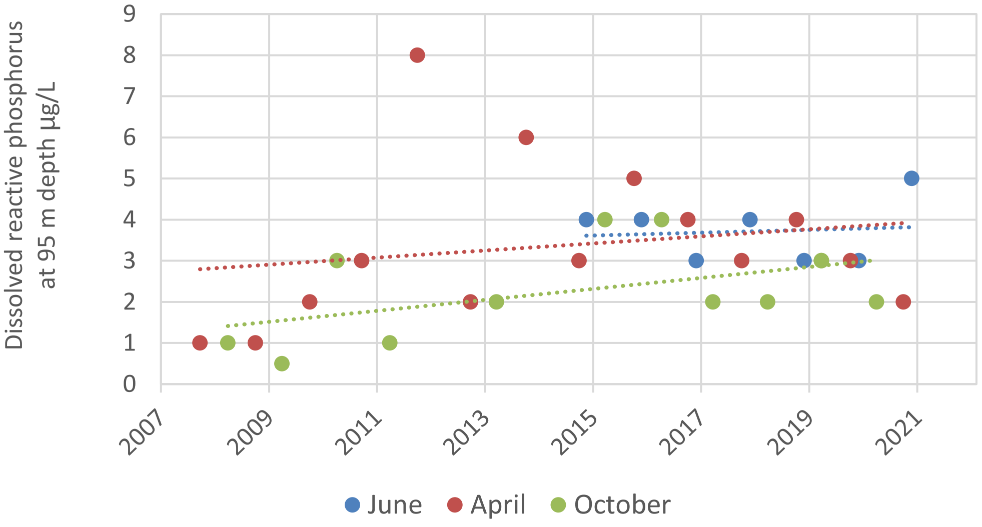


Figure 7 Dissolved reactive phosphorus concentrations measured in June, April, and October at a depth of 95 m, located at the central lake site. There is no data for June pre-2015.

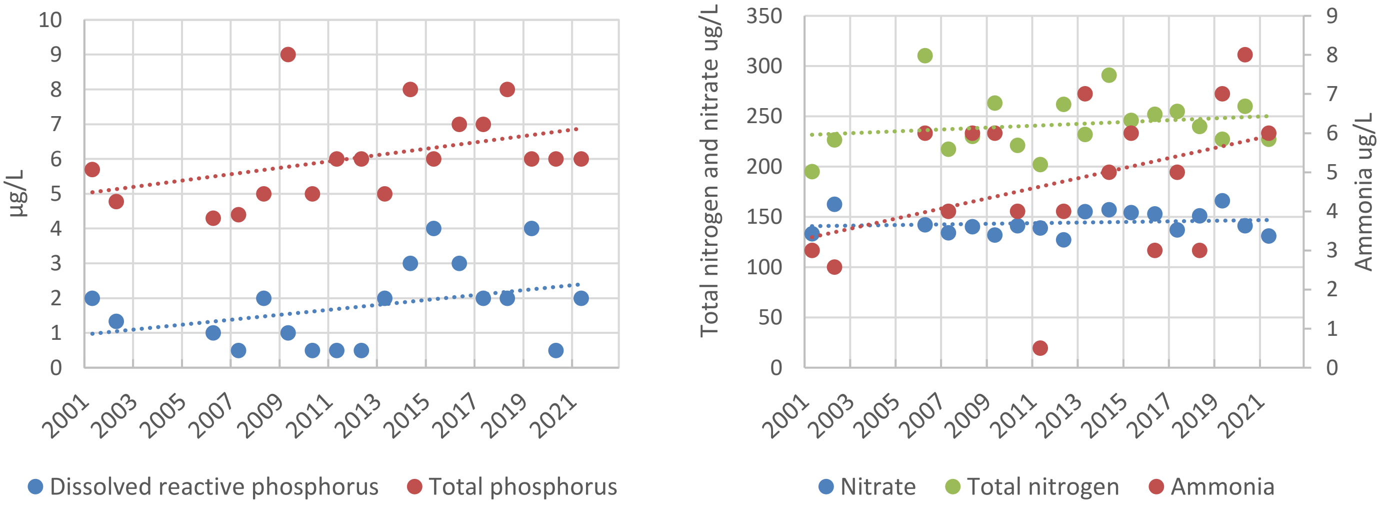


Figure 8 Dissolved reactive phosphorus, total phosphorus, nitrate, ammonia and total nitrogen concentrations measured every August at the central lake site using the 0-25 m composite sampling method.

