Lake Pūkaki Hydro Storage and Dam Resilience Works

Air Quality Assessment – Lake Shore Wind Erosion

Meridian Energy

05 November 2025

→ **The Power of Commitment**

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Abbreviations

Term/ acronym	Definition
CALMET	The meteorological model portion of the CALPUFF modelling package
CALPUFF	A pollution dispersion model recognised by regulatory authorities for the assessment of dust.
DMP	Dust management plan
EPA	Environment Protection Authority
FIDOL	A qualitative assessment that considers the factors of **F**requency, **I**ntensity, **D**uration, **O**ffensiveness and **L**ocation of a dust source.
FTAA	Fast Track Approvals Act
GHD	GHD Pty Ltd
ha	Hectares
IAQM	Institute of Air Quality Management
kg	kilograms
kg/day	kilograms per day
km	kilometres
km/h	kilometres per hour
m	Metres
m^3	cubic metres
MFE	Ministry for Environment (New Zealand)
mm	millimetres
Mt	megatonnes
Mtpa	megatonnes per annum
MW	megawatts
NPI	National Pollution Inventory (Australia)
NZ	New Zealand
^oC	Degrees Celsius
OCC	Official Conservation Campaign
PC1	Plan Change 1. Conducted in 2012.
PC3	Plan Change 3.
PM_{10}	Particulate matter less than 10 µm in aerodynamic equivalent diameter
$PM_{2.5}$	Particulate matter less than 2.5 µm in aerodynamic equivalent diameter
RL	Reference level (refers to dam water level in metres above sea level)
SO	System Operator
SSA	Security of Supply Alert
t	Tonnes
tpa	Tonnes per annum
tpd	Tonnes per day
TSP	Total suspended particulate
WAP	Waitaki Catchment Allocation Regional Plan

Term/ acronym	Definition
WPS	Waitaki Power Scheme

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1. Introduction

Meridian Energy Limited (Meridian) has engaged GHD Limited (GHD), to assist with obtaining consents to authorise the operation of Lake Pūkaki below the current normal minimum level of 518 m above mean sea level (m RL) for a three-year period, and for civil works at Pūkaki Dam to improve the structure's resilience to wave action during lower lake operational levels.

1.1 Project Background

1.1.1 Waitaki Power Scheme

The Waitaki Power Scheme (WPS) is a nationally and regionally significant component of New Zealand's electricity supply infrastructure. It is New Zealand's largest and most flexible hydroelectricity power scheme and therefore has a critical role to play in the electricity system and economy. It consists of six power stations, commissioned between 1936 and 1985, together having an installed capacity of 1,553 MW, being ~29 percent of New Zealand's installed hydro capacity.

Lake Pūkaki is a modified natural lake and is managed as part of the WPS. It is New Zealand's largest hydro storage lake and provides an average of 1,767 GWh of stored water in normal operating conditions, with an additional 546 GWh available during a national hydro shortage.

Meridian is currently authorised to dam the Pūkaki River to control and operate Lake Pūkaki between the levels of 518 m RL (normal consented minimum lake level) and 532.5 m RL (maximum consented storage level).

1.1.2 Previous Plan Changes - Waitaki Catchment Allocation Regional Plan (WAP)

The WAP is a sub-regional plan and provides objectives, policies and rules for the use and development of water resources within the Waitaki Catchment. Prior to 2012, it was a prohibited activity in the WAP for Meridian to draw the lake level below 518 m RL.

1.1.2.1 Plan Change 1 (PC1)

In 2012, Meridian initiated Plan Change 1 (PC1) to the WAP which sought to introduce a new minimum lake level for Lake Pūkaki during circumstances when the System Operator (SO) had commenced an Official Conservation Campaign (OCC) in regard to electricity supply. PC1 allowed additional water from Lake Pūkaki to be used for generating electricity as a permitted activity when an OCC is declared by the SO.

When assessing the potential operation of Lake Pūkaki below 518m for PC1, the duration of an entire event (time below 518 m RL) was considered likely to be between 4 to 7 months (this includes the time spent operating below 518 m RL, as well as the time required to restore the lake level to above 518 m RL once an electricity supply emergency ended). Supporting technical effects assessments were submitted as part of this plan change process. It was ultimately concluded that allowing access for electricity generation purposes to water stored between 513 and 518 m RL, as a permitted activity once an electricity supply emergency had been declared, was appropriate and promoted the sustainable management purpose of the Resource Management Act (RMA). PC1 was adopted by Environment Canterbury on 27 September 2012.

This report relies on the PC1 2012 effects assessments as being appropriate and focuses on both the changes that have occurred since 2012, and the differences between the activities permitted by PC1 and the proposed activities. This is the 'Baseline' that is referred to throughout this report. The PC1 evaluation with respect to air quality was undertaken by Jeff Bluett and is summarised in Section 4.5.

1.1.2.2 Plan Change 3 (PC3)

PC3 included a new rule regarding the use of Lake Pūkaki between 518 m RL and 515 m RL. In addition to the PC1 Permitted Activity rule, at times of a Security of Supply Alert (SSA) initiated by the SO, the lake may be operated between the alert minimum control level of 515 m RL and 518 m RL. The rule is not a permitted activity and to implement this, Meridian applied for and was a granted resource consent in 2018 (CRC185833). This consent expired on 30 April 2025 but has been granted a section 124 continuance while the new replacement consent (CRC240441) is being processed.

1.1.3 Meridan's Application

Meridian is seeking approvals under the Fast Track Approvals Act (FTAA) to enable access to water stored in Lake Pūkaki below 518 m RL, without the currently applicable security of supply triggers, thereby enabling the better planning and utilisation of the available stored generating capacity. Further information on the background to the proposal and the benefits of allowing access to additional water is provided in the Substantive Application[1] document that supports the FTAA application.

Meridian is proposing to access the additional storage for a time-bound period of three years, until the end of 2028. For the purpose of this report 'Eased Access', refers to the ability to use water from Lake Pūkaki between 513 m RL and 518 m RL without a SSA or OCC being initiated by the SO. The ability to access stored water below 518 m RL will be incorporated into Meridian's electricity generation models and water stored in Lake Pūkaki (both above and below 518 m RL) will continue to be managed to supply the market. The three-year period is to allow for additional generation capacity that is currently being built, to come online. For further clarification, the existing lake operation framework and proposed activity is detailed below in Table 1.

In addition to the temporary ability to lower the lake level, Meridian seeks consent for the installation of rip-rap on the upstream face of the Pūkaki dam and its left and right abutments to provide protection from wave erosion, when operating the lake below 518 m RL. Rip-rap will be placed to a maximum depth of 510.5 m RL, with earthworks/site preparation activities extending to a maximum depth of 509.6 m RL. Rock armouring will take a total of 12 to 18 weeks to complete but is expected to be done over multiple stages over several years as lake levels allow, and works may be required to be completed beyond 2028.

Meridian has stockpiled rock for this purpose on its land adjacent to the Pūkaki dam since 2014, but the rock armouring has not been undertaken due to the existing supply triggers never being initiated by the SO, with the result that the lake level has not been low enough over that period to allow the works to be completed.

Table 1 Proposed activity – eased access

Existing Framework	Proposed Activity
Operation of Lake above 518 m RL (CRC905321.7).	Operation of Lake above 518 m RL (CRC905321.7). UNCHANGED.
Operation of Lake between 518 m RL and 515 m RL as a discretionary activity at times of a Security of Supply Alert initiated by the System Operator (CRC185833).	Operation of Lake between 518 m RL and 513 m RL for a period of 3 years without a Security of Supply Alert or Official Conservation Campaign being initiated by the System Operator.
Operation of Lake between 518 m RL and 513 m RL as permitted activity during an Official Conservation Campaign initiated by the System Operator (Permitted Activity).	

1.2 Purpose of this report

The purpose of this report is to briefly describe the proposal, review the available information regarding meteorology and dust generating processes, and to provide qualitative and quantitative assessments of wind erosion generated dust associated with the lake shoreline as a potential consequence of operating Lake Pūkaki below 518 m RL.

Note: The air quality assessment associated with the rock armouring is provided in a separate report.

[1] Lake Pukaki Hydro Storage and dam resilience works - Substantive Application under the Fast-track Approvals Act 2024 dated 5 November 2025

1.3 Assumptions

This document has been prepared based on the following assumptions:

- Lake Pūkaki will only be operated below its existing consent level for no more than a three-year period ending in 2028.
- The representative meteorological year is 2015. Refer to Section 7.2.2.
- CALMET used with TAPM 3km resolution 3D wind fields and two surface observations stations (Maryburn and Pūkaki Aero) provides an accurate representation of the short term (1-hour) and longer term (annual) wind parameters of speed direction and turbulence. Refer to Appendix B.
- Emissions source characterisation is representative of actual dispersion. Refer to Appendix B.
- A threshold friction velocity of 0.4 m/s is representative of the wind erosion of the glacial till. This is discussed in detail in Section 5.3.
- The particle size distribution is as defined in Section 5.7, consisting of 57 percent PM_{10} and 23 percent $PM_{2.5}$.
- Suppression of dust via 3 mm of rainfall in the preceding 24 -hours, based on Maryburn observations, is representative. Refer to Section 10.6.
- Dust storm event likelihood and wind speed is as described by Jeff Bluett. Refer to Section 4.5.
- Wind eroded dust intensity is proportional to the amount of lake lowering.
  - Lake lowering (and rising) rate is linear across a full year. Refer to Section 4.2.1.
  - Lake level is only less than 518 m for six months of the year – conservative scenario.
- Dust emissions are scaled from Australian National Pollution Inventory (NPI) factors based on a nominal lake annual average wind speed. Refer to Section 5.5.

1.4 Scope of Work and Document Structure

This document consists of:

- A description of the background reasons for the project and the assessment scope. (Section 1)
- A description of the proposed activities. (Section 2)
- A general description of Lake Pūkaki. (Section 3)
- A summary of the reviewed information supplied by Meridian relevant to this assessment (Section 4)
- A review of generalised dust generation mechanisms and the potential dust sources and characteristics associated with wind erosion from around Lake Pūkaki. (Section 5)
- A summary of the relevant ambient dust concentration criteria for areas around Lake Pūkaki. (Section 6)
- An analysis of the meteorology around Lake Pūkaki. (Section 7)
- Identification of sensitive receptors around Lake Pūkaki. (Section 8)
- A FIDOL assessment for dust (Section 9)
- A qualitative assessment of dust potential, especially examining the potential for increased dust storm events due to lake lowering. (Section 10)
- Dust suppression (Section 11)
- An assessment of environmental effects and comparison to PC1 assumptions (Section 12)
- The appendices contain:
  - Assessors' curriculum vitae
  - A summary of the CALMET and CALPUFF dispersion modelling.
  - Wind roses showing wind speed and direction from different locations around Lake Pūkaki.
  - A copy of the Phase 1 assessment Technical Memorandum.

1.5 Associated concurrent reports

This report should be read in conjunction with the following report that provides supplementary and complementary information.

– GHD Report Pūkaki Reservoir Hydro Storage and Dam Resilience Works – Air Quality Assessment – Dam Construction (12656630-REP-Air_Quality_Phase2_Air_Qual_Assessment_construction_dust, 4 November 2025).

1.6 Report Author and Contributions

The qualifications and experience of the report authors are set out in Appendix A. The authors confirm that they have read the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note (2023) and agree to comply with it. In that regard the lead author confirms that this air quality report is written within their expertise, except where stated that the author is relying on the assessment of another person. The author confirms that they have not omitted to consider material facts known to them that might alter or detract from the opinions expressed.

1.7 Limitations

This report has been prepared by GHD Limited on the instructions of Meridian Energy, in accordance with the agreed scope of work. It is intended to support Meridian's application under the Fast-track Approvals Act 2024 and may be relied upon by the Expert Panel and relevant administering agencies for the purposes of assessing the application.

While GHD Limited has exercised due care in preparing this report, it does not accept liability for any use of the report beyond its intended purpose. Where information has been supplied by the Client or obtained from external sources, it has been assumed to be accurate unless otherwise stated.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described throughout this report and particularly in this report (refer section(s) 1.3 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

2. Proposed activities

Meridian is proposing two activities, being:

- Over a three-year period, having the ability to lower the lake levels below 518 m RL to a minimum level of 513 m RL, so that stored lake water can be used to generate electricity.
- When the lake levels are low, this enables civil works near the Pūkaki Dam, specifically extending rip-rap armouring to reduce the risk of erosion on the dam face and other critical infrastructure.

The focus of this report will be on the short-term change to the lake operating level for electricity generation. The following provides a summary of the modelling undertaken by Meridian (2025) to determine the likelihood, magnitude and frequency of the lake lowering, together with a summary of the lake level lowering magnitude and frequency adopted in the PC1 hearing. The approach adopted for this assessment is detailed in Section 9, which provides a conservative approach to assessing the potential significance of the eased restrictions on dust generation, informed by the information and analysis provided in Sections 4 to 8.

2.1 Short-term change to lake operating level

Meridian undertook modelling to understand potential changes to lake levels from the proposed activity (Meridian, 2025). The modelling draws on 91 years of hydrological and meteorological data for the lake, and the current understanding of the NZ energy system (supply and demand analysis) resulting in forecasts of stored water (energy), which can be used to understand potential changes to lake levels (Figure 1). The Meridian modelling indicates the following.

Modelled First Year of Eased Operation (2026)

- Under eased conditions of operation, typically lake levels are held lower, but still within the normal operating range above 518 m RL most of the time, only falling below 518 m RL on occasion.
- It has been estimated that there is an approximate three (3) percent probability that lake levels in any given week will be below 518 m RL. Therefore, on average the lake level will be below 518 m RL for approximately 1.5 weeks in the first year of operation.
- It is estimated that 23 percent of the modelled hydrological sequences dip below 518 m RL in the first year. However, most instances are short in duration and less than two (2) metres below 518 m RL with only one instance greater than three (3) metres below the current consent level of 518 m RL. Of the 91 hydrological sequences modelled, 21 sequences fall below 518.0m and of these 21 sequences:
  - 9 fall between 518 – 517 m
  - 6 fall between 517 m – 516.5 m
  - 3 fall between 516.5 m – 516 m
  - 2 fall between 516 m - 515 m
  - 1 falls below 515 m
- In terms of duration, in the worst-case scenario, the lake level falls below 518 m RL in early September and does not return above 518 m RL until December. However, the likelihood of this scenario is low – approximately 1 percent (1 of the 91 hydrological sequences modelled).

Modelled Subsequent Years of Eased Operation (2027 and 2028)

- The pattern is broadly the same in subsequent years although the probability of falling below 518 m RL in any given week increases very slightly to 3.5 percent in 2027 and 4 percent in 2028.

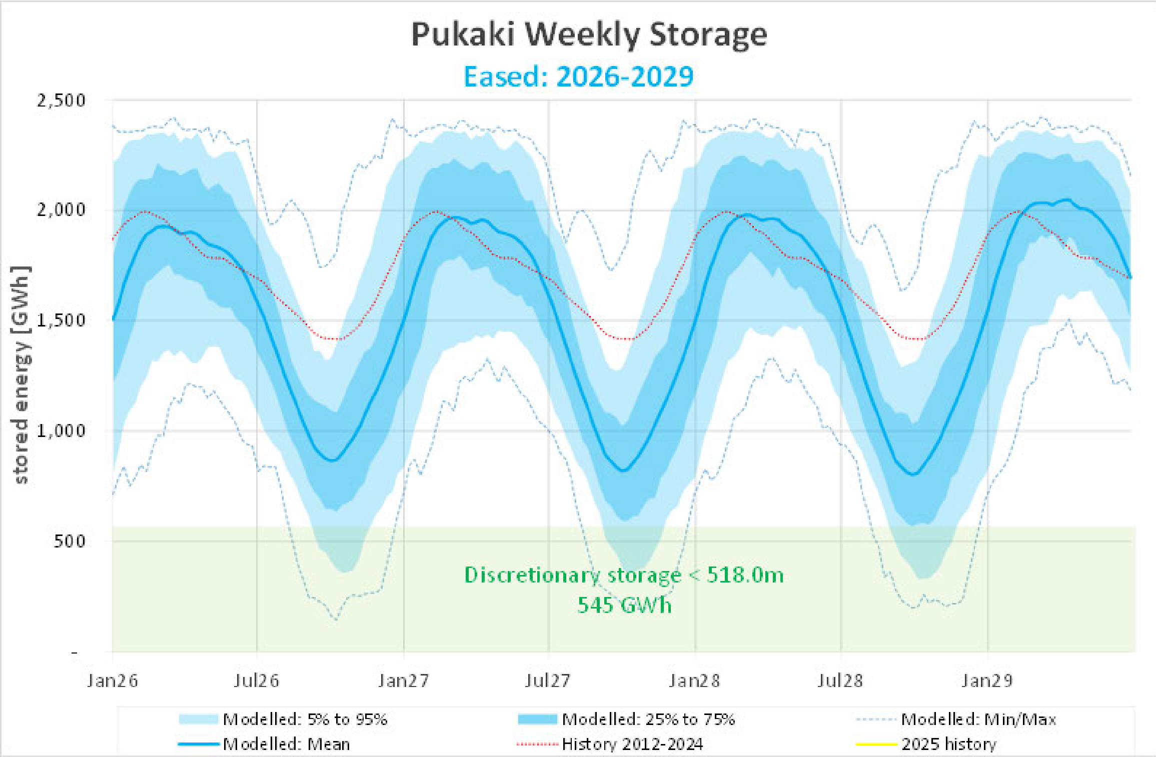


Figure 1 ***Meridian (2025) modelling results for stored lake water***

2.2 Plan Change 1

The PC1 application stated:

- The duration of an event (time below 518 m) is likely to be between 4 to 7 months, with 7 months being an extreme scenario. Refilling of the lake to return above 518 m RL was by late December and sometimes into early January.
- The rate of drawdown of lake levels was estimated to be 1.5 m to 3 m per month in low flow conditions.
- The PC1 application did not consider the frequency of lake levels going below 518 m RL.

3. Site description

3.1 Location

Lake Pūkaki is located in the South Island of New Zealand and makes up part of the Mackenzie Basin. It is located approximately 200 km west-southwest of Christchurch, in the middle of New Zealand's South Island and almost directly south of Mount Cook (Aoraki), as shown in Figure 2 and Figure 3.

