Harmful Algal Bloom Field Study: Lake Waikare 2024

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EXECUTIVE SUMMARY

Harmful algal blooms (HABs) are increasing across many locations globally. Cyanobacterial HABs in freshwater systems cause many environmental issues, and because many species produce natural toxins, known as cyanotoxins, they are also a risk to human health. Aerosols from lakes with cyanobacterial HABs could pose potentially serious health risks to people. However, the health risk posed by toxin aerosolisation, and the environmental factors that promote aerosolisation, are unclear. The objectives of this field study were to develop evidence to support the development of future guidance. Specifically, the field study investigated the environmental drivers that may influence aerosol production during a cyanobacterial bloom and the measurement of cyanotoxins in aerosols downwind of a bloom.

Lake Waikare is the largest lake in the lower Waikato catchment, with 3,442 hectares of open water. A history of extensive land clearance within the catchment has caused increased sediment and nutrient loading in Lake Waikare. Combined with the decision to lower the lake for flood control purposes, Lake Waikare has become hypertrophic with very poor water quality.

In this field study, continuous measurement of meteorological parameters (wind speed, wind direction, temperature, relative humidity), particulate matter less than 10 micrometres in diameter (PM_{10}) and less than 2.5 micrometres ($PM_{2.5}$) was undertaken for four weeks near Lake Waikare in the Waikato. Daily (high volume) and weekly / two-weekly (low volume) air samplers were employed at different distances from Lake Waikare with subsequent analysis of filters for microcystins (the cyanotoxin present in Lake Waikare at the time of the study).

High volume air samplers were located at 50 metres (m), 100 m, 150 m and 200 m downwind of the lake and operated at 1,000 L/min, collecting aerosols on glass fibre filters for 24-hour periods over seven days (13 – 19 April 2024). Each high volume monitor sampled approximately 1,400 m^3 of air for a limit of detection (LoD) of ≤ 0.05 picograms of microcystins per cubic metre of air (pg/m^3).

A single low volume air sampler was located 50 m from the lake and operated at 2.5 L/min, collecting aerosols on PTFE filters. Weekly (2), and two-weekly (1) samples were collected from 13 April to 10 May 2024, sampling approximately 25 m^3 and 50 m^3 respectively, for a limit of detection of ≤ 0.6 pg/m^3 (one week) or ≤ 0.3 pg/m^3 (two weeks) of microcystins.

Lake water sampling was also undertaken three times a day from three locations (total of 54 samples) over the first six days (13 – 18 April 2024), concurrently to air monitoring. *Aphanizomenon* was the dominant cyanobacterial genus identified in the lake water samples over the sampling period, but microcystin-producing *Microcystis* was also present at high concentrations (15,100 – 1,800,600 cells/mL).

Total microcystin concentrations averaged 18 ng/mL (min 2.3, max 483, std dev ± 9 ng/mL). On seven occasions microcystin concentrations exceeded the Situation 4 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines for Aotearoa New Zealand (≥ 24 µg/L; 13% of the samples). Extracellular / dissolved microcystins in the water samples were generally low throughout the study (0.04 – 0.8 ng/mL). The proportion of extracellular microcystin, relative to the total microcystin concentration, ranged from 0.2% to 9.7%, with a median of 1.8%. The concentrations of microcystins measured in the water

samples are comparable to, or higher than, concentrations measured in other studies evaluating microcystins in aerosols from lakes.

Microcystins were not detected in any of the air samples collected. This was unexpected because most other studies reporting lower lake water microcystin concentrations had detected microcystins in concurrent air samples. If extracellular microcystins are more prone to aerosolisation than cellular / particulate microcystins, then the low levels of extracellular microcystins observed in Lake Waikare (max 0.8 µg/L) may have contributed to a lack of aerosolised microcystins during the current study. However, there were some studies that also found none so it is not unprecedented. Aerosol sample performance testing confirmed the limits of detection in this field study were as good, or better, than other studies.

Measured PM_{10} and $PM_{2.5}$ concentrations support the presence of aerosols at the air sampler locations near to Lake Waikare. It is hypothesised that in this field study, whilst toxin-producing cyanobacteria were measured in substantial concentrations in lake water samples on most days, either the winds did not reach the sustained threshold needed to generate aerosols and / or the winds did not direct any aerosols present towards the air monitors.

The presence of cyanobacteria at levels exceeding current and revised Recreational Cyanobacteria Guidelines is consistent with a history of poor water quality in Lake Waikare. The non-detection of microcystins in aerosols collected downwind of the lake during a cyanobacterial bloom, may augur well for potential public exposure to aerosolised HABs. However, the physical and chemical mechanisms for aerosolisation and transport of toxins from HABs are complex and would require additional research before firm conclusions can be drawn.

Such hypotheses would not be applicable to HABs in the marine environment, for which wave break is more generally a persistent feature.

1. INTRODUCTION

Harmful algal blooms (HABs) are algal blooms that cause negative impacts to other organisms by production of natural algae-produced toxins, mechanical damage to other organisms, or by other means (Heisler et al., 2008).

HABs are increasing across many locations globally and with climate change and increasing eutrophication it is reasonable to expect this to continue (Griffith and Gobler, 2020). Toxins from HABs can be incorporated into aerosols (a suspension of fine solid particles or liquid droplets in air) and transported significant distances (Lim et al., 2023), with subsequent inhalation and exposure potentially inducing adverse health effects in large segments of the population. In 1998, a large marine HAB on the central east coast of Aotearoa New Zealand resulted in hundreds of cases of respiratory distress (Chang et al., 2001). However, the relationship between HAB aerosols and health outcomes remains unclear despite the potential for population-level exposures.

A recent review in the Lancet found (Lim et al., 2023):

> "In this review, we synthesized the current state of knowledge and identified evidence gaps in the relationship between HAB aerosols and human health. Aerosols from *Karenia brevis*, *Ostreopsis* sp., and cyanobacteria were linked with respiratory outcomes. However, most works did not directly measure aerosol or toxin concentrations and instead relied on proxy metrics of exposure, such as cell concentrations in nearby waterbodies. Furthermore, the number of studies with epidemiological designs was limited. Significant uncertainties remain regarding the health effects of other HAB species; threshold dose and the dose–response relationship; effects of concurrent exposures to mixtures of toxins and other aerosol sources, such as microplastics and metals; the impact of long-term exposures; and disparities in exposures and associated health effects across potentially vulnerable subpopulations. Additional studies employing multifaceted exposure assessment methods and leveraging large health databases could address such gaps and improve our understanding of the public health burden of HABs."

Specifically of note for Aotearoa New Zealand, the Lancet review noted:

> "The public health burden of HAB aerosols is likely to be considerable. One study estimated that approximately 15% of global asthma cases are attributable to the inhalation of aerosolized HAB toxins in coastal regions."

The Lancet review concluded that the disease burden associated with exposure to HABs is likely to be underestimated and recommended the development of inhalation standards to address the potential risk to public health.

The objectives of this field study were to develop evidence to support the development of future guidance. Specifically, the field study investigated the environmental drivers that may influence aerosol production during a cyanobacterial bloom and the measurement of cyanotoxins in aerosols downwind of a bloom.

1.1 MECHANISMS OF AEROSOL FORMATION AND TRANSPORT

Lim et al. (2023) reports that the primary mechanism for HAB aerosolisation is via the formation of spray aerosols when wind-driven wave action entrains plumes of air bubbles beneath the water followed by bubbles bursting at the air-water interface, ejecting water droplets into the atmosphere that can contain organic material from cells or whole cells themselves (Figure 1). Richter and Veron (2016) also provides a detailed breakdown of the physics of spray aerosol formation (Figure 2).

Cyanobacterial blooms form when cyanobacteria are provided with optimal growth conditions (e.g., nutrients, heat, light) that enable growth to high abundances within a short timeframe. In freshwater systems these blooms cause environmental issues and because many species produce natural toxins known as cyanotoxins, they can pose a risk to human health when present in sufficiently high concentrations. In New Zealand, freshwater cyanobacteria that produce anatoxins (Wood et al., 2007a, 2007b), cylindrospermopsins (Wood et al., 2003), microcystins (Wood et al., 2010; Puddick et al., 2019) and saxitoxins (Smith et al., 2011) have been identified, but microcystin-producing *Microcystis* is the most prevalent planktonic (free-floating) cyanobacterial taxon in lake systems (Wood et al., 2017). Studies on freshwater and estuarine spray aerosol generation and HAB toxin aerosolisation remain relatively limited compared to marine environments.

Backer et al. (2008) found low concentrations (< 1 ng/m^3) of microcystins in air samples from high volume monitors placed on a boat in a lake. Similarly low concentrations (2 – 5 µg/L) of microcystins were found in coincidental lake water samples.

The transport of spray aerosols in the environment is dependent primarily on the aerodynamic diameter and meteorology. The aerosols generated from seawater and freshwater cover a wide size range important for inhalation exposure including:

- **coarse** aerosols or particles that are smaller than 10 micrometres in diameter but larger than 2.5 micrometres in diameter ($PM_{10-2.5}$). These are small enough to be inhaled into the thoracic region but too large to reach the alveolar region of the lungs; and
- **fine** aerosols or particles less than 2.5 micrometres in diameter. These are small enough to reach the alveolar region of the lungs where inhaled gases can be absorbed into the blood stream.

It is well established that particulate matter (including aerosols) less than 10 micrometres in size (PM_{10}) can travel significant distances (tens of kilometres). May et al. (2018) measured lake spray aerosol concentrations to observe their transport over significant distances (> 30 km) inland (noting that this study considered only the fine fraction, $PM_{2.5}$).

Marine aerosol generation is likely to be substantially more significant than freshwater, not least because of its relative size but also because of differences in the prevalence of wave action.

FIGURE 1: Mechanisms of aerosolisation, transport and exposure to harmful algal bloom toxins. [Source: Lim et al., 2023]

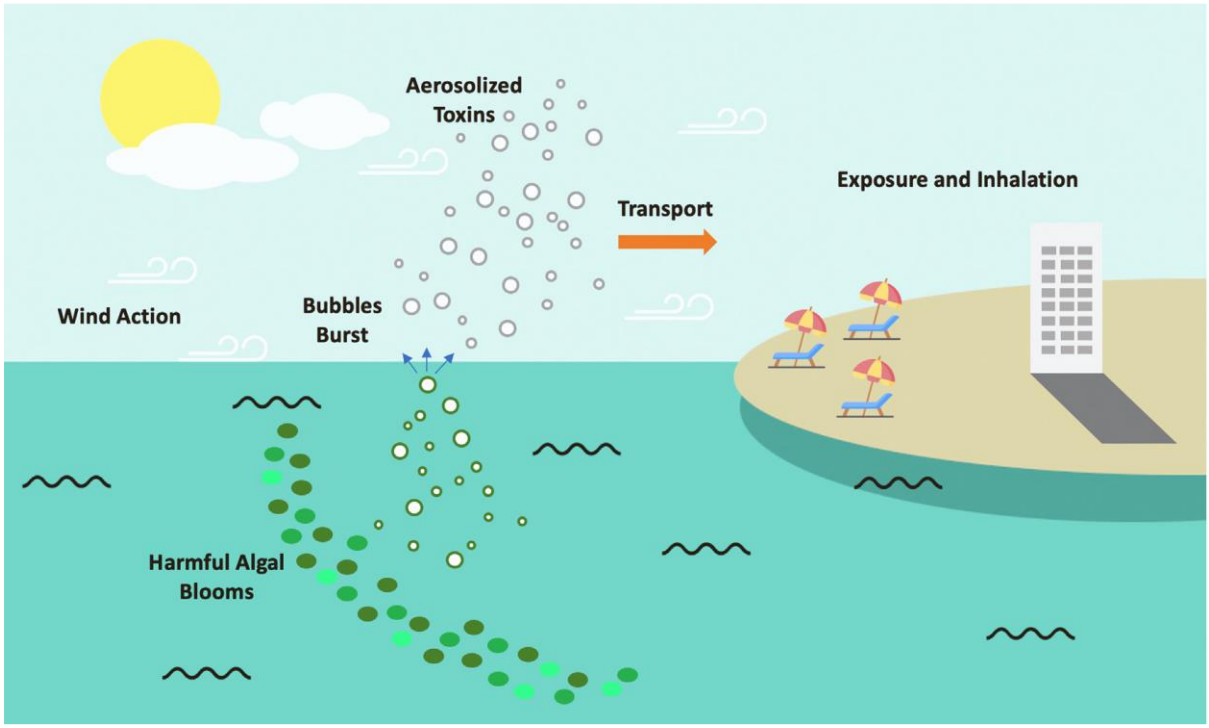
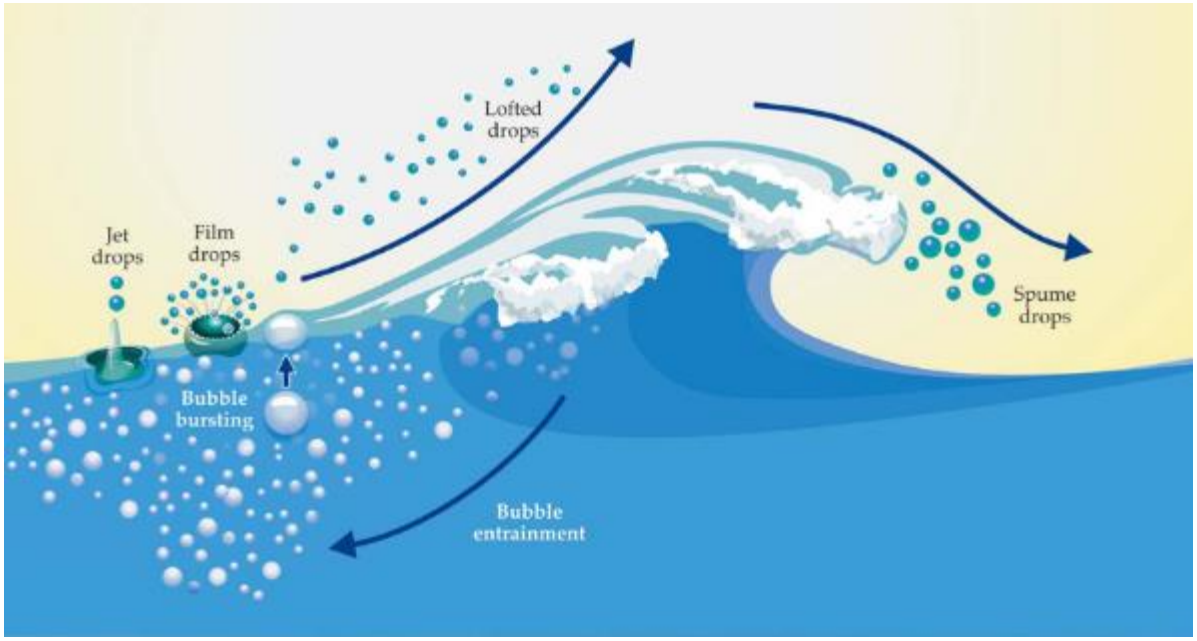


FIGURE 2: The formation of water drops. Spume drops, between roughly 20 micrometres and several millimetres in radius, are torn by the wind from the crest of a breaking wave. Film and jet droplets are smaller, generated when air bubbles entrained by breaking waves rise to the surface and burst. The film droplets, typically 0.01–2 μm in size, are sprayed outward. Immediately afterward, surrounding water surges in to fill the cavity left behind and creates a rising jet whose tip pinches off the jet droplets, with sizes between 2 μm and 100 μm. Both classes of smaller droplets can become lofted upward with the wind. Illustration courtesy of Tamara Beeson, University of Delaware. [Source: Richter and Veron, 2016].



1.2 MICROCYSTINS IN AEROSOLS - RESEARCH TO DATE

We performed a literature review of aerosolised HABs from lakes and whether there was a relationship between toxin levels in the lake and aerosolised concentrations.

Multiple studies have evaluated microcystins in aerosols near lakes (Table 1) with varied results. In the studies using high volume air samplers, microcystins were detected in six of the eight studies using this air sampling strategy. However, some studies sampled air from agitated environments (e.g. spillway) or employed mechanical aeration of the water to increase the presence of aerosols (Labohá et al., 2023). The highest microcystin concentration observed in a high volume air sample was 156 pg/m^3 (Shi et al., 2023) from near a spillway. Two studies using high volume air samplers did not detect microcystins in air samples (Cheng et al., 2007; Plaas et al., 2022). All four studies using high-volume air samplers with a cascade impactor detected aerosolised microcystins. Microcystins were detected in each of the three studies that used personal air samplers, with maximum concentrations of 2,900 pg/m^3 observed (Backer et al., 2010). One study used a low volume air sampler (Wood and Dietrich, 2011), but no microcystins were detected. Backer et al. (2010) also detected microcystins in nasal swabs.

The studies evaluated did not clearly identify any variables that consistently affect microcystin aerosolisation. While some studies observed higher levels of aerosolisation in relatively calm conditions (e.g., Wood and Dietrich, 2011), others identified a relationship with wind direction (Shi et al., 2023). None of the studies evaluated in Table 1 were able to establish a relationship between the concentration of microcystin (or cyanobacteria) in the lake water and the microcystin concentration in the air samples. Two studies indicated that extracellular microcystins (toxins that are no longer present inside cyanobacteria cells, whether due to export or cell lysis) are more prone to aerosolisation than cellular / particulate microcystins (Carter and Haney, 2022; Shi et al., 2023).

TABLE 1: Collated information from studies investigating aerosolised microcystins (MCs) near freshwater lakes.

Study	MC Analysis Approach	Air Sampling Approach	MCs in Air Samples	MCs in Lake Water	Patterns Observed	Other Comments
Cheng et al. (2007)	ELISA.	High volume air sampler and cellulose filters.	ND (< 4 pg/m^3; LoD) 432 m^3 sampled	Approximately 1 µg/L total MCs (exact values not stated).	Low levels of MC in aerosol (20-80 pg/m^3) measured when low levels present in lake water (~1 µg/L)	- High background was observed in ELISA when using glass fibre filters leading to adoption of cellulose filters instead. - Location of high volume samplers not stated.
		High volume air sampler with cascade impactor and cellulose filters.	Max = 57 pg/m^3 Min = 23 pg/m^3 432 m^3 sampled			
		Personal air samplers (IOM Inhalable Dust Sampler).	Max = 80 pg/m^3 Min = < 9 pg/m^3 (LoD) 0.6 m^3 sampled			
Backer et al. (2008)	ELISA and LC-MS/MS to investigate one blood sample.	High volume air sampler with cascade impactor and cellulose filters located on boat.	Max = 57 pg/m^3 Min = 23 pg/m^3 * 675 m^3 sampled	Total MCs Max = 4 µg/L Min = 2 µg/L	Low levels of MC in aerosol (< 100 pg/m^3) measured when low levels present in lake water (~2-5 µg/L)	- No MCs detected in the blood samples.
		Personal air samplers (SKC pumps 10.6 L/min).	Max = 456 pg/m^3 Min = 5 pg/m^3 10.6 m^3 sampled			
Backer et al. (2010)	ELISA and LC-MS/MS to confirm MC congener composition.	High volume air sampler with cascade impactor and cellulose filters located on boat and shoreline.	Max = 52 pg/m^3 Min = < LoD (LoD not stated) 432 m^3 sampled	Total MCs Max = 357 µg/L Min = 15 µg/L Extracellular MCs Max = 10 µg/L Min = 1.6 µg/L	- No patterns observed between water MC conc and air MC conc. - Levels of MCs in nasal samples were similar to the expected exposure level.	- No MCs detected in the blood samples. - MCs detected in nasal swabs.
		Personal air samplers (IOM Inhalable Dust Sampler and SKC Eighty Four).	Max = 2,900 pg/m^3 Min = < 100 pg/m^3 (LoD) 3.8 m^3 sampled			

Study	MC Analysis Approach	Air Sampling Approach	MCs in Air Samples	MCs in Lake Water	Patterns Observed	Other Comments
Wood and Dietrich (2011)	ELISA and LC-MS/MS to confirm MC congener composition and ELISA accuracy.	High volume air sampler and glass fibre filters located on shoreline (one high vol deployed 20 m away).	Lake Forsyth Max = 16 pg/m^3 Min = 0.2 pg/m^3 720 m^3 sampled	Total MCs Max = 10 µg/L Min = 0.5 µg/L Extracellular MCs Max = 10 µg/L Min = 0.04 µg/L	- Between the lakes, higher MC concs in the water did not result in higher MC concs in the air. - At Lake Forsyth, higher MC concs in the air were linked with higher MC concs in the water (at the beginning of study).	
			Lake Rotorua Max = 1.8 pg/m^3 Min = 0.3 pg/m^3 240 – 2,880 m^3 sampled	Total MCs Max = 2,140 µg/L Min = 2.5 µg/L Extracellular MCs Max = 19 µg/L Min = 1 µg/L		
		Low volume air sampler and PTFE filters.	Lake Rotorua ND (LoD not stated) 0.3 – 1.7 m^3 sampled 3.5 m^3 sampled			
Gambaro et al. (2012)	LC-MS/MS in negative ion mode.	High volume air sampler and pre-combusted quartz filters.	Max = 0.9 pg/m^3 Min = 0.091 pg/m^3 Volume sampled not stated	Not measured.		- Location of high volume samplers not clear (“on island near harbour”).
Murby and Haney (2016)	ELISA.	Custom built air sampler.	Max = 384 pg/m^3 Min = < 13 pg/m^3 (LoD) 0.24 – 0.48 m^3 sampled	Not measured	- No pattern between MC air conc and cyanobacteria cell conc in water.	
Plaas et al. (2022)	LC-MS/MS.	High volume air sampler and pre-combusted quartz filters located on piers.	ND (< 100,000 pg/m^3; LoD) 5,760 – 8,640 m^3 sampled	Approximately 1 µg/L total MCs (exact values not stated).	- No pattern between cyanobacteria observed in air samples and cyanobacteria present in the water.	- Cyanobacteria were detected in the (8-12 day) samples.

Study	MC Analysis Approach	Air Sampling Approach	MCs in Air Samples	MCs in Lake Water	Patterns Observed	Other Comments
Carter and Haney (2022)	ELISA.	Compact Lake Aerosol Monitor (CLAM) using glass fibre filters and a water trap.	Lower Mill Pond Max = 530 pg/m^3 Min = 102 pg/m^3 0.48 m^3 sampled --- Cliff Pond Max = 460 pg/m^3 Min = 186 pg/m^3 0.48 m^3 sampled	Not measured.	- Most of the MCs in the air samples (90%) were extracellular (they were observed in the water trap). - Relationship between particulate MC in the air and the temperature differential between the water and the air.	- Airflow of the CLAM air sampler was not mentioned.
Shi et al. (2023)	LC-MS/MS.	High volume air sampler with cascade impactor and glass fibre or pre-baked quartz filters located on shoreline.	Max = 156 pg/m^3 Min = < LoD (LoD not stated) < 100 m^3 sampled	Max = 23 µg/L Min = 2.6 µg/L	- Site with highest agitation (spillway) had highest MC concs in the air. - Wind direction had an effect on whether MCs were detected in the air, or not.	- Air samples contained mostly extracellular MCs (rather than cellular MCs) because of the PM size fraction the MCs were detected on.
Labohá et al. (2023)	LC-MS/MS.	High volume air sampler and quartz filters sampling mechanised aerated, water.	Max = 0.4 pg/m^3 Min = < 0.035 pg/m^3 (LoD) 1,500 m^3 sampled	Max = 13.5 µg/L Min = < 0.001 µg/L (LoD)	- Inverse relationship between MCs in air samples and total MCs in water.	- Study undertaken of mechanical water agitation (i.e. not natural air). - Cyanobacterial DNA detected in air samples.

* Value presented in the paper was incorrect, but the revised value presented in the table was confirmed with the author of the study.

DNA = Deoxyribonucleic acid, ELISA = Enzyme-linked immunosorbent assay, LoD = Limit of detection, LC-MS/MS = Liquid chromatography-tandem mass spectrometry, Max = Maximum, Min = Minimum, ND = Not detected, PM = Particulate matter, PTFE = Polytetrafluoroethylene.

1.3 LAKE WAIKARE HISTORY

Glen Tupuhi (Ngāti Hine, Ngāti Naho, Ngāti Paoa) a local kaumātua kindly provided a brief oral history of Lake Waikare. When he was a boy, children used to swim in Lake Waikare. The water used to be very clean and clear, with a pumice sand bottom. The name of the current township of Te Kauwhata derives its name from Taa Kauwhata a waahi tapu (sacred historical site) at a mid-point on the northern foreshore. The name kauwhata were food storehouses on stilts above water.