3.3. General lake and tributary trends

A number of attributes are assessed monthly at the lake center in the 0-25 m zone. Analyses incorporating this data record, from 2001-2019, indicated that there were significant increasing trends for a number of nitrogen species (Table 1). Mention has already been made of the significant but small changes in phosphorus forms over time.

It is likely that agricultural intensification has contributed to an increase in nitrogen over this period. Nitrate is easily leached, particularly in wet places such as the Lake Brunner catchment. Among the tributaries of the lake, TN deteriorated at two sites (Poerua River and Hohonu River), nitrate also deteriorated at Poerua River and improved at one site (Pigeon Ck) (Table 2). Total phosphorus improved at three sites suggesting a reduction in phosphorus inputs from agriculture. Agricultural intensification was evident in the lower reaches of the Hohonu River catchment, based on deterioration observed in a number of water quality attributes (Table 2).

Despite increases in nitrogen and dissolved reactive phosphorus there were no increases in trophic indicators (TLI and chlorophyll *a*, Table 1). The TLI incorporates total nitrogen, total phosphorus, clarity (vertical Secchi), and chlorophyll *a* levels to form one score indicative of a lake's overall nutrient status (Burns et al. 2000), with the most favourable levels for many of them peaking in 2015 (Figure 9).

Clarity (vertical secchi) has significantly improved. Algal abundance, driven by nutrient concentrations, can contribute to changes in clarity. Chlorophyll *a,* our indicator of algal abundance, has improved but not significantly. Phosphorus, being the limiting nutrient, is likely to be more influential than nitrogen, with significant but small improvements observed for both TP and PP. Interestingly, particulate nitrogen (PN) as well as PP has improved despite increases in other nitrogen forms, suggesting a reduction in particulate nutrient sources overall.

3.4. National objectives framework categories

The National objectives framework (NOF) attribute states for the central lake site were "A'' for total phosphorus and chlorophyll *a*. An "A" indicates 'ecological communities that are healthy and resilient, similar to natural reference conditions' (Table 3). Total nitrogen, ammonia, and lakebed oxygen levels were a "B", which indicates that 'ecological communities are slightly impacted by additional algal and plant growth arising from nutrient levels that are elevated above natural reference conditions' (New Zealand Government 2020). A wet climate will promote leaching of dissolved nitrogen. Higher nitrogen in Brunner (primarily in dissolved forms), relative to phosphorus and chlorophyll *a* levels, could be due to increased leaching associated with the cool, wet climate.

Table 1 Seasonal Kendall trend analysis for water quality data collected at central Lake Brunner. Trends in red are undesirable and trends in blue are desirable. Trends that are considered 'extremely likely' are those with a rate of change (percent annual change, PAC) larger than ± 1% of the median per year, a P value of <0.05, and a probability of occurring at >0.95. Paler colouration demarcates trends that meet the same criteria but with a smaller PAC of < 1% per annum.

Variable	Samples used	Sampling period	Median	Units	P	PAC [δ]	Likelihood
Ammonia*	186	19/7/01-20/4/21	5.00	µg/L	0.28	0.28	0.85
Nitrate	194	5/1/01-20/4/21	111.00	µg/L	0.00	0.88	0.99
Dissolved Inorganic Nitrogen	187	19/7/01-20/4/21	119.00	µg/L	0.00	1.01	0.99
Dissolved organic nitrogen	171	19/7/01-20/4/21	76.00	µg/L	0.01	0.97	0.99
Total dissolved nitrogen	171	19/7/01-20/4/21	194.00	µg/L	**0.00**	**1.07**	**1.00**
Total particulate nitrogen	171	19/7/01-20/4/21	20.60	µg/L	**0.00**	**-1.42**	**1.00**
Total nitrogen	187	19/7/01-20/4/21	212.00	µg/L	0.00	0.59	0.99
Dissolved reactive phosphorus	194	5/1/01-20/4/21	0.55	µg/L	0.00	0.00	0.99
Dissolved organic phosphorus	171	19/7/01-20/4/21	2.00	µg/L	0.12	0.00	0.94
Total dissolved phosphorus	171	19/7/01-20/4/21	3.00	µg/L	0.02	0.00	0.99
Total particulate phosphorus	171	19/7/01-20/4/21	3.00	µg/L	0.00	-1.40	0.99
Total phosphorus	187	19/7/01-20/4/21	6.00	µg/L	0.00	-0.66	0.99
Clarity (vertical)	186	19/7/01-20/4/21	6.09	m	0.00	1.10	0.99
Total suspended solids	166	29/9/03-20/4/21	950.00	µg/L	0.63	0.00	0.61
CDOM (Absorbance g340)	165	29/9/03-20/4/21	5.92	g340	0.12	0.33	0.90
CDOM (Absorbance g440)	165	29/9/03-20/4/21	1.20	g440	0.11	-0.60	0.90
Chlorophyll a	186	19/7/01-20/4/21	1.00	µg/L	0.24	-0.89	0.88
Trophic level index (TLI)	185	19/7/01-20/4/21	2.79	TLI score	0.52	-0.13	0.75