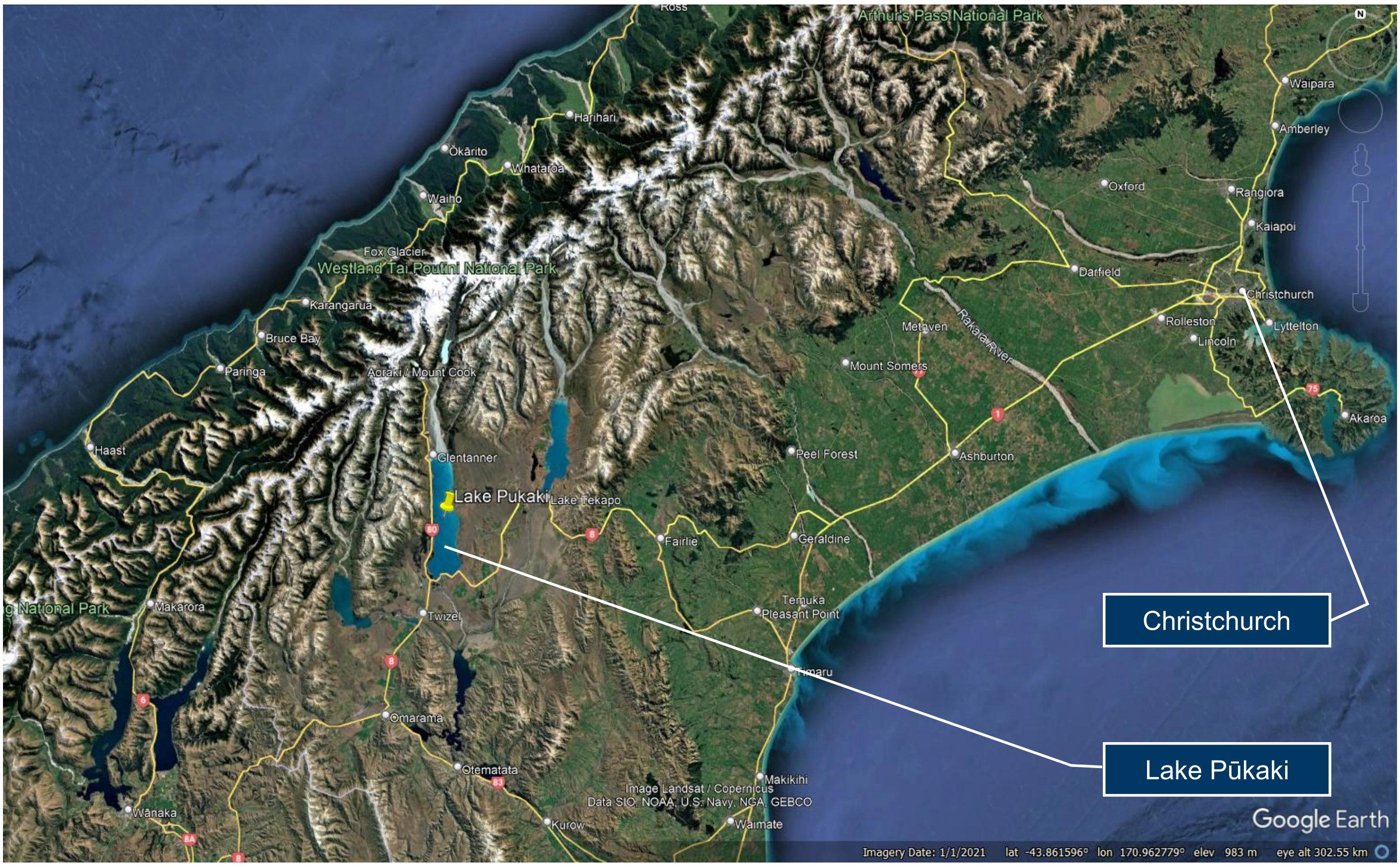


Figure 2 Location of Lake Pūkaki with respect to other locations on the South Island of New Zealand (Source: Google Earth)

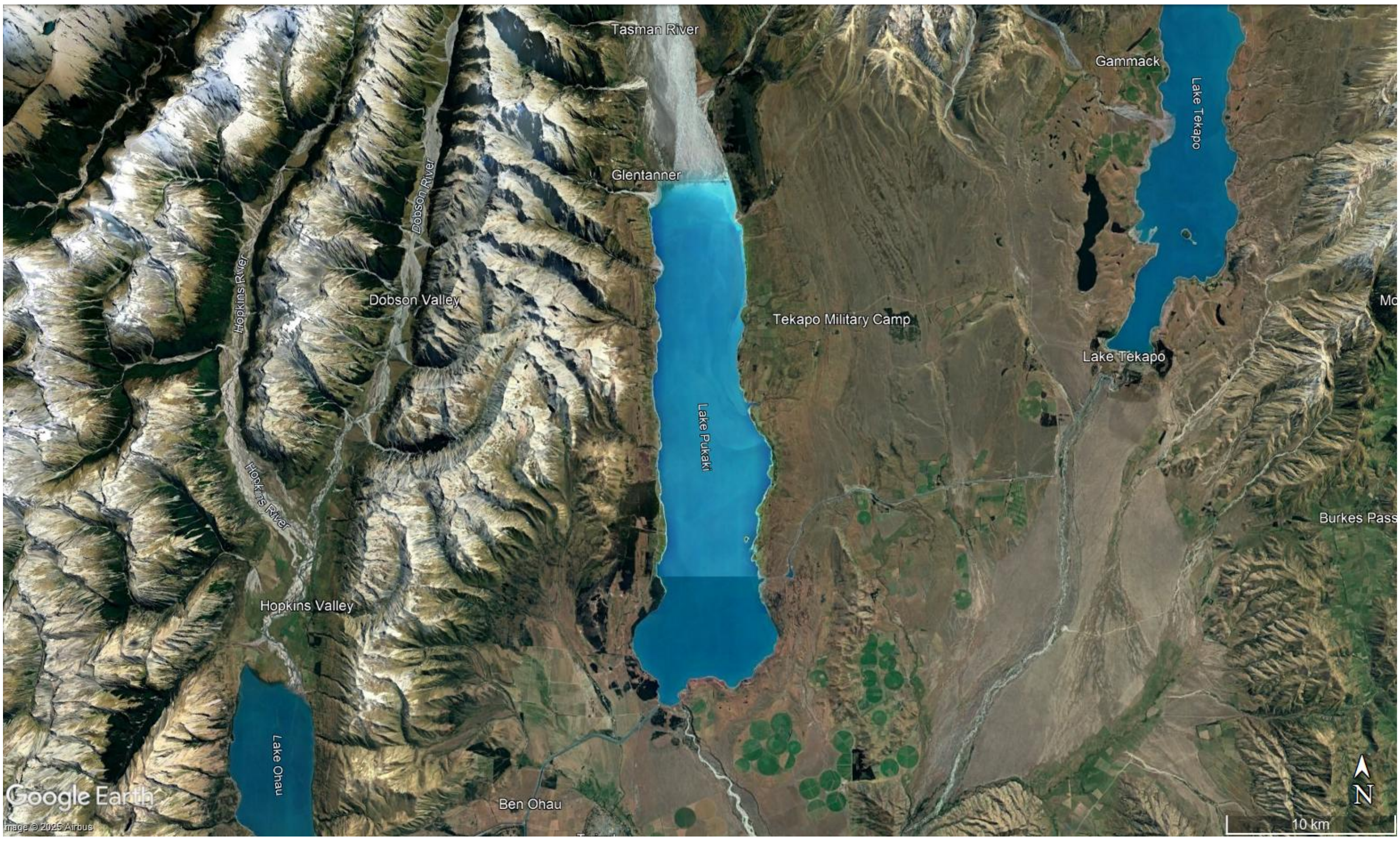


Figure 3 Location of Lake Pūkaki (Source: Google Earth)

3.2 Pūkaki High Dam location

The dam is located at the southern end of the lake. The nominal flow direction in the lake is from north to south, with water discharging from the lake via Gate 18 (into the Pūkaki canal) or Gate 19 into the Pūkaki River.

3.3 Lake dimensions

In general terms, Lake Pūkaki is approximately 30 km long (north to south) and 5 km wide (east to west). It is approximately rectangular in shape.

The lake sits at the southern end of the Tasman River delta, which is comprised primarily of glacial till and sediments. The lake comprises a surface area of approximately 172 km² based on an average lake level of 528 m RL and an estimated water volume of 5,604,000,000 m³ (5.6x10^9 m³) (Opus International Consultants Limited, 2002).

For the current minimum allowable lake level under normal operating conditions of 518 m RL, the lake water surface level is estimated to be approximately 155km². This equates to a rectangular lake shape with length of 28.5 km, and width of 5.44 km. The exact perimeter of the lake is extremely complicated to quantify due to the fluctuating nature of the lake levels and the morpho-dynamics of the lake and its tributaries. However, Single (2022) reported that the shoreline length (or perimeter) of Lake Pūkaki was 84.6 km, with a maximum lake length of 30.8 km and a maximum lake width of 8.4 km.

3.4 Lake levels

Under resource consent CRC905321.7, Meridian is authorised to dam the Pūkaki River to control and operate Lake Pūkaki between the levels of 518 m RL (normal consented minimum lake level) and 532.5 m RL (maximum consented storage level). There are various operational procedures in place to manage the lake between these levels, all of which are beyond the scope of this assessment. The proposal seeks to ease the restrictions applied to the current operating regime as described in Section 2.

4. Review of supplied information

Meridian supplied a range of documents pertaining to the operations, existing conditions, previous environmental studies, and proposed changes. A total of 116 documents were key word searched with documents identified as being of high relevance being reviewed in more detail regarding information about air quality and/or able to inform air quality studies.

A summary of key information relevant to the assessment of wind erosion and dust at lake Pūkaki is provided below.

4.1 Dam level

The proposed minimum operational dam level of 513 m RL is the lowest the dam has operated since 1978, when the high dam was commissioned, as shown in Figure 4.

A higher resolution graph of the lake level over the past 10 years is shown in Figure 5. Annual peak level occurs in the first third of the calendar year, with minimum levels around July/August. The greatest maximum-to-minimum difference occurred in 2020 with a change in lake level of approximately 11 m. The average maximum-to-minimum difference across the 10 year period shown Figure 5 is approximately 7.5 m.

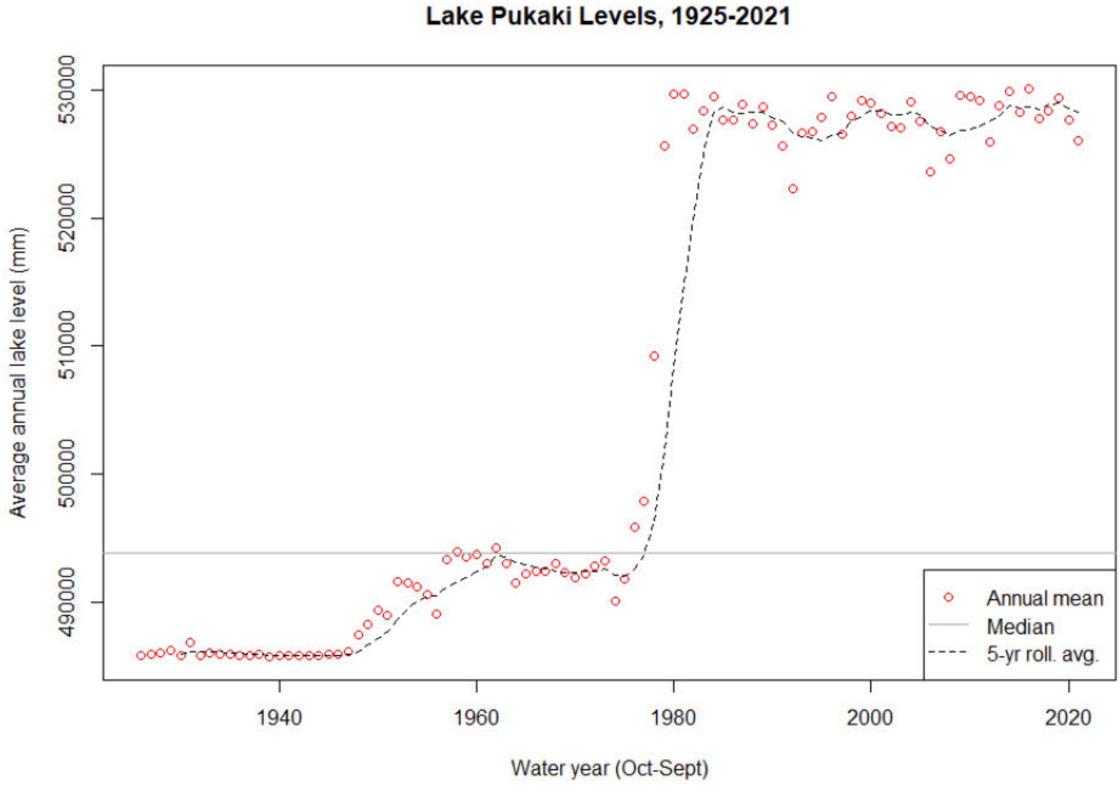


Figure 2-4: Mean annual lake levels in Lake Pūkaki from 1925 to 2021. The Pettit (1978) test identified 1975 as the year after which the central tendency of the data changed. This step change reflects the change in operations whereby the targeted operational level in Lake Pūkaki was raised by 37 m and later achieved by November 1978.

Figure 4 Historical Lake Pūkaki levels – 1925 to 2021 (National Institute of Water & Atmospheric Research Ltd (NIWA 2024)

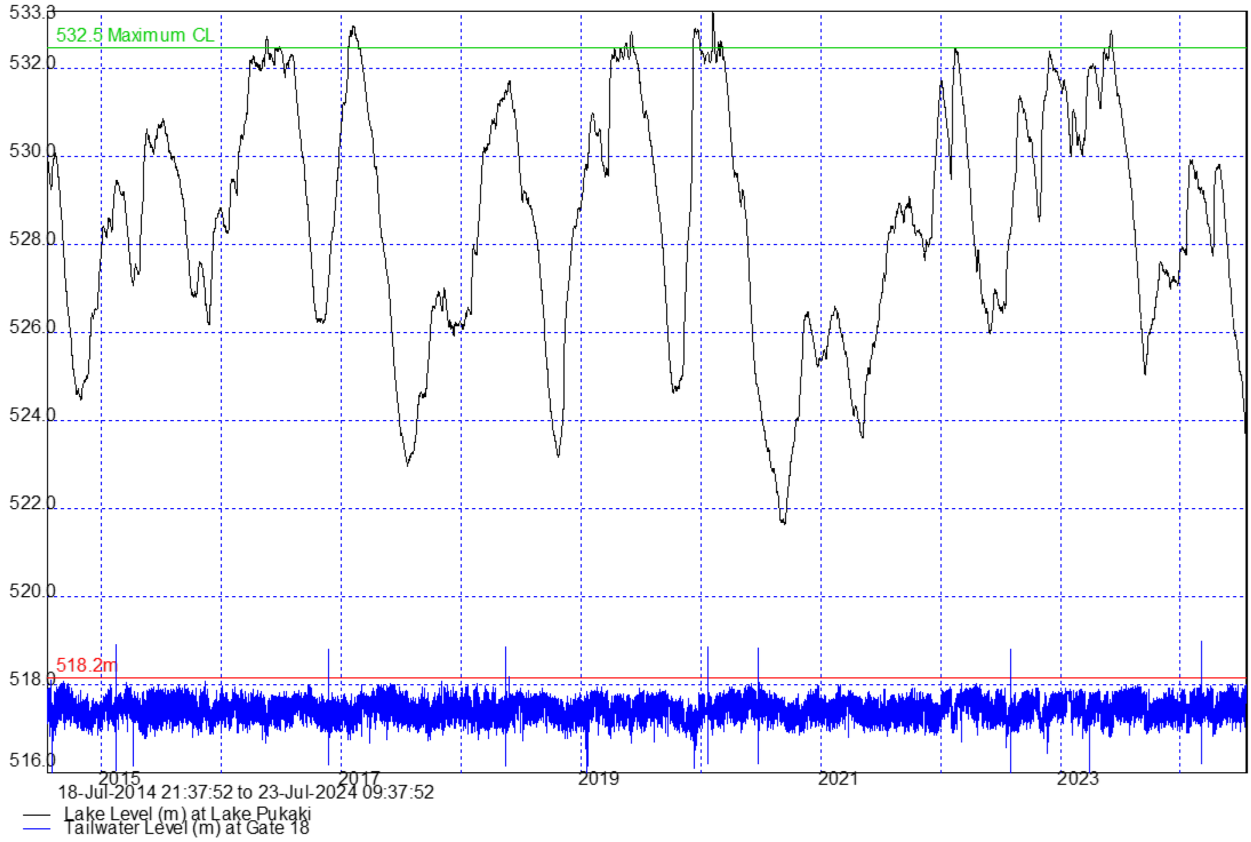


Figure 5 Lake Pūkaki levels – 2014 to 2024 (Stead, 2024)

4.1.1 Control levels under Normal Operating Controls

Lake Pūkaki Spillway, Operating Instruction No. 25, Amendment B February 1981 states the following.

- Design Flood Level 534.10 m
- Maximum Control Level (MCL) – September to April 532.00 m
- Maximum Control Level – May to August 532.50 m
- Minimum Control Level 518.20 m
- Extreme Minimum Control Level 518.00 m

4.2 Lake area/volume with lake height

Meridian supplied information relating to the variation of lake area and volume with respect to lake level. This information, derived from satellite imagery, has been processed into a function that relates lake water level to lake water surface area, shown in Figure 6.

Using the relationship shown in Figure 6, reducing the lake water level from 518.0 m to 513 m will result in approximately 9.55 km² of reduced water surface area, or additional lake shoreline exposed area. This is consistent with the information provided in the Jeff Bluett advice (refer to Section 4.5.1).[2]

Compared to the historical average lake level of 528 m RL, the current minimum lake level of 518.2 m RL exposes 17.2 km² of shoreline, which would increase to 27.1 km² for the proposed minimum lake level of 513 m RL.

[2] Jeff Bluett advice states 9.5 km² of extra shoreline exposed, corresponding to the difference between 513 and 518 m. This is considered to be consistent with the advice provided by Jeff Bluett (Section 4.5.1).

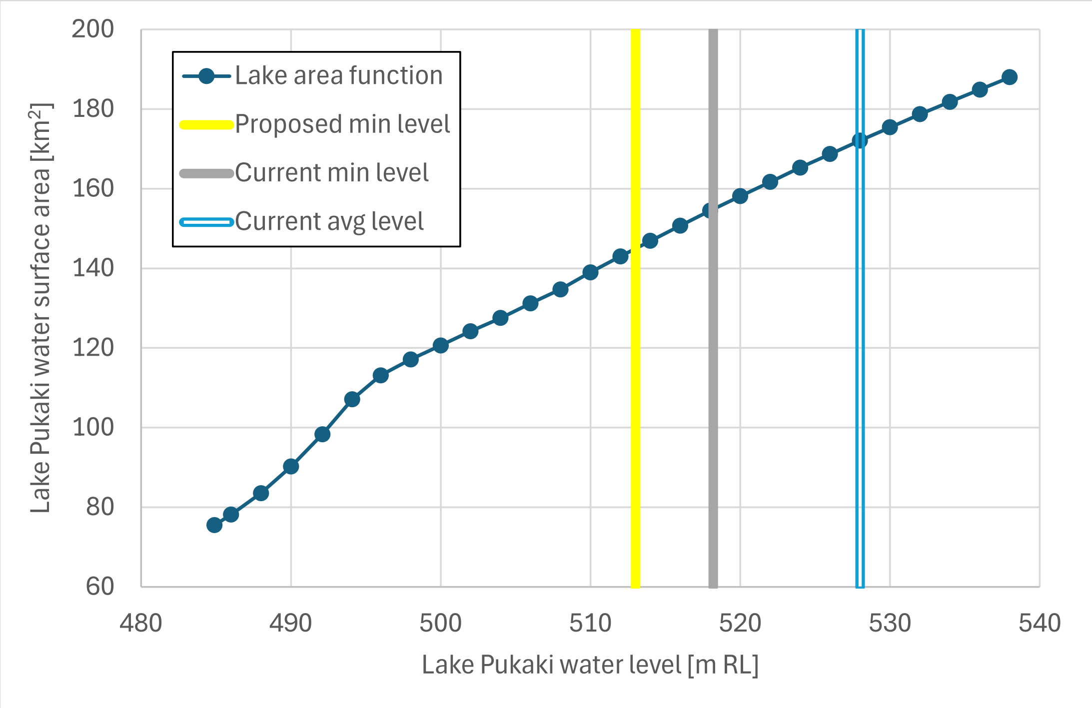


Figure 6 ***Lake Pūkaki water surface area function with lake level. Source: Lake Pūkaki and Lake Tekapo area/volume curves derived from satellite imagery, January 2002. Report prepared by Opus International Consultants Limited for Meridian Energy. Document: Reference: 39c186.u2. 14 January 2002. Section 4.2, Table 2***

4.2.1 Lake lowering rate

Based on the recent lake levels, shown in Figure 5, a linear lake lowering rate of approximately 1.7 m per month was calculated (as indicated by the red lines in Figure 7). Conversely, when the lake level increases, it typically occurs at a similar rate (i.e., 1.7 m per month rise). These rates are consistent with the rates of lake level recession that were presented in the PC1 hearing. The modelling presented by Meridian (2025) indicates that the frequency, magnitude and duration of lake levels falling below 518 m RL and then recovering are likely to be less significant than presented at PC1, with a worse-case modelled scenario (i.e. approximately one percent probability of occurrence) indicating a lake level below 518 m RL (falling below 515 m RL) with a duration of up to four months.

For the purposes of this assessment a conservative approach was adopted to both magnitude and duration. For the assessed single year of meteorology, it was assumed that the eased restrictions will result in a lake level below 518.0 m for six months of the year, across the winter and spring period. Therefore, the assumed lake level change across a year adopted for this assessment is shown in Figure 7. The minimum lake level was set at 513 m, occurring on 1 August. The current control level of 518.0 m was assumed to be breached on 1 May, with a return to this level on 1 November.