Like other tribal areas, the history of Waikato in the 1800's is bookended by invasion firstly from northern tribes well-armed with muskets in the early period and then by colonial troops, with confiscation and systematic impoverishment from 1860 onward. There was a brief 1840's to 1860's period of economic prosperity when all hapuu contributed to the Waikato Tainui collective trading with the infant cities of Sydney, Auckland and elsewhere. Hapuu across the northern Waikato including those with fertile gardens and flour mills in close proximity to Lake Waikare enjoyed a geographical advantage in getting produce to those markets. This included trade through the waterways of the Whangamarino (*tranquil waters*) and portage across a saddle in the hills on state highway 2 where Smythe's Quarry is situated into the Miranda Flats. Maize was grown in the Waiterimu Valley to the southeast and this was brought over to Lake Waikare, then barged to the Manukau Heads before being exported to Sydney.

Matua Glen noted that prior to 1965 (the year the lake outlet was commissioned) the Waikato River in flood would spill into Lake Waikare and trigger an annual mass migration of tuna (*eels*) spilling out of the lake at the Ruahine corner (prior to the construction of the canal) across the wetland plains and into the Whangamarino maze of waterways and wetlands. Local whanau took advantage of the floods that flowed across the Waerenga Road especially at night when thousands of tuna would swim across the road barrier. With crude candles in cans, lamps or using headlights of the old Ford and Chevrolet trucks with a high wheelbase to shine their lights into the floodwaters black with eels, they could selectively harvest by stunning the tuna with ripi (flat iron clubs). The job of the tamariki (children) was to gather the tuna before they floated into the drains on the other side of the road. These were highly prized, Glen recalls his grandfather continuing an ancient practice with coastal whanau in the Pukorokoro (Miranda) Kaiaua area trading eels for kaimoana (seafood) which had been gathered, shelled, half cooked, dried then brought back from the coast which was a significant distance. Once steamed, the dried fish, shellfish and karingo (seaweed) added a salt and mineral balance to the diet of inland iwi.

The cumulative effects of land clearance (resulting in hill country erosion), farming practices including intensification and the prolific use of synthetic nitrogen to boost grass growth, as well as the introduction of pest fish species contributed to the irreversibility of suspended sediment suffocating the native filtering plant growth on the floor of Lake Waikare. The Lower Waikato flood protection plan of 1965 effectively altered the hydrology and changed the annual river spill and nutrient food source replenishment into Lake Waikare and the Whangamarino significantly. Within a few years plant growth ceased and eels and other taonga species such as inanga, matamata and murihau (whitebait) declined rapidly with some species extinct or present only in limited numbers. Pest fish (koi carp) have since further degraded water quality.

Matua Glen brought our attention to a number of culturally significant areas at Lake Waikare. These including the Takapuruharuha (burial caves) to the east of the lake, now collapsed due to wave action from the rising and falling of the lake. Survivors from the fierce and bloody

battle of Rangiriri[1] in 1863 hid in these caves. Tauanui is the area of remnant Kahikatea forest adjacent to the Ruahine floodgate.

Motu Kanae on the eastern shoreline is the name of a geothermal vent protrusion leaching sulphur and other minerals into the lake. This created a unique microenvironment for kōura (*freshwater prawns*) and other aquatic invertebrates that, in turn, attracted schools of freshwater patiki (flounder), kanae (mullet) and the wading birds including the kōtuku (white heron), kōtuku moana (*white faced grey heron*), matuku-hūrepo (*bittern*) and kotuko ngutupapa (*spoonbill*). Motu Kanae was located near the confluence with the Matahuru river but the lowering of the lake has exposed the former wading flats. An area close to the thermal vent was named tutaepiro (stinking excrement) which indicates that the vent was more active in former times causing a strong sulphur smell in the area. Bathing in the waters around the vent assisted in the healing of skin and respiratory ailments.

According to Ngati Hine oral history, the lake now known as Ohinewai or Te Wai o Hine is where the tupuna Hine bathed, Papa Atawhai, Puia (another sulphur leach) and Waikaukau (*swimming waters*) are near to that area.

1.4 WATER QUALITY IN LAKE WAIKARE

Lake Waikare is the largest lake in the lower Waikato catchment, with 3,442 hectares of open water (Figure 3). It is shallow with an average depth of 1.5 metres and a maximum depth of 1.8 metres. Over time, extensive land clearance within the lake catchment has resulted in increased sediments and nutrients entering Lake Waikare.

By the 1940s, aerial photographs show turbid water (WRC, 2024). In 1965, in accordance with the Lower Waikato Waipa Flood Control Scheme, the level of Lake Waikare was lowered by one metre. In its natural state, lakes and wetlands dominated the Lower Waikato floodplain. The purpose of the scheme was to drain the land and bring it into agricultural production.

Waikato Regional Council reports the wetlands surrounding the shores of Lake Waikare have been reduced by two-thirds (67%) since 1963. The Matahuru River, which empties into Lake Waikare, is the primary source of sediment to the lake and the intensification of dairy farming in the catchments up-river has increased the nitrogen loading in Lake Waikare to the point where it is now hypertrophic (i.e. supersaturated in phosphorus and nitrogen; WRC, 2024). Hypertrophic lakes are highly fertile with excessive phytoplankton growth which contributes to poor water clarity, poor suitability for recreational uses, and restricts the habitat for desirable fish.

Lake Waikare now discharges to the Whangamarino Wetland from the artificial Pungarehu Canal. Waikato Regional Council manages the lake with a strict seasonal fluctuation regime of approximately 0.3 metres.

Results from water quality monitoring carried out by Waikato Regional Council show that Lake Waikare has very poor water quality and is hypertrophic with extremely high levels of inorganic suspended sediments. The high sediment levels reduce light penetration into the water, limiting the plant life that can survive. Waikato Regional Council reports there are no large submerged aquatic plants growing in the lake (WRC, 2024). Lake Waikare has a recurring history of HABs and is a prime candidate for a field study into the aerosolisation of HABs.

[1] https://nzhistory.govt.nz/memorial/rangiriri-nz-wars-cemetery-arch

FIGURE 3: Lake Waikare [Source: WRC]

2. METHOD

The purpose of the field study was to:

1. investigate the environmental drivers such as meteorology and distance that may influence aerosolisation and air transport of toxins from harmful algal blooms; and

2. measure cyanobacterial toxins in aerosols downwind of a bloom.

If feasible, we further endeavoured to investigate both acute (daily) potential exposure to aerosols at varying distances from a water body, and chronic (weekly / monthly) potential exposure to aerosols.

Aerosol sampling was undertaken using *high volume* air samplers to detect daily levels of aerosolised toxins (if present) at varying distances away from a HAB. High volume samplers take in 1,000 L per minute of air permitting a very low minimum toxin detection threshold (picograms per cubic metre, pg/m^3).[2]

Aerosol sampling was also undertaken using a *low volume* air sampler to measure weekly/monthly levels of aerosolised toxins (if present) downwind from a HAB. Low volume samplers draw in 2 – 4 L per minute and are more appropriate for long-term monitoring.

Continuous meteorological monitoring (wind speed, wind direction, temperature, relative humidity) and coincidental PM_{10} and $PM_{2.5}$ monitoring was also undertaken throughout the entire field study to inform data analyses.

To endeavour to understand if there is a relationship between cyanotoxins and cyanobacteria in the lake water and toxin concentrations detected in air samples, lake water samples were collected three-times daily and analysed for cyanobacteria and microcystin concentrations.

2.1 SITE SELECTION

The original proposal was to undertake a field study either in the Auckland marine area (at times experiencing lyngbyatoxin-producing *Okeania* blooms) or a lake (experiencing a bloom of toxin-producing cyanobacteria).

By February 2024 samples from a marine bloom on Waiheke Island only had low levels of toxins indicating reduced potential suitability for field research of aerosolisation (of toxins). The algal mats were further cleared from the beaches by Auckland Council in January 2024.

Samples from 74 lakes in six regions (Auckland, Manawatū, Rotorua, Southland, Taranaki, Waikato; 360 samples in total) were analysed for microcystins, nodularins, anatoxins and cylindrospermopsins. Most samples contained no cyanotoxins or only low levels of cyanotoxins (for recreational freshwaters; e.g., < 1 µg/L).

Microcystin results from Lake Waikare were very high (16,000 µg/L, sampled on 15 February 2024) and Waikato Regional Council offered support, suggesting the outlet gate may provide a suitable aerosol monitoring location. Initial scouting at Lake Waikare established:

- the outlet gate at Lake Waikare offered access to mains power;

[2] A picogram is one trillionth of a gram (1×10^{-12})

- a cooperative landowner at a kūmara field located adjacent to the outlet gate and close to the lake, also offered mains power from a shed;
- there were additional potential monitoring locations in the vicinity of the outlet gate; and
- the lake had a significant cyanobacterial bloom which contained microcystins.

Provision of mains power, as opposed to the use of a generator which requires multiple refills per day, was highly attractive as it should improve the reliability of data collection.

Mana whenua permission was obtained, facilitating concurrent lake water **and** aerosol sampling at multiple locations adjacent and downwind from Lake Waikare.

2.2 WATER SAMPLING AND OBSERVATIONS OF RECREATIONAL USERS

Lake water samples were collected three times a day (ca. 8am, 12pm and 4pm) for six days from three sites on the northern end of Lake Waikare (Figure 4):

- Site 1 (Lake 1 in Figure 4) was at the Lake Waikare boat ramp at 'Lake View'.
- Site 2 (Lake 2 in Figure 4) was at the 'outlet gate' at the end of Ruahine Rd (where water gates are used to control the lake level.
- Site 3 (Lake 3 in Figure 4) was at the eastern side of the 'Lakeside' residential development accessed from Scott Rd.

Precise sampling locations are in Appendix A.

At each site and each timepoint (Appendix A), a 1 litre (L) water sample was collected using a sampling pole with a plastic container attached to it. The sampling container was rinsed with lake water three times prior to collecting the lake water sample for analysis. As per the guidance in the Recreational Cyanobacteria Guidelines (MfE and MoH, 2009), when cyanobacterial scums were present these were targeted for sampling to provide a 'worst-case scenario' for human health. Half of the lake water sample was used to rinse a 500 millilitre (mL) plastic sampling container three times, before a 500-mL subsample was transferred to the container. Prerinsing with lake water assists with reducing the risk of sample contamination. This was stored in a chilly bin until further processing was undertaken (within an hour).

While undertaking the water sampling, the number of recreational users present at each site was recorded (the research team were not included in the tally). The activity being undertaken by each user was broadly categorised at the time and the categories were later refined to the following: physical activity, fishing, boating, eating, camping, outdoor employment, and sedentary activity. Because of the large residential population at Lake 3, the area for observation was from the first sighting of the embayment and only included people who were outside and only within one house block from Rimu Street, Whites Way and Scott Road (which were used to access the sampling site). These streets are all adjacent to Lake Waikare.

FIGURE 4: Map of Lake Waikare indicating the location of lake water sampling sites (Lake 1, 2 and 3; pink) in the bottom panel and air sampling sites (Air 1, 2, 3 and 4; blue) in the top panel (a zoomed in view of the yellow box in the bottom panel)

After the three sites had been sampled, the lake water samples were processed for storage until analysis. The 500 mL water sample was mixed thoroughly before subsamples for total microcystin measurements (40 mL) and cell enumeration (10 mL) were transferred to plastic tubes. A sample for extracellular / dissolved microcystins was prepared by gently syringe-filtering (0.22 µm pore size) 1 – 2 mL of the water sample directly into a glass liquid chromatography (LC) vial. The subsample for cell enumeration was preserved by adding 2 drops of Lugol's iodine solution and storing in the dark at ambient temperature until microscopy analysis. The total and extracellular microcystin samples were stored at −20°C until extraction (total microcystin samples only) and analysis.

2.3 AEROSOL SAMPLING

A key determinant for aerosol sampling site selection was the availability of mains power. While generators could potentially be employed to operate high volume air samplers, they present drawbacks such as high cost, environmental impact and the need for frequent refuelling.

One identified location, adjacent to the outlet gate of Lake Waikare, featured an abandoned fish processing facility (originally used for producing fish meal from koi carp), which retained access to mains electricity. Waikato Regional Council facilitated access to this site and to the adjacent stop bank (northwest of the outlet gate). Mains electricity was also accessed from the shed of a kūmara farm located just to the northwest of the fish compound. These areas were deemed suitable for establishing four high volume sampling stations, at increasing distances from the lake, as depicted in Figure 4 and detailed in Table 2.

The presence of mains electricity at the former fish compound and the kūmara field obviated the need for generator use at all but one site (Air 4).

Long-term sampling activities were concentrated at the site nearest to the lake (Air 1). Meanwhile, meteorological monitoring occurred at the highest point within the secure confines of the fish compound (Air 2), where meteorological sensors were positioned approximately 6 meters above the lake's surface level.

Precise locations of all monitoring instruments are provided in Appendix A.

The Lear Sigler high volume samplers were operated continuously for 24-hours commencing and concluding at midnight over a span of 7 days. Following collection (glass fibre) air filters were double bagged, labelled and stored in freezers prior to shipment to Cawthron with ice packs.

Low volume air sampling was conducted on a weekly basis during the initial two weeks, followed by a final two-week exposure period. Similar handling procedures to those adopted for the high volume filters were followed for the low volume (PTFE) air filters destined for laboratory analysis.

Field blanks were taken into the field, attached to the high volume sampler and then air was drawn through the monitor for a few minutes (only). One field blank was prepared for each high volume sampler. One, non-draw through blank was taken into the field (but not removed from its bag) before being labelled and sent for analysis. Another (true) blank was kept at base (i.e., not taken into the field) before being bagged, labelled and sent for analysis as per remaining samples. There were a total of six blanks analysed.

Concurrent, continuous sampling of particulate matter smaller than 10 micrometres (PM_{10}) and $PM_{2.5}$ was carried out throughout the entire field study. This was achieved using SDS-011 sensors employing dual side scattering technology, coupled with inlet heaters calibrated to maintain air temperatures 5°C above ambient levels, thereby mitigating the influence of water droplets (which are known to impact on light scattering sensor techniques). Sensor data was recorded at 1-second intervals and subsequently converted to 1-minute averages.

TABLE 2: Aerosol monitoring locations and distance from lake (refer Figure 4)

Site ID	Monitoring Site	Instrument	Exposure Period	Distance from Lake (m)*	Wind Directions from Lake towards Monitoring Location
Air 1	Ika Tahi	High volume	Short-term	50	SW – E
	Ika Toru	Low volume	Long-term	50	SW – E
Air 2	Ika Rua	High volume	Short-term	100	SW – E
	Met Station	Meteorological	Long-term	100	SW – E
Air 3	Kūmara	High volume	Short-term	150	SW – E
Air 4	Whenua	High volume	Short-term	200	WSW – SSE

*Measured in a southwest direction, rounded to nearest 5 m

2.4 ANALYSES

Air and water samples were analysed for microcystins and cyanobacteria to evaluate whether a relationship between cyanotoxin concentrations in the water and the air existed. Microcystins were evaluated, rather than other cyanotoxin classes, because preliminary investigations identified the presence of microcystin-producing cyanobacteria (i.e., *Microcystis*) and microcystins in Lake Waikare.

2.4.1 Microcystin Extraction of High Volume Air Filters (Glass Fibre)

One quarter of each glass fibre filter was cut into small pieces using scissors (cleaned with ethanol and a tissue) and deposited into a 15 mL centrifuge tube. The glass fibre filter was extracted using 90% methanol + 0.5% formic acid (10 mL) and sonication (30 min, with ice for cooling). The extract was transferred to a glass vial and the filter was extracted a second time using 90% methanol + 0.5% formic acid (8 mL) and sonication (30 min, with ice for cooling). The second extract was pooled with the first extract and dried at 40°C under a stream of nitrogen gas. The dried extract was resuspended in 0.5 mL of 80% methanol + 0.1% formic acid and centrifuged to clarify (12,000 × *g*; 5 min). The supernatant was transferred to a liquid chromatography (LC) vial with a small-volume glass insert and stored at −20°C until analysis by liquid chromatography-tandem mass spectrometry (LC-MS/MS).

2.4.2 Microcystin Extraction of Low Volume Air Filters (PTFE)

The entire PTFE filter was cut into small pieces using scissors (cleaned with ethanol and a tissue) and deposited into a 15 mL centrifuge tube. The PTFE filter was extracted using 90% methanol + 0.5% formic acid (10 mL) and sonication (30 min, with ice for cooling). The extract was transferred to a glass vial and the filter was extracted a second time using 90% methanol + 0.5% formic acid (5 mL) and sonication (30 min, with ice for cooling). The second extract

was pooled with the first extract and dried at 40°C under a stream of nitrogen gas. The dried extract was resuspended in 0.5 mL of 80% methanol + 0.1% formic acid and centrifuged to clarify (12,000 × *g*; 5 min). The supernatant was transferred to a LC vial with a small-volume glass insert and stored at −20°C until analysis by LC-MS/MS.

2.4.3 Cyanobacteria Identification and Enumeration

Microscopy analysis was undertaken by the Cawthron Natural Toxins testing laboratory for the lake water samples (only). Cyanobacteria identification and enumeration was undertaken using an inverted microscope (IX70, Olympus). Subsamples or dilutions of samples were settled in Utermöhl chambers (Utermöhl 1958), and cyanobacteria cells were enumerated by scanning 1 – 2 transects at 400 – 600× magnification. Species identification was undertaken with reference to Baker and Fabbro (2002), Komárek and Anagnostidis (1999), McGregor and Fabbro (2001), and Wood et al. (2005). Biovolumes were determined using cell volume conversion factors from the Recreational Cyanobacteria Guidelines (MfE and MoH, 2009) and a database built up by the Cawthron Natural Toxins testing laboratory.

2.4.4 Total Microcystin Extraction of Lake Water Samples

Lake water samples were thawed at ambient temperature and a subsample (10 mL) was transferred to a 15 mL centrifuge tube containing concentrated formic acid (10 µL each; 0.1% final concentration). The subsample was frozen at −20°C, then thawed in a bath sonicator (30 min), before being frozen again. The freeze-thaw-sonicator cycle was repeated and the samples were clarified by centrifugation (3,200 × *g*; 10 min). The supernatant was transferred to a LC vial and stored at −20°C until analysis by LC-MS/MS.

2.4.5 Microcystin Analysis by LC-MS/MS

Microcystin analysis of all samples was undertaken using the multiple-reaction monitoring (MRM) method described in Puddick et al. (2016). Extracellular microcystin samples, total microcystin extracts from lake water and air filter extracts were analysed using an Acquity I-Class ultra-performance LC system (Waters Co.) using a C_{18} column (Acquity BEH-C_{18}, 1.7-µm, 50 × 2.1 mm; Waters Co.) maintained at 40°C in a column oven. Sample components were eluted using a flow rate of 0.4 mL/min and a gradient of 10% acetonitrile (mobile phase A) to 90% acetonitrile (mobile phase B), each containing 100 mM formic acid and 4 mM ammonia. The samples were injected at 5% mobile phase B and held for 12 s before a linear gradient up to 35% mobile phase B over 24 s, to 50% mobile phase B over a further 72 s and to 65% mobile phase B over a final 42 s, before flushing with 100% mobile phase B (at 0.6 mL/min) and returning to the initial column conditions. Sample components were analysed on a Xevo-TQS mass spectrometer (Waters Co.) operated in positive-ion electrospray ionization mode (source temperature 150°C; capillary voltage 1.5 kV; nitrogen desolvation gas 1,000 L/h at 500°C; cone gas 150 L/h).

2.4.6 Performance Tests for Aerosol Samples

Microcystin adsorption to air sampling filters (both glass fibre and PTFE) was investigated by preparing a broad mixture of microcystins and nodularins (NODs) using extracts from *Microcystis* CAWBG11 and *Microcystis* CAWBG617 (which together produce the range of

microcystin congeners commonly encountered in microcystin-producing cyanobacteria from Aotearoa New Zealand; Puddick et al., 2014; Puddick et al., 2019) and *Nodularia spumigena* CAWBG703 (which produces NOD-R and dmNOD-R) diluted in 90% methanol + 0.5% formic acid. This test is to ensure that the microcystins were not binding to the glass fibre and PTFE air sampling filters at levels that would impact their detection in samples.

Nine aliquots of the microcystin / nodularin solution (1 mL each) were placed in plastic micro-centrifuge tubes and either a quarter of a PTFE filter, the equivalent area of a glass fibre filter or no filter were placed in the tubes (each in triplicate). The tubes were capped and sonicated for 30 min, before the filters were removed using tweezers and the samples were clarified by centrifugation (12,000 × *g* for 5 min). The supernatant was transferred to a glass LC vial and stored at −20°C until analysis by LC-MS/MS.

The concentration measured in the two treatments (PTFE filter and glass fibre filter) and the control (no filter) were compared to determine the amount of toxin that had been removed from the solution by the filter and concentrations were expressed as the proportion remaining. For simplicity, concentrations for desmethyl microcystin congeners (dmMC-RR, dmMC-LR and dmNOD-R) were included with their respective parent congener for results interpretation.

The accuracy of the air sample extraction and analysis was determined by spiking blank glass fibre filters (a quarter of a filter each; in triplicate) or PTFE filters (the whole filter; in triplicate) with microcystins at two concentrations (low = anticipated final concentration of 0.05 nanograms per millilitre, ng/mL); high = anticipated final concentration of 4.6 ng/mL). Spikes were prepared using 100 µL of a solution containing MC-RR, MC-YR, MC-LR and NOD-R in 80% methanol + 0.1% formic acid (at 0.25 ng/mL for the low spike and at 23 ng/mL for the high spike). The spike samples were then prepared as per usual for a high volume air sample (see Section 2.4.1) and analysed by LC-MS/MS.

The limits of detection (LoD) and quantitation (LoQ) for the high-volume air sample extraction were determined using the signal-to-noise ratio (S/N) for each analyte in each of the triplicate low spike samples (described above). Using the equations below, theoretical LoDs and LoQs were calculated based on achieving a S/N of 3.14 (for the LoD) and 10 (for the LoQ).

$$LoD\ (in\ ng/mL) = \frac{3.14}{S/N} \times 0.05\ ng/mL$$

$$LoQ\ (in\ ng/mL) = \frac{10}{S/N} \times 0.05\ ng/mL$$

Where:

LoD	=	Limit of detection.
LoQ	=	Limit of quantitation.
3.14	=	The 99% confidence interval.
10	=	The 99.9% confidence interval.
S/N	=	Signal-to-noise ratio determined by LC-MS/MS.
0.05 ng/mL	=	The anticipated concentration of the microcystin standards spiked onto the glass fibre filter and measured by LC-MS/MS.

The equation below was used to convert the LoDs and LoQs from ng/mL (the LC-MS/MS measurement) into picograms per cubic metre (pg/m^3, what would be measured in an air sample) for the high volume samples (glass fibre filters).

$$LoD\ or\ LoQ\ \ (in\ pg/m^3)\ =\ \frac{LoD\ or\ LoQ\ (in\ ng/mL)\ \times 0.5\ mL\ \times 4}{1{,}400\ m^3}\ \times\ 1{,}000$$

Where: LoD = Limit of detection (determined using the equation above).

LoQ = Limit of quantitation (determined using the equation above).

0.5 mL = The resuspension volume for the glass fibre filter extracts.

4 = To account for one-quarter of the glass fibre filter being extracted.

1,400 m^3 = The volume of air sampled during the study using the high volume air samplers for one day.

1,000 = To convert nanograms (ng) into picograms (pg).

The equation below was used to convert the LoDs and LoQs from ng/mL (the LC-MS/MS measurement) into picograms per cubic metre (pg/m^3, what would be measured in an air sample) for the low volume samples (PTFE filters).

$$LoD\ or\ LoQ\ \ (in\ pg/m^3)\ =\ \frac{LoD\ or\ LoQ\ (in\ ng/mL)\ \times 0.5\ mL}{25.2\ m^3}\ \times\ 1{,}000$$

Where: LoD = Limit of detection (determined using the equation above).

LoQ = Limit of quantitation (determined using the equation above).

0.5 mL = The resuspension volume for the glass fibre filter extracts.

25.2 m^3 = The volume of air sampled during the study using the low volume air samplers for one week.

1,000 = To convert nanograms (ng) into picograms (pg).

2.4.7 Data Visualisation

Cyanobacteria graphical visualisations were conducted using R version 4.4.0 (Posit Team 2024; R Core Team 2024) with ggplot2 (Wickham 2016), ggbreak (Xu et al. 2021), cowplot (Wilke 2024) and ggpubr (Kassambara 2023).

The microcystin adsorption plot was produced using Microsoft Excel.

Meteorological and PM graphical visualisations were conducted using RStudio version 2023.06.1 +524 with OpenAir (Carslaw & Ropkins 2012) and Microsoft Excel.

3. RESULTS

3.1 LAKE WATER SAMPLING OBSERVATIONS

Lake water sampling was undertaken over six days from 13 April 2024 until 18 April 2024 (Table 3). The weather during sampling was generally fine with frequent intermittent rain showers that were occasionally heavy. The wind ranged from still to a moderate breeze as inferred with reference to the Beaufort Scale (Appendix B). The lake water consistently had a brown or green tinge, and at times *Microcystis* colonies were visible in the water. On Day 3 (15 April 2024), *Microcystis* colonies were abundant – particularly at Sites 1 and 2.