** Ammonia represents 'total ammonia', hence the sum of ammonia and ammonium ions.*

[δ] *Percent annual change (PAC) of the median for that variable.*

Table 2 Seasonal Kendall trend test and percentage change for data collected at Lake Brunner tributary water quality sites, from 2008 to 2021. Only trend confidences that are 'extremely likely' are reported in the table below. For a trend to be 'extremely likely' a P value of <0.05 and a >0.95 probability of occurring is required. The percent annual change (PAC) reflects the percentage change of the median per year. The PAC scale goes out to +/- 28%, with a yellow bar indicating deterioration, and a blue bar indicating improvement. Flow measurements have been used to adjust this analysis should flow be a biasing factor affecting the attributes measured. The NPSFM 2020 attribute states are added where applicable.

Water quality	Site	PAC		Median	Units	State
Ammonia	Pigeon Ck @ NIWA stage	-8.659	-8.659	0.012	mg/L	C
Ammonia	Crooked Rv @ Te Kinga	-2.715	-2.715	0.006	mg/L	A
Ammonia	Poerua Rv @ Station Rd end	-1.194	-1.194	0.006	mg/L	A
Ammonia	Hohonu Rv @ Mouth	1.363	1.363	0.006	mg/L	A
Clarity	Hohonu Rv @ Mitchells-Kumara Rd Br	-4.695	-4.695	10.46	m	A
Clarity	Hohonu Rv @ Mouth	-3.18	-3.18	4.165	m	A
Conductivity	Hohonu Rv @ Mitchells-Kumara Rd Br	-2.338	-2.338	47	uScm	N/A
Conductivity	Hohonu Rv @ Mouth	-2.412	-2.412	46.2	uScm	N/A
DRP	Crooked Rv @ Te Kinga	-2.568	-2.568	0.003	mg/L	A
E.coli	Hohonu Rv @ Mouth	5.487	5.487	90	E. coli/100	C
Nitrate	Poerua Rv @ Station Rd end	2.477	2.477	0.045	mg/L	A
Total nitrogen	Hohonu Rv @ Mouth	2.562	2.562	0.14	mg/L	N/A
Total nitrogen	Pigeon Ck @ NIWA stage	-4.057	-4.057	0.361	mg/L	N/A
Total nitrogen	Poerua Rv @ Station Rd end	1.037	1.037	0.27	mg/L	N/A
Total phosphorus	Crooked Rv @ Te Kinga	-3.034	-3.034	0.01	mg/L	N/A
Total phosphorus	Pigeon Ck @ NIWA stage	-4.713	-4.713	0.027	mg/L	N/A
Total phosphorus	Poerua Rv @ Station Rd end	-3.22	-3.22	0.017	mg/L	N/A
Turbidity	Hohonu Rv @ Mouth	28.13	28.13	0.1	FNU	N/A

Table 3 NPSFM 2020 attribute states for Lake Brunner at the middle lake site, composite 1-25 m depth sample. States are calculated using both maximum and medians for ammonia and chlorophyll a. A five-year block of preceding data is used to calculate states for each year represented below.

Mid Lake - 0-25 m tube	**2016**		**2017**		**2018**		**2019**		**2020**	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
Ammonia	A	A	A	A	A	A	A	A	A	B
Chlorophyll a	A	A	A	A	A	A	A	A	A	A
Total nitrogen	B		B		B		B		B	
Lake bottom DO	B		B		B		B		B	
Total phosphorus	A		A		A		A		A	