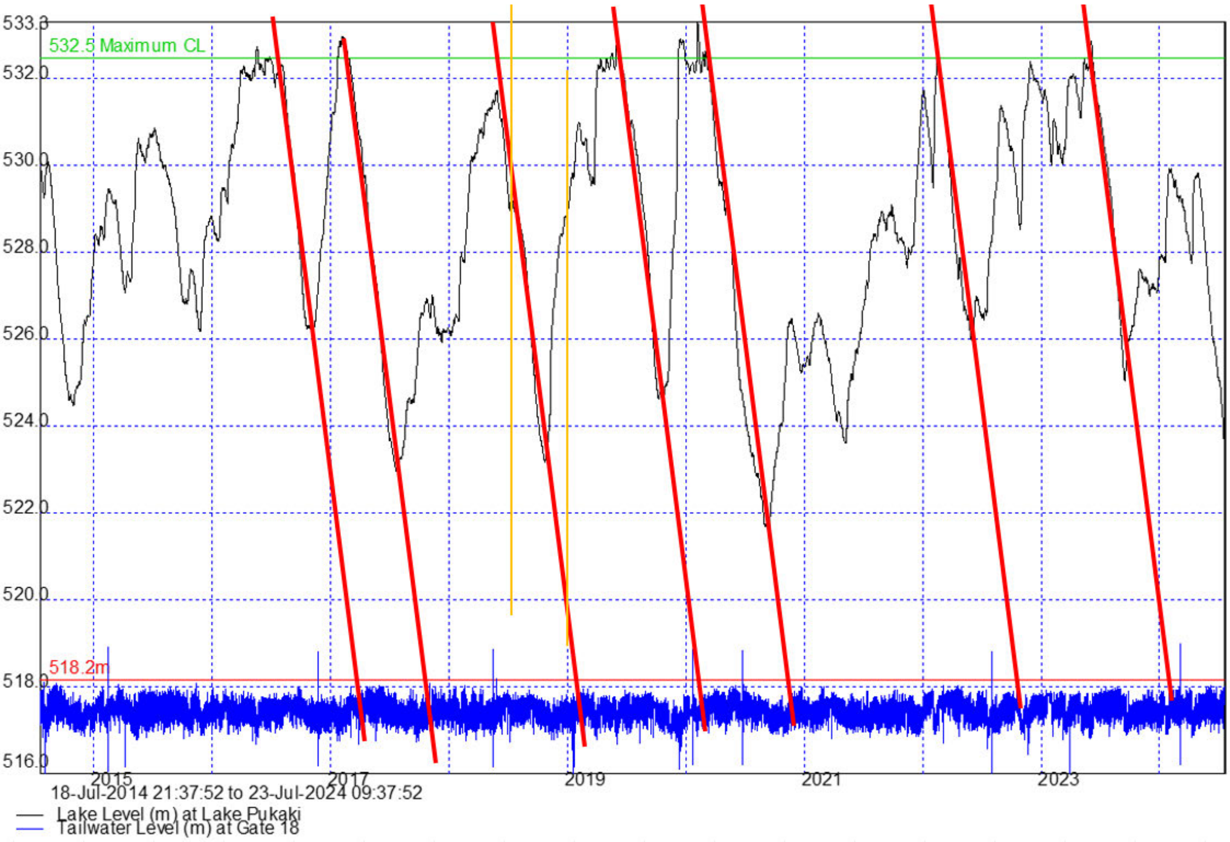


Figure 7 Lake lowering rate lines shown in red

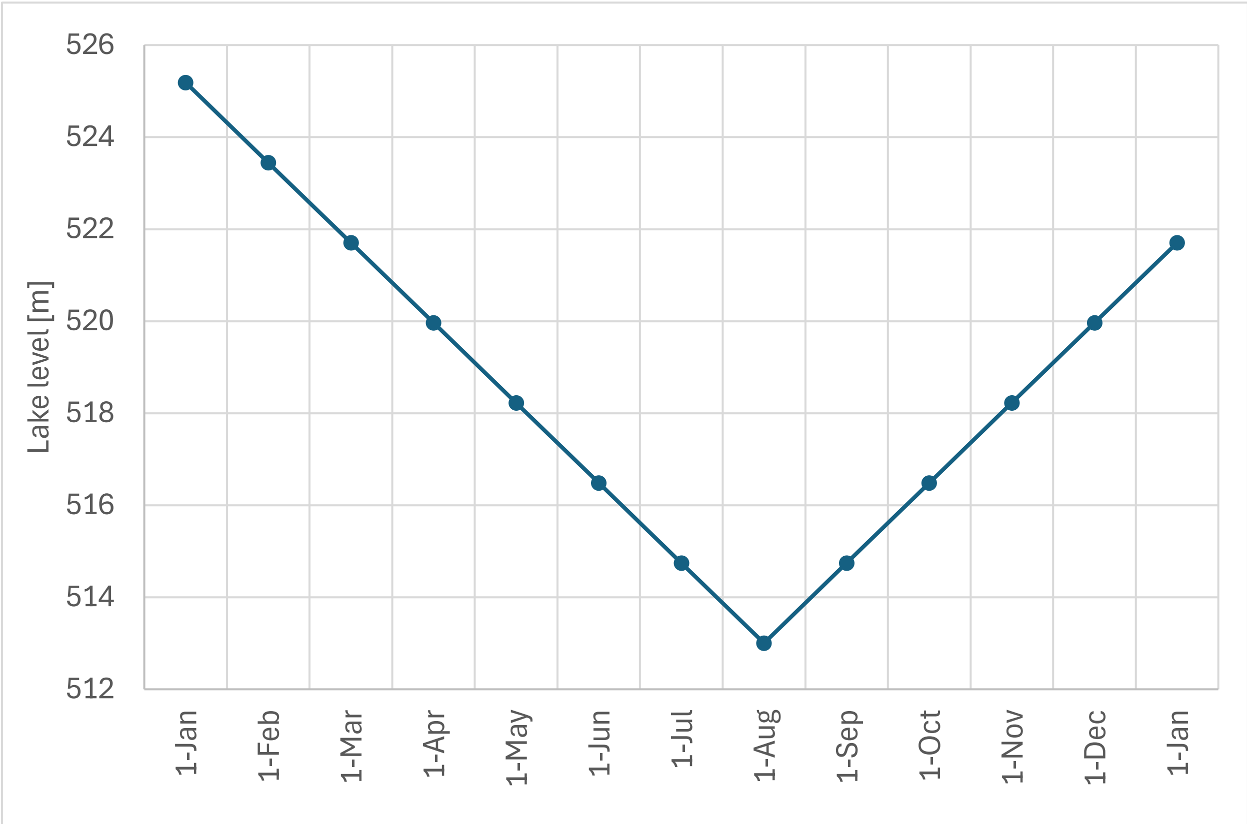


Figure 8 Modelled lake level change with time.

4.3 Climate change

Based on reviewing supplied documents relating to climate change impacts, the annual impact appears to be minimal, especially in the short term. There have been identified seasonal trends due to differing climate patterns such as El Nino, Southern Annular Mode, etc., however, with regards to lake inflows and catchment rainfall, decreases in one season appear to be offset by increases in another, i.e., little net annual impact (National Institute of Water & Atmospheric Research Ltd (NIWA, 2024).

Therefore, given the short duration of the proposed lower lake levels, the impact of climate change is expected to be negligible.

4.4 Amenity

The landscape and visual amenity of the Pūkaki Dam, lake and surrounding environs is described by Goodfellow (2025), which is appended to the Substantive Application. The landscape assessment by Goodfellow (2025) stated that the MacKenzie Basin is recognised an an Outstanding Natural Landscape in the Canterbury Regional Landscpe Study 2010, and notes that the Waitaki Power Scheme (which includes Pukaki Dam) does not detract from the scale or quality of the Mackenzie Basin.

A document prepared by landscape architect Stephen Brown (March 2024) (Brown, 2024) described the Mackenzie Basin and Pūkaki Lake area as:

– *“Aesthetic Values*
  - *The vast basin, large river valleys and enclosing mountain ranges form a dramatic and spectacular landscape. While some parts of the basin have been substantially modified by residential, hydro and agricultural development, the basin as a whole retains its openness and largely coherent character.*
  - *Impressive views up the wide u-shaped valleys to the snow and ice covered peaks of the Alps are experienced from the basin.*
  - *Pūkaki* [sic] *and Tekapo reflect a striking milky-blue colour in sunlight. They form an integral part of one of the most memorable landscapes in the country.*
  - *The golden tussock-laden slopes which surround the basin have high aesthetic values.*

– *Transient Values*
  - *Snow coats the ranges and basin floors during much of the winter months.*
  - *The distinctive turquoise colour of the lakes in sunny conditions is spectacular.*
  - *Nowhere else in the country can the effects of 'norwester' weather patterns and the rainfall gradient from west to east be as vividly experienced as in the Mackenzie Basin.”*

4.5 Jeff Bluett evidence August 2012

In August 2012, air quality scientist Jeff Bluett provided expert advice to Meridian with regards to Plan Change 1 to Waitaki Catchment Water Allocation Regional Plan. The advice was in regard to “*the increased potential for dust storm effects associated with lowering the minimum level of Lake Pūkaki to 512 [sic] metres above sea level (masl).”* The advice consisted of the following.

– Description of the processes and sources which generate dust storms in the Lake Pūkaki basin
– Summary of the outcomes of a sediments survey of the head of Lake Pūkaki
– Description of the receiving environment potentially impacted from Lake Pūkaki dust storm events
– Outline four main potential adverse effects that can be created by dust storms in the Pūkaki Basin
– Detailed the meteorological risk factors for dust storms
– Detailed the hydrological risk factors for dust storms
– Investigated the influence that lowering the lake level will have on the frequency, duration and intensity of dust storms

– Assessed the potential adverse effects of increased dust storm intensity
– Summarised dust related issues raised by submitters on the plan change
– Discussed dust relevant planning issues from Environment Canterbury's Proposed Policy Statement and the Waitaki Water allocation plan

The advice provided by Bluett (2012) was extensive and upon review is still considered to be valid for the current proposal. Some pertinent information regarding this assessment is summarised below.

It is understood by GHD that the Bluett (2012) evidence has never been made publicly available. The above summary, immediately below additional details and subsequent sections in this document (Sections 5.9, 5.10, 5.11 and 5.12) are extracts of this Bluett (2012) evidence. Authorship of information is attributed to either Jeff Bluett or GHD where appropriate.

4.5.1 Increased lake bed exposure

Bluett (2012) found that lowering of the minimum lake level from 518 to 513 m and the resultant reduction in water area will result in approximately 9.5 km² of lake bed being exposed that would otherwise be under water. It was estimated that 6 km² would be from the Tasman River delta and the remaining 3.5 km² from the remaining lake foreshore.

4.5.2 Dust storms

Bluett (2012) states that "*dust storms are natural events that form an integral component in the evolution of the landscape. Historically, dust storms have been instrumental in the formation of extensive loess deposits that cover the eastern South Island. However, dust storms are currently confined to geomorphically active areas in the landscape where unconsolidated surfaces are exposed to strong winds, such as the inner mountain basins and river valleys of the Southern Alps.*"

The sources of the dust storms are the dry braid channels of the Tasman River, the exposed lacustrine delta of the Tasman River at the northern end of the lake and numerous smaller river deltas that enter Lake Pūkaki at points along the eastern and western lake shores.

Fine sediments are deposited onto these areas by "*fluvio-galcial processes"*, which varies diurnally and seasonally with rainfall and snowmelt.

Minor sources of dust, particularly for locations in close proximity to the source are "*degraded tussock grasslands, gravel roads, scree slope and lakeshore cliffs*."

4.5.2.1 Dust storm criteria

Bluett (2012) identified from previous studies (McGowan et al. 1995) that dust storms usually occurred during moderate to strong "foehn wind" events, defined as wind speeds greater than 10 m/s. This has been adopted as an assessment metric for this study (Section 10.7). An additional metric was added for dust storm potential by Bluett in that the high wind conditions had to occur for a period of at least two hours, which was also adopted in this assessment (Section 10.7).

Bluett (2012) identified these events as "*typically associated with warm ambient air temperatures and low humidity, which promote the drying of the surface sediments and increase their susceptibility to entrainment by the wind."*

4.5.2.2 Dust size

Bluett (2012) stated, based on McGowan et al. (1995), that the primary particulate size in dust storms was between 7 to 63 μm.

4.5.2.3 Rainfall

Bluett (2012) found that rainfall has two opposing effects on dust storm prevalence. Firstly, rainfall wets the surface silt and therefore suppresses its tendency to become airborne during high wind events. However, it is equally responsible for the river flood events which deposit the silt in the lake regions once the flood water recedes, becomes exposed to the wind. Bluett (2012) conclude that "*following a flood there is an increased risk of a dust event due to the greater amount of silt material available to be entrained by winds.*"

4.5.2.4 Meteorological risk

Bluett (2012) identifies that the combination of wind speed and low rainfall risks lead to spring and summer as being the highest risk periods for dust storms, insofar as there is more chance of a rainfall/flood event that deposits silt, followed by a combination of warmer temperatures and foehn winds that both dry and entrain the deposited silt. Bluett (2012) states that "*anecdotally dust storms occur most frequently in spring*."

4.5.2.5 Lake level

Bluett (2012) identified that a lower lake level will increase the risk of dust storms. The provided advice went further in identifying that the lowest lake levels will tend to occur during the end of winter to early spring, with lake refilling during spring/summer and peaking in March/April.

4.5.3 Potential impact of dust storms

4.5.3.1 Human health

Bluett (2012, cl.12.3) provided advice that the prevalence of dust storms and any increased frequency or intensity of the storms were unlikely to impact human health.

4.5.3.2 Stock health

Bluett (2012, cl.12.8) provided advice that increased dust storm activity would be unlikely to affect the lungs or eyes of stock within the area.

4.5.3.3 Amenity and nuisance

Bluett (2012) stated that during a dust storm event, with a lower lake and potentially a more intense storm, visual amenity would be degraded more than currently occurs.

Additionally, there was likely to be greater nuisance dust deposited into the wool of sheep around Lake Pūkaki due to a lower lake level, however, Bluett was unable to quantify the impact.

5. Dust generation

This assessment is limited to dust generated as a result of wind erosion from exposed lake shore surfaces.

5.1 Geology

The Tasman River delta, which is the primary source of water for Lake Pūkaki, is fed sediment from the Tasman Glacier.

Glacial till, defined as unsorted sediments deposited directly by a glacier and moraines (accumulations of rock debris along the glacier edges) dominate the sediment load. As the glacier retreats, large quantities of gravel, sand, and silt are carried downstream, forming braided river systems.

The Tasman River is a braided river, characterised by multiple interwoven channels. This morphology reflects high sediment loads and fluctuating water flows. The river deposits layers of gravel, sand, and finer sediments, which are redistributed by water flows and seasonal flooding.

The delta itself is an active depositional environment, with new material constantly added from glacial meltwater and tributaries. The sediment is primarily composed of greywacke, schist, and other rocks derived from the Southern Alps. Grain sizes range from coarse gravels and rocks near the glacier to finer silts and sands further downstream.

The delta is highly dynamic due to the interplay of glacial retreat, sediment supply, and water flow. Seasonal variations, heavy rainfall, and periodic floods results in a continual supply of new sediments to the delta and Lake Pūkaki.

5.2 Dust generation mechanisms

There are multiple methods by which dust can be generated. Small particles can be dislodged through aerodynamic induced forces and stresses. Another method, known as saltation, involves small particles being dislodged when larger particles, entrained by wind shear stresses, fall back to ground (shown in Figure 10).

The potential for long-term, long-distance entrainment of a particle depends on its size, or equivalent aerodynamic diameter (EAD), which also accounts for particle density. A pictorial representation of the different modes of dust entrainment is shown in Figure 9.

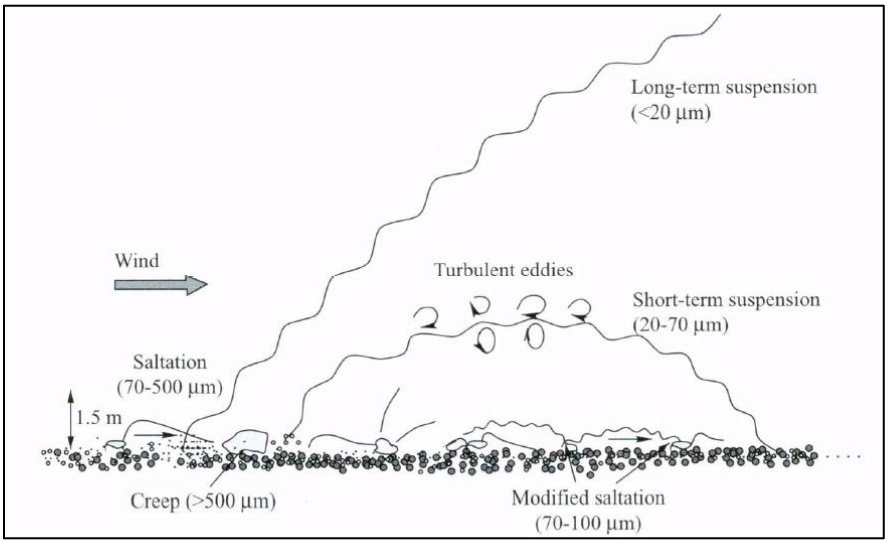


Figure 9 ***Different types of sand particle motion that can occur during wind erosion (Source: NFPA 2011)***

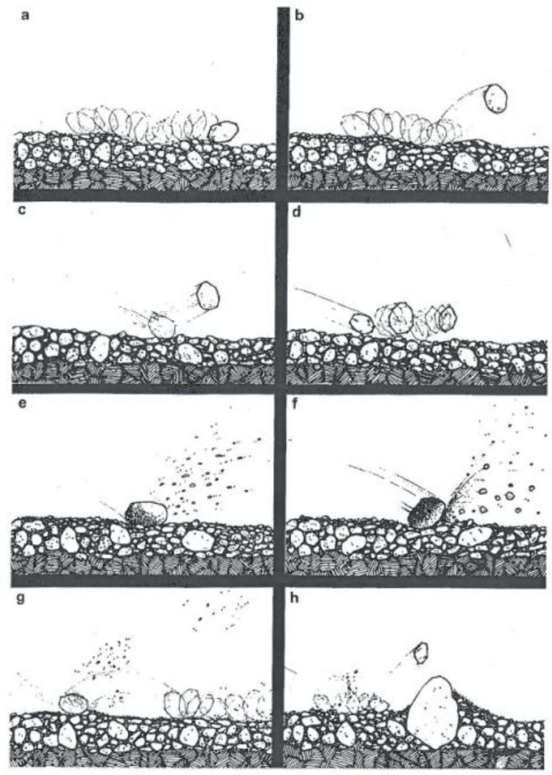


Figure 2.10 Production of fine particles (After Gillette, 1981)

Figure 10 Production of fine particles through saltation impact, from Jia (2011)

5.3 Threshold friction velocity

The threshold friction velocity, U^*_t, is the minimum induced shear stress that can dislodge a dust particle. A typical threshold curve representative of many reviewed sources is shown in Figure 11. The long-term suspension zone shown in Figure 9 is the critical area for long range transport of dust. However, Figure 11 below does show that larger particles can be dislodged at a lower friction velocity but will not be transported long distances. Upon landing the impact can dislodge smaller particles that will remain in suspension in the wind, (i.e., long range transport).

The threshold friction curve shown in Figure 11 is consistent with the observations of dust entrainment concentrations measured in desert areas, as shown in Figure 12. Dust can be measured with friction velocities lower than 0.2 m/s, but increases substantially when the friction velocity reaches 0.4 m/s.

For very small particles, cohesive forces (van der Waals and electrostatic forces) dominate, requiring higher friction velocities than for larger, sand-sized particles.

There are known sources of threshold friction velocity, for example, AP42, shown in Figure 13. However, most of the published values are for either sand or coal and not specifically for glacial till.