To understand the level of recreational use at the three water sampling sites, the number of people present was tallied. The number of people present at each site at each sampling time (excluding the research team) ranged from 0 to 23 (Table 3). Over the 18 observation periods, Site 3 (the 'lakeside' residential development) had the highest number of people present (max = 23, median = 7). Lower numbers of people were present at Site 1 (the Lake Waikare boat ramp; max = 3) than at Site 2 (the outlet gate; max = 10), but people were more consistently present at Site 1 (median = 1) than Site 2 (median = 0).

The activities being undertaken at the three sites were physical activity (walking, running, biking), fishing, boating, eating / picnicking, camping, outdoor employment, and sedentary activity (sitting; Appendix A). Outdoor employment was the most highly observed activity (max = 23, median = 10) and this was primarily centralised at Site 3 where construction of the residential development was being undertaken. The next two most frequently observed activities were physical activity (max = 12, median = 2.5) and sedentary activity (sitting; max = 5, median = 2), followed by fishing (max = 5, median = 2).

TABLE 3: Information and observations related to the lake water sampling at Lake Waikare including weather, water appearance and the number of people observed outside at the sampling site at the time of sampling (refer Appendix A for a breakdown of the type of activity being undertaken).

Day	Date	Time	Site	Weather *	Water Appearance	People Observed
1	13/04/2024	1 – 8:00 am	1	Sun, gentle breeze	Green tinge	0
			2	Sun, gentle breeze	Green tinge, some *Microcystis* colonies	2
			3	Sun, gentle breeze	Brown / green tinge	3
		2 – 12:00 pm	1	Overcast, moderate breeze	Green tinge	1
			2	Rain, moderate breeze	Green tinge, some *Microcystis* colonies	0
			3	Sun with some cloud, moderate breeze	Brown / green tinge	3
		3 – 4:00 pm	1	Showers and sun in distance, gusting breeze	Green tinge	0
			2	Overcast, moderate breeze	Green tinge	8
			3	Fine, moderate breeze	Brown / green tinge	1
2	14/04/2024	1 – 8:00 am	1	Fine weather, very light breeze	Green tinge	0
			2	Fine, still (no breeze)	Green tinge	0
			3	Fine, still (no breeze)	Brown / green tinge	3
		2 – 12:00 pm	1	Sunny, moderate breeze	Brown / green tinge	1
			2	Sun, some cloud, moderate breeze	Brown / green tinge	7
			3	Sun, some cloud, light breeze	Brown / green tinge	10
		3 – 4:00 pm	1	Gentle breeze, fine	Green tinge	1
			2	Gentle breeze, fine	Green tinge	4
			3	Very still, fine	Brown / green tinge	3
3	15/04/2024	1 – 8:00 am	1	Light air, fine with clouds in distance	Green tinge	2
			2	Light air, clouding over	Green tinge, abundant *Microcystis* colonies	0
			3	Light air, fine with clouds	Brown / green tinge, *Microcystis* colonies	0
		2 – 12:00 pm	1	Drizzle, sun with cloud, still	Green tinge, lots of *Microcystis*, tiny fish / tadpoles feeding	1
			2	Drizzle, overcast. Light breeze	Green tinge, lots of *Microcystis*	1
			3	Sun with clouds, very light breeze	Brown / green tinge	7
		3 – 4:00 pm	1	Gentle breeze, drizzle, fine with clouds	Brown / green tinge	0
			2	Overcast, gentle breeze	Green tinge	10
			3	Partially overcast, gentle breeze	Brown tinge	7

Day	Date	Time	Site	Weather [a]	Water Appearance	People Observed
4	16/04/2024	1 – 8:00 am	1	Fine, light air	Green tinge	0
			2	Sunny, calm	Green tinge, some *Microcystis* colonies	0
			3	Fine, light air	Green / brown tinge, some *Microcystis* colonies	14
		2 – 12:00 pm	1	Mostly fine, moderate breeze	Green / brown tinge	3
			2	Overcast, moderate breeze	Green tinge	1
			3	Spitting (very light rain) but sunny, light breeze	Green tinge	23
		3 – 4:00 pm	1	Fine, moderate breeze	Brown tinge	0
			2	Fine with clouds, moderate breeze	Green / brown tinge	0
			3	Fine, gentle breeze	Green / brown tinge	4
5	17/04/2024	1 – 8:00 am	1	Sunny, fine, light air	Green tinge	0
			2	Sunny, calm	Green tinge, some *Microcystis* colonies	0
			3	Sunny, light air	Green / brown tinge, a few *Microcystis* colonies	12
		2 – 12:00 pm	1	Fine, gentle breeze	Green / brown tinge	1
			2	Overcast, gentle breeze (gusting to moderate)	Green / brown tinge	0
			3	Overcast, gentle breeze	Green / brown tinge	14
		3 – 4:00 pm	1	Sunny, light breeze	Green / brown tinge	1
			2	Overcast, light breeze	Green / brown tinge	0
			3	Sunny, light breeze	Brown tinge	4
6	18/04/2024	1 – 8:00 am	1	Sunny, light air	Green tinge	1
			2	Sunny, calm	Green tinge, some *Microcystis* colonies	0
			3	Sunny, light air	Green tinge, a few *Microcystis* colonies	12
		2 – 12:00 pm	1	Overcast, gentle breeze	Brown tinge	1
			2	Sun with clouds, light breeze	Green tinge	6
			3	Sun with clouds, light air	Brown tinge	18
		3 – 4:00 pm	1	Gentle breeze, overcast	Green / brown tinge	3
			2	Overcast, light breeze	Green / brown tinge	0
			3	Partially overcast, light air	Brown tinge	15

[*] All wind references in accordance with Beaufort Scale.

3.2 CYANOBACTERIA AND MICROCYSTINS IN LAKE WATER SAMPLES

Evaluated as biovolumes (to account for different cell sizes), *Aphanizomenon* was the dominant cyanobacterial genera across all samples (mean ± standard error: 12.3 ± 0.8 mm^3/L), with *Pseudanabaena* (1.9 ± 0.3 mm^3/L) and *Microcystis* (1.45 ± 0.3 mm^3/L) the next most abundant cyanobacterial taxa. Average biovolumes for all other cyanobacterial genera were < 1 mm^3/L.

The highest recorded biovolume for a cyanobacterial genus in an individual sample was 30 mm^3/L and was measured for *Aphanizomenon* at Site 3 (Time 3, Day 2; 4 pm on 14 April 2024) and *Microcystis* at Site 1 (Time 2, Day 3; 12 pm on 15 April 2024; Figure 5).

Total cyanobacterial biovolume throughout the study period averaged 19.7 ± 1.2 mm^3/L, with a maximum of 46 mm^3/L (Site 3, Time 3, Day 2; 4 pm on 14 April 2024) and a minimum of 6 mm^3/L (Site 1, Time 3, Day 1; 4 pm on 13 April 2024). Across all sampling sites and time points, 93% of the samples had a total cyanobacterial biovolume ≥ 10 mm^3/L, the Situation 2 Action Level / Red Mode threshold in the Recreational Cyanobacteria Guidelines (MfE and MoH 2009; the horizontal dashed line in Figure 5).

Evaluated as a cell concentration, there was a ten-fold difference in the range of total cyanobacteria, from 257,000 cells/mL (Site 1, Time 3, Day 1; 4 pm on 13 April 2024; Figure 6 and Table 3) to 2,446,000 cells/mL (Site 1, Time 2, Day 4; 12 pm on 16 April 2024). Total cyanobacteria cell concentrations averaged 1,111,000 ± 64,000 cells/mL across all samples.

The cell concentration of *Microcystis* spp. (multiple *Microcystis* species) ranged over two orders of magnitude from 15,000 cells/mL (Site 3, Time 2, Day 4; 12 pm on 16 April 2024; Figure 6) to 1,801,000 cells/mL (Site 1, Time 2, Day 3; 12 pm on 15 April 2024). *Microcystis* spp. cell concentrations averaged 99,000 ± 33,000 cells/mL across all samples. and 81% of the samples had *Microcystis* spp. cell concentrations ≥ 30,000 cells/mL. This is the Situation 1 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines due for release in the second half of 2024 (MfE and Te Whatu Ora *pending*; Figure 6).

Total microcystin concentrations showed 200-fold differences, ranging from 2.3 ng/mL (ng/mL is the equivalent of µg/L; Site 3, Time 1, Day 2; 8 am on 14 April 2024; Figure 6) to 480 ng/mL (Site 1, Time 2, Day 3; 12 pm on 15 April 2024). Total microcystin concentrations averaged 18 ± 9 ng/mL across all samples. Counter to that observed for total cyanobacterial biovolumes (Situation 2) and *Microcystis* spp. cell concentrations (Situation 1), only 13% of the samples had microcystin concentrations that exceeded the Situation 4 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines (≥ 24 µg/L or ng/mL; MfE and Te Whatu Ora *pending*; Figure 6).

Extracellular / dissolved microcystins were generally low throughout the study (min = 0.04 ng/mL, max = 0.8 ng/mL; Appendix C). The proportion of extracellular microcystin, relative to the total microcystin concentration, ranged from 0.2% to 9.7%, with a median of 1.8% for the 54 samples collected and analysed through the six-day sampling period.

FIGURE 5: Taxonomic composition of total cyanobacterial biovolume measured in water samples collected from three sites from Lake Waikare at three time points per day over six days. The horizontal dashed line at 10 mm^3/L indicates the Situation 2 Action Level / Red Mode threshold for cyanobacteria for recreational waters in Aotearoa New Zealand (MfE and MoH 2009). * Picocyanobacteria aren't a cyanobacterial genus but are a collection of cyanobacteria with a small cell size (<2 µm in diameter).

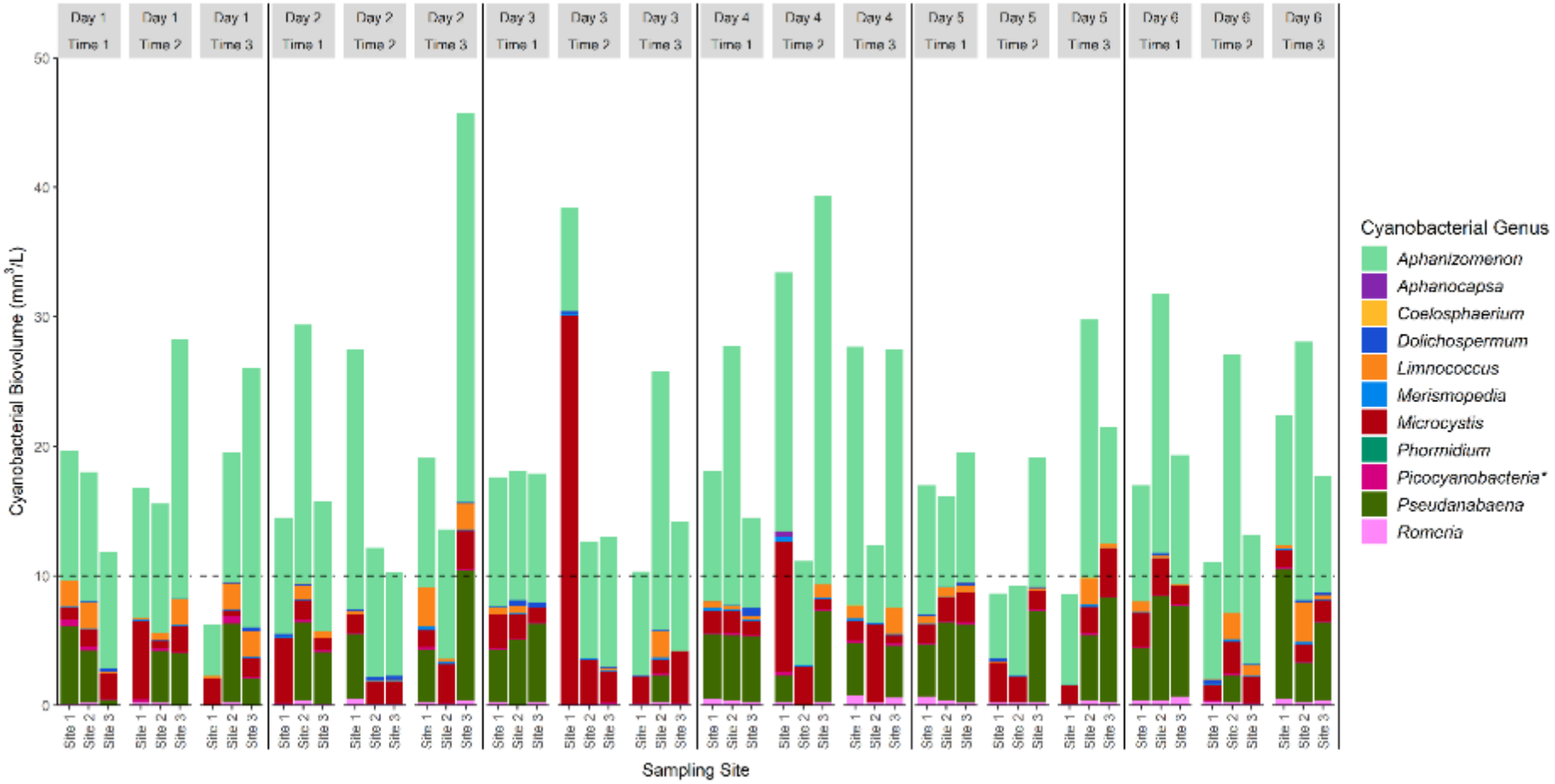
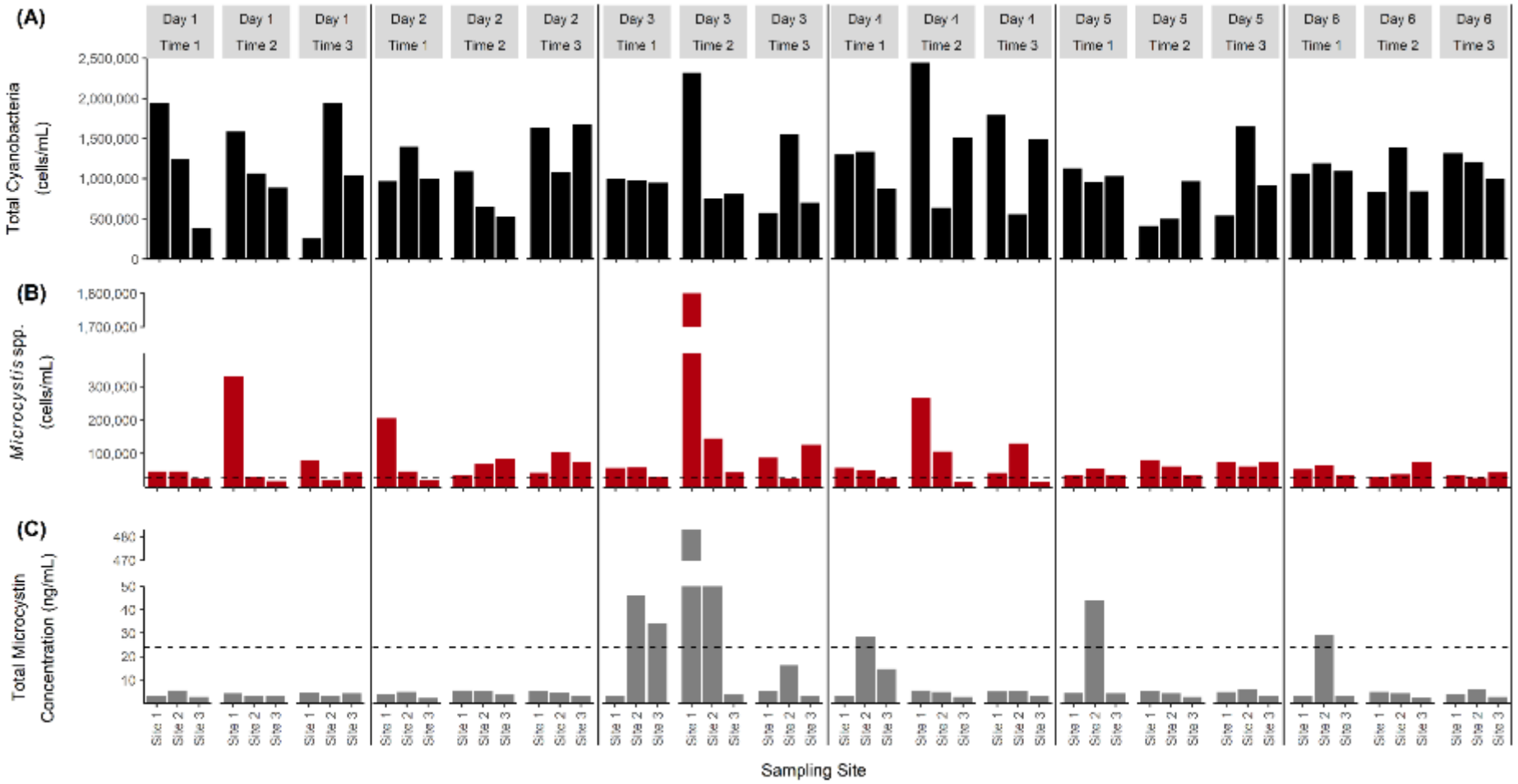
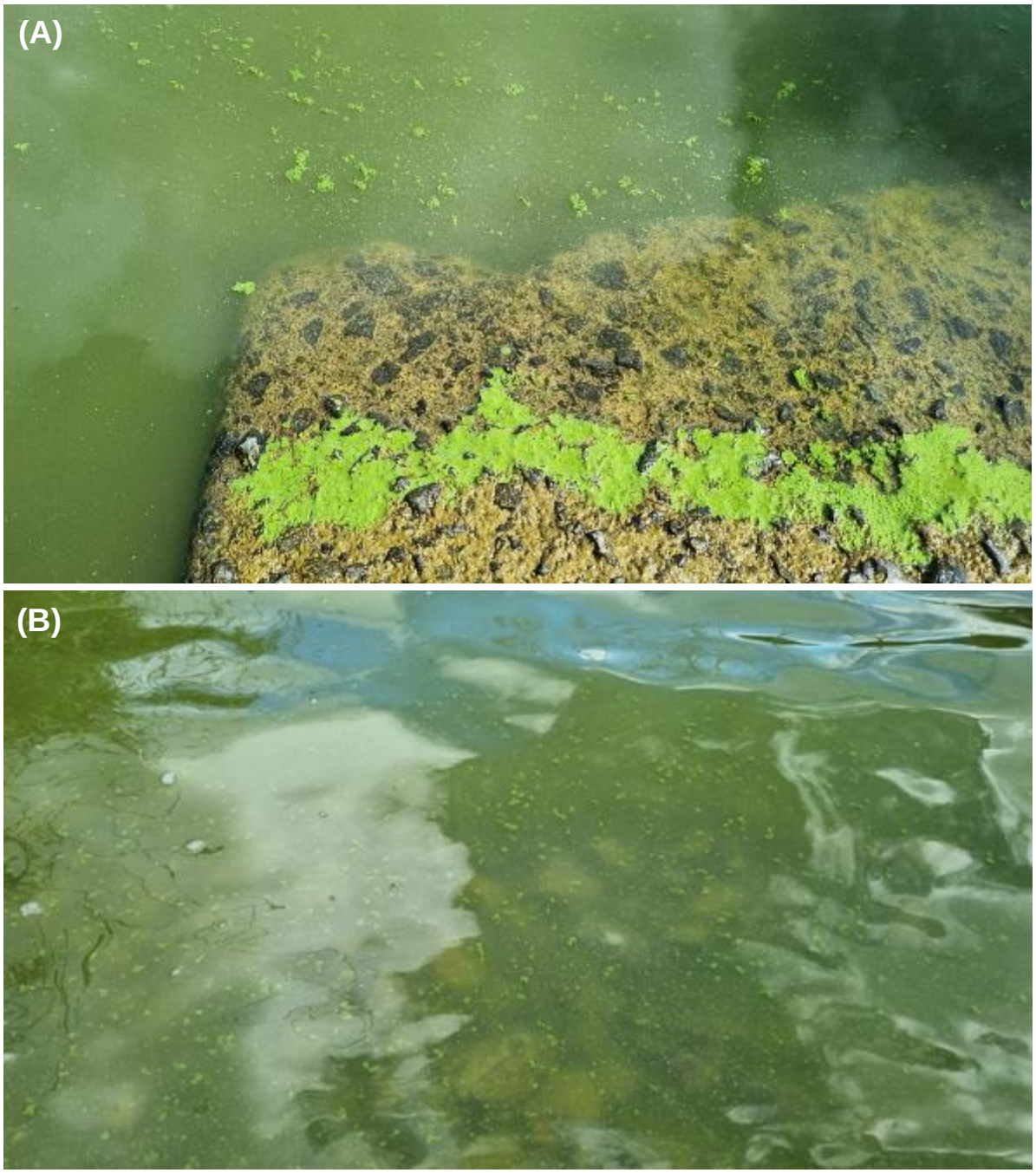


FIGURE 6: Total cyanobacteria (A) and Microcystis spp. (B) cell concentrations, and total microcystin concentrations (C) measured in water samples collected from three sites from Lake Waikare at three time points per day over six days. The horizontal dashed lines at 30,000 cells/mL for Microcystis spp. (in B) and 24 µg/L of microcystins (in C) indicates the relevant revised Action Level / Red Mode thresholds for cyanobacteria and cyanotoxins in recreational waters in Aotearoa New Zealand (revised Recreational Cyanobacteria Guidelines are due to be released in 2024; MfE and Te Whatu Ora *pending*).



There was an obvious peak in *Microcystis* spp. and microcystin concentrations in the Site 1 sample collected at Time 2 on Day 3 (12 pm 15 April 2024; Figure 5 and 6). The *Microcystis* spp. and microcystin concentrations observed in this sample were 5- and 4-times higher (respectively) than in any of the other samples. This sampling coincided with the formation of *Microcystis* scums (Figure 7A) at Site 1 at this time. While abundant *Microcystis* colonies were also observed at Site 2 (Figure 7B), the concentration of *Microcystis* cells and microcystins was much lower than at Site 1 (Figure 5 and 6).

FIGURE 7: Images of *Microcystis* blooms from Time 2 on Day 3 (12 pm on 15 April 2024) where surface *Microcystis* colony accrual was occurring at Site 1 (A; the boat ramp) and Site 2 (B; the outlet gate).



3.2.1 Additional Sampling

On Day 5 (17 April 2024), three additional samples were collected from embayments near the Lake 3 sampling site (close to the lakeside residential development) as shown in Figure 8. 'Lakeside Lagoon A' and 'Lakeside Lagoon B' were collected around 100 m and 40 m to the northwest of the Lake 3 sampling site and 'Lakeside Lagoon C' was collected from close to the end of the unsealed road (refer Figure 8). The samples were collected because there were intense *Microcystis* scums present in the embayment.

Very high concentrations of *Microcystis* spp. were present in each sample (> 5,000,000 cells/mL; Panel B in Appendix D) and the samples were dominated by *Microcystis* spp. with other taxa comprising ≤ 1% of the total cyanobacterial biovolume (Appendix D). Microcystin concentrations here were 200 ng/mL, 44 ng/mL and 60 ng/mL (for Lakeside Lagoon A, B and C respectively; Panel C in Appendix D) – all exceeding the 24 µg/L Situation 4 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines due for release in the second half of 2024 (MfE and Te Whatu Ora *pending*).

FIGURE 8: Location of additional lake water sampling locations (Lakeside Lagoon A, B and C). The smaller panel shows this location in relation to other lake water sampling locations (a zoomed-out view of the yellow box in the larger panel).

3.3 METEOROLOGY SAMPLING OBSERVATIONS

Aerosol sampling was undertaken over both short-term (daily) and long-term (two one-week periods and one two-week period) exposure periods to investigate potential acute and chronic public exposure to microcystin-containing aerosols. Unless noted otherwise, meteorological data are 1-minute averages.

3.3.1 Meteorological Observations during High Volume Sampling (Week 1)

Table 4 summarises key meteorological parameters during Week 1 (13 – 19 April 2024), including the summed frequency of winds directed towards the monitoring instruments.

A detailed review of winds is provided in Appendix E.

TABLE 4: Meteorology in Week 1: 13 – 19 April 2024.

Time period	Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Wind Towards Air 1 – 3 (%)	Wind Towards Air 4 (%)
Day 1	18 ± 2.2	76 ± 6.8	2.3 ± 2.2	59%	49%
Day 2	17 ± 2.8	76 ± 9.3	1.2 ± 0.9	25%	38%
Day 3	16 ± 3.6	75 ± 6.8	1.0 ± 0.8	44%	51%
Day 4	17 ± 2.3	78 ± 4.0	1.2 ± 0.9	40%	44%
Day 5	18 ± 3.3	76 ± 6.4	1.3 ± 0.8	32%	49%
Day 6	17 ± 3.6	72 ± 8.5	1.0 ± 0.7	40%	51%
Day 7	19 ± 2.4	76 ± 6.8	0.7 ± 0.4	30%	52%
Week 1 Average	**18 ± 3.0**	**76 ± 7.3**	**1.2 ± 1.2**	**39%**	**48%**

Throughout this period, wind speeds remained predominantly light, averaging below 4 meters per second (m/s) as a 1-hour average, except for Day 1 (13 April 2024), when maximum wind speeds approached just under 10 m/s as a 1-minute average (Figure 9).