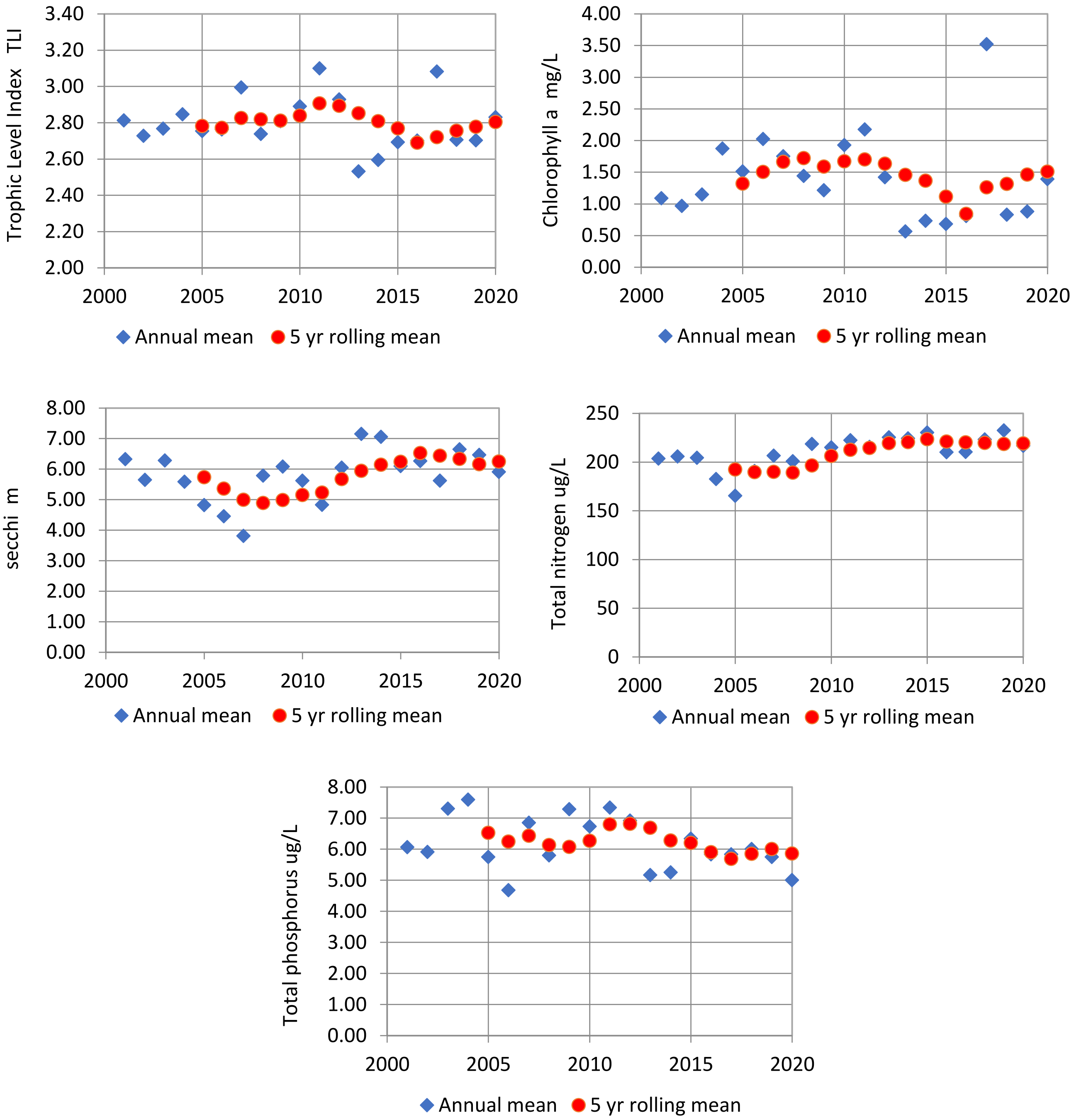


Figure 9 Annual means, and five yearly rolling means, for Trophic Level Index, chlorophyll a, clarity (vertical Secchi), TN, and TP, measured at the central lake site (GYBS).

4. Cashmere Bay water quality

Cashmere Bay is a small bay in the far eastern corner of Lake Brunner. Its size is small compared to the rest of the lake and mixing of its waters with the rest of the lake is confined by a narrow channel that links it to the larger Iveagh Bay. Changes in Cashmere Bay water quality won't significantly affect the main lake.

Cashmere Bay is not deep (12 m), but its depth is sufficient for annual thermal stratification to occur. Vertical mixing of water ceases once stratification has occurred and oxygen is progressively used up at the bottom until it's gone. At this point, different biological and chemical processes occur.

From 2009 to 2020 the annual duration of low oxygen conditions at the bottom of Cashmere Bay increased (Table 4, Figure 6). Lower oxygen levels will have caused increases in ammonia, and dissolved forms of phosphorus (Table 4). On average, ammonia was three times higher at the bottom compared with the surface, and 30-40 times higher during peak stratification.