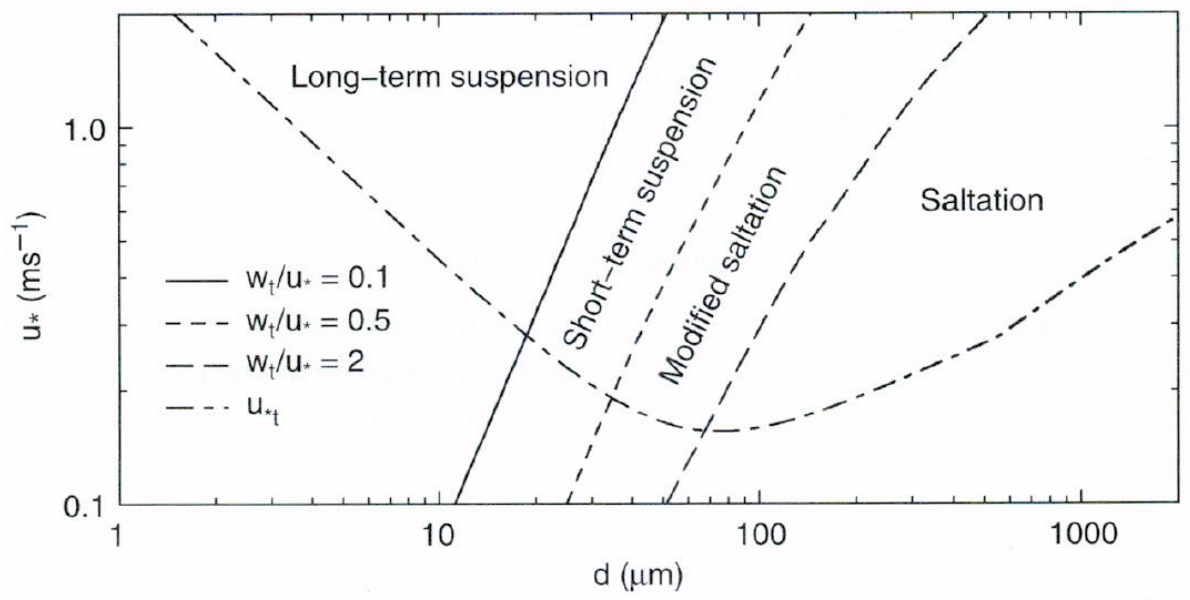


Figure 11 ***Threshold friction velocity and suspension modes for wind erosion of sand, density = 2.5 g/cm³. Source: NFPA 2011***

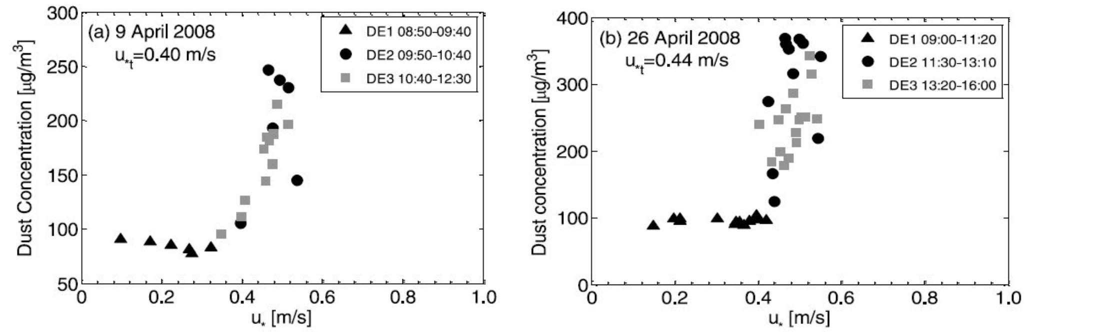


Figure 8. Variations in dust concentration with friction velocity u_* during the DE1, DE2, and DE3 periods in the local dust emission events over the Gobi area on (a) 9 April and (b) 26 April 2008.

Figure 12 ***Measurements of airborne dust concentrations with friction velocity from Li and Zhang (2010)***

Table 13.2.5-2 (Metric Units). THRESHOLD FRICTION VELOCITIES

Material	Threshold Friction Velocity (m/s)	Roughness Height (cm)	Threshold Wind Velocity At 10 m (m/s)	
			z_o = Act	z_o = 0.5 cm
Overburden[a]	1.02	0.3	21	19
Scoria (roadbed material)[a]	1.33	0.3	27	25
Ground coal (surrounding coal pile)[a]	0.55	0.01	16	10
Uncrusted coal pile[a]	1.12	0.3	23	21
Scraper tracks on coal pile[a,b]	0.62	0.06	15	12
Fine coal dust on concrete pad[c]	0.54	0.2	11	10

[a] Western surface coal mine. Reference 2.
[b] Lightly crusted.
[c] Eastern power plant. Reference 3.

Figure 13 ***AP42 (2006) threshold friction velocity for different materials***

5.4 Moisture content

With reference to Figure 11, for a given substance there is generally seen a rise in the threshold friction velocity curve as particle size is decreased. The literature suggested that a major factor in this rise is due to increased attractive adhesion forces between the particles, such as those enhanced by moisture. The moisture content of the soil (at 5 cm depth) for the measurements shown in Figure 12 was approximately five (5) percent (v/v). For soils with a higher moisture content, it is expected that the wind erosion rate will be lower, and therefore the threshold friction velocity higher, as indicated by the information provided in (Jia, 2011), shown in Figure 14.

There are likely other parameters involved such as, but not limited to, particle shape or binding matrix. However, control of any of the parameters over the entirety of the lake shoreline is virtually impossible.

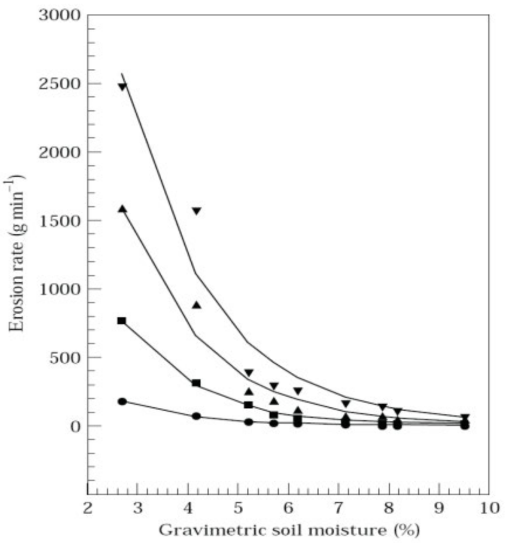


Figure 2.18 Relationship between wind erosion rate and moisture content under different wind velocity (from bottom to top) 10, 15, 20, 25 m/s (after Chen et al., 1996)

Figure 14 ***Wind erosion rates with wind speed and moisture, from Jia (2011)***

For a given moisture content and particle density, finer dust is less likely to be entrained through pure wind shear forces alone. However, once freed from a surface, finer dust will be transported longer distances than larger particles. Therefore, the determination of a single threshold friction velocity, which relates to wind erosion, has to balance the different mechanisms of dust generation, namely pure aerodynamic dust entrainment and saltation dislodgement.

AP-42 recommends friction velocity values of 0.55 m/s for ground coal and 0.54 m/s for fine coal. However, for fine glacial till particles the application of a lower threshold friction velocity value of 0.4 m/s has been adopted. This is considered to also include the effects of saltation impact dislodgement of finer particles that can be moved with lower wind speeds.

A threshold friction velocity of 0.4 m/s corresponds to a particle diameter of 20 µm being held in long term suspension as per Figure 15.

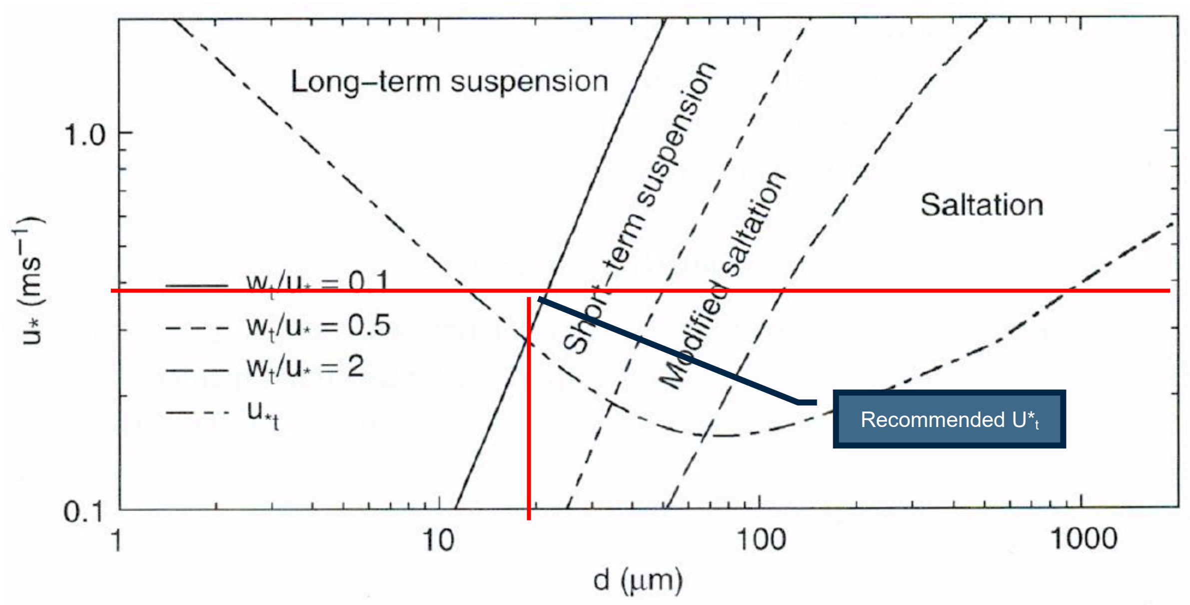


Figure 15 *Threshold friction velocity analysis (Source: NFPA 2011)*

5.5 Erosion potential

The Australian National Pollutant Inventory (NPI Mining Emissions Estimation Technique Manual Version 3.1 January 2012) uses the AP-42 method to estimate the erosion potential for stockpiles. Relevant extracts are provided below.

> Once the friction velocity and threshold friction velocity have been determined, the erosion potential for a dry, exposed surface can be calculated using the following equation:

> **Equation 2**
>
> $$P = 58(u^* - u_t)^2 + 25(u^* - u_t) \text{ for } u^* \geq u_t$$
>
> $$P = 0 \text{ for } u^* \leq u_t$$
>
> where:
>
> P = erosion potential (g/m²)

Source: AP-42 Section 13.2.5

This equation has been used as a measure of wind erosion potential. Results from this equation have been combined with the NPI default wind erosion emissions factor of 0.4 kg/hectare/hour for total suspended particulate dust. (NPI Mining Emissions Estimation Technique Manual Version 3.1 January 2012, Appendix 1.1.17).

5.6 Crusting

5.6.1 Crust formation

Vos et al. (2020) provides a significant reference list of studies regarding wind erosion and crust formation, mostly from and for agricultural purposes generated by rainfall events and none with glacial till.

A common feature of all crust formation is the application of a wetting agent, in particular water. (Vos et al., 2020) Vos et al. (2020) examined differing quantities of water application, followed by crust formation (drying) and then exposure to wind. In summary, the experimental measurements found that once a crust had formed, the wind erosion dust emissions were virtually zero – less than 0.3 percent of the non-crusted surface – with a threshold friction velocity unmeasurable due to the emissions being so low.

Crust formation of any significance for wind erosion prevention can only occur when an agent has been applied, and then allowed to dry, thus forming the crust. For the Vos et al. (2020) study, a nominal 15 mm of water was applied at a rate of 100 mm/h. However, a significant crust can still be formed with 5 mm of applied water. In comparison with NPI Mining (2012) recommendation of water controls, 50 percent reduction equates to 2 mm of applied water per hour.

The drying (evaporation) of an already moist shoreline is unlikely to result in significant crust formation. Vos et al. (2020) described two methods of crust formation – presence of salts and presence of fines. Both of which are redistributed across the surface with the application of water – chemical attraction and physical kinetic energy impact[3] – and forming a cohesive matrix upon water evaporation.

In the case of exposed shoreline, the effect of 'crusting' can occur when water is applied during periods of rainfall. Section 9 describes how this natural process has been applied in the modelling.

5.6.2 Crust break-up

Once a crust is formed, it can be broken up by the saltation process described in Section 5.2. Vos et al. (2020) included an abrasion process in their assessment. The authors made the following comments.

"*This important influence of abraders on dust emission has been described by many wind tunnel studies. Although the dust emission in runs with abraders is greater than without abraders, the amounts are still more than an order of magnitude smaller than those from loose surfaces. However, it might be possible that with longer duration of the experiments[4], the crusts could have been completely destroyed by abrasion and emission values could have reached the level of loose soils, as suggested by a field study on loamy sandy crusts from Goossens. Future studies on field crusts will have to focus on the longevity of the crusting-induced reduction of dust emissions.*"

Given the relative short duration of the Vos experiments in comparison with days or weeks between rainfall events[4], eventual significant crust break-up is highly likely on most areas of the exposed shoreline. Section 9 describes the assumption adopted for crust break-up in the modelling.

5.7 Dust particle size distribution

Bluett (2012) indicated that dust storm particulate sizes range between 7 to 63 μm. Measurements of Lake Pūkaki sediments by Chikita et al. (2000) are shown in Figure 16. Site A in Figure 16 is the most representative of the potential location of dust storm origin as it is located closest to the Tasman River delta and potentially in an area that could be exposed during a lake lowering event below 518 m.

Site A sediments vary between phi scale values of approximately 5.5 to 9.5 (10^{th} to 90^{th} percentiles), corresponding to particle sizes of 22 to 1.4 μm.[5] The mean phi scale value is 7.09, corresponding to a particle size of 7.3 μm. The Chikita et al. (2000) study is more conservative than the Bluett (2012) advice and therefore has been used in this assessment.

A particle size distribution profile for modelling dust dispersion and deposition has been created and is detailed in Table 2.

[3] Water was applied through 2.6 mm diameter droplets with a fall height of 5.8 m.
[4] The experiments performed by Voss ran for a maximum of 400 seconds (<7 minutes).

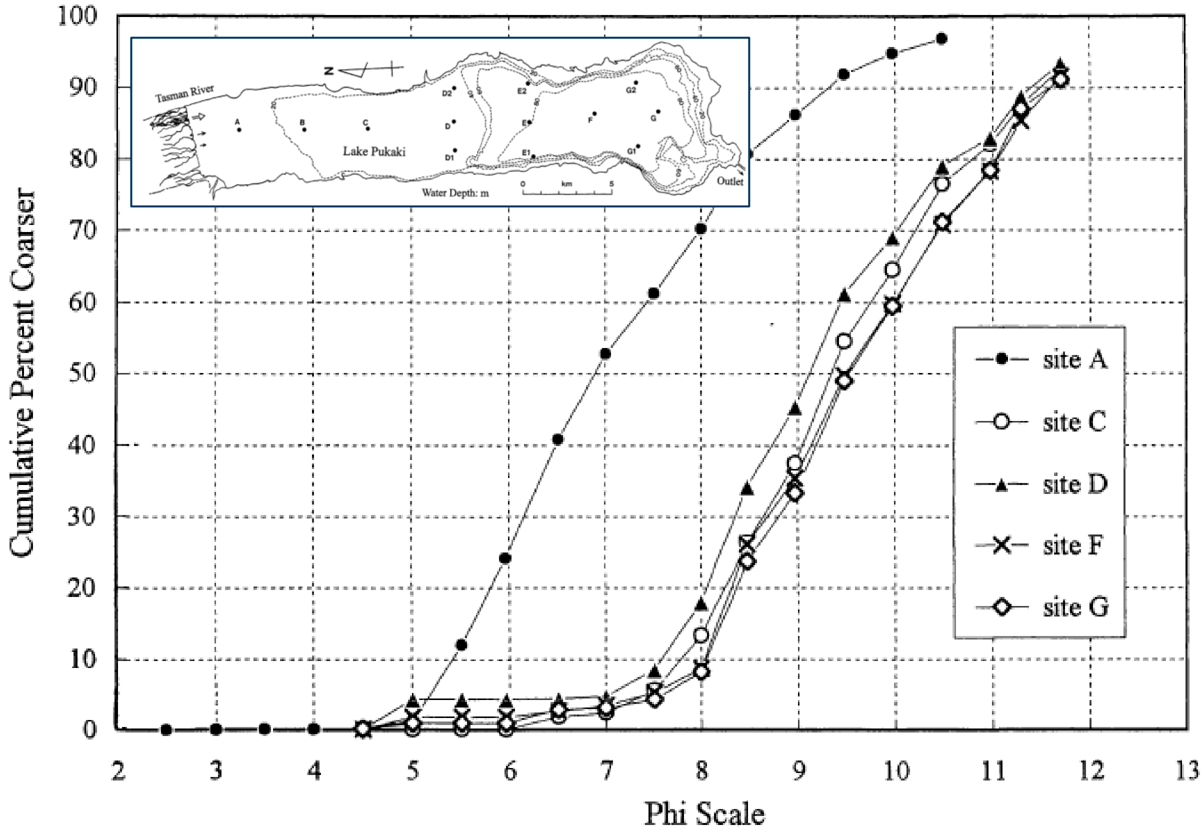


Fig. 11 Grain size distributions of lake bottom sediment sampled at sites A, C, D, F, and G.

Figure 16 ***Lake Pūkaki sediment particle size distribution. Inset image: site locations with respect to Lake Pūkaki. Site A furthest north. Site G closest to outlet (south). Size scaling based on Phi scale.[5] Source: (Chikita et al, 2000) Sedimentary environments in Laker Pūkaki, New Zealand. J.Sed.Soc.Japan, No.51, 55-66, 2000.***

[5] Phi scale. $D = D_0.2^{-(phi)}$ $D_0 = 1000$ µm. For phi = 7, $D = 1000.2^{-7} = 1000\ (0.00781) = 7.8$ µm

Table 2 Adopted PM size distribution for dispersion modelling. Based on distribution shown in Figure 16.

Modelled PM diameter [µm]	Fraction of total dust [%]	Cumulative fraction [%]	Contributes to criteria for:
1.2	23	23	$PM_{2.5}$, PM_{10}, TSP
6.3	34	57	PM_{10}, TSP
15	26	83	TSP
25	17	100	TSP

5.7.1 Particle density

Chikita et al. (2000) states that the sediment density for Lake Pūkaki is 2779 kg/m³. This value has been adopted for this assessment.

5.8 Common emissions factors

Emission factors supplied by either US EPA AP-42 or the Australian National Pollution Inventory Emission Factor Manuals (NPI) are considered acceptable factors for dust projects in New Zealand.

5.9 Dust storm generation processes and sources

The following information is extracted from Bluett (2012).

As described by Bluett (2012), dust storms are defined as the physical and meteorological phenomena occurring when "*blowing dust reduces visibility at eye level to less than 1,000 metres by dust actively raised from the surface by the wind*" (Pye 1987). Dust storms are natural events that form an integral component in the evolution of the landscape. Historically, dust storms have been instrumental in the formation of extensive loess deposits that cover the eastern South Island. However, dust storms are currently confined to geomorphically active areas in the landscape where unconsolidated surfaces are exposed to strong winds, such as the inner mountain basins and river valleys of the Southern Alps.

McGowan et al. (1995) describe three principal sources of windblown dust exist within the Lake Tekapo basin. The principal sources of windblown dust in the Lake Pukaki basin are geo-physically very similar to those found in the Lake Tekapo basin. So, the findings of McGowan et al. (1995) are used to describe the three principal sources of windblown dust that exist within the Lake Pukaki basin. These sources are: the dry braid channels of the Tasman River (a fluvio-glacial river), the exposed lacustrine delta of the Tasman River, which enters Lake Pukaki at the northern shoreline; and numerous smaller river deltas, which enter Lake Pukaki at points along the eastern and western lake shores.

Figure 17 shows a satellite image of the northern end of Lake Pukaki and indicates the three principal types of dust sources. Lake Pukaki's shoreline is principally composed of pebbles, cobbles and boulders, which are not susceptible to entrainment by wind. Additional, but less significant sources of dust also exist in the basin. These include; degraded tussock grasslands, gravel roads, scree slope and lakeshore cliffs. While these sources may only contribute a small part of the total dust budget they may be of importance at sites in close proximity to the source.