Figure 10 depicts the wind directions (from, °True) documented during this first week. Blue rectangles indicate wind directions directed towards the air sampling sites.

Figure 11 presents a wind rose showing the frequency of wind speeds and directions observed during this time.

Whilst Table 4 shows winds were oriented towards the sampling sites for less than 50% of the time, arguably it is the daylight hours when wind speeds are higher with the greatest potential for aerosolisation that are the most important. Figure 9 illustrates that wind speeds frequently peaked during midday to late afternoon periods. Should wave action serve as the primary mechanism for aerosolisation, the Beaufort Scale (Appendix B) suggests sustained wind speeds exceeding 3.3 m/s will be a requisite for wave break conditions.

Figure 6C shows there were five occasions when total microcystins were detected in elevated concentrations in lake water at Site 2 (the water sampling site closest to the aerosol monitoring locations). Review of the meteorological data for these time periods (allowing an hour either side) is provided in Table 5. This analysis suggests that the presence of elevated concentrations of microcystins did **not** coincide with either elevated wind speeds conducive to aerosolisation of cyanobacteria in the lake environment, or their subsequent transport to the monitors located at the lakeside.

FIGURE 9: Wind speed (m/s, 1-minute average) at Lake Waikare, Week 1: 13 – 19 Apr 2024.

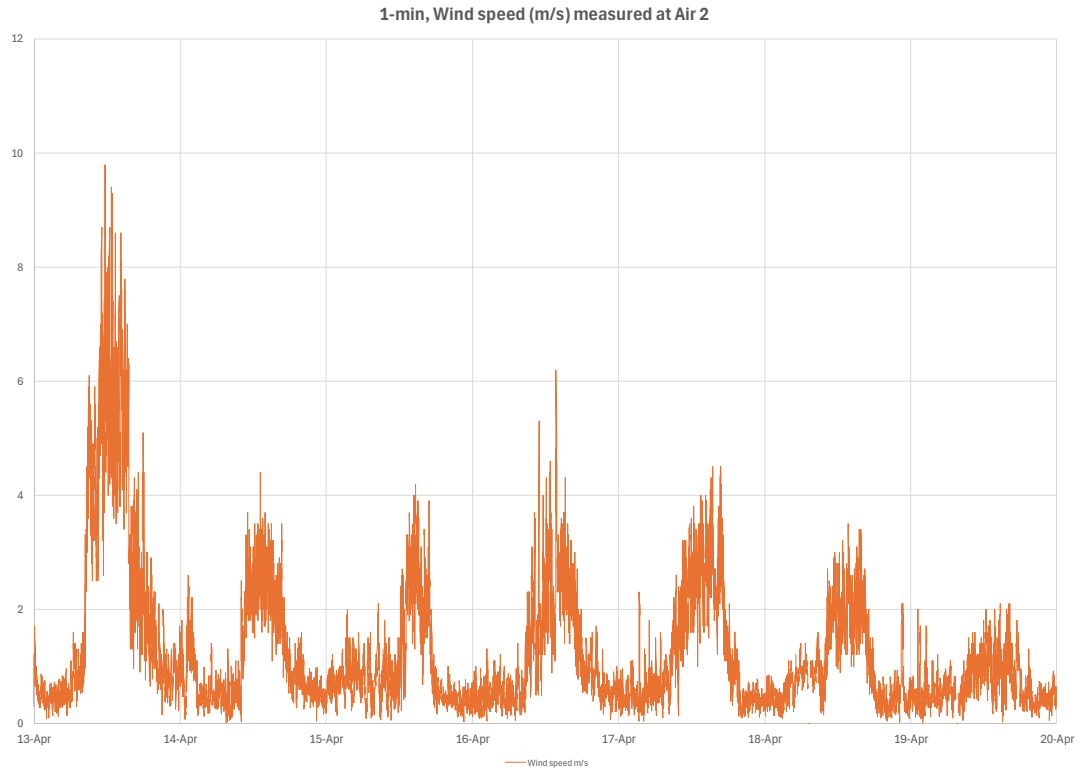


FIGURE 10: Wind direction at Lake Waikare, Week 1: 13 – 19 Apr 2024. Blue rectangles indicate winds directed toward the air sampling sites.

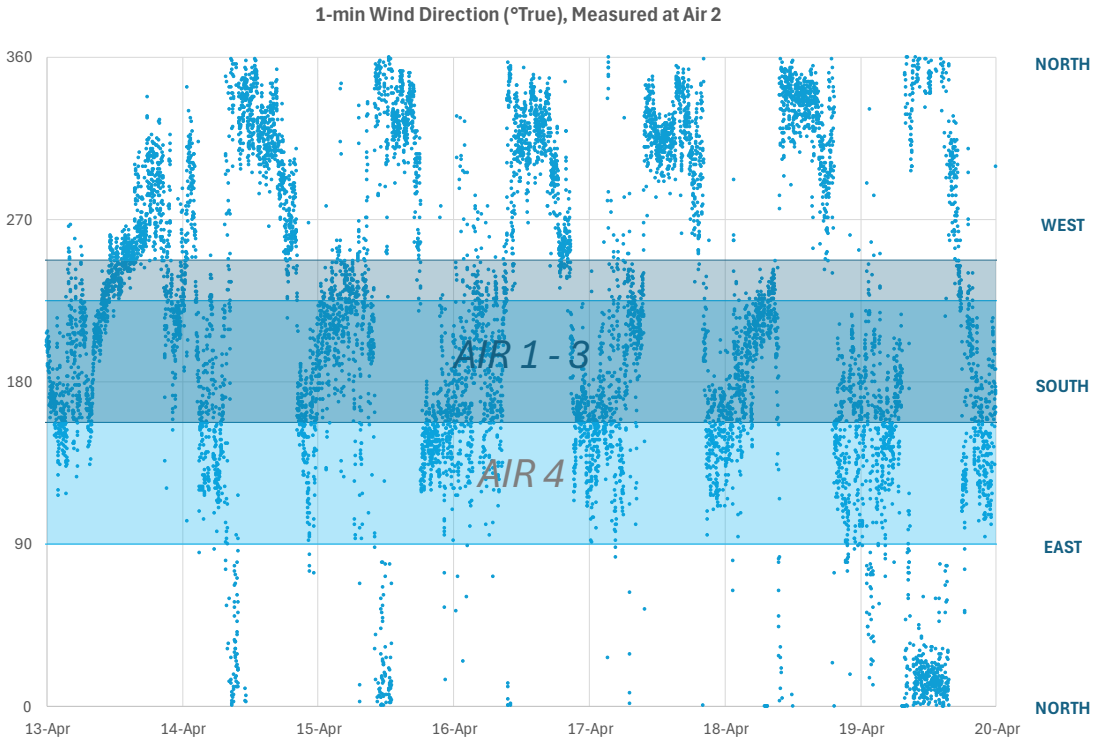


FIGURE 11: Frequency of (1-minute) wind directions and wind speeds at Lake Waikare, Week 1: 13 – 19 Apr 2024.

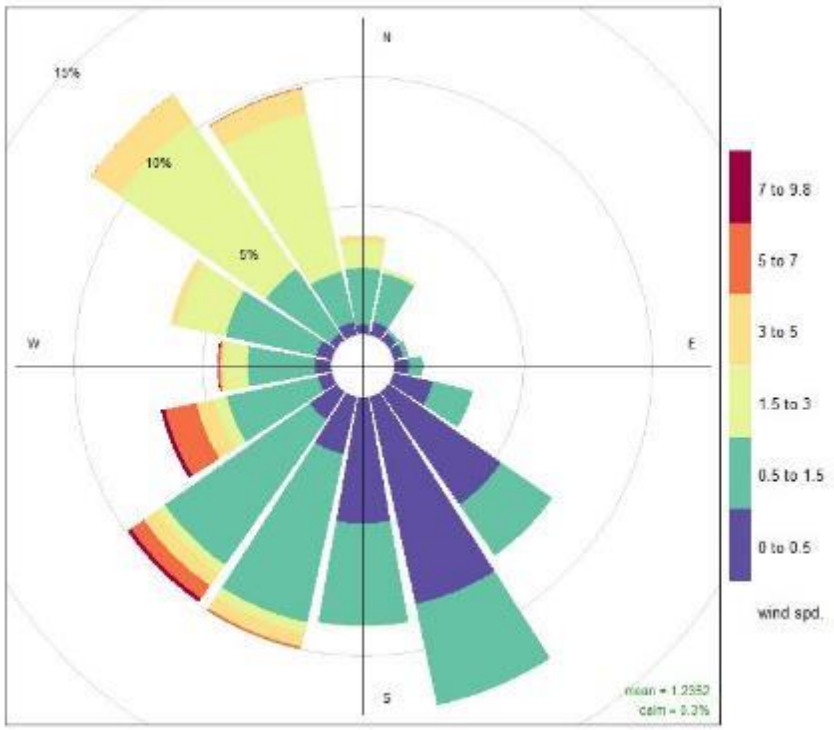


TABLE 5: Wind speed and frequency of winds directed towards short-term sampling locations when microcystins detected at elevated concentrations in lake water samples from Site 2 (Refer Appendix E).

Time period	Total MCs Concentration (µg/L)	Wind Directed Towards Air 1 – 3 (SSE – SW)	Mean Wind Speed ± std dev (m/s)	Max Wind Speed (m/s)	Wind Speed > 3.3 m/s? (min)
Day 3					
7 am – 9 am	46	54%	0.8 ± 0.5	2.1	0
11 am – 1 pm	110	1%	1.1 ± 0.6	2.7	0
3 pm – 5 pm	16	0%	2.2 ± 0.6	3.9	6
Day 4					
7 – 9 am	28	79%	0.6 ± 0.3	1.7	0
Day 5					
7 – 9 am	44	86%	0.8 ± 0.3	1.8	0
Day 6					
7 – 9 am	29	76%	0.8 ± 0.4	1.6	0

3.3.2 Meteorological Observations during Low Volume Sampling (Weeks 1 – 4)

Table 6 presents key meteorological parameters during the four-week field study (13 April – 10 May 2024), including the summed frequency of winds directed towards the monitoring instruments.

Figure 12 presents the recorded wind speeds and Figure 13 presents a wind rose showing the frequency of wind speeds and directions observed during the four-week deployment of low-volume aerosol sampling. The first day of deployment (13 April 2024) was unusually windy, however, for the remainder of the field study wind speeds remained predominantly light, typically well below 4 m/s as a 10-minute average.

The diurnal increase in wind speeds from midday to early afternoon is clear, with reduced wind speeds and more settled conditions in the evenings and overnight.

TABLE 6: Meteorology in Weeks 1 – 4: 13 April – 10 May 2024.

Time period	Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Wind Towards Air 2 (%)
Week 1	18 ± 3.0	76 ± 7.3	1.2 ± 1.2	39%
Week 2	17 ± 3.3	76 ± 8.3	1.3 ± 1.0	39%
Week 3 – 4	13 ± 4.2	73 ± 9.4	1.1 ± 0.8	34%
Week 1 – 4	**15 ± 4.2**	**74 ± 8.8**	**1.2 ± 1.0**	**36%**

FIGURE 12: Wind speeds (m/s, 10-minute average) at Lake Waikare, Weeks 1 – 4: 13 Apr – 10 May 2024.

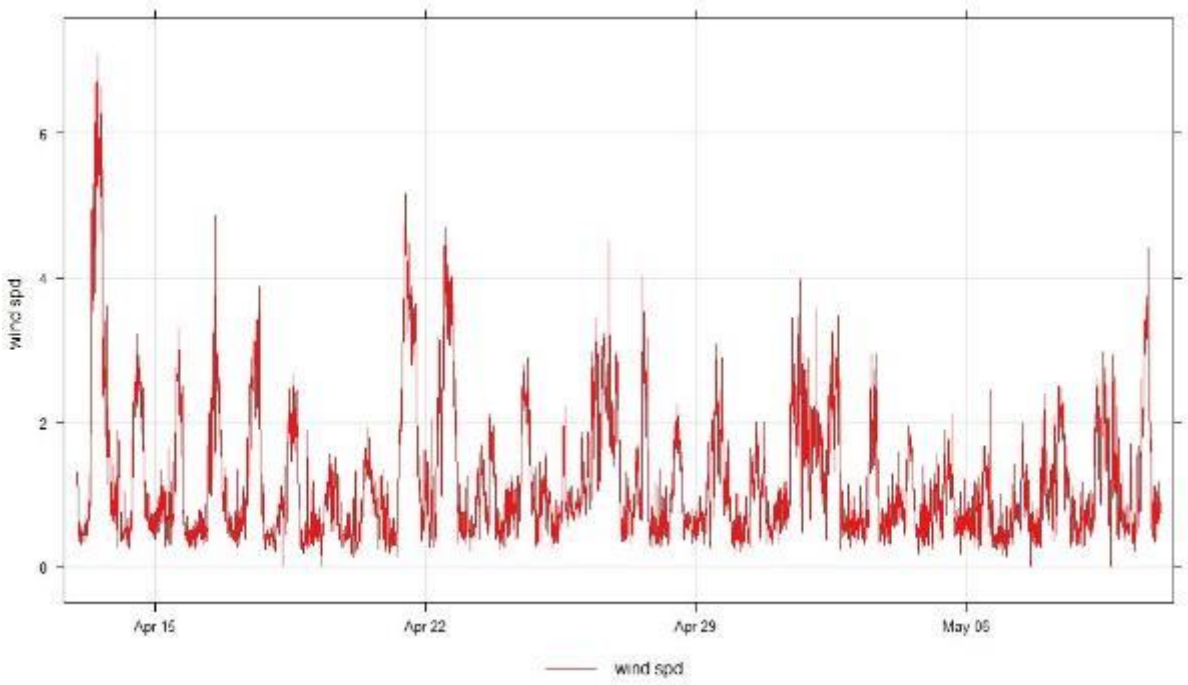
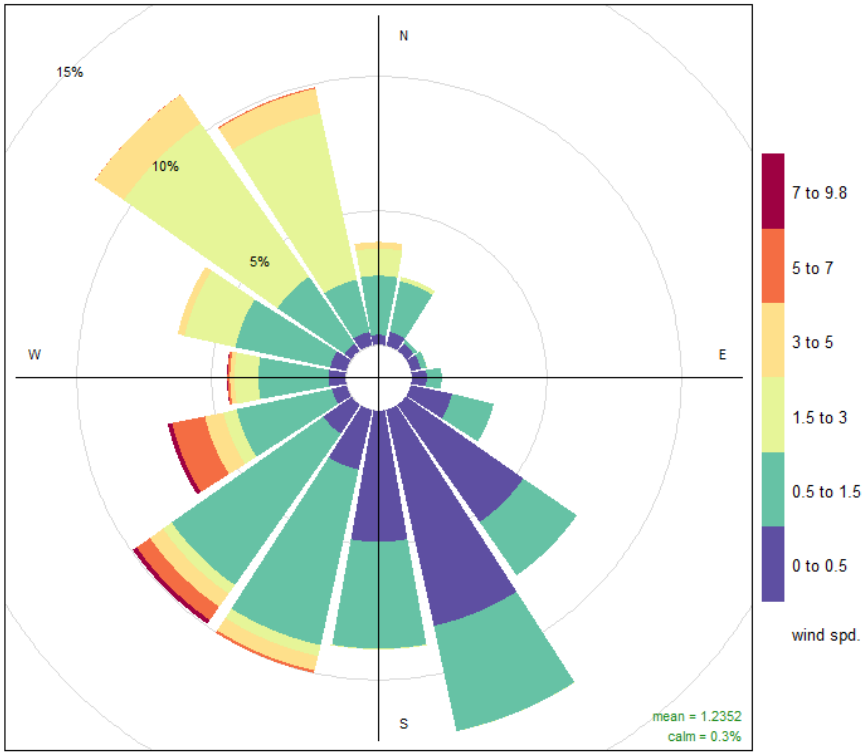


FIGURE 13: Frequency of (1-minute) wind directions and wind speeds at Lake Waikare, Weeks 1 – 4: 13 Apr – 10 May 2024.



3.4 PM_{10} AND $PM_{2.5}$ CONCENTRATIONS

Monitoring for particulate matter less than 10 micrometres (PM_{10}) and less than 2.5 micrometres ($PM_{2.5}$) was undertaken continuously through the entire duration of the field study at the Air 1 sampling site, situated close to the lake. An objective of this monitoring was to determine whether aerosols originating from the lake were being transported downwind and could be detected.

Aerosols from large water bodies are typically in the coarse fraction (i.e. $PM_{10\text{-}2.5}$) so this is the focus of the investigation.

3.4.1 PM Concentrations during High Volume Sampling (Week 1)

Figure 14 illustrates 1-minute measurements of PM_{10} and $PM_{2.5}$ recorded during Week 1. Aerosol concentrations remained predominantly low (< 15 µg/m^3) as would be expected for a low air pollution, rural environment such as Lake Waikare. The exception was during periods coinciding with fog presence, which is known to affect the light scattering measurement of PM (despite the use of inlet heaters).

Figure 15 displays a time series plot of PM_{10} concentrations and wind speeds (10-minute average) during the first week of the study. Figure 16 presents the same data with PM_{10} concentrations plotted as a function of wind speed. There was no correlation. This is not unexpected given PM_{10} concentrations can rise with *increasing* wind speed (and associated increased aerosol formation) but also rise with *decreasing* wind speed (when local sources do not disperse permitting local accumulation due to reduced dispersion).

Figure 17 and Figure 18 present polar plots (pollution roses) of 1-minute PM_{10} and $PM_{2.5}$ measurements obtained during Week 1. Both plots show a pronounced influence from the southwest direction, suggesting that aerosols generated over the lake were being directed towards the monitoring sites at Air 1 – Air 3 throughout the high-volume sampling in Week 1.

The presence of the sawmill and motorway to the southwest may also be contributing to background concentrations. However, these are nearly seven kilometres to the southwest so their emissions should be well dispersed and are unlikely to be a significant contribution.

FIGURE 14: 1-minute PM_{10} and $PM_{2.5}$ concentrations (µg/m^3) for Week 1: 13 – 19 April 2024.

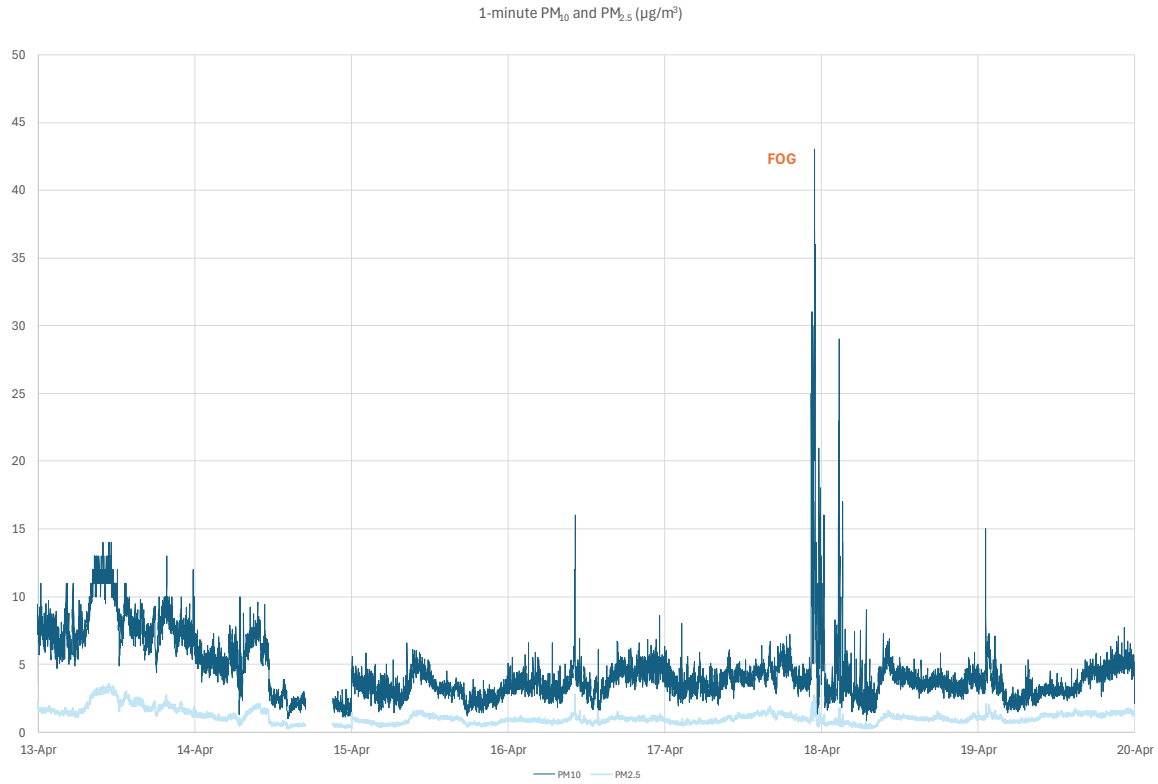


FIGURE 15: 10-minute PM_{10} concentrations (µg/m^3) and wind speeds (m/s) for Week 1: 13 – 19 April 2024.

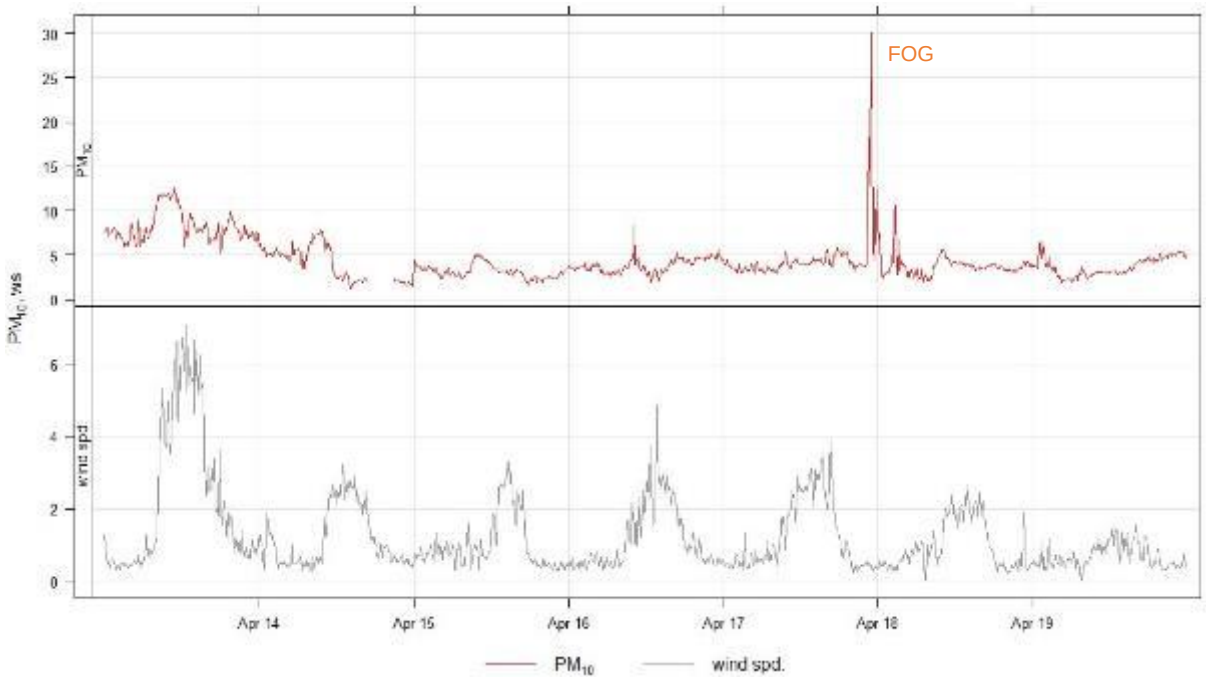


FIGURE 16: 10-minute PM_{10} concentrations (µg/m^3) as a function of wind speeds (m/s, 10-minute average) for Week 1: 13 – 19 April 2024.