Nutrient increases at the bed of Cashmere Bay have not led to any significant increases in phytoplankton (as indicated by chlorophyll *a*), with clarity significantly improving (Table 5).

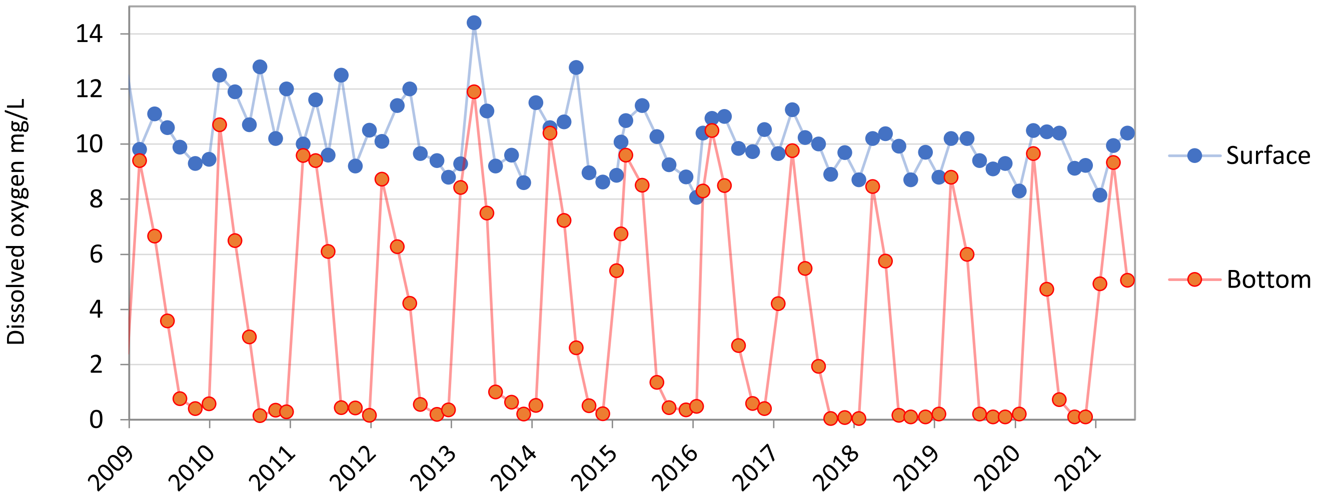


Figure 10 Dissolved oxygen levels at the surface and the bottom of Cashmere Bay, Lake Brunner.

In Cashmere Bay the NOF attribute states for surface water, based on median concentrations, were "A'' for ammonia and total phosphorus. Total nitrogen was consistently "B" at all depths. Chlorophyll *a* levels were "A" at both the top and bottom of the bay in 2019.

Table 4 Seasonal Kendall trend analysis for water quality data collected at the deepest point of Cashmere Bay, Lake Brunner. Statistically significant trends (P value <0.05) where the rate of change is larger than ± 1% per year, and the probability of occurring is >0.95, are described as being "extremely likely" (red).

Site	Variable	Samples used	Sampling period	Median	Units	P	PAC $^{\delta}$	Likelihood
Bottom	**Dissolved oxygen**	86	2/3/05-16/3/21	3.3	mg/L	0.00	-4.9	1.00
10	**Ammonia**	103	29/9/03-16/3/21	33	ug/L	0.01	4.5	1.00
10	Nitrate	103	29/9/03-16/3/21	89	ug/L	0.98	0.0	0.53
10	Total dissolved nitrogen	89	29/9/03-16/3/21	249	ug/L	0.21	0.6	0.89
10	**Total dissolved phosphorus**	89	29/9/03-16/3/21	6	ug/L	0.00	3.6	1.00
10	Dissolved organic nitrogen	64	24/2/11-16/3/21	8.7	ug/L	0.39	0.8	0.81
10	**Dissolved organic phosphorus**	64	24/2/11-16/3/21	5	ug/L	0.00	7.4	0.99
10	Chlorophyll a	100	29/9/03-16/3/21	0.7	ug/L	0.59	-0.4	0.73
10	Total nitrogen	103	29/9/03-16/3/21	284	ug/L	0.93	0.0	0.54
10	Total phosphorus	103	29/9/03-16/3/21	11.7	ug/L	0.24	0.6	0.88
10	Total organic nitrogen	55	29/9/03-14/9/15	96.7	ug/L	0.20	-1.1	0.92
10	**Dissolved inorganic nitrogen**	102	29/9/03-16/3/21	158	ug/L	0.00	1.5	1.00
10	**Dissolved reactive phosphorus**	102	29/9/03-16/3/21	1	ug/L	0.01	2.6	1.00