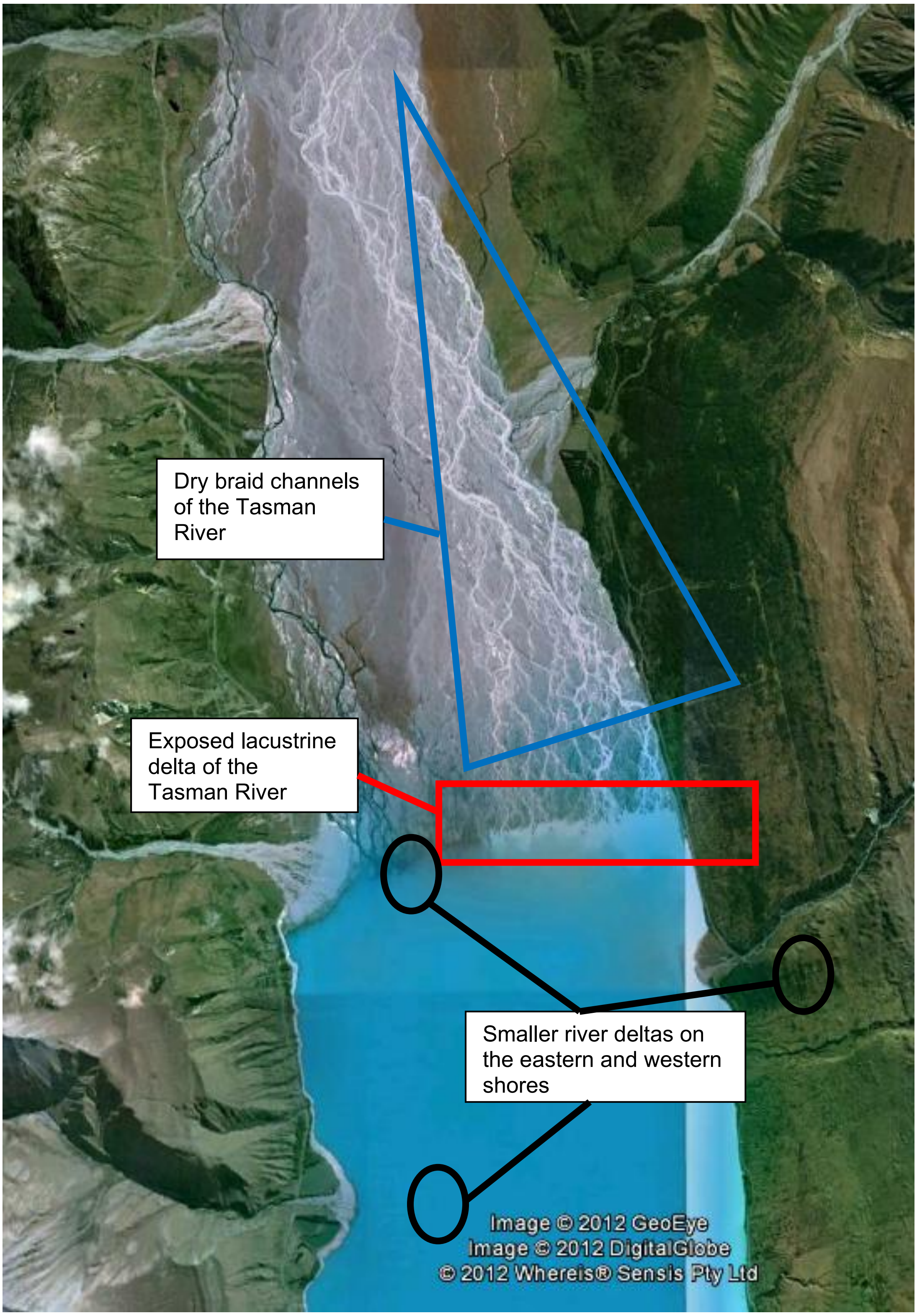


Figure 17 *Northern End of Lake Pukaki indicating the three principal types of dust sources. (Bluett, 2012)*

The exposed braided riverbed of the Tasman River provides an environment suited to the supply of fine sediment. Bluett (2012) estimated that approximately 40 km^2 of alluvial riverbed is exposed when the level of Lake Pukaki is at 526 m. The supply of sediment to these fluvial systems varies significantly diurnally and seasonally in response to rainfall and snowmelt. Flood events deposit silts and fine sands in low energy environments such as back waters, stranded stream channels and overbank deposits.

Lake deltas are formed by fluvial and fluvio-glacial alluvial systems depositing materials into a standing of body of water overtime (McPherson et al. 1987). Fluvio-glacial processes are the most important means by which sediment is supplied to the delta surface.

Dust storms usually occur during moderate to strong foehn wind events, when the wind speeds are in excess of 10 m/s (McGowan et al. 1995). Such conditions are typically associated with warm ambient air temperatures and low humidity, which promote the drying of the surface sediments and increase their susceptibility to entrainment by the wind.

Dust particles transported by the airstream are typically less than 100 μm in size (McGowan et al. 1995) with particles larger than 20 μm quickly settling back to the surface. Smaller particles may remain in suspension for days or weeks until filtered out of the air stream by vegetation or scavenged from the atmosphere by rain.

A number of meteorological and geophysical mechanisms generate silt grains these include; frost weathering and mechanical grinding caused by glacial, fluvial and aeolian abrasion. A study at Lake Tekapo found that the principle size range of silt grains transported in dust storms was 7 to 63 μm (McGowan et al. 1995).

The Lake Pukaki area may therefore be considered to have an abundance of fine grained sediments, which during foehn wind events, may become entrained into the airstream resulting in the blowing dust and dust storms.

The thermal and dynamic characteristics of foehn wind events are of primary importance in initiating dust storms. The airflow within the Pukaki basin during favourable conditions for dust storms determines if dust particles are entrained, where they are transported to and where they are deposited.

5.10 Meteorological risk factors for dust storms

The following is an analysis of meteorological risk factors for dust storm generation and occurrence as provided by Bluett (2012).

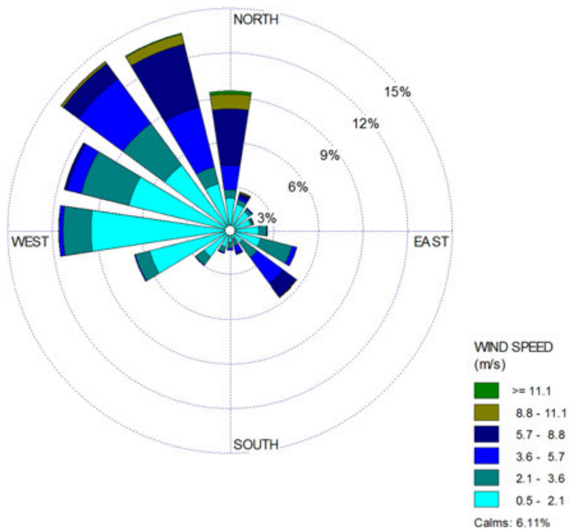
Bluett (2012) undertook an analysis of meteorological data to create a meteorological risk profile for dust storms occurring. The table below shows the meteorological sites that data for in the Pukaki basin area was considered. The Bluett (2012) analysis focussed on the Mount Cook Village data due to its favourable location within the valley system for dust storm generation from the Tasman delta and the data availability.

Meteorological stations within or close to the Pukaki Basin.

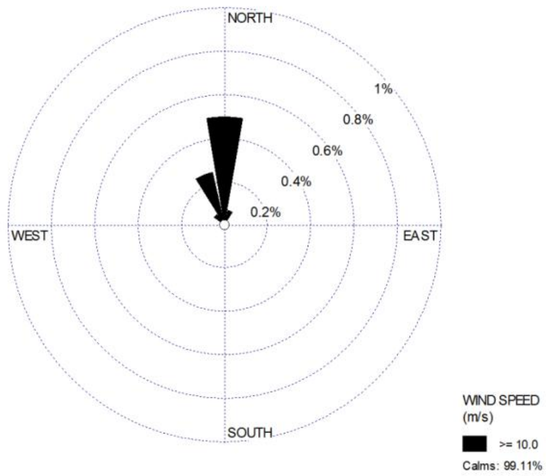
Met. Station,	Data availability	Years available	NZMG (x)	NZTM (y)	Latitude	Longitude
Pukaki Aero AWS	100 %	2008 - 2012	2,279,726	5,659,855	-44.233	170.117
Mt Cook Village EWS	80 %	2000 - 2012	2,276,118	5,714,982	-43.736	170.096
Lake Pukaki M.W.D	40 %	1969 - 1984	2,280,724	5,665,671	-44.181	170.132

Bluett's (2012) analysis of the Mount Cook electronic weather station (EWS) between 2008 and 2011 is shown below: (a) all wind speeds and (b) for winds greater than 10 m/s (b). Bluett (2012) concluded that these wind roses indicate that the prevailing winds are from the northwest quarter, but that strong winds likely to generate dust events are predominately from the north-northwest to north, meaning that winds that are most likely to generate dust events blow more or less directly down the Pukaki valley.

Bluett (2012) undertook an analysis of the wind data to establish if there is any diurnal or seasonal association with winds likely to generate dust events. Bluett found that the wind roses shows a clear diurnal pattern of wind speed whereby strong winds are most prevalent during day time hours.



(a) all winds speeds

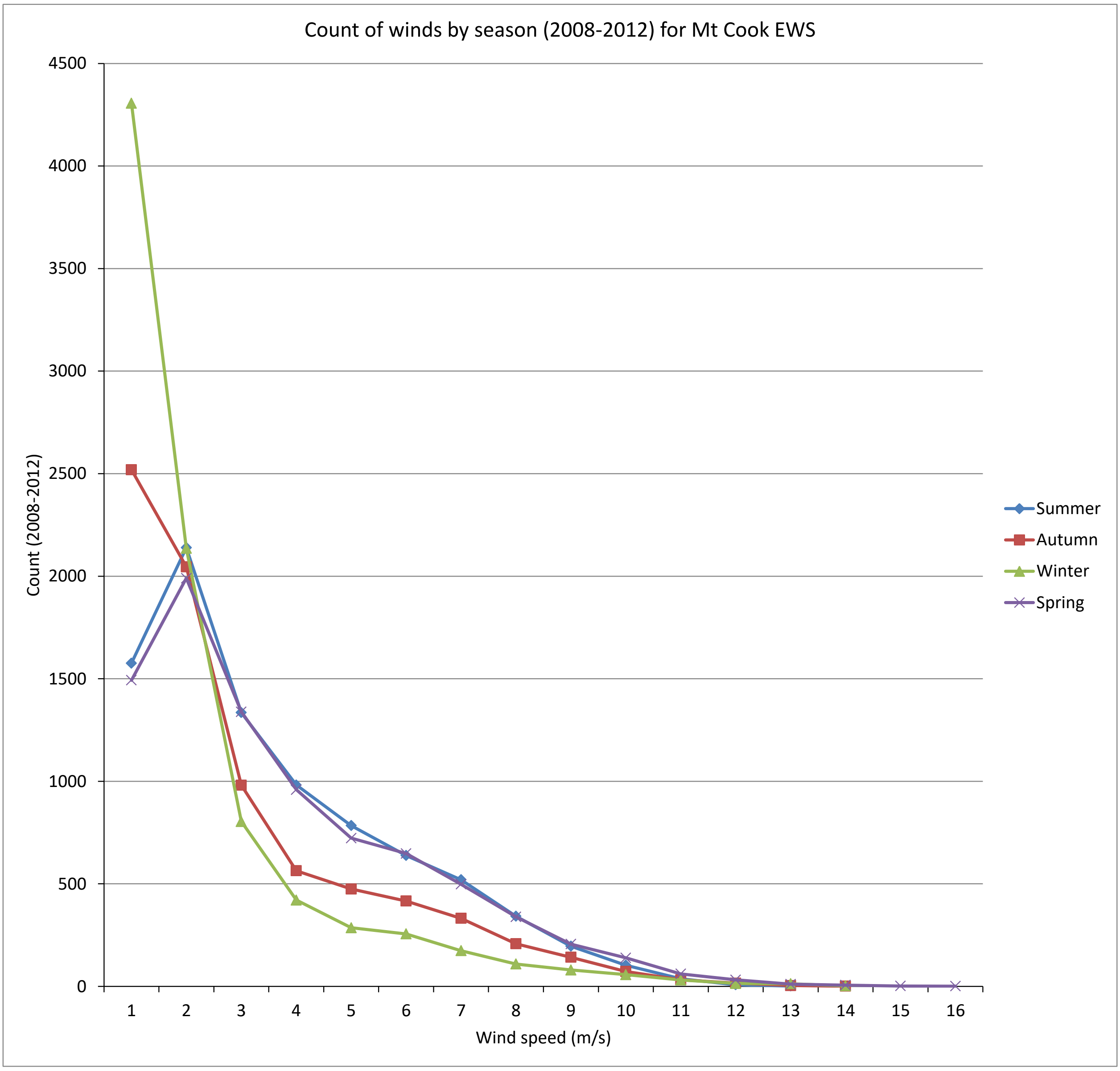


(b) winds greater than 10 m/s

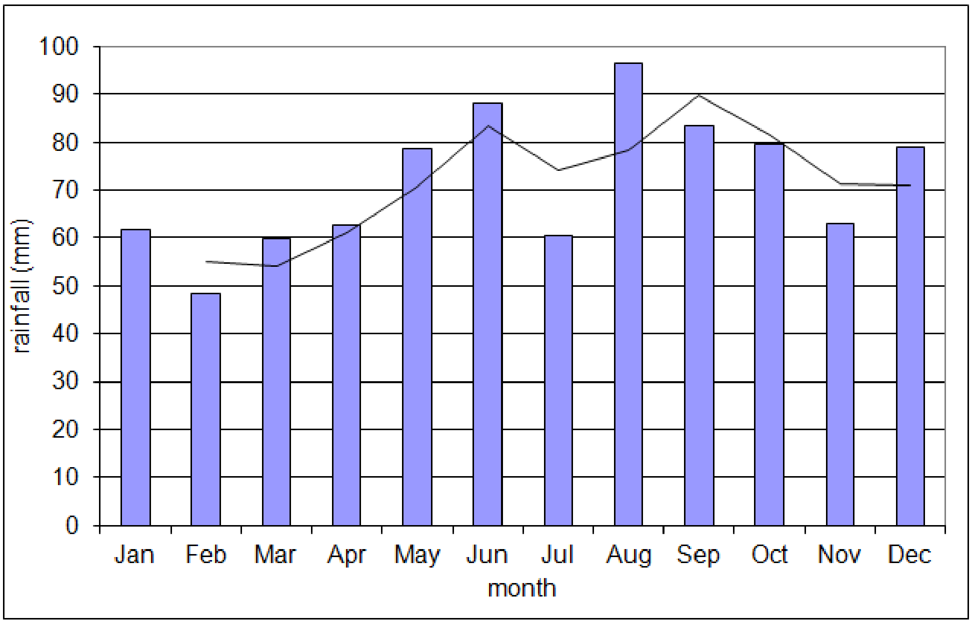
Wind roses for Mount Cook EWS - all hours - 2008 to 2011 inclusive. (Bluett, 2012)

Bluett (2012) extended the analysis to examine the seasonal pattern of winds measured at Mount Cook EWS to better understand the time of year when there is a greater risk of dust storms (i.e., during strong wind events). Based on the Bluett (2012) analysis of seasonal wind roses, and wind speed seasonal frequency plots, shown below, there is a clear seasonal pattern whereby the strongest winds (>10 m/s) are most prevalent in spring and summer and less prevalent in autumn and winter. However, in the mid-range of winds (3 to 10 m/s), the order of frequency of occurrence is different, with summer typically having the greatest frequency of strong winds, closely followed by spring, then autumn and winter.

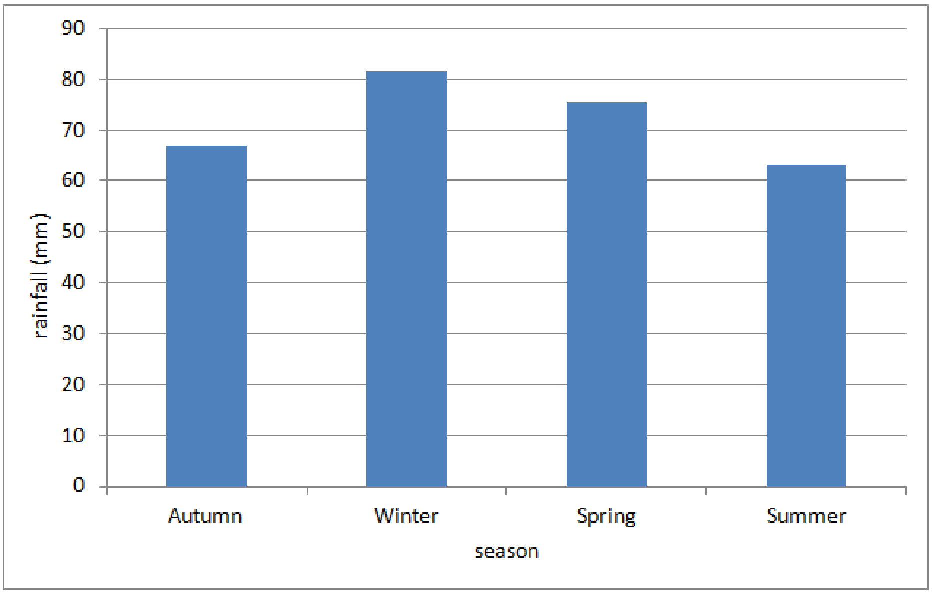
Following wind speed, as identified by Bluett (2012), the next most important factor in determining the potential of dust events occurring is rainfall. Rain will reduce the potential of dust events occurring by wetting the silt deposits, reducing their ability to be entrained by strong winds. The monthly mean total rainfall recorded at Braemar Station 1998-2012 and the monthly mean total rainfall by season recorded at Braemar Station 1998-2012 are shown below. Bluett (2012) selected the Braemar Station data as being representative of dust generation estimation due to its proximity to the Tasman River delta.



Frequency of wind speed events (1-hour average) by season (Mount Cook EWS). (Bluett, 2012)



Monthly mean total rainfall (mm) recorded at Braemar Station 1998-2012. (Bluett, 2012)



Monthly mean total rainfall (mm) by season recorded at Braemar Station 1998-2012. (Bluett, 2012)

The rainfall data shows that on average the highest rainfall occurs in winter (June, July and August), followed in order by spring (September, October and November), autumn (March, April and May) and finally summer (December, January and February).

Rainfall in sufficient quantities within a relatively short time span will cause floods on the Tasman Delta. As flood waters recede silts and fine sands are deposited in low energy environments such as back waters, stranded stream channels and overbank deposits on the Tasman Delta. Most floods occur over the months October to March with December being the most flood prone (*pers. comm.* between Jeff Bluett and Eddie Stead, Meridian Hydrologist 07/08/12). Floods are relatively rare in the middle of winter due to most headwater precipitation falling as snow. This same precipitation often falls as rain at Braemar Station.

Once the flood waters recede, the silts deposited create a patchwork of dust sources which can be entrained by foehn winds. In summary following a flood there is an increased risk of a dust event due to the greater amount of silt material available to be entrained by winds.

Bluett (2012) identifies that the metrological risk factors of windspeed and rainfall suggest that spring and summer are the two relatively high risk seasons for dust storms. This is due to the combined influence of relatively strong and frequent foehn winds, and more frequent floods which increase the amount of silt on the river braids. However, the spring rainfall will to some degree mitigate the risk of dust storms by increasing the moisture content of the deposited silt, making it less susceptible to entrainment into the wind. Anecdotally dust storms occur most frequently in spring.

5.11 Hydrological risk factors for dust storms

Bluett (2012) identified and analysed the hydrological state of the lake, i.e., the lake water level. Below are extracts from that analysis that also align with the current hydrological assessment of the lake future operations.

The hydrological state of the Lake Pukaki is one of the primary risk factors associated with the potential for dust storms. This occurs as a result of a larger area of Tasman River delta and larger areas of the other smaller river deltas being exposed to winds when lake levels are low.

The lake level undergoes pronounced seasonal cycles related to rainfall, snow-melt and runoff as well as electricity demand. Across Lake Pukaki’s full catchment area, rainfall is highest in summer and lower in winter, when precipitation is locked up in snow. The increased rainfall and snow melt in spring and summer months usually restore higher lake levels following the winter lows and high electricity demand, with the highest levels generally found in March and April.

The hydrology of Lake Pukaki is described by James (2012). A summary of the hydrology issues potentially relevant to the generation of dust storms is provided in the following paragraphs.

The amount of time the lake remains below the current consented level of 518 m in each emergency event is a function of the balance between the lakes natural inflows and hydro-electricity outflows. Based on previous patterns an electricity emergency is likely to be triggered in late autumn to early spring when electricity demand is high. The drawdown could occur at between 1.5 and 3 m per month. This means it would take about two months to go from 518 to 513 m. Refilling the lake is likely to occur to and beyond the 518 m in late spring and summer when inflows typically increase (rainfall and snow melt) and electricity demands decrease.

James (2012) considers it is reasonable to expect that in emergency conditions the lake will need to be managed below 518 m for a period of between four and seven months, with the upper estimate being an extreme value.

McGowan et al. (1995) noted that the delayed refilling of the lake may occur under strongly negative El Niño–Southern Oscillation (ENSO) conditions, which are linked to increased frequency of southwesterlies, below average temperatures and below average rainfall in the eastern alpine catchments of the Southern Alps. As a result, lower temperatures may delay the spring thaw and prolong low lake levels following winter drawdown period, thereby extending the period deltaic surfaces are exposed.