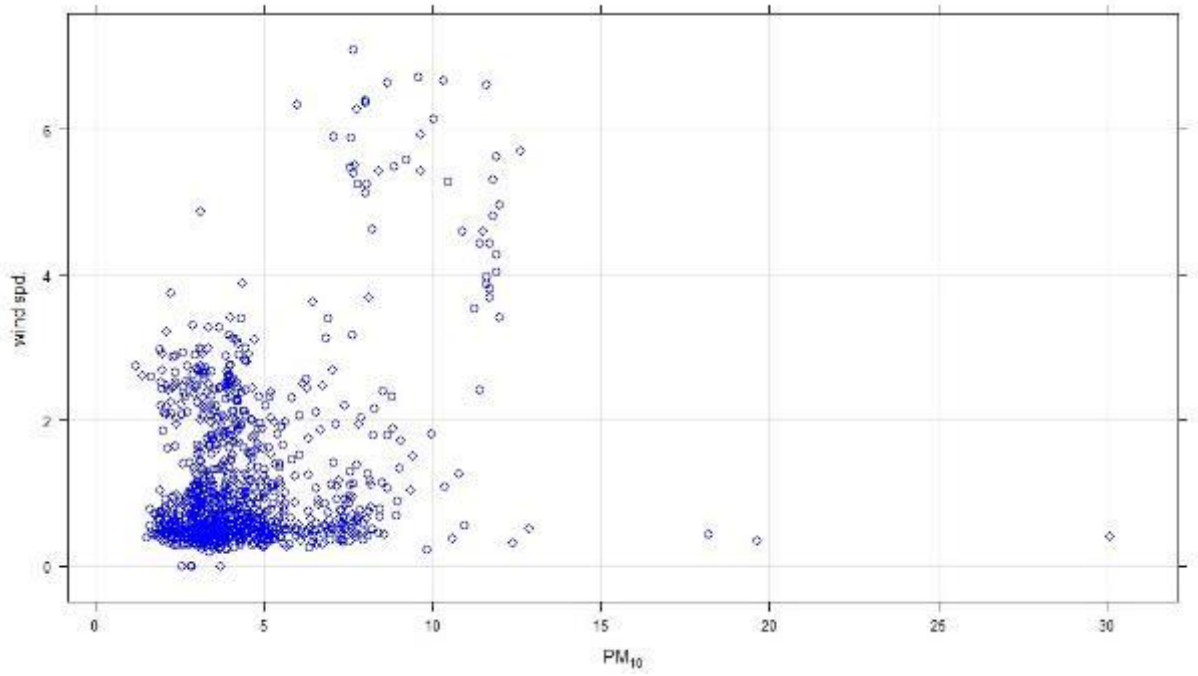


FIGURE 17: Pollution rose of 1-minute PM_{10} concentrations (µg/m^3) for Week 1: 13 – 19 April 2024.

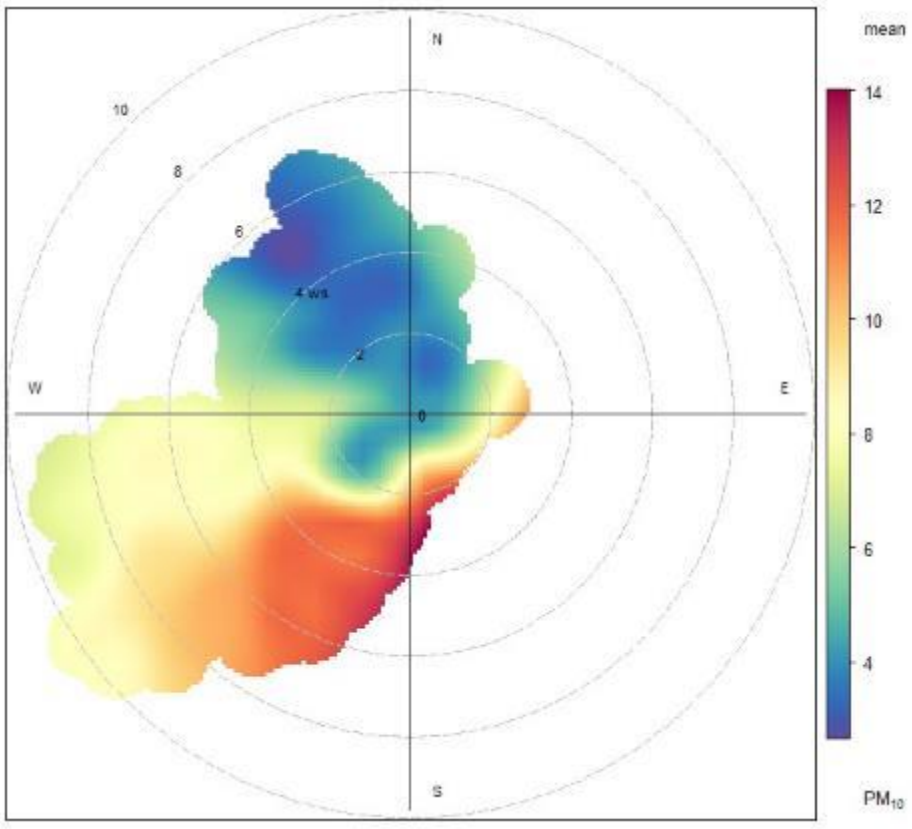
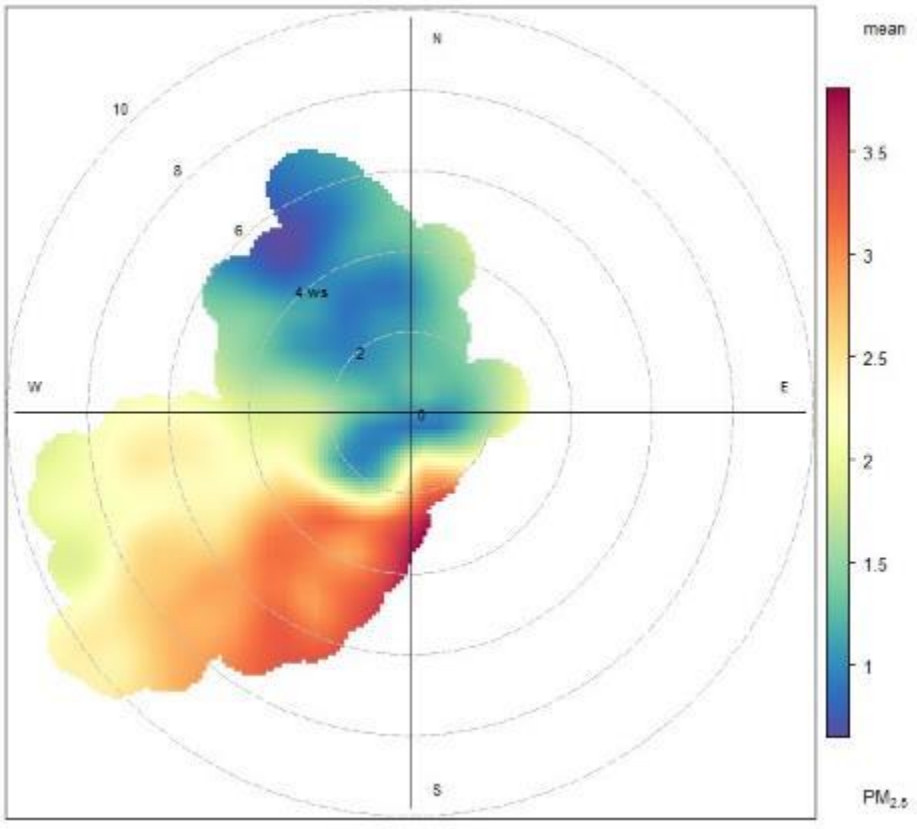


FIGURE 18: Pollution rose of 1-minute $PM_{2.5}$ concentrations (µg/m^3) for Week 1: 13 – 19 April 2024.



3.4.2 PM Concentrations during Low Volume Sampling (Weeks 1 – 4)

Figure 19 presents 10-minute measurements of PM_{10} recorded during the four weeks of low volume air sampling. Aerosol concentrations remained predominantly low (< 15 µg/m^3) except during periods that appear to coincide with fog.

Figures 20 and 21 present polar plots (pollution roses) of 1-minute PM_{10} and $PM_{2.5}$ measurements obtained during the field study. Both plots show a pronounced influence from the southwest direction, suggesting that aerosols generated over the lake were being directed towards the monitoring sites at Air 1 – 3 throughout the four-week study.

The polar plots also appear to show a source of particulate to the northwest direction, which is the direction of the kūmara fields.

FIGURE 19: 10-minute PM_{10} concentrations (µg/m^3) and wind speeds (m/s) for low volume sampling, Weeks 1 – 4: 13 Apr – 10 May 2024.

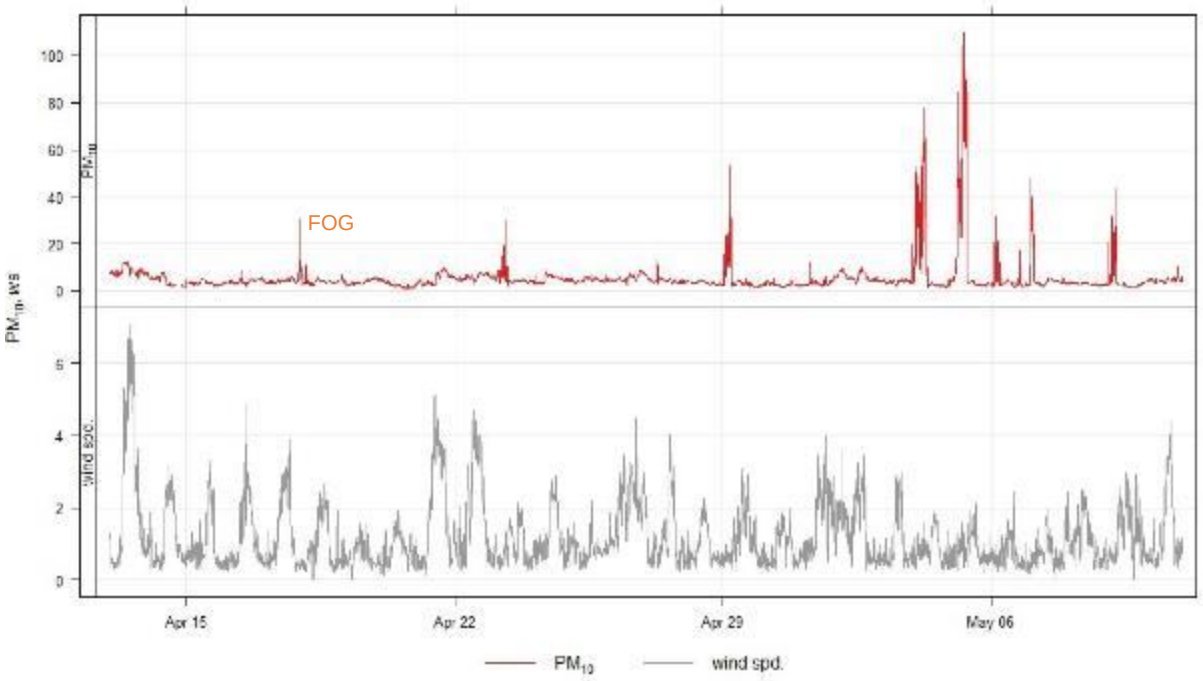


FIGURE 20: Pollution rose of 1-minute PM_{10} concentrations ($\mu g/m^3$) for low volume sampling, Weeks 1 – 4: 13 Apr – 10 May 2024.

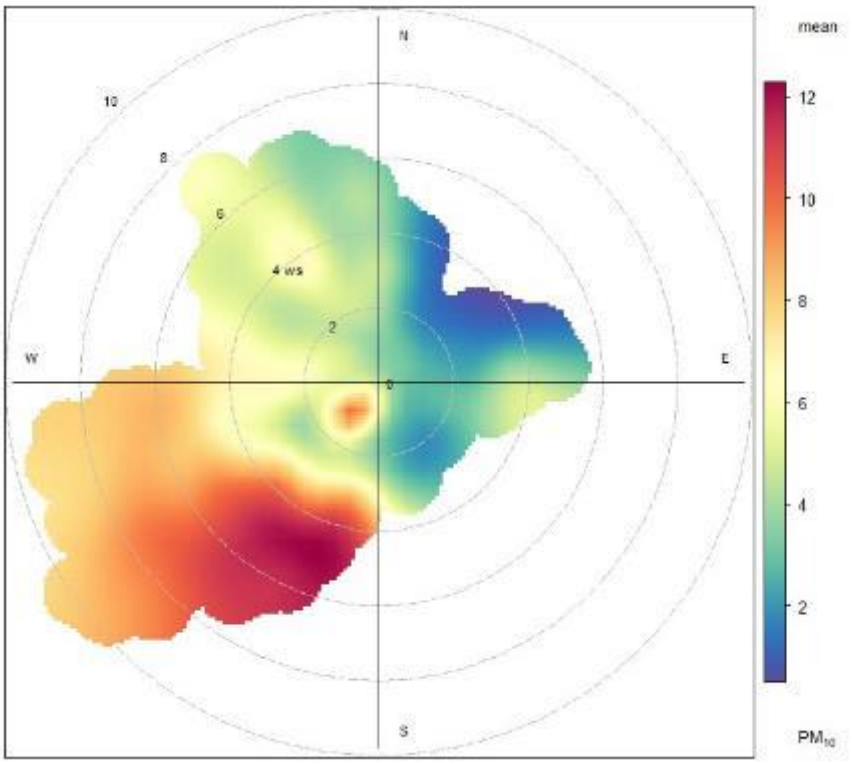
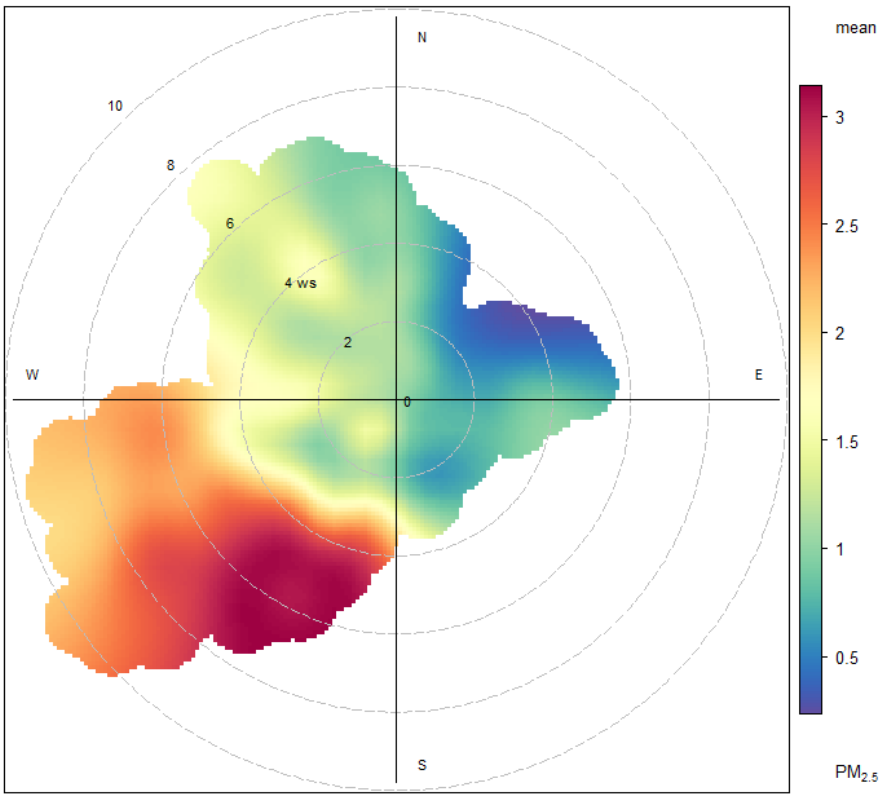


FIGURE 21: Pollution rose of 1-minute $PM_{2.5}$ concentrations ($\mu g/m^3$) for low volume sampling, Weeks 1 – 4: 13 Apr – 10 May 2024.

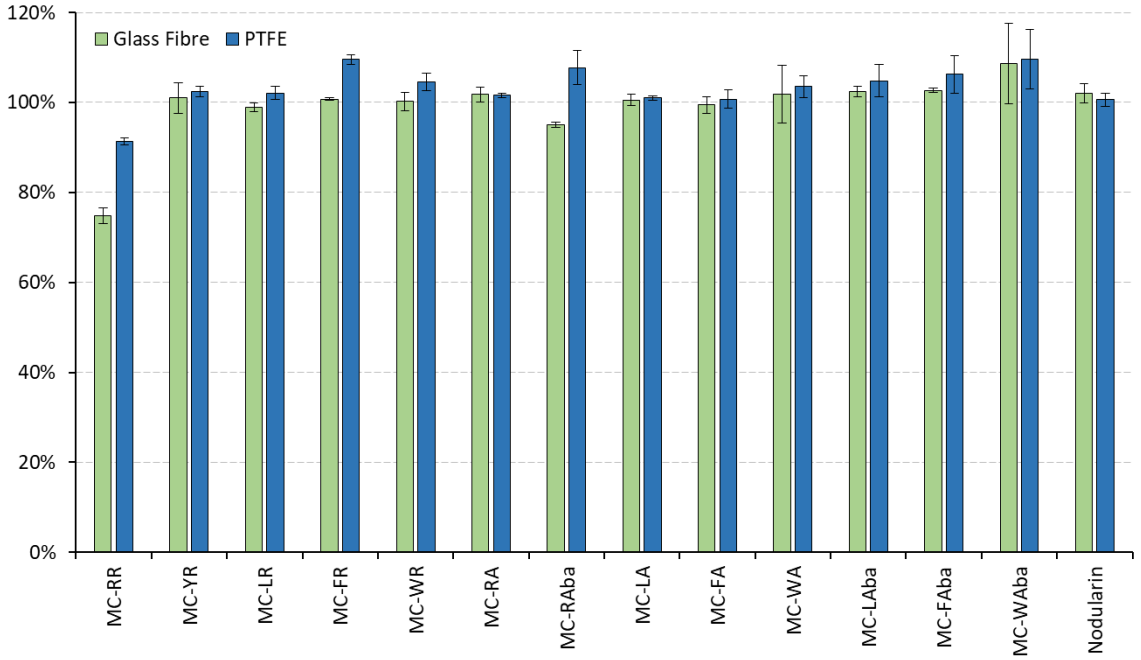


3.5 CYANOBACTERIA AND MICROCYSTINS IN AEROSOLS

Microcystins were not detected in any of the air samples collected during the study. This included 28 high volume air samples collected over one day each (sampling approximately 1,400 m^3 of air), two low volume samples collected over one week (each sampling approximately 25 m^3 of air), and one low volume sample collected over two weeks (sampling 54 m^3 of air). Appendix F summarises the results of the aerosol analyses for microcystins.

A microcystin adsorption test was undertaken to ensure that microcystins were not binding to the glass fibre and PTFE air sampling filters at levels that would impact the detection of microcystins in samples (Figure 22). The majority of the microcystin congeners assessed (and nodularin) did not adsorb to the air sampling filters under the extraction conditions used (in 90% methanol + 0.5% formic acid), they remained at 95 – 110% of the expected concentration. MC-RR was the exception, which had minor adsorption effects with the PTFE filter (91% of the expected concentration) and moderate adsorption with the glass fibre filter (75% of the expected concentration; Figure 22).

FIGURE 22: Test to determine the level of microcystin (MC) adsorption by measuring the % of different MC congeners remaining in a solution following incubation with glass fibre (A) and PTFE (B) air sampling filters.



MC-RR contains arginine (R) in Positions 2 and 4, MC-YR contains tyrosine (Y) in Position 2 and arginine (R) in Position 4, MC-LR contains leucine (L) in Position 2 and arginine (R) in Position 4, MC-FR contains phenylalanine (F) in Position 2 and arginine (R) in Position 4, MC-WR contains a tryptophan (W) in Position 2 and arginine (R) in Position 4, MC-RA contains arginine (R) in Position 2 and alanine (A) in Position 4, MC-RAba contains arginine (R) in Position 2 and aminobutyric acid (Aba) in Position 4, MC-LA contains leucine (L) in Position 2 and alanine (A) in Position 4, MC-FA contains phenylalanine (F) in Position 2 and alanine (A) in Position 4, MC-WA contains tryptophan (W) in Position 2 and alanine (A) in Position 4, MC-LAba contains leucine (L) in Position 2 and aminobutyric acid (Aba) in Position 4, MC-FAba contains phenylalanine (F) in Position 2 and aminobutyric acid (Aba) in Position 4, MC-WAba contains tryptophan (W) in Position 2 and aminobutyric acid (Aba) in Position 4, nodularin is a cyclic pentapeptide hepatotoxin with similar structural and toxicological properties as MCs.

Spike recovery tests to evaluate the accuracy of the extraction used for the high volume air samples (glass fibre filters) indicated that acceptable recovery (80% recovery or better) was observed in the low spike (at 0.05 ng/mL, near to the anticipated LoD / LoQ; Table 7). Accuracy was lower in the high spike (72 – 81% recovery at 4.6 ng/mL), but this did not impact the study results since microcystins were not detected in the air samples from the study.

Spike recovery evaluation of the extraction used for the low volume air samples (PTFE filters) indicated more variable recovery (74 – 135% recovery; Table 8). Recoveries observed for MC-RR (81% recovery at 0.05 ng/mL and 74% recovery at 4.6 ng/mL; Table 8) were similar to those observed with the glass fibre filters (84% recovery at 0.05 ng/mL and 72% recovery at 4.6 ng/mL; Table 7). Recoveries for other microcystins congeners (MC-YR, MC-LR and NOD-R) were higher in the PTFE filters (Table 8). The higher-than-expected recoveries observed for MC-YR (129% recovery) and MC-LR (135% recovery) at 0.05 ng/mL (near the anticipated LoD / LoQ) are due to the effects of background noise, which can be more evident when making measurements at low concentrations.

TABLE 7: Performance tests undertaken on the high-volume air sample (glass fibre filters) extraction and analysis for microcystins (MCs) and nodularin-R (NOD-R)

Performance Metric	MC-RR	MC-YR	MC-LR	NOD-R
Low spike recovery (at 0.05 ng/mL)	84%	111%	80%	90%
High spike recovery (at 4.6 ng/mL)	72%	76%	81%	84%
Limit of detection (LoD)	0.03 ng/mL	0.03 ng/mL	0.03 ng/mL	0.01 ng/mL
	0.04 pg/m^3	0.05 pg/m^3	0.05 pg/m^3	0.02 pg/m^3
Limit of quantitation (LoQ)	0.09 ng/mL	0.11 ng/mL	0.11 ng/mL	0.03 ng/mL
	0.13 pg/m^3	0.16 pg/m^3	0.15 pg/m^3	0.05 pg/m^3

TABLE 8: Performance tests undertaken on the low volume air sample (PTFE filters) extraction and analysis for microcystins (MCs) and nodularin-R (NOD-R)

Performance Metric	MC-RR	MC-YR	MC-LR	NOD-R
Low spike recovery (at 0.05 ng/mL)	81%	129%	135%	102%
High spike recovery (at 4.6 ng/mL)	74%	96%	106%	89%
Limit of detection (LoD)	0.02 ng/mL	0.04 ng/mL	0.03 ng/mL	0.02 ng/mL
	0.3 pg/m^3	0.9 pg/m^3	0.6 pg/m^3	0.3 pg/m^3
Limit of quantitation (LoQ)	0.05 ng/mL	0.15 ng/mL	0.10 ng/mL	0.06 ng/mL
	1.1 pg/m^3	2.9 pg/m^3	1.9 pg/m^3	1.1 pg/m^3

LoDs and LoQs for the microcystins present in the spiking standard indicated that the extraction and LC-MS/MS analysis was able to detect microcystins down to 0.04 – 0.05 pg/m^3 in the high volume air samples (glass fibre filters and using an air volume of 1,400 m^3; Table 7). In the low volume air samples, it was able to detect microcystins down to 0.3 – 0.9 pg/m^3 (PTFE filters and using an air volume of 25.2 m^3; Table 8).

Although nodularins were not expected in the study samples, the performance for NOD-R was also evaluated and yielded good recoveries with both glass fibre filters (90% recovery in the low spike and 84% recovery in the high spike; Table 7) and PTFE filters (102% recovery in the low spike and 89% recovery in the high spike; Table 8). The LoD / LoQ for NOD-R was also lower than observed for the microcystin congeners evaluated with both filters (Tables 7 and 8).

4. DISCUSSION

4.1 CYANOBACTERIA AND MICROCYSTINS IN LAKE WAIKARE

Throughout the first six days of the study (when lake water samples were collected) cyanobacteria were present in Lake Waikare in high abundances. Of the cyanobacterial taxa observed, *Microcystis* was the only confirmed microcystin-producer in Aotearoa New Zealand (Puddick et al., 2019). While *Dolichospermum* (which was observed in low levels in Lake Waikare) has been reported to produce microcystins overseas (Capelli et al., 2017; Dreher et al., 2019), microcystin-producing *Dolichospermum* has not been confirmed in Aotearoa New Zealand to date.

Aphanizomenon, and not *Microcystis*, was the dominant taxa in the majority of the lake water samples collected. The exception was a sample from 15 April 2024 (Day 3) where buoyant *Microcystis* colonies had accumulated at the lake surface at Site 1. Almost all the lake water samples had total cyanobacterial biovolumes that exceeded the Situation 2 Action Level / Red Mode threshold in the Recreational Cyanobacteria Guidelines (≥ 10 mm^3/L; 93% of the samples). Further, the majority of samples had *Microcystis* cell concentrations that exceeded the Situation 1 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines (≥ 30,000 cells/mL; 81% of the samples).