** Ammonia represents 'total ammonia', hence the sum of ammonia and ammonium.*

$^{\delta}$ *Percent annual change (PAC) of the median for that variable.*

Table 5 Seasonal Kendall trend analysis for water quality data collected at the surface of Cashmere Bay, Lake Brunner. Statistically significant trends (P value <0.05) where the rate of change is larger than ± 1% per year, and the probability of occurring is >0.95, are described as being "extremely likely" (blue and red). Blue trends are desirable while red are undesirable. Note that Secchi disk clarity is measured vertically.

Site	Variable	Samples used	Sampling period	Median	Units	P	PAC [δ]	Likelihood
Surface	Dissolved oxygen	86	2/3/05-16/3/21	10.1	mg/L	0.25	-0.6	0.89
4	Ammonia *	103	29/9/03-16/3/21	14	ug/L	0.23	1.2	0.89
4	Nitrate	103	29/9/03-16/3/21	75	ug/L	0.06	1.5	0.97
4	Total dissolved nitrogen	89	29/9/03-16/3/21	188	ug/L	0.34	0.2	0.83
4	Total dissolved phosphorus	64	24/2/11-16/3/21	4	ug/L	0.76	0.0	0.62
4	Dissolved organic nitrogen	64	24/2/11-16/3/21	85	ug/L	0.17	0.6	0.91
4	Dissolved organic phosphorus	88	29/9/03-16/3/21	4	ug/L	0.75	0.0	0.63
4	Chlorophyll a	103	29/9/03-16/3/21	2.1	ug/L	0.95	0.0	0.55
4	**Clarity (horizontal)**	63	29/9/03-21/3/18	3.12	m	0.00	5.7	1.00
4	**Clarity (vertical)**	157	29/9/03-16/3/21	4.96	m	0.00	2.6	1.00
4	Total nitrogen	104	29/9/03-16/3/21	214	ug/L	0.86	0.0	0.57
4	Total phosphorus	104	29/9/03-16/3/21	8	ug/L	0.24	-0.3	0.89
4	Total organic nitrogen	55	29/9/03-14/9/15	88	ug/L	0.23	-1.1	0.91
4	**Dissolved inorganic nitrogen**	103	29/9/03-16/3/21	91	ug/L	0.05	1.2	0.98
4	Dissolved reactive phosphorus	103	29/9/03-16/3/21	1	ug/L	0.11	0.0	0.95

** Ammonia represents 'total ammonia', hence the sum of ammonia and ammonium ions.*

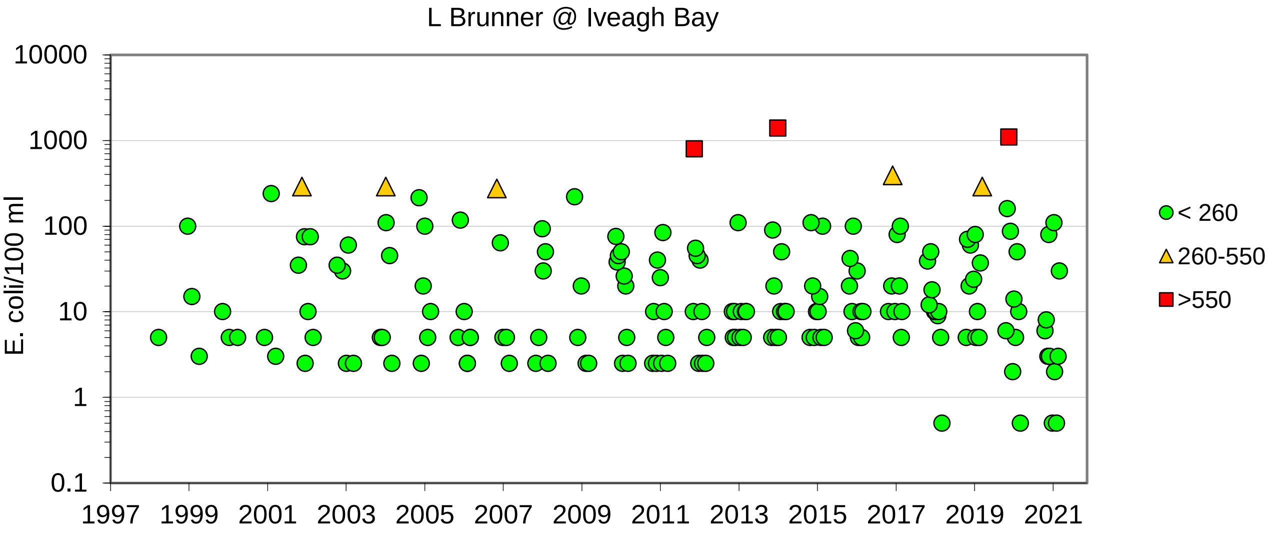
[δ] *Percent annual change (PAC) of the median for that variable.*