The frequency of needing to draw down the lake below 518 m is difficult to predict. Since the lake was raised to the new operating level in 1979 it has been lowered to between 520 and 518.2 m twice (1992 and 2008). Based on this data, a conservative estimate of the frequency that the lake could be lowered below 518 is once every 15 to 30 years.

Bluett (2012) concluded that a lower lake level tended to provide a higher risk of dust storms. The lowest lake levels tend to occur in the later months of winter and early spring. The lake refills in spring and summer and reaches peak levels in March and April. If the lake was to be drawn down below 518 m it would most likely occur in later months of winter and early spring (August and September). It is most likely that the lake would be back above 518 m in November/December. In an extreme season it may take until March to fill above 518 m. A conservative estimate of the frequency that the lake could be lowered below 518 m is once every 15 to 30 years.

5.12 Potential influence of lowering the lake level on dust storms

Bluett (2012) provided an analysis of the effect of lake lowering on dust storm frequency, duration and intensity. Below are extracts from this analysis. A similar analysis has been undertaken by GHD and is detailed in Section 7.5.

Bluett (2012) identified that frequency, duration and intensity of dust storms are the key factors in evaluating whether dust effects are likely to create an offensive or objectionable effect.

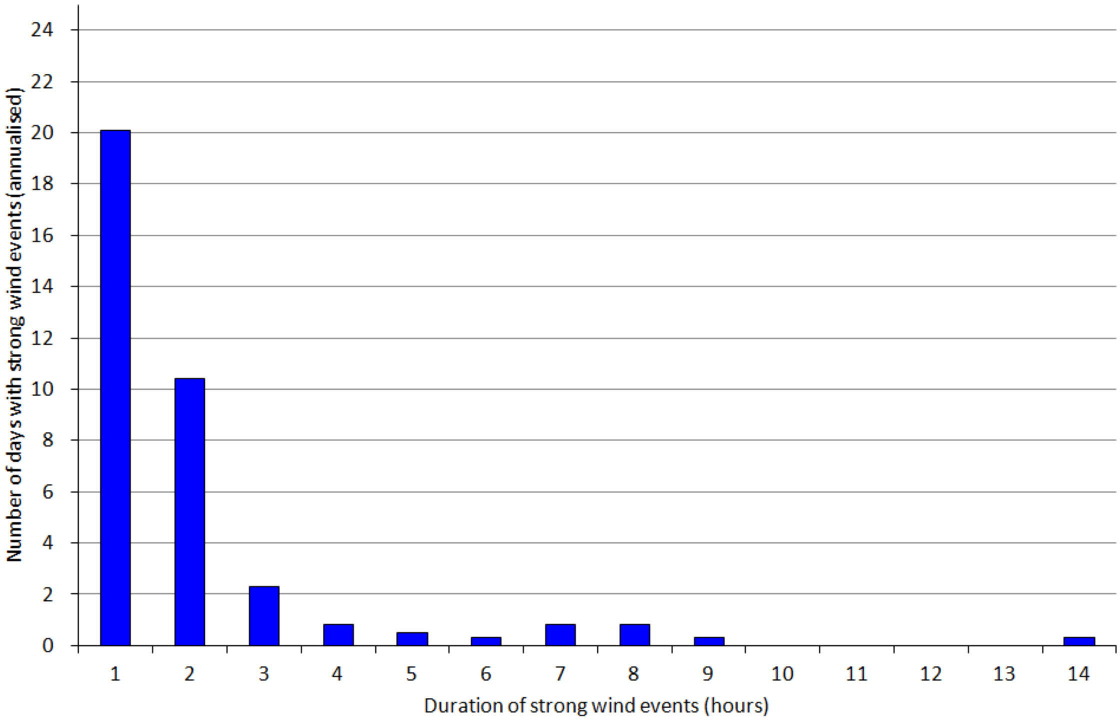
"There are no known recorded observations of or data on the frequency or duration of dust storms in the Pukaki Valley. In absence of observations or data, the frequency of dust storms can be estimated using meteorological data." (Bluett, 2012)

5.12.1 Frequency and duration of meteorological conditions conducive to dust storms

Bluett (2012) considered that a combination of wind speeds greater than 10 m/s from the northerly sector persisting for a period of 2 hours or longer and with little or no rain gives rise to a "high risk dust day" for the occurrence of dust storms. The figure immediately below shows the duration and frequency of strong wind events (≥10 m/s), when the wind direction is between 280° and 40° and when rainfall is less than 10 mm/day (Mount Cook EWS - 2008 - 2012).

This figure shows that there are at total of approximately 16 high risk dust days per year that fit the criteria. Approximately 50 % of these high risk dust days occur in spring, with the remaining 50 % spread across the other seasons.

Approximately 65 % of high risk events have a relatively short duration (two hours), with approximately 25 % of events lasting for four or more hours. The relatively long duration high risk events (>=4 hours) occur on a frequency of approximately four days per year, two of which are likely to occur in spring.



Duration and frequency of strong wind events (≥10 m/s), wind direction between 280°N and 40°N and rainfall >10 mm/day. (Bluett, 2012)

5.12.2 Availability of silt materials when lake levels are below 518 m

The duration and frequency of high risk dust events are primarily driven by meteorology, which is not directly dependent on the level of water in the lake. Accordingly, the frequency and duration of high risk dust events are likely to be the same (or very similar) whether the lake level is above or below 518 m.

The intensity of a dust storm will be primarily driven by the amount of fine silt that is available to be entrained into the airstream. Bluett (2012) identified two scenarios that need to be considered when comparing the relative intensity of dust storms with higher (>518 m) and lower (<518 m) lake levels. The first of the two scenarios can be referred to as "steady-state conditions". These occur when the amount and location of silt deposits reflect a period of reasonably steady hydrological activity (normal river flows). The second scenario is "post flood" when there is likely to be additional silt deposited on the braided river beds and delta as the flood waters recede.

A NIWA silt survey (Sykes and Bind, 2012) suggests that under steady state conditions fine sediments were generally found in localised low areas like shallow river channels. They also found the largest deposits of fine sediments occurs along the lake edge and noted that they were generally confined to a narrow strip about 60 m from the lake shore. Some small silt deposits were observed on higher parts of the river delta, but the majority of the silts observed were found on the near-shore delta. The near-shore silts appear to have been deposited by the receding lake, but some influence of upstream sources and the fluvial reworking of delta swale silt deposits were observed.

Bluett (2012) noted that if the lake level is lowered from 518 to 513 m then the fine sediment on the exposed delta surfaces would reflect the recent history of the lake level and the amount of time that the lake bed had been exposed. As the lake recedes a greater area of lake bed is exposed to the air and the NIWA survey suggests that it is likely that a large proportion of that recently exposed bed would be covered in a layer of fine sediment. Not all of this sediment would present an immediate risk for dust storms as lake water keeps the sediment within about 50 to 60 m of the shore wet. The lake needs to recede below that level before the recently exposed silts can dry and potentially be entrained into a dust event or storm.

NIWA also note that rapid lowering of the lake will maximise silt exposure, while a slow lowering will allow time for the lake wave and river to sluice silt from the delta shore and reduce amount of additional silt potentially available for entrainment into dust storms. At this point it is helpful to consider the area of the delta when the lake level is at 518 m is approximately 38 km^2 and the delta area will be increased by approximately 6.5 km^2 (17 percent) when the lake level is lowered to 513 m. (Bluett, 2012)

In addition to increasing the size of the Tasman River delta, lowering the lake also creates two other sources of additional fine silt. The lowering of the lake exposes an additional area of approximately 3 km^2 around the lakeshore. Lake Pukaki's shoreline is principally composed of pebbles, cobbles and boulders which are not susceptible to entrainment by wind. Therefore, it is unlikely the additional foreshore exposed will be a significant source of additional dust if the lake level is lowered to 513 m.

There are four smaller rivers that enter Lake Pukaki. These rivers would have their deltas entirely exposed if the lake is lowered to 513 m, which would create localised hot-spots where fine sediment may potentially entrained into strong winds. This would result in an increase in the amount of fine sediments potentially exposed to wind blow. These rivers are: Twin and Whale Streams, which flow into Lake Pukaki's north-western shoreline above 513 m, and Landslip Creek which flows into Lake Pukaki's north-eastern shoreline above 513 m. The location of these three rivers is shown in Figure 2. A fourth river, Camp Stream, flows into the lake just below the level of 513 m.

In summary, under steady state conditions the lowering of lake levels is likely to increase the amount of silt available for dust storms and therefore increase the intensity of some events. Bluett (2012) noted that it is difficult to quantify to what extent lowering the lake will increase the intensity of dust storms, as this will be dependent on the rate at which the lake is lowered and the amount of time between high risk wind events. But it is likely that the silt deposits left by the receding lake and the increased exposure of four small river deltas that some dust storm events will be more intense (i.e., contain higher concentrations of dust particles) than those at lake levels above 518 m.

In a post flood scenario, there will be a patchwork of silt deposits over a wider area of the braided Tasman river network and its delta. Under a post flood scenario, the amount of silt available is greater and the sources of silt more diverse than is found under steady state conditions. Following a flood there is likely to be a patchwork of silt deposits in low energy environments such as back waters, stranded stream channels and overbank deposits scattered over the braided network of the Tasman river and its delta.

As with the steady state, the post flood scenario with the lake below 518 m is likely to provide a greater amount of silt than if the lake level is above 518 m. However, the difference in the amount of silt available between the two lake levels state will be much smaller under the post flood scenario. This is because the relatively large amount of silt made available by the flood is independent of lake level.

In summary the dust storms occurring at lower lake levels under a post-flood scenario will be more intense (i.e., contain higher concentrations of dust particles) than at higher lake levels, but the difference in intensity will be much smaller than under the steady state scenario.

5.12.3 Frequency of lake levels being below 518 m

It is useful to understand the frequency and return period of increased intensity dust events. If lake levels are lowered below 518 m this is likely to occur in late winter and early spring (August and September/October). Under normal inflows the lake level will be back above 518 m in November. Under extreme low inflow conditions, the lake level may not return to above 518 m until February. Therefore, during an extreme year, an area of additional lake bed below 518 m may be exposed for a period of up to 6 months (spring and summer). Bluett (2012) estimated that the frequency of high risk wind events with a duration of two hours or more during these six months is approximately 11, three of which are estimated to have a duration of four hours or more.

A conservative estimate of the frequency that the lake could be lowered below 518 m is once every 15 to 30 years (Bluett, 2012).

6. Dust assessment criteria

The assessment criteria and methodology for assessing dust impacts in New Zealand is best described in the Good Practice Guide for Assessing and Managing Dust (Ministry for the Environment New Zealand (MFE), 2016).

6.1 Health

The ambient particulate matter (dust) criteria are tabulated in Table 3. These criteria are applied everywhere in the open air, including residences, businesses, and parks.

PM_{10} and $PM_{2.5}$ are non-threshold contaminants, i.e., carcinogenic substances with no known safe level of exposure. Any increase in ambient concentrations will result in adverse effects. This means that the air quality criteria for PM_{10} and $PM_{2.5}$ should not be used as a limit to pollute up to.

The Canterbury Air Regional Plan (Environment Canterbury, Regional Council, October 2017) has values that are the same as the Ministry for the Environment, New Zealand.

Table 3 Ambient air quality guidelines for particulate matter

Pollutant	Concentration limit [μg/m³]	Averaging time	Comment
PM_{10}	50	24-hours	Allowance of one exceedance per year.
	20	Annual	-
$PM_{2.5}$	25	24-hours	-
	10	Annual	-

6.1.1 Trigger level

MFE (2016, Section 3.1.3, Table 5) has a “trigger level” for PM_{10}. This is a value that can be used when there is an active monitor that provides feedback to an activity. Exceedance of this value – 150 μg/m³ 1-hour averaged – means that the chance of exceeding the regulated ambient air quality guideline is high, thus allowing for active operations to be modified.

For general wind erosion, given that the rate of wind erosion cannot be actively controlled, application of a trigger level is not appropriate.

6.2 Amenity

The (MFE, 2016) contains a qualitative risk assessment guide, rating land use categories with respect to a relative sensitivity rating. The areas around Lake Pūkaki are rated as “high” sensitivity for the following reasons:

– MFE (2016) specifies that District Councils provide guidance with regards to the amenity expectations.
– MFE (2016, Section 2.4, Table 2) rates “tourist, cultural, conservation” land use as highly sensitive as these areas have high environmental values where adverse effects are unlikely to be tolerated.
– Mackenzie District policy (Mackenzie District Council. 2025) describes the area around Lake Pūkaki as:

  “*The landscape value of areas close to Lakes Tekapo, Pūkaki, Ohau and Benmore and their rivers is high. This value is largely due to the naturalness of this environment with little or no built development. These riparian areas are also a great recreational asset as they provide a setting for a variety of activities and also provide access to waterbodies*.”

  “*The Mackenzie Basin contains two of the South Island’s significant ‘Southern Lakes’; Tekapo and Pūkaki. … Although modified and in two cases man-made, these lakes variously are jewels of the Basin, and of the most outstanding value. Pūkaki and its setting is a tourist icon, both visually and as the approach to Mount Cook/Aoraki and the National Park.*”

– Stephen Brown (Brown, 2024) report description of the area (refer to Section 4.4).

A good measure for amenity, in addition to previously stated air quality guidelines, is dust deposition. A dust deposition rate of greater than 2 g/m²/30-days above background levels (for high sensitive areas) is recommended as being applicable (MFE, 2016, Section 3.1.4, para.2).

7. Meteorology

7.1 General meteorology

The prevailing wind in the Lake Tekapo and Pūkaki region is from the northwest, however, due to the mountainous terrain in places, local winds can vary with topography. A publicly available wind rose for the Lake Tekapo area is shown in Figure 18. Lake Tekapo is a local flat area where the winds tend to originate from more westerly than northwest, which compares to the insert wind rose from Mount Cook Village, at the northern end of the Tasman River, which has a very strong northwest alignment that corresponds to the valley it is located in.

Wind speeds are highest during the summer months, as shown in the average monthly wind speed plot in Figure 19.These higher wind speeds also correspond to lower rainfall, which may result in higher wind erosion rates.

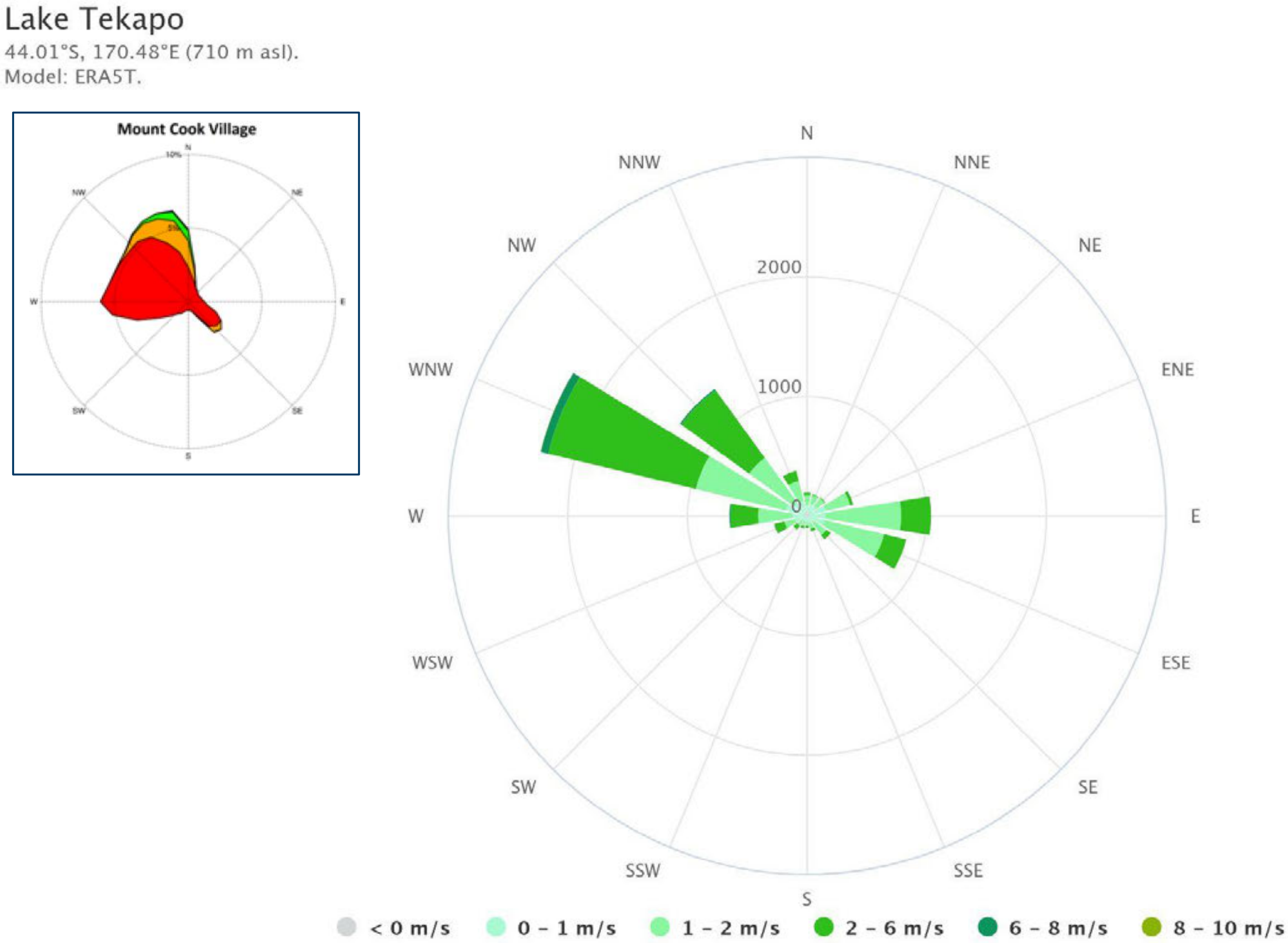


Figure 18 Wind rose for Lake Tekapo (Meteoblue, 2025) Insert image: Month Cook Village wind rose (Macara, 2016).