Microcystins were detected in every water sample collected and on seven occasions concentrations exceeded the Situation 4 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines (≥ 24 µg/L; 13% of the samples). The lower level of threshold exceedances for the Situation 4 Action Level / Red Mode threshold (toxin concentrations) compared to Situation 1 Action Level / Red Mode threshold (cell concentrations for confirmed toxin-producing taxa) is expected because the Situation 4 threshold measures the actual hazard (the cyanotoxin) whereas the Situation 1 threshold measures an indicator of that hazard (the cyanobacteria).[3]

The presence of cyanobacteria at levels exceeding current and revised recreational guidelines is consistent with a history of poor water quality at Lake Waikare.

4.2 MICROCYSTINS IN AIR SAMPLES

Microcystins were not detected in any of the air samples collected. This was unexpected because most other studies reporting microcystin concentrations in lake water had detected microcystins in the air samples collected concurrently (Table 1). The minimum total microcystin concentration measured in lake water in the current study was 2.3 µg/L and the maximum was 480 µg/L. Only Wood and Dietrich (2011) reported higher microcystin concentrations (2,140 µg/L at Lake Rotorua, Kaikōura). Backer et al. (2010) reported a similar maximum total microcystin concentrations to those observed in the current study (357 µg/L), but the majority of studies reported concentrations ≤ 20 µg/L.

The microcystin detection limits for high volume air samples in the current study (0.05 pg/m^3 for MC-LR) were lower than the aerosolised microcystin levels reported using similar sampling

[3] The Situation 2 Action Level / Red Mode threshold (total cyanobacterial biovolume) is to protect people from mild respiratory symptoms associated with high levels of cyanobacterial biomass (Stewart et al., 2006; irrespective of whether cyanotoxins are present) and is therefore not linked to the Situation 1 and Situation 4 thresholds in the Recreational Cyanobacteria Guidelines.

(high volume air samplers) and analytical set-ups (LC-MS/MS); 0.4 pg/m^3 (Labohá et al., 2023), 0.9 pg/m^3 (Gambaro et al., 2012), 1.8 pg/m^3 (Wood and Dietrich, 2011), 16 pg/m^3 (Wood and Dietrich, 2011). We note that several studies that also employed high volume air samplers did not detect aerosolised microcystins in any of those samples (Cheng et al., 2007; Plaas et al., 2022) and most studies did not detect aerosolised microcystins in all of the air samples they collected (refer to Table 1).

Lim et al. (2023) suggests that the primary mechanism for aerosolisation of cyanobacteria is as follows:

> "*Spray aerosols are formed when wind-driven wave action entrains plumes of air bubbles beneath the water followed by bubbles bursting at the air-water interface, ejecting water droplets into the atmosphere that can contain organic material from cells or whole cells themselves*."

On this basis, it seems reasonable to suggest that to detect cyanobacterial toxins in aerosols downwind of a lake, three factors must occur simultaneously:

(i) Toxin-producing cyanobacteria must be present;

(ii) Wind speeds must be sufficient to enable wave action to facilitate aerosolisation of the cyanobacteria from the lake into aerosols present in the air above the lake; and

(iii) Winds must then direct the aerosols above the lake towards the monitors.

This is somewhat simplistic. For example, it is feasible that wave action during periods of high wind could create aerosols which may then be transported in any direction under subsequent periods of low wind speed. However, following this simplified approach, it is hypothesised that in the current study, whilst toxin-producing cyanobacteria were measured in substantial concentrations in lake water samples on most days, either the winds did not reach the sustained threshold needed to generate aerosols and / or the winds did not then direct any aerosols present towards the monitors.

A review of the meteorology when microcystins were detected in the highest concentrations at the location closest to the high volume samplers (Site 2 – refer Table 5) on Days 3 – 6 is consistent with this hypothesis (Appendix E). It is also consistent with the literature indicating no correlation between microcystins in water samples and air samples (Table 1), noting a dearth of detail on meteorology in the literature.

However, the mechanisms of aerosolisation and spray aerosol transport are complex and caution is advised. It is possible that the intermittent showers present during the field study mitigated the presence of toxins in aerosols, rainfall being one of the primary mechanisms for removal of PM_{10} via precipitation scavenging. Alternatively, it may be that the high volume samplers in the current field study were located too far from the lake (50 m). Most studies detecting microcystins in aerosols were located either *on* a lake (on boats), or very close to it (piers or shoreline of a lake).

Some previous studies have employed alternative air sampling approaches which have resulted in higher frequencies of microcystin detection. Our review of the literature (Table 1) suggests that high volume air samplers coupled with a cascade impactor may improve the frequency of microcystin detection. In a cascade impactor, the air sample is directed through increasingly smaller nozzles to impact on sampling surfaces with each stage collecting finer particles than its predecessor. We hypothesise that, the cascade impactor may improve microcystin detection through the concentration of finer aerosols onto a smaller filter area. It

is also possible that the cascade impactors may increase cell lysis and subsequent availability of extracellular / dissolved microcystins (which were found to be low in the current study). High volume air samplers equipped with a cascade impactor were not available for the current study.

Similarly, more frequent detections, and higher concentrations detected, have been reported for aerosolised microcystins using personal air samplers (Table 1). Personal air samplers utilise small, portable, battery-operated pumps that can be attached to clothing to measure contaminants in air that are representative of a person's personal breathing zone. Higher detection and measured concentrations of microcystins in personal samplers is unexpected because of the much lower air volume sampled (typically 2 L/min for 1 – 2 hrs which samples only 0.2 m^3 using a personal air sampler vs. approximately 1,400 m^3 in a 24-hour high volume air sample). The design for the current study did not include a component to recruit recreational water-users to collect air samples using personal air samplers, but future studies might consider including this approach.

One air sampler design (Carter and Haney, 2022) included a 'water trap' to sample aerosolised microcystins that are not captured on air filters. In theory, this air sampling method would be more effective for detecting extracellular microcystins. Another study using an air sampler equipped with a cascade impactor (Shi et al., 2023) suggested that the majority of the microcystins detected in their study were extracellular, because of the particle size where they were concentrated (<2.5 microns). If extracellular microcystins are more prone to aerosolisation than cellular / particulate microcystins, then the low levels of extracellular microcystins observed in Lake Waikare (max 0.8 µg/L) may have contributed to a lack of aerosolised microcystins during the current study.

Because the literature has used a range of air sampling strategies and not all studies measured extracellular microcystin concentrations, it is difficult to confirm the observations of Carter and Haney (2022) and Shi et al. (2023); that extracellular microcystins are dominant in air samples and that extracellular microcystin concentrations in lake water might be a predictor for microcystin concentrations in air samples. To investigate this further, future studies evaluating microcystins in aerosols from lake water could incorporate air sampling methods that may be more likely to capture extracellular microcystins (e.g., air samplers that incorporate water traps and cascade impactors) and lake water sampling approaches that allow extracellular microcystin concentrations to be determined (i.e., a portion of the lake water sample is gently filtered within several hours of sampling).

4.3 IMPLICATIONS FOR PUBLIC HEALTH

The non-detection of microcystins in aerosols collected downwind of a lake with coincidental detection of elevated concentrations of microcystins in lake water samples may augur well for potential public exposure to aerosolised HABs near lakes in Aotearoa New Zealand. Of the three sites regularly assessed during the first six days of the field study, recreational use was observed at each site with the highest level of use observed at the 'lakeside residential development' (Lake 3). High frequency of recreational fishing was also observed at the outlet gate (Lake 2) and highlights the potential issue of exposure to microcystins via food consumption (which was outside of the scope of the current study).

The current study suggests that sustained wind action at a lake upwind of a populated area may be required to facilitate aerosolisation of cyanobacteria from a lake and subsequent potential downwind public exposure. Sustained wind action corresponds to the presence of large wavelets and wind speeds greater than 3.3 m/s (Appendix B). Sustained winds of this

nature were not present during the field study at Lake Waikare in late April 2024 and early May 2024. As noted above, caution is advised with this interpretation as the mechanisms of aerosolisation and aerosol transport are complex.

Irrespective, the implications are less positive for potential public exposure to aerosols from a marine algal bloom, for which wave break on beaches is more likely to be a persistent feature. Studies of marine HABs (for example, Backer et al., 2005; Fleming et al., 2008) have demonstrated clear links with asthma and reduced lung function. Investigation into the levels of cyanobacterial biomass present in lake aerosols might also be relevant since exposure to freshwater cyanobacteria is linked to mild respiratory symptoms in sensitive individuals (Stewart et al., 2006), irrespective of whether cyanotoxins are present. The current study only investigated microcystin concentrations in air and water samples, rather than compounds that might cause negative respiratory effects.

5. CONCLUSIONS

A field study to investigate the environmental drivers that may influence aerosol production during a cyanobacterial bloom and to measure microcystins in aerosols downwind of a bloom was undertaken on the shores of Lake Waikare between 13 April and 10 May 2024.

Lake water sampling was undertaken three times a day for six days to establish concentrations of cyanobacteria and microcystins in the aquatic environment. High volume air samplers utilising glass fibre filters were deployed for one week at varying distances from the lake (50 m, 100 m, 150 m and 200 m) to collect daily samples. Low volume sampling utilising PTFE filters was also undertaken at 50 m from the lake for a period of one month to collect weekly and two-weekly samples. Continuous measurement of meteorological parameters (wind speed, wind direction, temperature and relative humidity) as well as PM_{10} and $PM_{2.5}$ were undertaken concurrently.

Total microcystin concentrations averaged 18 ng/mL (min 2.3, max 483, std dev ± 9 ng/mL) across all 54 lake water samples. *Aphanizomenon* was the dominant cyanobacterial genera identified. Hepatotoxic microcystin were detected in every water sample collected and on seven occasions concentrations exceeded the Situation 4 Action Level / Red Mode threshold in the revised Recreational Cyanobacteria Guidelines (≥ 24 µg/L; 13% of the samples; MfE and Te Whatu Ora *pending*).

Extracellular / dissolved microcystin were generally low throughout the study (0.04 – 0.8 ng/mL). The proportion of extracellular microcystin, relative to the total microcystin concentration, ranged from 0.2% to 9.7%, with a median of 1.8%. The concentrations of microcystins measured in the lake water samples were comparable, or higher, to concentrations measured in other studies that have explored aerosolisation of cyanotoxins.

Microcystins were not detected in any of the air samples collected. This was unexpected because most other studies reporting lower lake water microcystin concentrations had detected microcystins in concurrent air samples. If extracellular microcystins are more prone to aerosolisation than cellular / particulate microcystins, then the low levels of extracellular microcystins observed in Lake Waikare (max 0.8 µg/L) may have contributed to a lack of aerosolised microcystins during the current study. However, there were some studies that also found none so it is not unprecedented. Aerosol sample performance testing confirmed the limits of detection in this field study were as good, or better, than other studies.

PM_{10} and $PM_{2.5}$ concentrations measured during the field study support the lake as being a source of aerosols at the air sampler locations. Assuming the primary mechanism for aerosolisation is wind-driven wave action, the current study supports sustained winds above a moderate breeze (> 3.3 m/s) being a requisite for aerosolisation of cyanobacteria to occur.

The presence of cyanobacteria at levels exceeding current and revised recreational guidelines is consistent with a history of poor water quality at Lake Waikare. The non-detection of microcystins in aerosols collected downwind of the lake during a cyanobacterial bloom, may augur well for potential public exposure to aerosolised HABs. However, the physical and chemical mechanisms for aerosolisation and transport of toxins from HABs are complex and would require additional research before firm conclusions can be drawn.

Such hypotheses would not be applicable to HABs in the marine environment, for which wave break is more generally a persistent feature.

REFERENCES

Baker PD, Fabbro LD. 2002. A Guide to the Identification of Common Blue-Green Algae (Cyanoprokaryotes) in Australian Freshwaters. 2nd edition. Cooperative Research Centre for Freshwater Ecology: Australia. 56 p.

Backer LC, McNeel SV, Barber T, Kirkpatrick B, Williams C, Irvin M, Zhou Y, Johnson TB, Nierenberg K, Aubel M. 2010. Recreational exposure to microcystins during algal blooms in two California lakes. *Toxicon*, 55(5): 909-921.

Backer LC, Carmichael W, Kirkpatrick B, Williams C, Irvin M, Zhou Y, Johnson TB, Nierenberg K, Hill VR, Kieszak SM. 2008. Recreational exposure to low concentrations of microcystins during an algal bloom in a small lake. *Marine Drugs*, 6(2): 389-406.

Backer LC, Kirkpatrick B, Fleming LE, Cheng YS, Pierce R, Bean JA, Clark R, Johnson D, Wanner A, Tamer R, Zhou Y, Baden DG. 2005. Occupational exposure to aerosolized brevetoxins during Florida red tide events: Effects on a healthy worker population. *Environmental Health Perspectives*, 113(5): 644-649. DOI: https://doi.org/10.1289/ehp.7502.

Capelli C, Ballot A, Cerasino L, Papini A, Salmaso N. 2017. Biogeography of bloom-forming microcystin producing and non-toxigenic populations of *Dolichospermum lemmermannii* (Cyanobacteria). *Harmful Algae*, 67: 1-12.

Carslaw DC, Ropkins K. 2012. openair — an R package for air quality data analysis. *Environmental Modelling & Software*. 27-28: 52-61.

Carter H, Haney J. 2022. Cyanobacteria toxins, microcystins and BMAA, in lake aerosols from Lower Mill Pond and Cliff Pond, Brewster, MA. Prepared for the Brewster Ponds Coalition. 11 p.

Cheng YS, Zhou Y, Irvin CM, Kirkpatrick B, Backer LC. 2007. Characterization of aerosols containing microcystin. *Marine Drugs*, 5(4): 136-150.

Chang FH, Chiswell SM, Uddstrom MJ. 2001. Occurrence and distribution of *Karenia brevisulcata* (Dinophyceae) during the 1998 summer toxic outbreaks on the central east coast of New Zealand. *Phycologia* (2001) Vol 40 (3) 215-222.

Dreher TW, Collart LP, Mueller RS, Halsey KH, Bildfell RJ, Schreder P, Sobhakumari A, Ferry R. 2019. *Anabaena/Dolichospermum* as the source of lethal microcystin levels responsible for a large cattle toxicosis event. *Toxicon: X*, 1: 100003.

Gambaro A, Barbaro E, Zangrando R, Barbante C. 2012. Simultaneous quantification of microcystins and nodularin in aerosol samples using high-performance liquid chromatography/negative electrospray ionization tandem mass spectrometry. *Rapid Communications in Mass Spectrometry*, 26(12): 1497-1506.

Griffith AW, Gobler CJ., 2020. Harmful algal blooms: a climate change costressor in marine and freshwater ecosystems. *Harmful Algae*. 91: 101590.

Heisler J, Glibert PM, Burkholder JM, Anderson DM, Cochlan W, Dennison WC, Dortch Q, Gobler CJ, Heil CA, Humphries E, Lewitus A. 2008. Eutrophication and harmful algal

blooms: A scientific consensus. *Harmful Algae.* 8(1): 3-13. DOI: 10.1016/j.hal.2008.08.006

Kassambara A. 2023. ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.6.0. Retrieved 18 June 2024. https://CRAN.R-project.org/package=ggpubr

Komárek J, Anagnostidis K. 1999. Cyanoprokaryota 1 Teil: Chroococcales. Ettl H, Gärtner G, Heynig H, Mollenhauer D (ed). Gustav Fisher Verlag Jena. 548 p.

Labohá P, Sychrová E, Brózman O, Sovadinová I, Bláhová L, Prokeš R, Ondráček J, Babica P. 2023. Cyanobacteria, cyanotoxins and lipopolysaccharides in aerosols from inland freshwater bodies and their effects on human bronchial cells. *Environmental Toxicology and Pharmacology*, 98: 104073.

Lim CC, Yoon J, Reynolds K, Gerald LB, Ault AP, Heo S, Bell ML. 2023. Harmful algal bloom aerosols and human health. *The Lancet*. 8 May 2023 *eBioMedicine*, 93. DOI: https://doi.org/10.1016/j.ebiom.2023.104604

May NW, Gunsch MJ, Olson NE, Bondy AL, Kirpes RM, Bertman SB, China S, Laskin A, Hopke PK, Ault AP, Pratt KA. 2018. Unexpected contributions of sea spray and lake spray aerosol to inland particulate matter. *Environ Sci Technol* Lett., 5(7): 405-412.

McGregor G, Fabbro LD. 2001. A Guide to the Identification of Australian freshwater planktonic Chroococcales (cyanoprokaryota/cyanobacteria). Cooperative Research Centre for Freshwater Ecology: Australia. 61 p.

Ministry for the Environment (MfE) and Te Whatu Ora. *pending*. Aotearoa New Zealand Guidelines for Cyanobacteria in Recreational Freshwaters. Wood SA, Puddick J, Hamilton DP, Paul WJ, Safi KA, Williamson WM, Thomson-Laing G, Hawes I, McBride G, Kelly LT, Holloway M, Cridge B, Cressey P, P. F (ed). New Zealand Ministry for the Environment: Wellington (NZ). 174 p.

MfE and Ministry of Health. 2009. New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters: Interim Guidelines. Wood SA, Hamilton DP, Paul WJ, Safi KA, Williamson WM (ed). New Zealand Ministry for the Environment: Wellington (NZ). 82 p.

MfE, 2009b. *Good practice guide for air quality monitoring and data management 2009.* Wellington. April. [Online]

Murby A, Haney JF. 2016. Field and laboratory methods to monitor lake aerosols for cyanobacteria and microcystins. *Aerobiologia*, 32: 395-403.

Plaas HE, Paerl RW, Baumann K, Karl C, Popendorf KJ, Barnard MA, Chang NY, Curtis NP, Huang H, Mathieson OL. 2022. Harmful cyanobacterial aerosolization dynamics in the airshed of a eutrophic estuary. *Science of The Total Environment*, 852: 158383.

Posit Team. 2024. RStudio: Integrated development environment for R. Retrieved 18 June 2024. http://www.posit.co/

Puddick J, Thomson-Laing G, Wood SA. 2019. Microcystins in New Zealand: A review of occurrence, congener diversity and cell quotas. *New Zealand Journal of Botany*, 57(2): 93-111.

Puddick J, Wood SA, Hawes I, Hamilton DP. 2016. Fine-scale cryogenic sampling of planktonic microbial communities: Application to toxic cyanobacterial blooms. *Limnology and Oceanography: Methods*, 14: 600-609.

Puddick J, Prinsep MR, Wood SA, Kaufononga SAF, Cary SC, Hamilton DP. 2014. High levels of structural diversity observed in microcystins from *Microcystis* CAWBG11 and characterization of six new microcystin congeners. *Marine Drugs*, 12: 5372-5395.

R Core Team. 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved 18 June 2024 http://www.R-project.org/

Richter DH, Veron F. 2016. Ocean spray: An outsized influence on weather and climate. *Physics Today*, 69(11): 34-39. https://doi.org/10.1063/PT.3.3363

Shi JH, Olson NE, Birbeck JA, Pan J, Peraino NJ, Holen AL, Ledsky IR, Jacquemin SJ, Marr LC, Schmale III DG. 2023. Aerosolized cyanobacterial harmful algal bloom toxins: Microcystin congeners quantified in the atmosphere. *Environmental Science & Technology*, 57(51): 21801-21814.

Smith FMJ, Wood SA, van Ginkel R, Broady PA, Gaw S. 2011. First report of saxitoxin production by a species of the freshwater benthic cyanobacterium, *Scytonema* Agardh. *Toxicon*, 57(4): 566-573.

Stewart I, Webb PM, Schluter PJ, Fleming LE, Burns JW, Gantar M, Backer LC, Shaw GR. 2006. Epidemiology of recreational exposure to freshwater cyanobacteria – An international prospective cohort study. *BMC Public Health*, 6: 93.

Utermöhl H. 1958. Towards a perfection of quantitative phytoplankton methodology − Zur Vervollkommung der quantitativen Phytoplankton Methodik. *Mitteilungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie*, 9: 1-38.

Waikato Regional Council. 2024. *Lake Waikare*. [Online]

Wickham H. 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag: New York (USA). 260 p.

Wilke C. 2024. Cowplot: Streamlined plot theme and plot annotations for 'ggplot2'. R package version 1.1.3. Retrieved 18 June 2024. https://CRAN.R-project.org/package=cowplot

Wood SA, Maier MY, Puddick J, Pochon X, Zaiko A, Dietrich DR, Hamilton DP. 2017. Trophic state and geographic gradients influence planktonic cyanobacterial diversity and distribution in New Zealand lakes. *FEMS Microbiology Ecology*, 93(2): fiw234.

Wood SA, Dietrich DR. 2011. Quantitative assessment of aerosolized cyanobacterial toxins at two New Zealand lakes. *Journal of Environmental Monitoring*, 13(6): 1617-1624.

Wood SA, Heath MW, Holland PT, Munday R, McGregor GB, Ryan KG 2010. Identification of a benthic microcystin-producing filamentous cyanobacterium (Oscillatoriales) associated with a dog poisoning in New Zealand. Toxicon, 55(4): 897-903.

Wood SA, Rasmussen JP, Holland PT, Campbell R, Crowe ALM. 2007a. First report of the cyanotoxin anatoxin-a from *Aphanizonmenon issatschenkoi* (cyanobacteria). *Journal of Phycology*, 43(2): 356-365.

Wood SA, Selwood AI, Rueckert A, Holland PT, Milne JR, Smith KF, Smits B, Watts LF, Cary CS. 2007b. First report of homoanatoxin-a and associated dog neurotoxicosis in New Zealand. *Toxicon*, 50(2): 292-301.

Wood SA, Crowe ALM, Ruck JG, Wear RG. 2005. New records of planktonic cyanobacteria in New Zealand freshwaters. *New Zealand Journal of Botany*, 43: 479-492.

Wood SA, Stirling DJ. 2003. First identification of the cylindrospermopsin-producing cyanobacterium *Cylindrospermopsis raciborskii* in New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 37(4): 821-828.

Xu S, Chen M, Feng T, Zhan L, Zhou L, Yu G. 2021. Use ggbreak to effectively utilize plotting space to deal with large datasets and outliers. *Frontiers in Genetics*, 12: 774846.

GLOSSARY

Acute exposure is short-term exposure, typically hours or days

Aerosol is a suspension of fine solid particles or liquid droplets in air.

Algae range in size from large seaweeds (macroalgae) to tiny phytoplankton (microalgae). They function much like plants, harvesting sunlight in order to grow. When a lot of these are in the water, it's known as an algal bloom. Blooms often appear as coloured patches (usually brown or red).

Coarse particles typically refers to the fraction of particulate matter that is smaller than 10 micrometres in diameter but larger than 2.5 micrometres in diameter ($PM_{10-2.5}$). These particles are small enough to be inhaled into the thoracic region but too large to reach the alveolar region of the lungs.

Chronic exposure is long-term exposure, typically months or years

Cyanobacteria are organisms with many characteristics of bacteria and some of algae. Like bacteria, their cells have no nucleus. However, like algae, they contain a green pigment (chlorophyll *a*) with which they can perform photosynthesis. They also contain another blue pigment (phycocyanin), which is mostly visible when cells in scums die and lyse, releasing the pigment into the water – this sometimes appears as if turquoise-coloured paint has been spilled. Intact cells and blooms of cyanobacteria usually look green, but some species look greenish-bluish; this has led to the popular term blue–green algae.

Cyanobacteria can contain several different types of potent toxins (cyanotoxins), most notably of microcystins and nodularins: the two are not easily differentiated. However, not all cyanobacterial blooms are toxic. Toxic and non-toxic strains can be distinguished only by molecular or chemical analyses, not visually.

Fine particles typically refers to particulate matter less than 2.5 micrometres in diameter. These are small enough to reach the alveolar region of the lungs where inhaled gases can be absorbed by the blood.

Harmful algal blooms (**HABs**) are algal blooms that cause negative impacts to other organisms by production of natural algae-produced toxins.

Microcystins (**MCs**) or *cyanoginosins* are a class of toxins produced by certain freshwater cyanobacteria, commonly known as *blue-green algae.* Microcystins are the cyanotoxins most frequently found at hazardous concentrations and are responsible for numerous animal deaths. They accumulate in scums and occur widely in fresh water and sometimes in brackish areas.

Microgram is one millionth of a gram (1×10^{-6} g)

Micrometre is one millionth of a metre (1×10^{-6} m)

Millilitre is one thousandth of a litre (1×10^{-3} L)

Nanogram is one billionth of a gram (1×10^{-9} g)

ng/mL nanograms per millilitre. This is the mass measured in billionths of a gram per millilitre of fluid.

Nodularins (**NODs**) are potent toxins produced by the cyanobacterium *Nodularia spumigena*, among others. This aquatic, photosynthetic cyanobacterium forms visible colonies that present as algal blooms in brackish water bodies throughout the world.