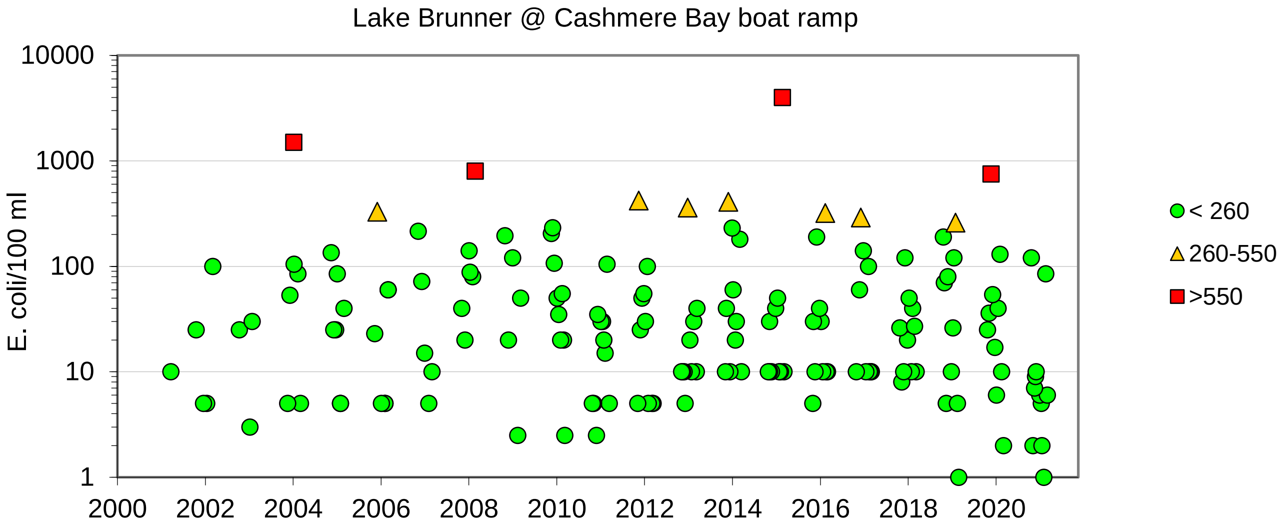
Table 6 NPS-FM NOF attribute states for Lake Brunner at Cashmere Bay, for 4 m and 10 m depths. States are calculated for both maximum and medians for ammonia and chlorophyll a. A five year block of data is used to calculate states – the final year is the year stated.

Cashmere Bay	**2016**		**2017**		**2018**		**2019**		**2020**	
	Median	Max	Median	Max	Median	Max	Median	Max	Median	Max
Ammonia @ 4 m	A	A	A	A	A	B	A	B	A	B
Ammonia @ 10 m	A	B	A	B	A	B	A	B	A	B
Chlorophyll a @ 4 m	A	A	A	A	A	A	A	A	A	A
Chlorophyll a @ 10 m	A	B	A	A	A	A	A	A	A	A
Total nitrogen @ 4 m	B		B		B		B		B	
Total nitrogen @ 10 m	B		B		B		B		B	
Total phosphorus @ 4 m	A		A		A		A		A	
Total phosphorus @ 10 m	B		B		B		B		B	

5. Suitability for swimming

The faecal pathogen indicator bacteria, *E. coli*, is monitored annually between November and March at Iveagh Bay, Cashmere Bay, and the Moana Boat Ramp. Occasional spikes in these indicators have occurred over time (Figure 11). This can be caused by waterfowl (based on records of waterfowl numbers concurrent with each *E. coli* sample), or significant rainfall events that wash off bacteria from the surrounding land. The NPS-FM has a NOF scoring system for primary contact recreation that ranges from A (best) to E (worst) – all swimming sites were in the B category, due to occasionally elevated *E. coli* levels.