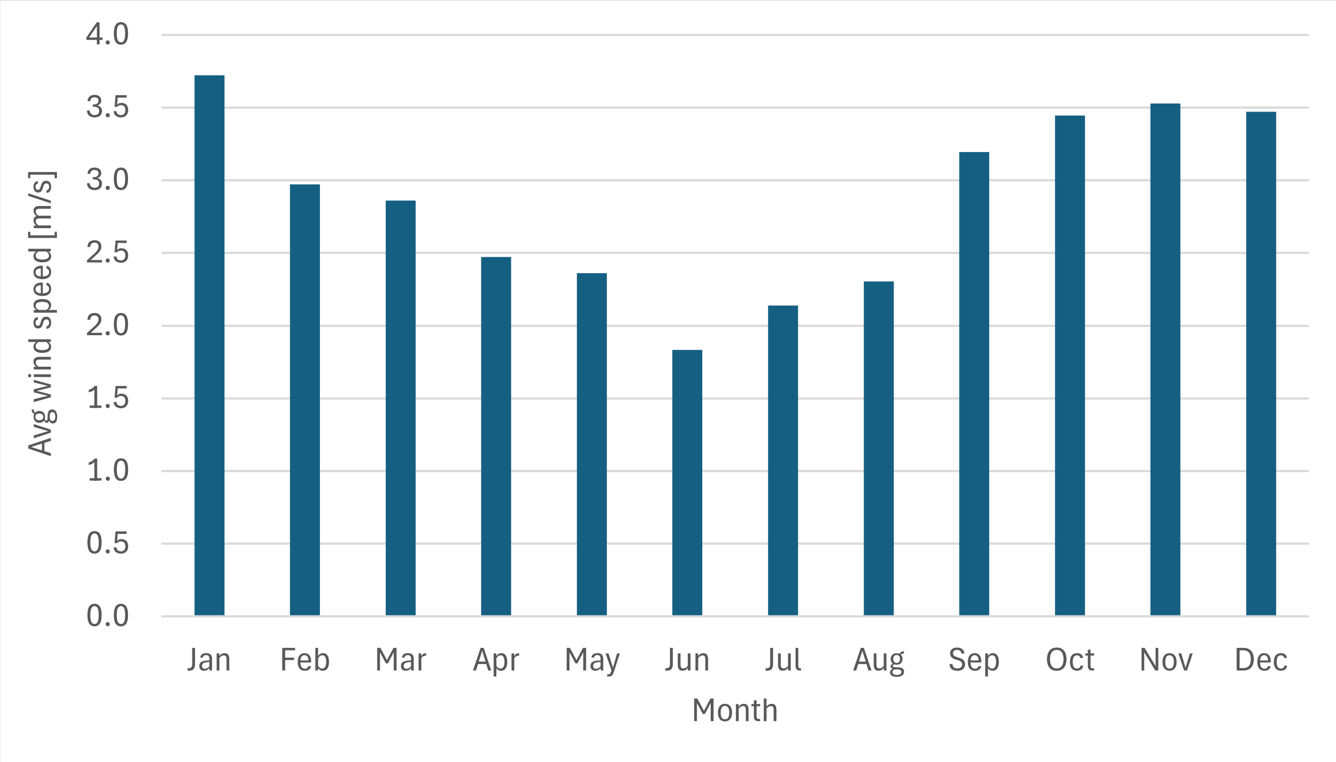


Figure 19 Average wind speed at Pūkaki Aerodrome. Source: Macara (2016)

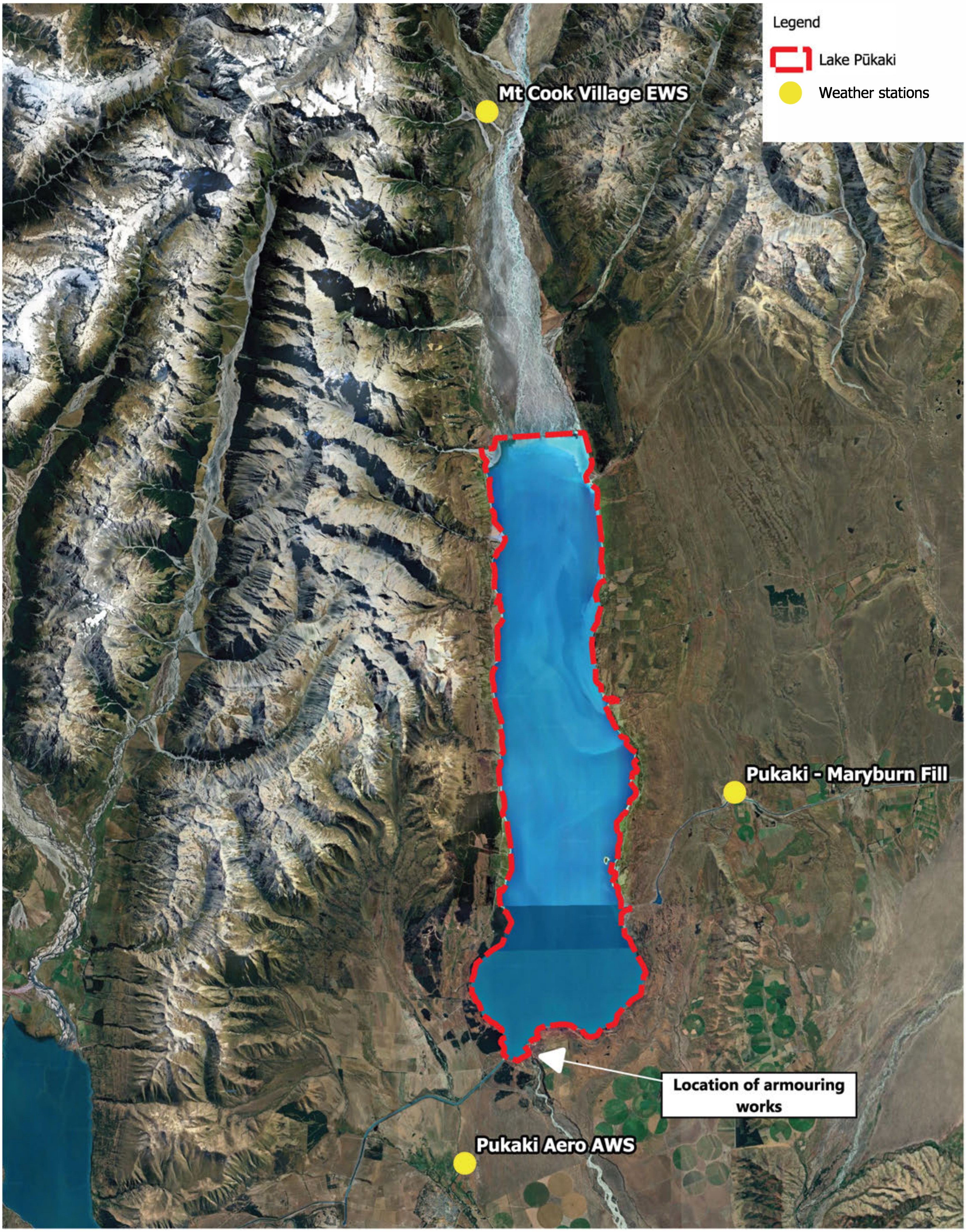
7.2 Detailed meteorology

Meridian supplied detailed meteorological data for three locations surrounding Lake Pūkaki. Data for two of the sites was kindy supplied by Met Services New Zealand for use in this project only. Information regarding the three sites and data is summarised in Table 4, with their locations shown graphically with respect to the site location in Figure 20.

Table 4 Summary of observational data used in this assessment

Site name	Maryburn	Pūkaki Aero	Mt Cook Village
Source	Meridan	Met Service	Met Service
Location	442,494 mE, 5,120,112 mS	429,498 mE, 5,100,535 mS	430,054 mE, 5,153,860 mS
Period	16 February 2006 to 28 May 2025	13 December 2008 to 2 June 2025	7 September 2012 to 2 June 2025
Number of full years[6]	17 (2007-2016, 2018-2024)	16 (2009-2024)	11 (2013-2014, 2016-2024)
Frequency	Hourly observations	Hourly observations	Hourly observations
Observational parameters	Wind speed, wind direction, temperature, humidity, pressure, rainfall	Wind speed, wind direction, temperature, humidity, pressure, rainfall, cloud cover, cloud height, weather description, visibility, gust speed	Wind speed, wind direction, temperature, humidity, pressure, rainfall, gust speed
Notes	Wind direction to 1° increments	Wind direction to 10° increments	Wind direction to 10° increments

[6] A “full year” here is considered to be one that is >90% complete and can be easily gap filled using US EPA methodology to generate a complete data year of 8760 hours (or 8784 for leap years).



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

N

Meridian Energy
WPS Pūkaki FTC

Location of meteorological observation stations

Project No. 12656630
Revision No. B
Date 24/10/2025

FIGURE 20

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 24/10/2025

Data Source:Google Earth Imagery 2025.
Created By: rwilson3

7.2.1 Annual wind roses

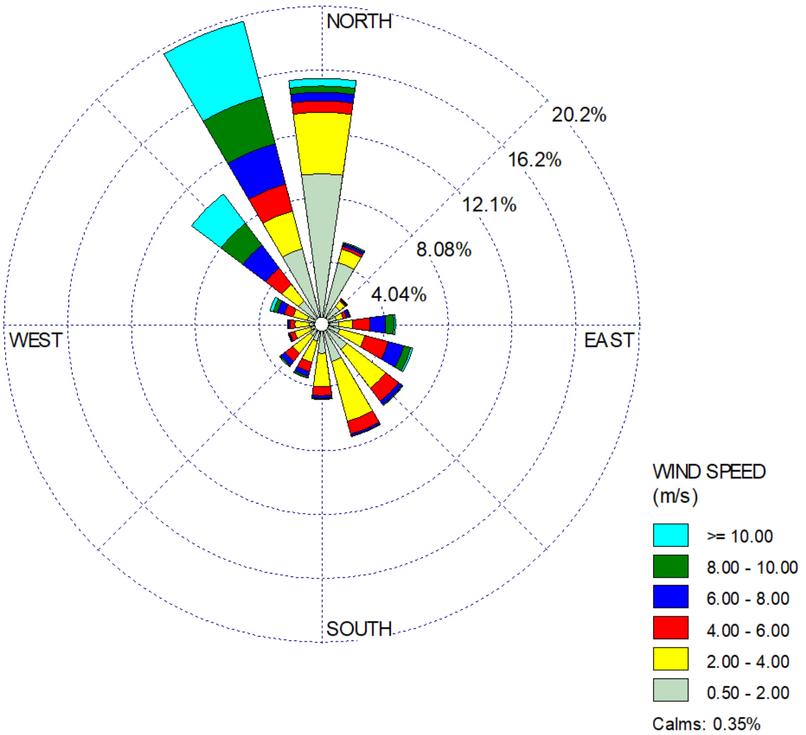
Annual wind roses based on all observational data for each site are shown in Table 5. Significant differences can be observed in both wind directions and wind speeds for each of the sites.

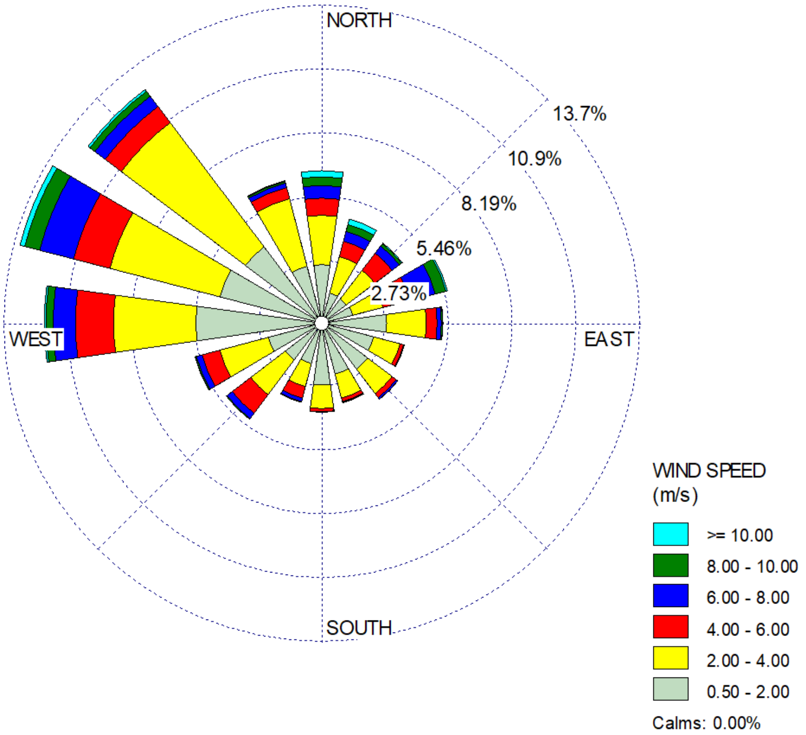
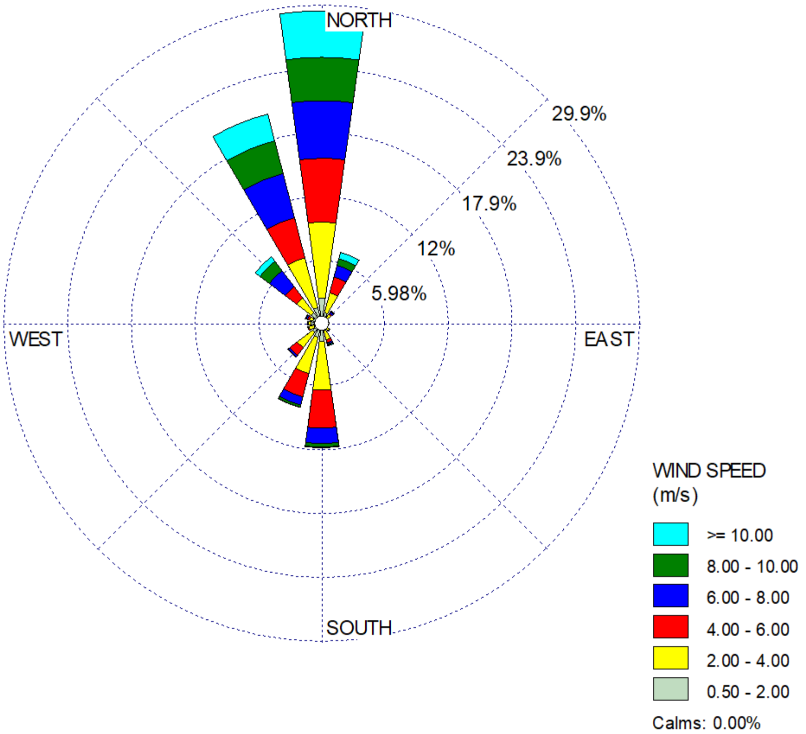
At the Mt Cook Village site, the winds are highly northerly due to the terrain features surrounding the site.

At the Maryburn site, the wind speed is lower and the direction has rotated slightly to the west with NNW winds dominant. However, there is a considerable SE wind component that has been identified as predominantly occurring during daylight hours. This indicates an interaction between land and lake conditions especially in the absence of strong northwest winds.

At the Pūkaki Aero site, wind speeds are significantly lower than the other two sites, especially noticeable by a much lower proportion of wind speeds greater than 10 m/s and have a significant westerly component.

Table 5 Annual wind roses for observational sites – Full data periods

Site	Annual wind rose
Maryburn Avg WS = 4.1 m/s Years = 2006 to 2025	

Site	Annual wind rose
Pūkaki Aero Avg WS = 2.8 m/s Years = 2008 to 2025	
Mt Cook Village Avg WS = 4.9 m/s Years = 2012 to 2025	

7.2.2 Selected single year – 2015

For a detailed quantitative air quality assessment, a single year was selected so that detailed CALPUFF modelling could be undertaken (refer to Appendix B). This single year was used for all air quality assessments for this project, not just the assessment detailed in this report.

A ranked multi-criteria analysis was applied for each of the sites. Detailed ranking tables are supplied in Appendix B that indicated the year 2015 was the most conducive for dust storm and wind erosion events.

The multi-criteria assessment used of all the available data, which included the following parameters.

- Annual rainfall
  - A drier year is generally associated with more frequent dust storms, i.e., dust wind erosion.
- July to December rainfall
  - Dust storms tend to occur during the later half of the year.
- Annual average relative humidity
  - Lower RH is generally favourable for exposed surfaces to lose moisture.
- Annual average wind speed
  - Wind erosion and dust storms increase in intensity with wind speed.
- Number of hourly observations with wind speed 10+ m/s
  - Highest wind speeds are associated with dust storms, consistent with Bluett (2012).
- Number of periods where the wind speed exceeded 10 m/s for longer than 24 consecutive hours.
  - Long duration high wind events are more likely to result in dust storms and exposed surface drying.
- Number of missing hours
  - Validity of the analysis needs to be maintained.
  - Used to exclude 2017 as a usable year given 52.5 percent of data was missing from the Maryburn site.

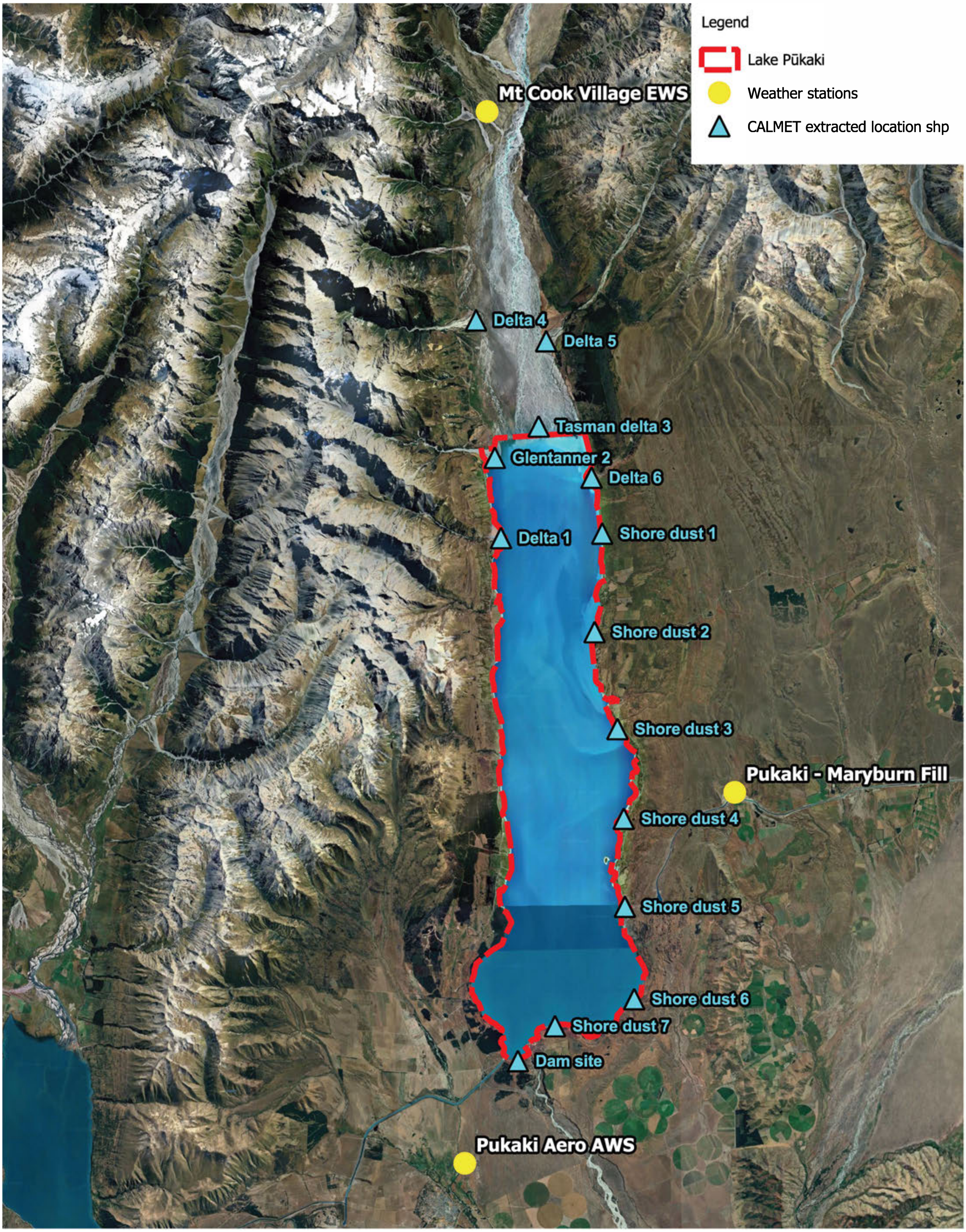
More weighting was given to the observations from Maryburn and Pūkaki Aero rather than Mt Cook Village given their better representation of winds across the plains east of Lake Pūkaki.

7.3 Lake meteorology

The meteorology around the lake varies considerably. A total of 15 modelled locations, shown in Figure 21, were used to compare meteorology. Annual wind roses for the 15 locations are shown in Table 6, with larger versions of the images shown in Appendix C. The sites are nominally listed in order travelling clockwise around the lake from the river delta adjacent to Ferintosh Station (ID = Delta vol 1).

The sites near the Tasman delta have been selected as corresponding to mountain river deltas entering Lake Pūkaki, consistent with the advice provided by Jeff Bluett (Section 4.5) as general/generic sources of potential dust for storms. The lake shoreline sites have been selected as being spaced at approximately 5 km of shoreline distance between each other heading south. This distance was selected as it provided a balance between site frequency and the bulk amount of data/information available from a CALMET simulation that can be processed, assessed and reported effectively. Eastern shoreline sites were selected instead of western shoreline locations as any receptors along the western edge of the lake will generally be upwind of the extra exposed glacial till along the shore, and the impact from windblown dust generated on the eastern side of the lake is likely to be attenuated by the presence of the lake itself.

Using Table 6 (and Appendix C) as a reference, the annual wind direction at the Tasman delta northern end of the lake is predominately north, which can skew either NNW or NNE depending on the local terrain, i.e., Delta 5 site on the Jollie River delta. Moving away from the Tasman delta, the average wind speed lowers and more easterly and south-westerly winds are introduced, likely as a result of the influence of the lake itself.