Particulate matter is a complex mixture of suspended particles and aerosols with components having diverse chemical and physical characteristics. It is generally classified by aerodynamic diameter (a summary indicator of particle size) because this determines dispersion and removal processes in the air and deposition sites and clearance pathways within the respiratory tract. The smaller the particle, the longer it remains suspended in the air. Particles larger than 50 micrometres (µm) in diameter will settle out quickly. However, for fine particles of 1 µm any settling due to gravity is negligible (i.e. they will stay suspended in the air).

PM_{10} is particulate matter smaller than 10 micrometres (µm) in diameter. PM_{10} is so small that it behaves like a gas, travelling for significant distances once emitted to air. PM_{10} includes inhalable particles that are sufficiently small to penetrate to the thoracic region of the lung. The coarse fraction of PM_{10} (i.e., $PM_{10\text{-}2.5}$) is primarily produced by mechanical processes such as construction activities, road dust resuspension and wind-blown dust, however, it also includes natural sources such as sea salt, pollen, mould and plant parts.

$PM_{2.5}$ is particulate matter smaller than 2.5 micrometres (µm) in diameter, also called fine particulate. $PM_{2.5}$ has a high probability of deposition in the smaller conducting airways and alveoli of the lungs where inhaled gases can be absorbed by the blood (WHO, 2006). $PM_{2.5}$ is mainly produced by combustion of fossil fuels and through secondary particle formation from nitrate, sulphate and organic aerosols and particles.

Picogram is one trillionth of a gram (1×10^{-12} g)

pg/m^3 picograms per cubic metre. This is the mass measured in trillionths of a gram per unit of (cube) space comprising 1 metre × 1 metre × 1 metre. In Aotearoa New Zealand concentrations are typically specified at 0°C (MfE, 2009b).

Time average is the length of time over which a parameter is measured. This is an important element of understanding meteorology and air pollution. For example, a 1-minute wind speed, is the speed of the wind measured over 1 minute and will be much higher than when averaged out over a whole day. Wind speeds typically rise during the day and reduce to more settled conditions over night. The daily average wind speed will reflect the average speed over the full 24-hour period from midnight to midnight.

µg/L micrograms per litre. This is the mass measured in millionths of a gram per litre of fluid.

µg/m^3 micrograms per cubic metre. This is the mass measured in millionths of a gram per unit of (cube) space comprising 1 metre × 1 metre × 1 metre. In Aotearoa New Zealand concentrations are typically specified at 0°C (MfE, 2009).

APPENDIX A: FIELD DATA

A.1 WATER SAMPLING LOCATIONS

Site ID	Monitoring Site	GIS Coordinates S	GIS Coordinates E
Lake 1	Boat Ramp	37°25'52.54"	175°13'23.79"
Lake 2	Outlet	37°24'23.53"	175°12'39.41"
Lake 3	Lakeside Residential	37°24'54.85”	175°9'33.30"

A.2 AEROSOL SAMPLING LOCATIONS

Site ID	Monitoring Site	Instrument	GIS Coordinates S	GIS Coordinates E	Distance from Lake (m)*	Wind Directions from Lake towards Monitoring Location
Air 1	Ika Tahi	High volume	37°24'22.14"	175°12'36.26”	50	SW – E
	Ika Toru	Low volume	37°24'22.05"	175°12'36.10"	50	SW – E
Air 2	Ika Rua	High volume	37°24'21.08"	175°12'36.90"	100	SW – E
	Met Station	Meteorological	37°24'21.04"	175°12'36.94"	100	SW – E
Air 3	Kumara	High volume	37°24'18.90"	175°12'34.38”	150	SW – E
Air 4	Whenua	High volume	37°24'24.49"	175° 11'57.97"	200	WSW - SSE

A.3 AEROSOL HIGH VOLUME (DAILY SAMPLING)

Day	Sample No.	Site	Time Start	Date	Time Stop	Date	Total Vol (m^3)	Comments
1	IT-A-B-130424	Ika Tahi-A	23:45	12/04/2024	NR	NR		Rainstorm at time of filter change
		Ika Tahi-B	8:36	13/04/2024	23:45	13/04/2024	1,187	
	IT Field Blank 130424	Ika Tahi	23:45	13/04/2024	23:47	13/04/2024	-	Draw through field blank (rainstorm)
	IR-130424	Ika Rua	23:49	12/04/2024	0:03	14/04/2024	1,454	
	K-130424	Kumara	23:56	12/04/2024	0:23	14/04/2024	1,467	
	W-130424	Whenua	0:09	13/04/2024	0:25	14/04/2024	1,456	
	Blank Field Blank	-	-	-	-	-	-	Filter left in sleeve but taken into field
2	IT-B-140424	Ika Tahi-B	23:45	13/04/2024	NR	14/04/2024		Power loss to Fish Compound during day
			16:35	14/04/2024	23:50	14/04/2024	1,273	
	IR-140424	Ika Rua	0:05	14/04/2024	NR	14/04/2024	778	Power loss to Fish Compound during day
	K-140424	Kumara	0:25	14/04/2024	0:03	15/04/2024	1,420	
	W-140424	Whenua	0:28	14/04/2024	0:16	15/04/2024	1,428	
	W Field Blank 140424	Whenua	0:19	15/04/2024	0:20	15/04/2024	-	Draw through field blank
3	IT-B-150424	Ika Tahi-B	23:55	14/04/2024	23:50	15/04/2024	1,435	
	IR-150424	Ika Rua	12:18	15/04/2024	23:55	15/04/2024	697	Power loss to Ika Rua only (silver box tripped)
	K-150424	Kumara	0:06	15/04/2024	0:04	16/04/2024	1,438	Kūmara harvesting underway during day
	K Field Blank 150424	Kumara	0:05	16/04/2024	0:06	16/04/2024	-	Draw through field blank
	W-150424	Whenua	0:21	15/04/2024	0:22	16/04/2024	1,441	
4	IT-B-160424	Ika Tahi-B	23:54	15/04/2024	23:49	16/04/2024	1,435	
	IR-160424	Ika Rua	23:59	15/04/2024	23:54	16/04/2024	1,435	
	IR Field Blank 160424	Ika Rua	23:58	16/04/2024	23:58	16/04/2024	-	Draw through field blank
	K-160424	Kumara	0:08	16/04/2024	0:05	17/04/2024	1,437	Kūmara harvesting underway during day
	W-160424	Whenua	0:31	16/04/2024	16:45	16/04/2024	974	Generator stopped when oil changed

Day	Sample No.	Site	Time Start	Date	Time Stop	Date	Total Vol (m^3)	Comments
5	IT-B-170424	Ika Tahi-B	23:51	16/04/2024	23:48	17/04/2024	1,437	
	IR-170424	Ika Rua	23:54	16/04/2024	23:53	17/04/2024	1,439	
	K-170424	Kumara	0:07	17/04/2024	NR	NR		Power tripped - restarted
			8:43	17/04/2024	0:00	18/04/2024	1,433	No kūmara harvesting
	W-170424	Whenua	0:20	17/04/2024	0:12	18/04/2024	1,432	
6	IT-B-180424	Ika Tahi-B	23:51	17/04/2024	23:49	18/04/2024	1,437	
	IR-180424	Ika Rua	23:56	17/04/2024	23:53	18/04/2024	1,437	
	K-180424	Kumara	0:02	18/04/2024	0:00	19/04/2024	1,438	No kūmara harvesting
	W-180424	Whenua	0:14	18/04/2024	0:11	19/04/2024	1,437	
7	IT-B-190424	Ika Tahi-B	23:51	18/04/2024	0:16	20/04/2024	1,465	
	IR-190424	Ika Rua	23:56	18/04/2024	0:21	20/04/2024	1,465	
	K-190424	Kumara	0:02	19/04/2024	0:06	20/04/2024	1,444	No kūmara harvesting
	W-190424	Whenua	0:14	19/04/2024	23:47	19/04/2024	1,413	
	Blank Blank	-	-	-	-	-	-	Kept at base during field study

NR – not recorded

A.4 AEROSOL LOW VOLUME (WEEKLY SAMPLING)

Week	Sample No.	Site	Time Start	Date	Time Stop	Date	Total Vol (m^3)	Comments
1	Ika Toru Wk1	Ika Toru	23:43 21:09	12/04/2024 14/04/2024	16:52 7:55	14/04/2024 20/04/2024	26	Fish Compound lost power
2	Ika Toru Wk2	Ika Toru	8:05	20/04/2024	6:25	27/04/2024	25	Bad odour
3	(Site Check)	Ika Toru	(6:15)	(04/05/2024)				Bad odour
4	Ika Toru Wk4	Ika Toru	6:30	27/04/2024	9:55	11/05/2024	54	2-week sample

A.5 LAKE WATER ACTIVITY FIELD SHEETS

Observations of recreational activities occurring at sampling sites during lake water sampling at Lake Waikare.

Day	Date	Time	Site	Physical Activity	Fishing	Boating	Eating	Camping	Outdoor Employment	Sedentary / Sitting	People Observed
1	13/04/2024	1 – 8:00 am	1								0
			2		2						2
			3	1			2				3
		2 – 12:00 pm	1	1							1
			2								0
			3	2	1						3
		3 – 4:00 pm	1								0
			2	1	5					2	8
			3	1							1
2	14/04/2024	1 – 8:00 am	1								0
			2								0
			3	3							3
		2 – 12:00 pm	1	1							1
			2	7							7
			3	6	4						10
		3 – 4:00 pm	1							1	1
			2		4						4
			3	3							3
3	15/04/2024	1 – 8:00 am	1			1		1			2
			2								0
			3								0
		2 – 12:00 pm	1					1			1
			2		1						1
			3						7		7
		3 – 4:00 pm	1								0
			2							10	10
			3	6					1		7

Day	Date	Time	Site	Physical Activity	Fishing	Boating	Eating	Camping	Outdoor Employment	Sedentary / Sitting	People Observed
			1								0
		1 – 8:00 am	2								0
			3	4					10		14
			1					1		2	3
4	16/04/2024	2 – 12:00 pm	2		1						1
			3						23		23
			1								0
		3 – 4:00 pm	2								0
			3	3					1		4
			1								0
		1 – 8:00 am	2								0
			3	2					10		12
			1					1			1
5	17/04/2024	2 – 12:00 pm	2								0
			3	2					12		14
			1					1			1
		3 – 4:00 pm	2								0
			3	1						3	4
			1			1					1
		1 – 8:00 am	2								0
			3						12		12
			1					1			1
6	18/04/2024	2 – 12:00 pm	2		2				4		6
			3	5					13		18
			1			2		1			3
		3 – 4:00 pm	2								0
			3	12	1				2		15

APPENDIX B: BEAUFORT WIND SCALE

The Beaufort wind force scale is an empirical measure that relates wind speed to observed conditions on land and at sea.

Table B-1: Beaufort wind scale

Beaufort Number	Description	Wind speed	Land conditions	Sea conditions
0	Calm	< 0.5 m/s < 2 km/h <1 knot	Smoke rises vertically	Sea like a mirror
1	Light air	0.5 – 1.5 m/s 2 – 5 km/h 1 – 3 knots	Direction shown by smoke drift but not by wind vanes	Ripples with appearance of scales are formed, without foam crests
2	Light breeze	1.6 – 3.3 m/s 6 – 11 km/h 4 – 6 knots	Wind felt on face, leaves rustle, wind vane moves	Small wavelets still short but more pronounced, crests have glassy appearance but do not break
3	Gentle breeze	3.4 – 5.5 m/s 12 – 19 km/h 7 – 10 knots	Leaves and small twigs in constant motion; light flags extended	Large wavelets; crests begin to break; foam of glassy appearance perhaps scattered white horses
4	Moderate breeze	5.5 – 7.9 m/s 20 – 28 km/h 11 – 16 knots	Raises dust and loose paper; small branches moved	Small waves becoming longer; fairly frequent white horses
5	Fresh breeze	8 – 10.7 m/s 29 – 38 km/h 17 – 21 knots	Small trees in leaf begin to sway; crested wavelets form on inland waters	Moderate waves taking a more pronounced long form; many white horses are formed; chance of some spray
6	Strong breeze	10.8 – 13.8 m/s 39 – 49 km/h 22 – 27 knots	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	Large waves begin to form; the white foam crests are more extensive everywhere; probably some spray
7	High wind, moderate gale, near gale	13.9 – 17.1 m/s 50 – 61 km/h 28 – 33 knots	Whole trees in motion; inconvenience felt when walking against the wind	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind; spindrift begins to be seen
8	Gale, fresh gale	17.2 – 20.7 m/s 62 – 74 km/h 34 – 40 knots	Twigs break off trees; wind generally impedes progress	Moderately high waves of greater length; edges of crests break into spindrift; foam is blown in well-marked streaks along the direction of the wind
9	Strong/severe gale	20.8 – 24.4 m/s 75 – 88 km/h 41 – 47 knots	Slight structural damage (chimney pots and slates removed)	High waves; dense streaks of foam along the direction of the wind; sea begins to roll; spray affects visibility

Beaufort Number	Description	Wind speed	Land conditions	Sea conditions
10	Storm, whole gale	24.5 – 28.4 m/s 89 – 102 km/h 48 – 55 knots	Seldom experienced inland: trees uprooted; considerable structural damage	Very high waves with long overhanging crests; resulting foam in great patches is blown in dense white streaks along the direction of the wind; on the whole the surface of the sea takes on a white appearance; rolling of the sea becomes heavy; visibility affected
11	Violent storm	28.5 – 32.6 m/s 103 – 117 km/h 56 – 63 knots	Very rarely experienced: accompanied by widespread damage	Exceptionally high waves; small- and medium-sized ships might be for a long time lost to view behind the waves; sea is covered with long white patches of foam; everywhere the edges of the wave crests are blown into foam; visibility affected
12	Hurricane force	>32.7 m/s > 118 km/h > 64 knots	Devastation	The air is filled with foam and spray; sea is completely white with driving spray; visibility very seriously affected

Notes: 'm/s' = metres per second; 'km/h' = kilometres per hour.

APPENDIX C: LAKE WATER SAMPLE DATA

Data from lake water samples; total cyanobacterial biovolume (Tot Cyano BV), and concentrations of total cyanobacteria cells (Tot Cyano Cell), *Microcystis* spp. cells (*Microcystis* Conc), total microcystins (Tot MCs Conc) and extracellular microcystins (Extra MCs Conc).

Day	Date	Time	Site	Sample ID	Tot Cyano BV (cells/mL)	Total Cyano Conc (cells/mL)	*Microcystis* Conc (cells/mL)	Tot MCs Conc (ng/mL or µg/L)	Extra MCs Conc (ng/mL or µg/L)	Proportion Extracellular MCs
1	13/04/2024	1 – 8:00 am	1	HABA-501	19.7	1,944,040	46,000	3.3	0.06	1.9%
			2	HABA-502	18.0	1,242,400	47,000	5.6	0.09	1.6%
			3	HABA-503	11.9	381,660	25,000	2.8	0.21	7.4%
		2 – 12:00 pm	1	HABA-504	16.8	1,584,560	330,000	4.2	0.07	1.6%
			2	HABA-505	15.6	1,066,700	29,000	3.3	0.09	2.6%
			3	HABA-506	28.3	884,880	18,000	3.1	0.22	7.0%
		3 – 4:00 pm	1	HABA-507	6.3	256,740	80,000	4.6	0.05	1.1%
			2	HABA-508	19.5	1,945,880	21,000	3.4	0.21	6.1%
			3	HABA-509	26.0	1,044,920	43,800	4.4	0.12	2.8%
2	14/04/2024	1 – 8:00 am	1	HABA-510	14.5	971,800	205,000	4.0	0.12	3.0%
			2	HABA-511	29.4	1,402,340	47,000	4.9	0.04	0.8%
			3	HABA-512	15.8	995,700	20,900	2.3	0.22	9.7%
		2 – 12:00 pm	1	HABA-513	27.5	1,089,420	34,700	5.6	0.09	1.6%
			2	HABA-514	12.2	657,560	68,000	5.3	0.05	1.0%
			3	HABA-515	10.3	526,400	85,100	3.7	0.07	1.9%
		3 – 4:00 pm	1	HABA-516	19.1	1,632,880	43,600	5.3	0.08	1.6%
			2	HABA-517	13.6	1,084,100	104,000	4.6	0.06	1.3%
			3	HABA-518	45.7	1,674,320	75,000	3.3	0.15	4.4%
3	15/04/2024	1 – 8:00 am	1	HABA-519	17.6	997,960	57,000	3.2	0.11	3.4%
			2	HABA-520	18.1	978,600	59,000	46.1	0.09	0.2%
			3	HABA-521	17.9	946,700	30,800	34.2	0.16	0.5%
		2 – 12:00 pm	1	HABA-522	38.5	2,316,540	1,800,620	483.1	0.78	0.2%
			2	HABA-523	12.7	755,280	144,700	111.8	0.30	0.3%
			3	HABA-524	13.0	805,680	44,000	3.8	0.25	6.4%
		3 – 4:00 pm	1	HABA-525	10.3	578,840	87,000	5.2	0.15	2.8%
			2	HABA-526	25.8	1,551,700	25,000	16.2	0.13	0.8%
			3	HABA-527	14.2	698,840	126,000	3.0	0.15	4.9%

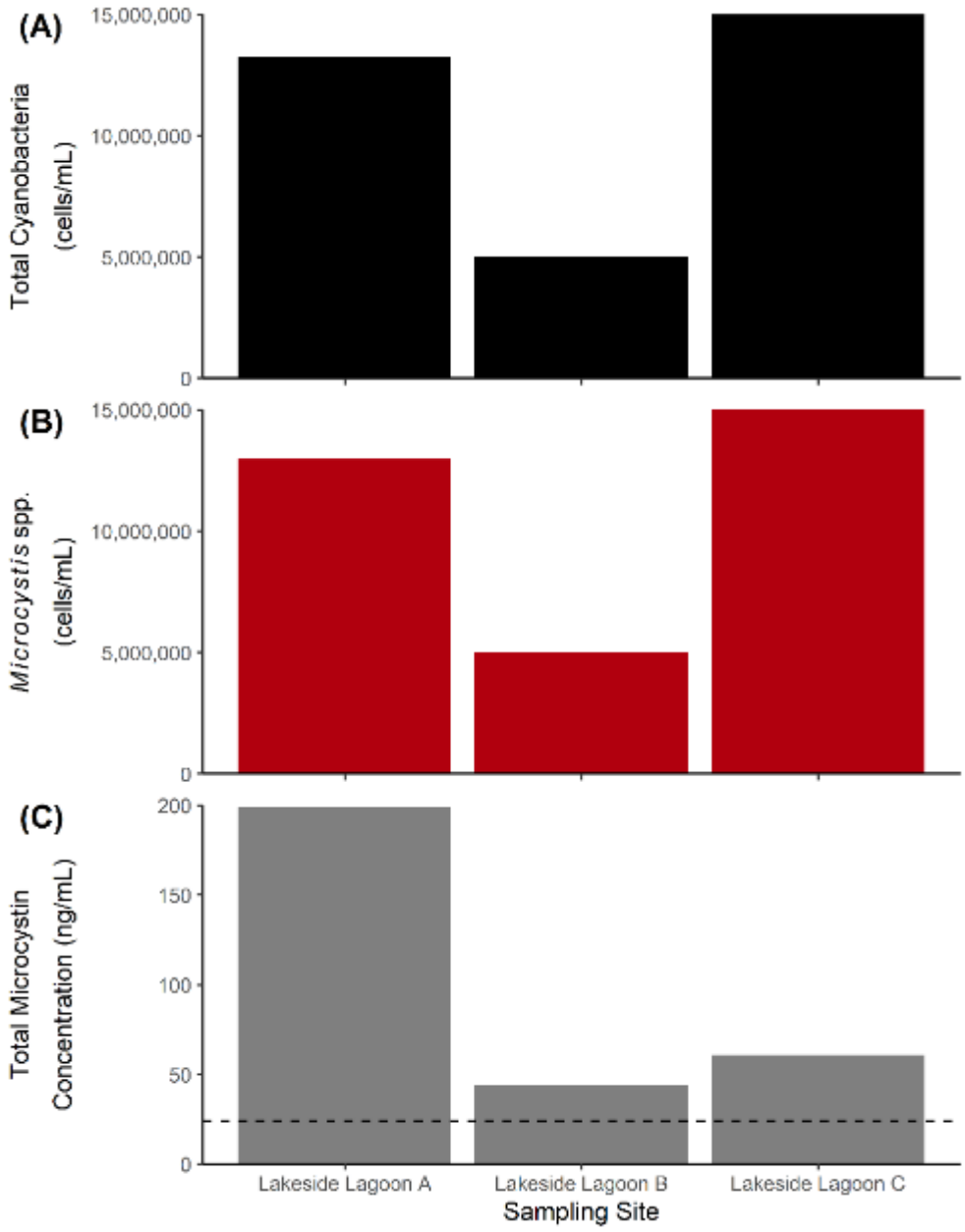
Day	Date	Time	Site	Sample ID	Tot Cyano BV (cells/mL)	Total Cyano Conc (cells/mL)	*Microcystis* Conc (cells/mL)	Tot MCs Conc (ng/mL or µg/L)	Extra MCs Conc (ng/mL or µg/L)	Proportion Extracellular MCs
4	16/04/2024	1 – 8:00 am	1	HABA-528	18.1	1,298,660	57,900	3.3	0.12	3.5%
			2	HABA-529	27.7	1,339,140	49,000	28.4	0.06	0.2%
			3	HABA-530	14.5	870,260	27,800	14.6	0.14	1.0%
		2 – 12:00 pm	1	HABA-531	33.4	2,446,020	266,000	5.5	0.07	1.2%
			2	HABA-532	11.1	639,700	106,000	4.8	0.04	0.9%
			3	HABA-533	39.3	1,515,900	15,100	2.9	0.07	2.3%
		3 – 4:00 pm	1	HABA-534	27.7	1,790,800	41,600	5.1	0.07	1.4%
			2	HABA-535	12.4	558,860	131,000	5.2	0.09	1.6%
			3	HABA-536	27.5	1,487,100	17,400	3.1	0.11	3.4%
5	17/04/2024	1 – 8:00 am	1	HABA-537	17.0	1,132,620	35,200	4.5	0.11	2.4%
			2	HABA-538	16.1	960,040	55,000	43.8	0.07	0.2%
			3	HABA-539	19.5	1,033,900	34,000	4.3	0.16	3.6%
		2 – 12:00 pm	1	HABA-540	8.6	408,680	81,000	5.2	0.07	1.3%
			2	HABA-541	9.3	499,080	61,600	4.2	0.05	1.2%
			3	HABA-542	19.1	968,160	37,000	2.7	0.13	4.7%
		3 – 4:00 pm	1	HABA-543	8.6	540,920	75,500	4.8	0.08	1.6%
			2	HABA-544	29.8	1,650,400	62,000	6.1	0.08	1.3%
			3	HABA-545	21.5	913,380	75,000	3.1	0.13	4.2%
6	18/04/2024	1 – 8:00 am	1	HABA-546	17.0	1,066,560	54,000	3.2	0.07	2.2%
			2	HABA-547	31.8	1,193,000	66,000	29.2	0.05	0.2%
			3	HABA-548	19.4	1,097,360	36,000	3.2	0.19	5.8%
		2 – 12:00 pm	1	HABA-549	11.0	832,520	31,600	5.0	0.07	1.3%
			2	HABA-550	27.1	1,387,000	39,000	4.3	0.04	0.9%
			3	HABA-551	13.2	840,140	75,000	2.6	0.08	3.2%
		3 – 4:00 pm	1	HABA-552	22.4	1,318,640	36,000	4.1	0.14	3.4%
			2	HABA-553	28.1	1,210,960	28,000	5.7	0.11	1.9%
			3	HABA-554	17.7	1,000,900	44,000	2.9	0.22	7.5%

APPENDIX D: ADDITIONAL SAMPLE DATA

D.1 TOTAL CELL CONCENTRATIONS

Total cyanobacteria (A) and *Microcystis* spp. (B) cell concentrations, and total microcystin concentrations (C) measured in water samples collected from three sites from three sites of an embayment near Site 3 (close to the 'Lakeside residential development) on 17 April 2024.