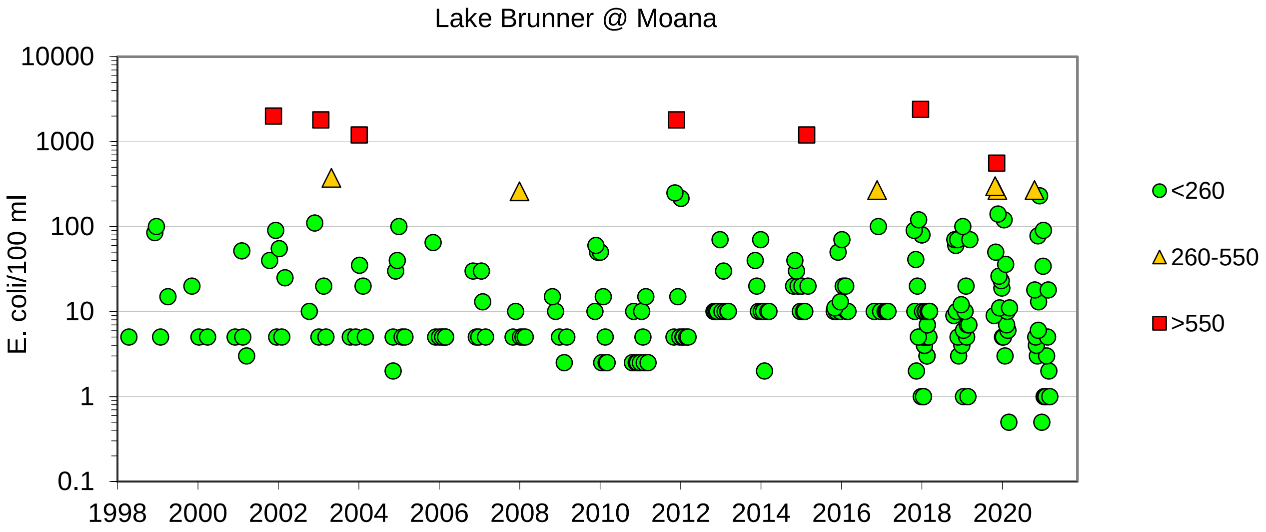


Figure 11 Individual sample results for Lake Brunner contact recreation monitoring sites. Single sample criteria are used; circles indicate acceptable pathogen levels for swimming, triangles indicate low risk, and squares indicate a moderate to high risk for bathing. Sampling is current up until the summer of 2020/2021.

6. Summary

Lake Brunner currently remains in an oligotrophic (low nutrient) state, generally safe for swimming and other recreational activities, as indicated by acceptable levels of pathogen indicator bacteria. The lake is phosphorus limited and there is continual interest as to both the potential inputs from the catchment and potential for recycling at the lakebed due to low oxygen levels. The two lowest lakebed oxygen readings on record were measured in 2019 and 2021, and potential drivers of oxygen depletion were investigated.

Climate change predictions predict significantly wetter winter/spring conditions, and more variable weather patterns (Ministry for the Environment 2018). The result of this may be longer periods of stratification and oxygen consumption. There was no evidence that the rate of oxygen depletion has increased, or that this rate is closely linked to phytoplankton abundance. The possibility for longer periods of thermal stratification was examined. While destratification is not necessarily occurring later, annual durations of depletion were loosely linked to winter lakebed oxygen minimums, both of which may be increasing over time. Lake temperature was not closely related to oxygen minimums.

Phosphorus sampling at the lakebed doesn’t indicate obvious increases in phosphorus release over time, although limited data points were available for evaluation. More phosphorus data has been collected at the surface where no meaningful deterioration was evident over time.

Many forms of nitrogen continue to increase in the lake, but fortunately not other trophic indicators like chlorophyll *a* and the trophic level index, while clarity has improved. Tributaries of the lake were most likely to display increasing trends for nitrogen and decreasing trends for phosphorus. A number of water quality attributes deteriorated in the lower Hohonu River.

The NPSFM 2020 provides lake target attribute states for a number of lake health attributes. Of these ammonia, total phosphorus and chlorophyll *a* were in the A category, with total nitrogen and lakebed dissolved oxygen in the B category.

Increasingly low oxygen levels at the bed of Cashmere Bay have corresponded with inorganic nitrogen and phosphorus releases from the sediments. Fortunately this has not appeared to have contributed to algal growth, with clarity improving.

Small increases in mean temperature aside, climate change predictions forecast significantly wetter winter/spring conditions, and different weather patterns (NIWA 2018). The result of this may be to delay de-stratification and subsequent hypolymnetic re-oxygenation, leading to lower hypolimnetic oxygen levels. This will continue to be evaluated closely.

7. References

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