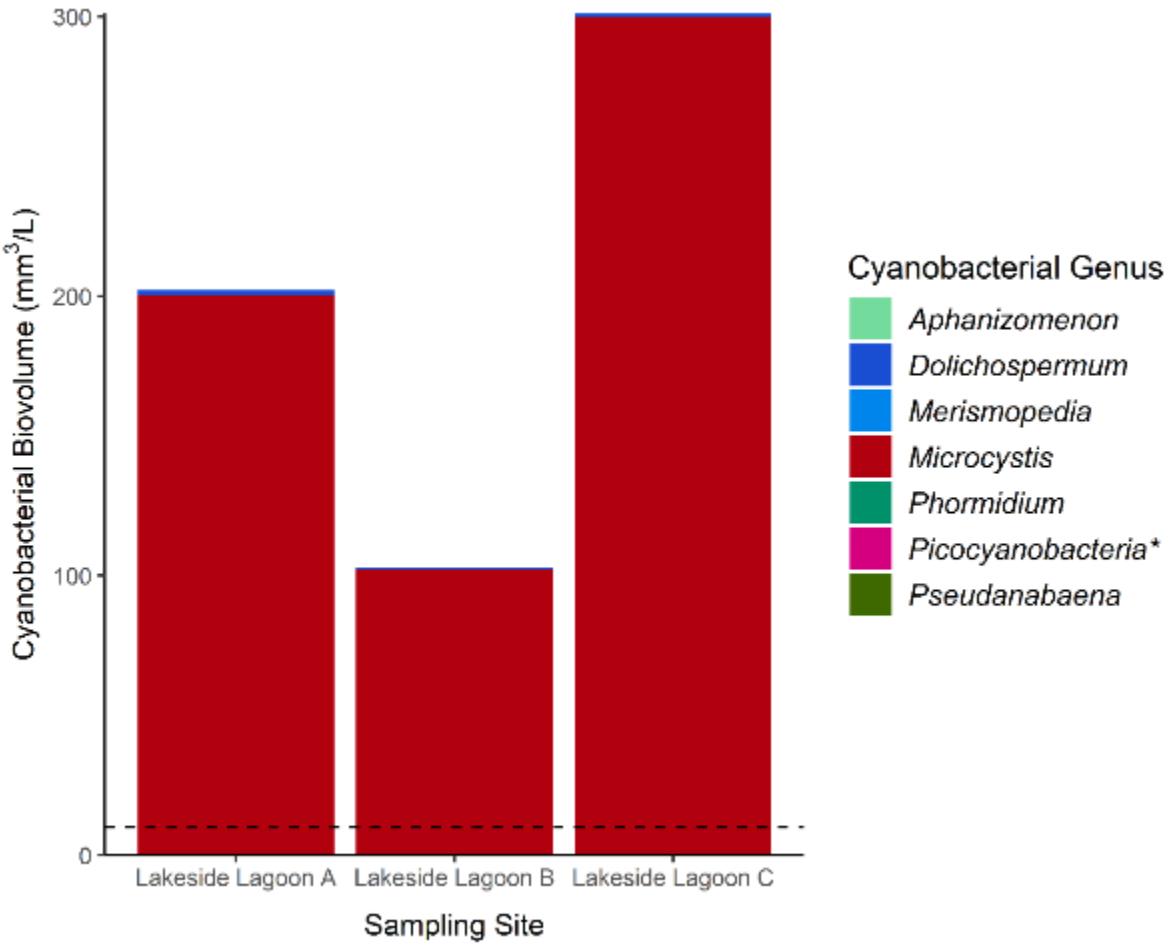
The horizontal dashed line at 24 µg/L of microcystins (in C) indicates the Situation 4 Action Level / Red Mode threshold for microcystins in recreational waters in Aotearoa New Zealand (revised Recreational Cyanobacteria Guidelines are due to be released in 2024; MfE and Te Whatu Ora *pending*).



D.2 TAXONOMIC COMPOSITION

Taxonomic composition of total cyanobacterial biovolume measured in water samples collected from three sites of an embayment near Site 3 (close to the 'Lakeside residential development) on 17/04/2024.

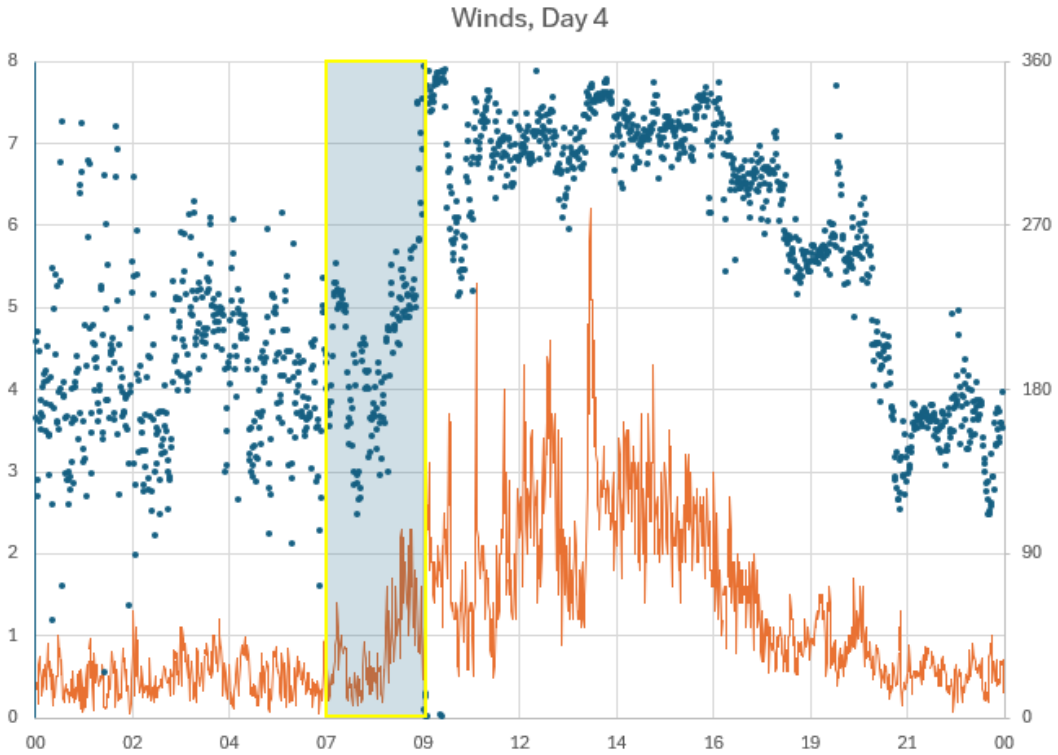
The horizontal dashed line at 10 mm^3/L indicates the Situation 2 Action Level / Red Mode threshold for cyanobacteria for recreational waters in Aotearoa New Zealand (MfE and MoH 2009).

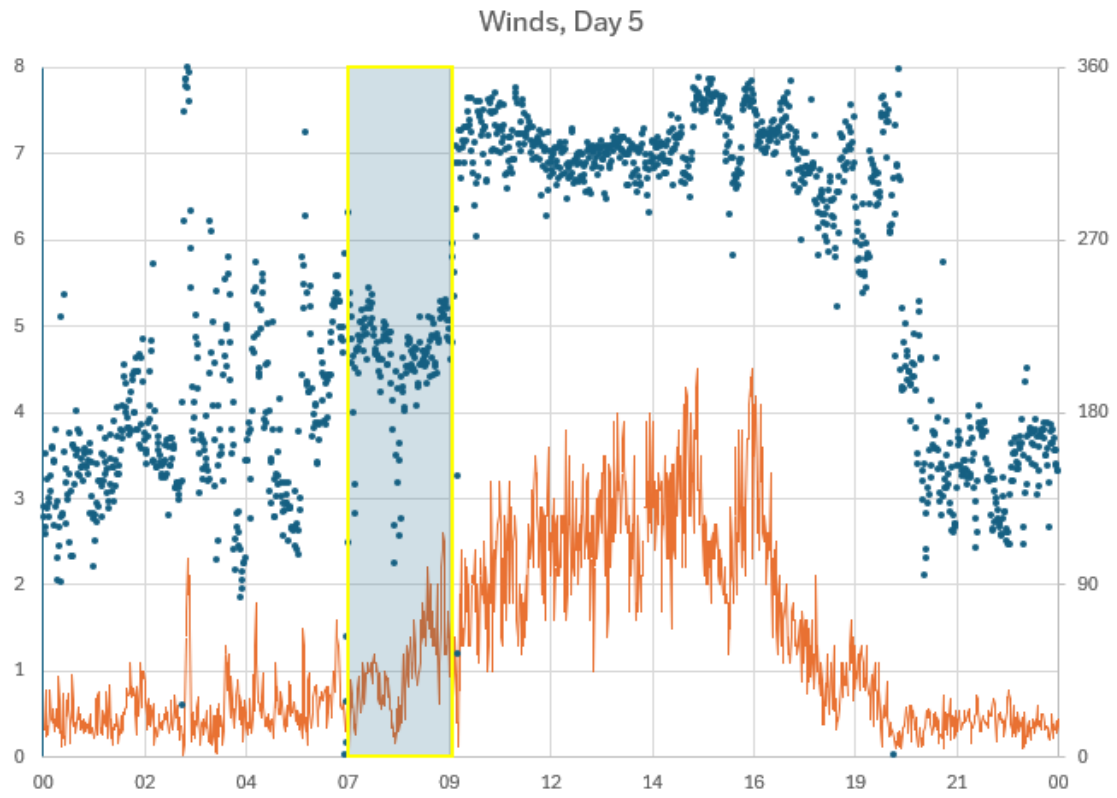


*Picocyanobacteria are not a cyanobacterial genus but are a collection of cyanobacteria with a small cell size (< 2 µm in diameter).

APPENDIX E: MET REVIEW

Blue rectangles indicate periods of elevated total microcystin concentrations in lake water samples




Winds, Day 5
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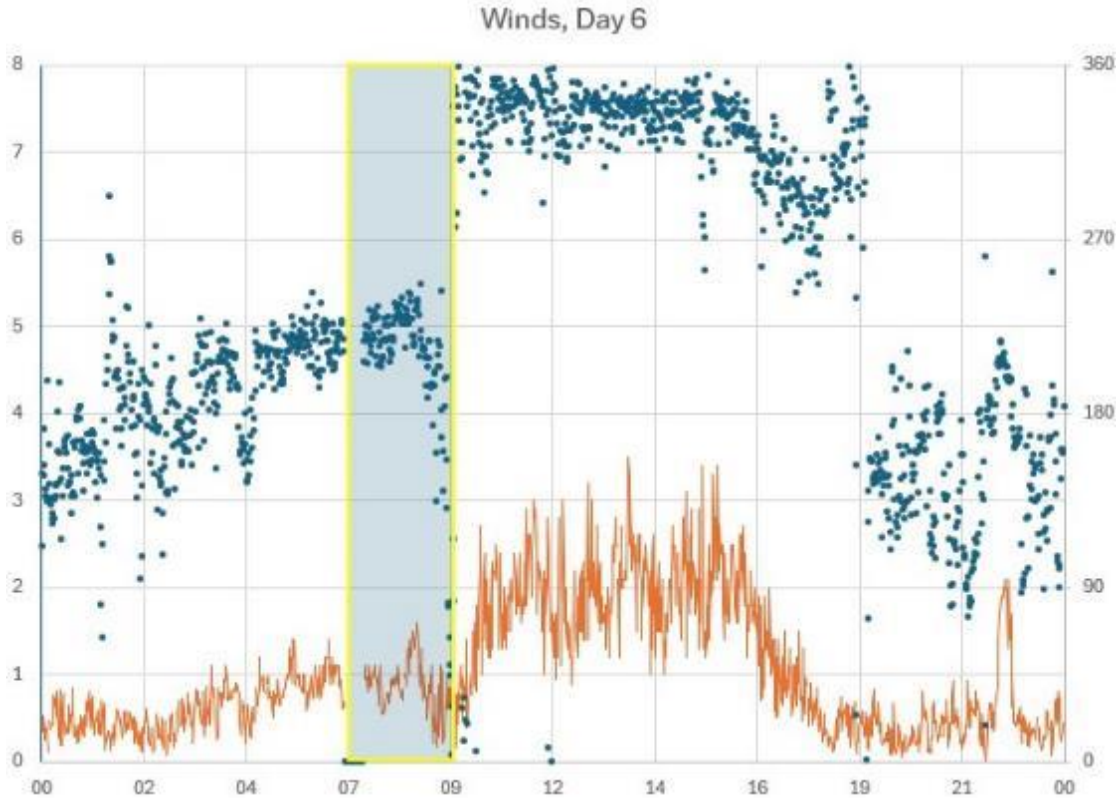
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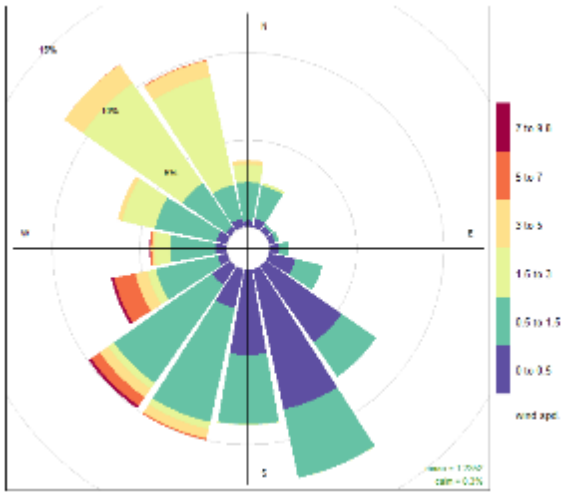
Day 1



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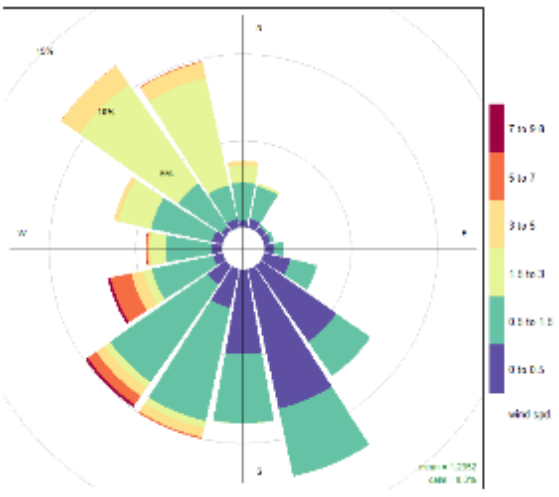

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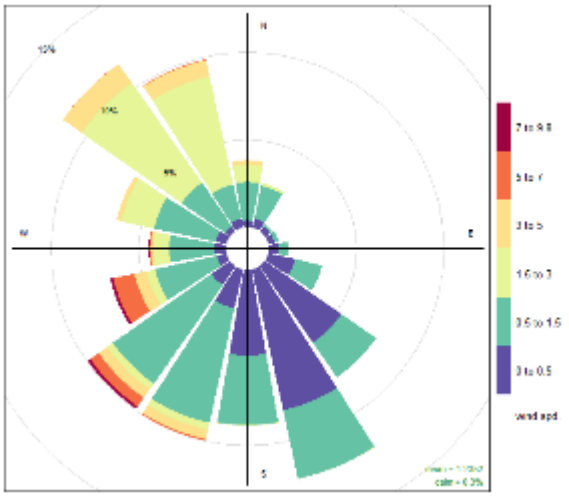
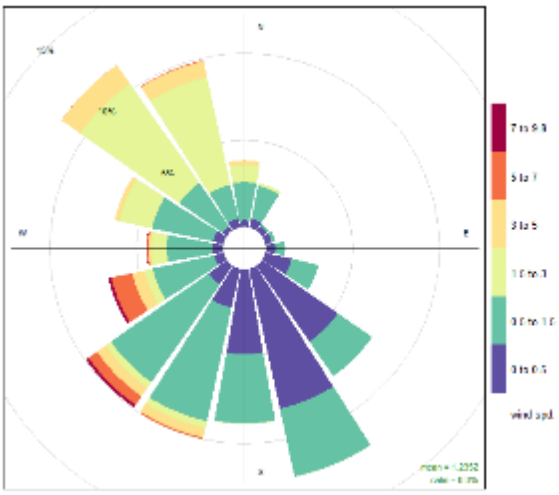


Day 4



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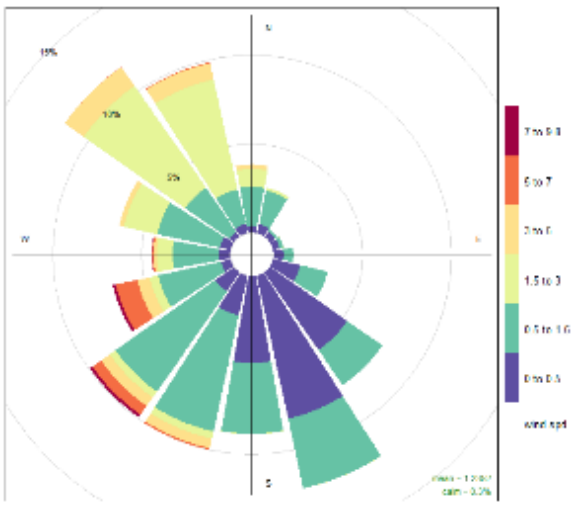

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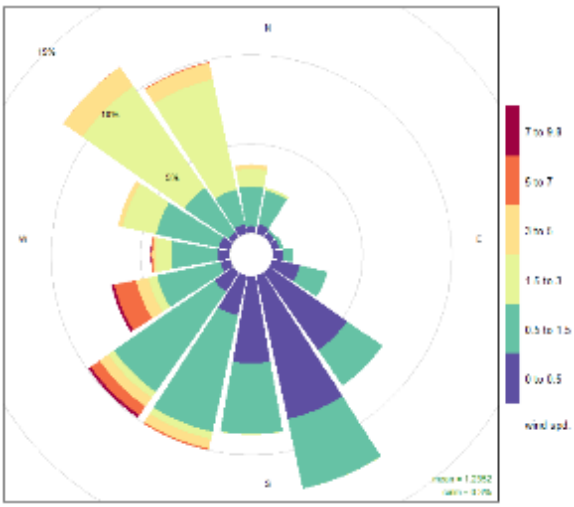
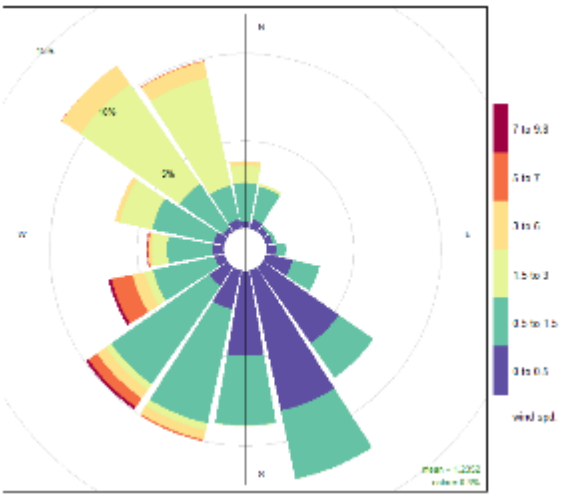
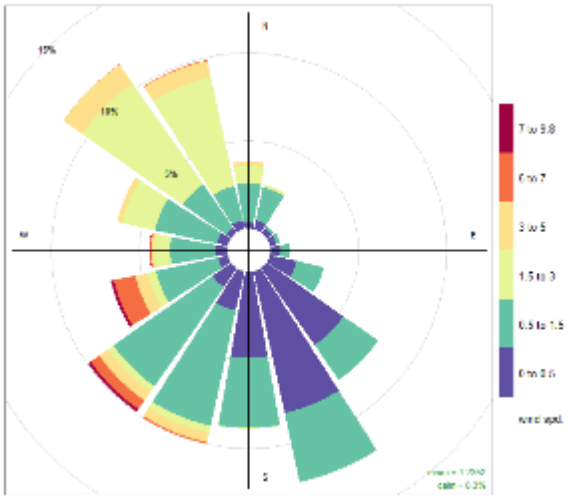


Day 7



Week 1



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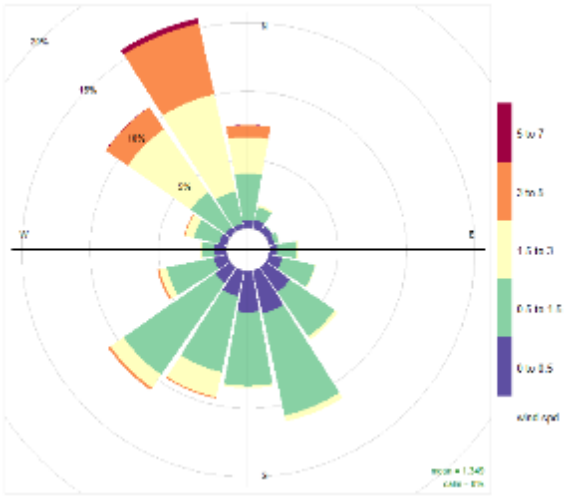
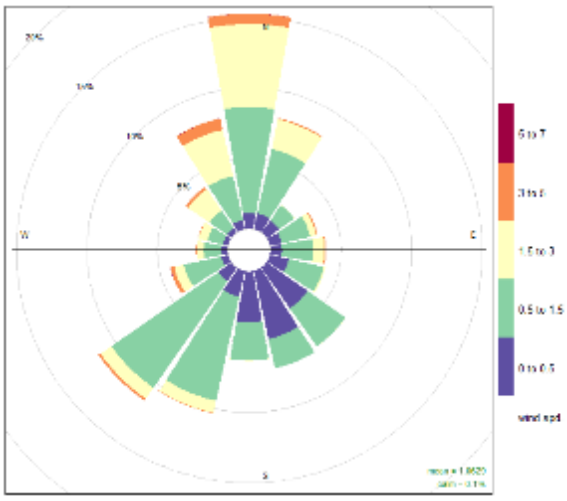
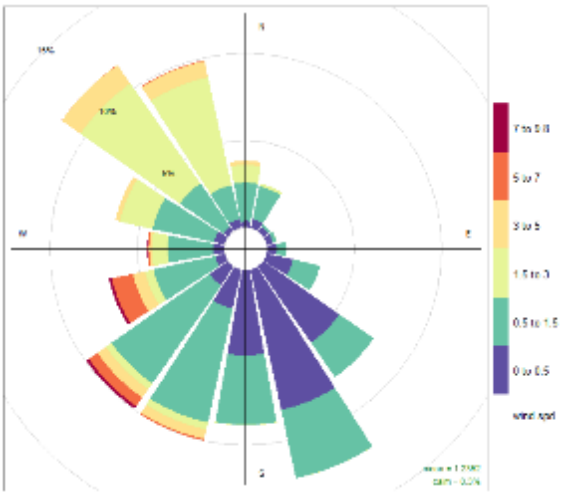


Weeks 3-4



Weeks 1-4



APPENDIX F: AEROSOL SAMPLE DATA

Day	Date	Wind Speed	Air Site	Wind Towards Air Site	Sample ID	Volume (m^3)	LoD * (pg/m^3)
1	13 Apr 2024	2.3 ± 2.2	1	59%	IT-A-B-130424	1,187	< 0.056
			2		IR-130424	1,454	< 0.045
			3		K-130424	1,467	< 0.045
			4	49%	W-130424	1,456	< 0.045
2	14 Apr 2024	1.2 ± 0.9	1	25%	IT-B-140424	1,273	< 0.052
			2		IR-140424	778	< 0.085
			3		K-140424	1,420	< 0.046
			4	38%	W-140424	1,428	< 0.046
3	15 Apr 2024	1.0 ± 0.8	1	44%	IT-B-150424	1,435	< 0.046
			2		IR-150424	697	< 0.095
			3		K-150424	1,438	< 0.046
			4	51%	W-150424	1,441	< 0.046
4	16 Apr 2024	1.2 ± 0.9	1	40	IT-B-160424	1,435	< 0.046
			2		IR-160424	1,435	< 0.046
			3		K-160424	1,437	< 0.046
			4	44%	W-160424	974	< 0.068
5	17 Apr 2024	1.3 ± 1.0	1	32%	IT-B-170424	1,437	< 0.046
			2		IR-170424	1,439	< 0.046
			3		K-170424	1,433	< 0.046
			4	49%	W-170424	1,432	< 0.046
6	18 Apr 2024	1.0 ± 0.7	1	40%	IT-B-180424	1,437	< 0.046
			2		IR-180424	1,437	< 0.046
			3		K-180424	1,438	< 0.046
			4	51%	W-180424	1,437	< 0.046
7	19 Apr 2024	0.7 ± 0.4	1	30%	IT-B-190424	1,465	< 0.045
			2		IR-190424	1,465	< 0.045
			3		K-190424	1,444	< 0.046
			4	52%	W-190424	1,413	< 0.047

* Calculated using the LoD determined for MC-LR in glass fibre filters (0.033 ng/mL) and the air volume sampled, as dmMC-LR was the dominant MC congener in the lake water samples.

Appendix X: Data from low volume aerosol samples and limits of detection (LoDs) for microcystin (MC) measurements.

Week	Date	Wind Speed	Air Site	Wind Towards Air Site	Sample ID	Volume (m^3)	LoD * (pg/m^3)
1	13 - 19 Apr 2024	1.2 ± 1.2	1	39%	Ika Toru Wk1	25.79	< 0.6
2	20 – 26 Apr 2024	1.3 ± 1.0	1	39%	Ika Toru Wk2	24.95	< 0.6
3 & 4	27 – 10 May 2024	1.1 ± 0.8	1	34%	Ika Toru Wk4	54.36	< 0.3

* Calculated using the LoD determined for MC-LR in PTFE filters (0.03 ng/mL) and the air volume sampled, as dmMC-LR was the dominant MC congener in the lake water samples.

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