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

N

Meridian Energy
WPS Pūkaki FTC

Lake and Tasman delta meteorological site location

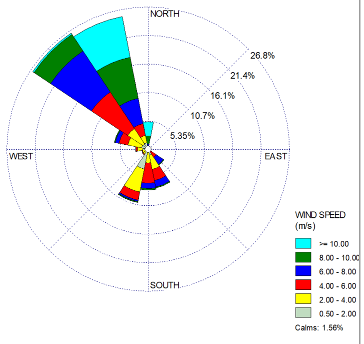
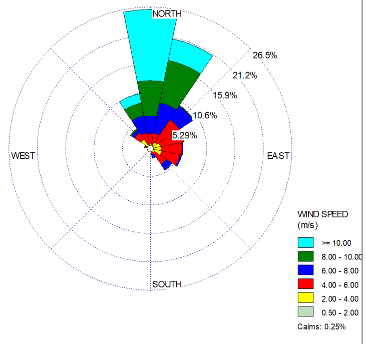
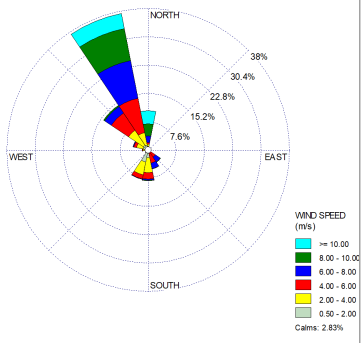
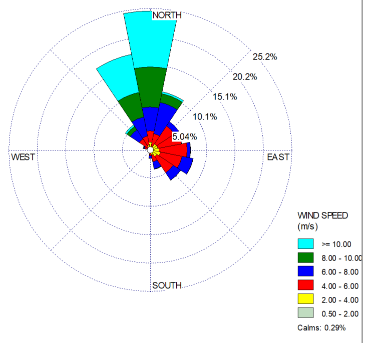
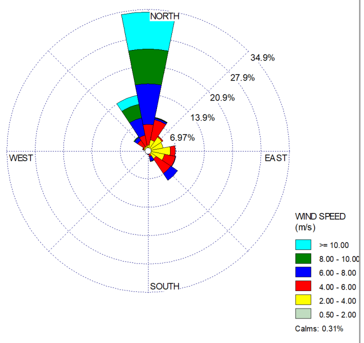
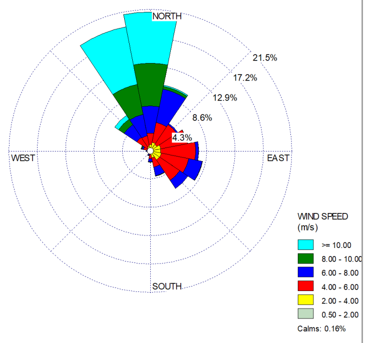
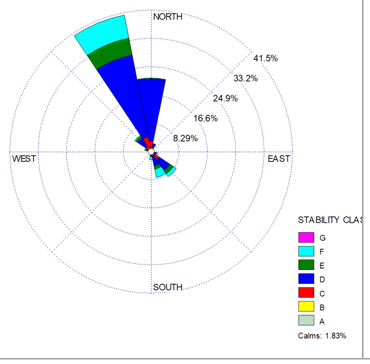
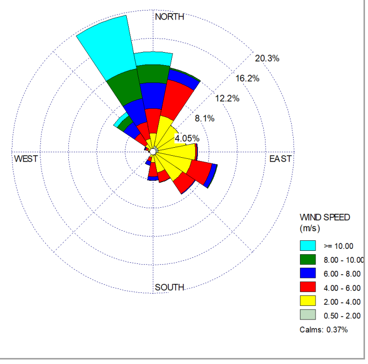
Project No. 12656630
Revision No. A
Date 24/10/2025

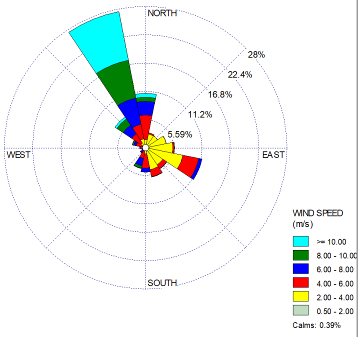
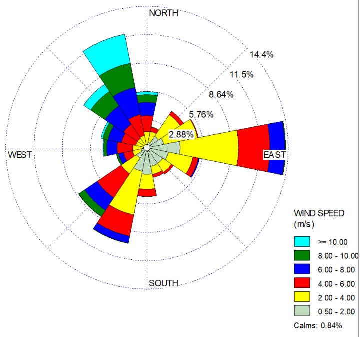
FIGURE 21

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 24/10/2025

Data Source:Google Earth Imagery 2025.
Created By: rwilson3

Table 6 CALMET generated annual wind roses around Lake Pūkaki. Refer to Appendix C for larger images.

Site	Annual wind rose	Site	Annual wind rose
Delta 1 Avg WS = 5.7 m/s		Delta 5 Avg WS = 7.1 m/s	
Glentanner 2 Avg WS = 5.3 m/s		Delta 6 Avg WS = 6.9 m/s	
Tasman delta 3 Avg WS = 5.9 m/s		Shore 1 Avg WS = 6.8 m/s	
Delta 4 Avg WS = 5.7 m/s		Shore 2 Avg WS = 5.2 m/s	

<table>
<tr><th>Site</th><th>Annual wind rose</th><th>Site</th><th>Annual wind rose</th></tr>
<tr><td>Shore 3
Avg WS = 5.5 m/s</td><td>
</td><td>Shore 6
Avg WS = 4.3 m/s</td><td>
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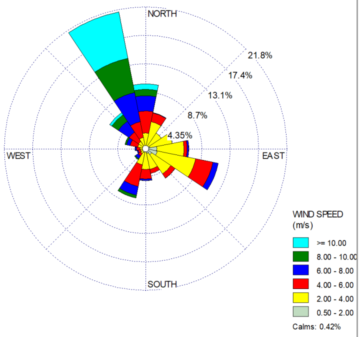
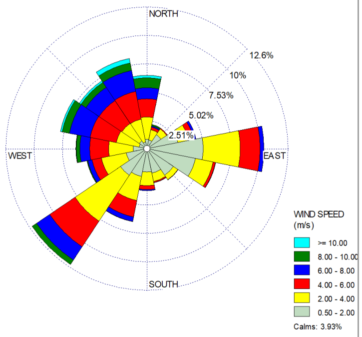
Avg WS = 4.9 m/s</td><td>
</td><td>Shore 7
Avg WS = 3.9 m/s</td><td>
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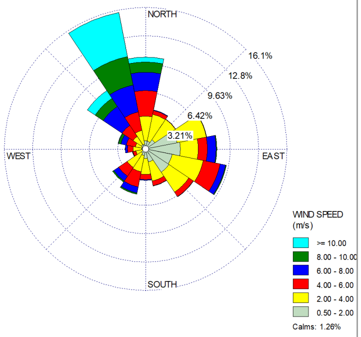
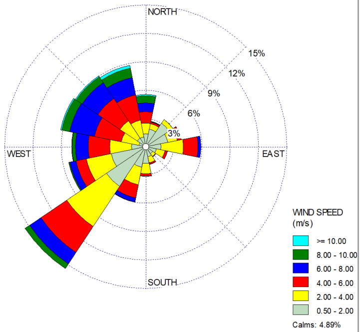
Avg WS = 4.3 m/</td><td>
</td><td>Dam site
Avg WS = 3.4 m/s</td><td>
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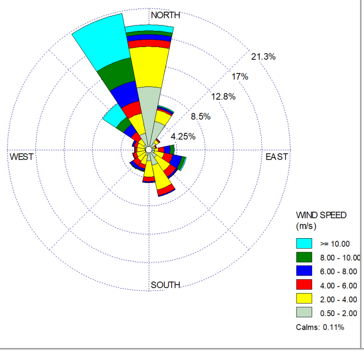
<tr><td>Maryburn
Avg WS = 4.1 m/s</td><td>
</td><td></td><td></td></tr>
</table>

7.4 Rainfall

Rainfall at Lake Pūkaki is of interest as it provides a measure of dust suppression to exposed lake bank areas at a distance from the water where any lake rise will not impact.

Rainfall rates within a 24-hour period, shown in the following sections, were used to inform a dust suppression model, as discussed in Section 10.6.

7.4.1 Annual rainfall

There is a significant annual rainfall gradient across the landscape where Lake Pūkaki resides. A plot of annual average rainfall (mm/year) for four locations across the catchment area (from north to south) is shown in Figure 22. Annual average variation at three of the locations is shown in Figure 23.

Up at the top of the Tasman River delta, Mt Cook Village receives over 2250 mm of rain annually, but can exceed 3300 mm. This reduces to 890 mm at Braemar station, located about three quarters of the way (north) from the southern end of the lake. At Maryburn (about halfway along the lake and further east) the annual rainfall reduces to 660 mm, which is slightly higher than Pūkaki Aerodrome at about 650 mm per year.

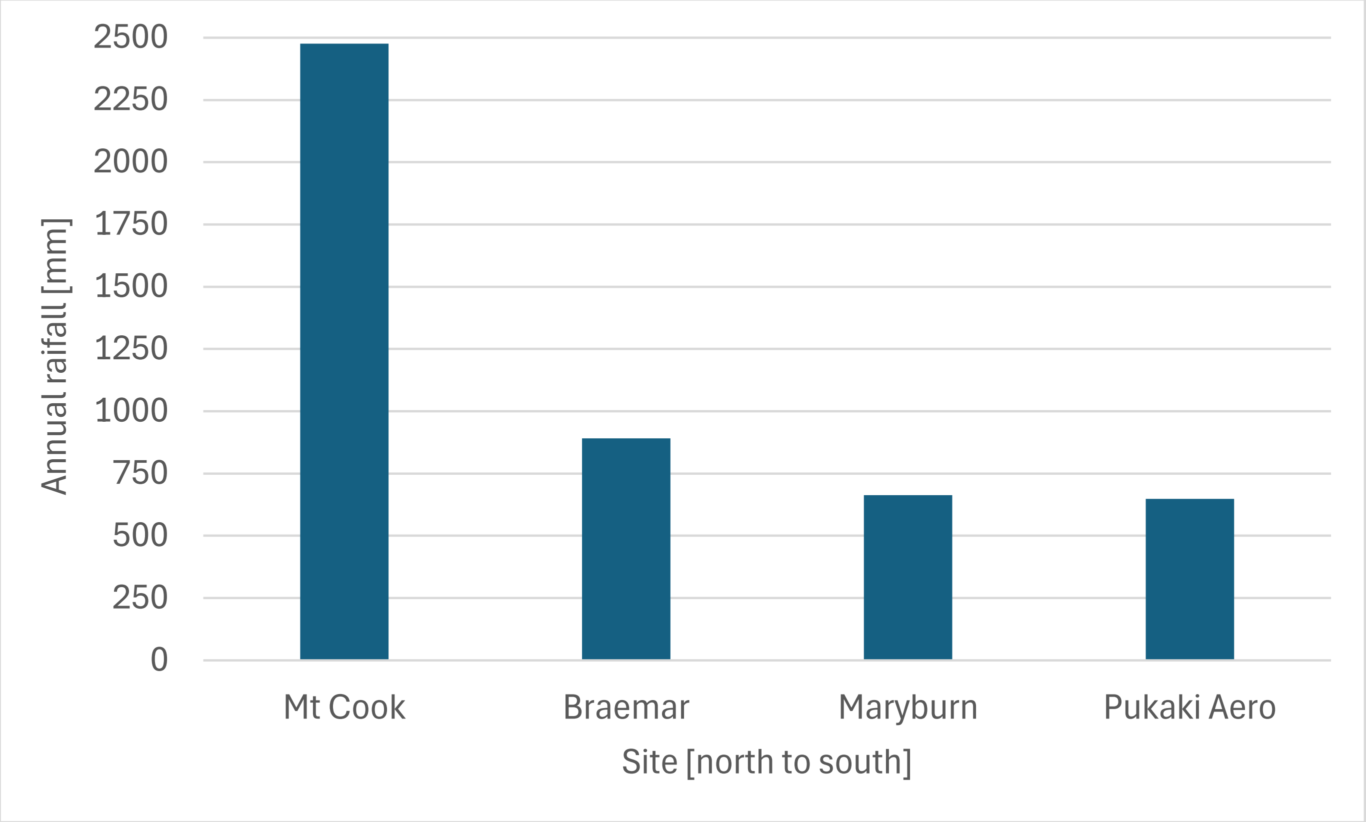


Figure 22 Annual average rainfall across Lake Pūkaki catchment

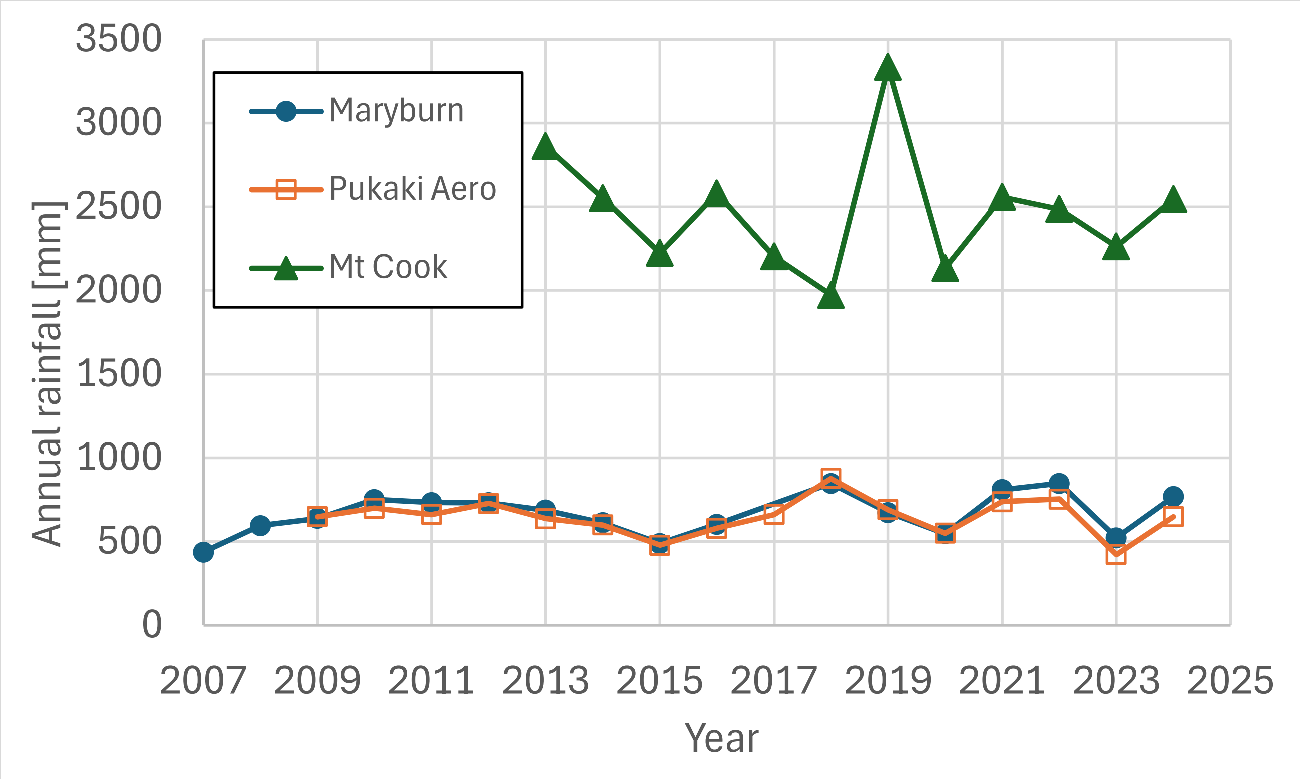


Figure 23 *Annual average rainfall variation*

7.4.2 Braemar Station

Rainfall monitoring undertaken at Braemar is a relevant monitoring station in the Lake Pūkaki catchment area, with data extending back to 1927. A plot of daily rainfall between 1927 and 2011 is shown in Figure 24, with monthly averages shown in Figure 25.

Annual average rainfall is 890 mm, with an average 2.4 mm of rain per event.

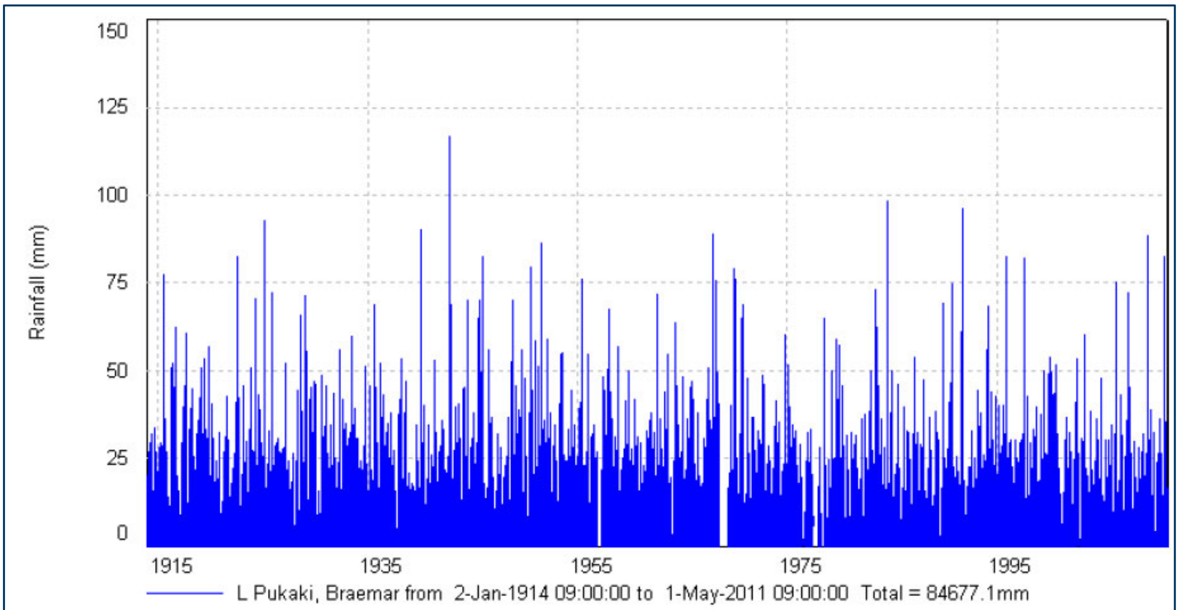


Figure 5.4: The Lake Pukaki at Braemar Daily Rainfall Record.

Figure 24 Daily rainfall record at Lake Pūkaki Braemar (Opus International Consultants, Jowett Consulting and Pickford Consulting, 2011)

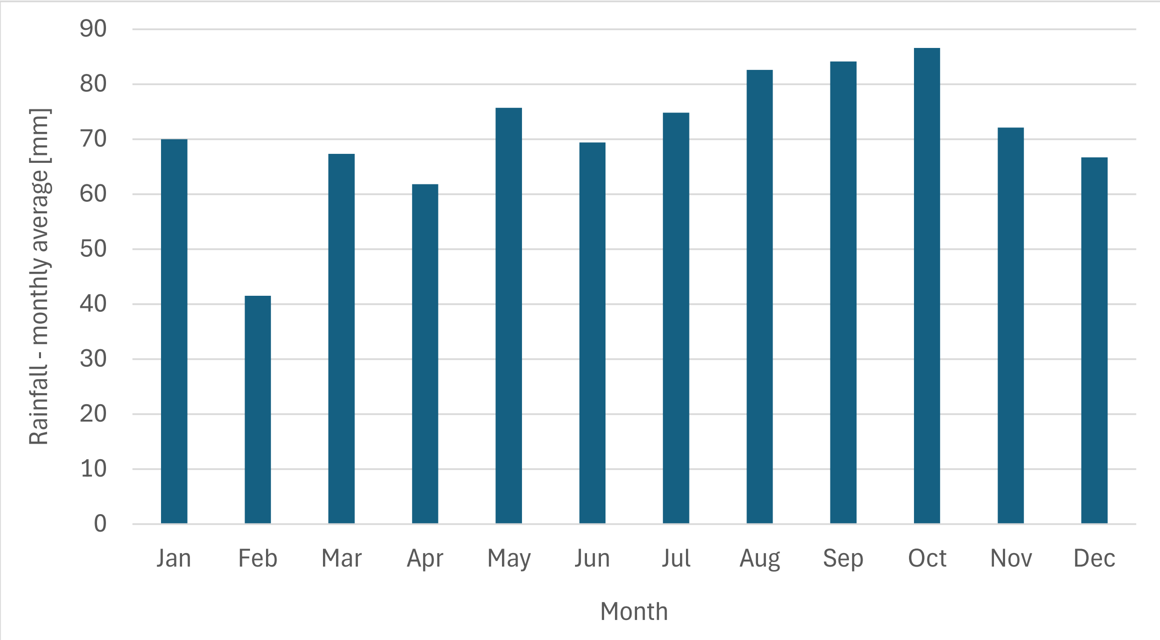


Figure 25 Monthly average rainfall record at Lake Pūkaki Braemar (Climate.Top, 2024)

7.4.3 Maryburn

A plot of daily rainfall between 2006 to 2025 is shown in Figure 26.

The average rainfall on a day when it rains is 6.5 mm, with a median value of 3.0 mm of rain.

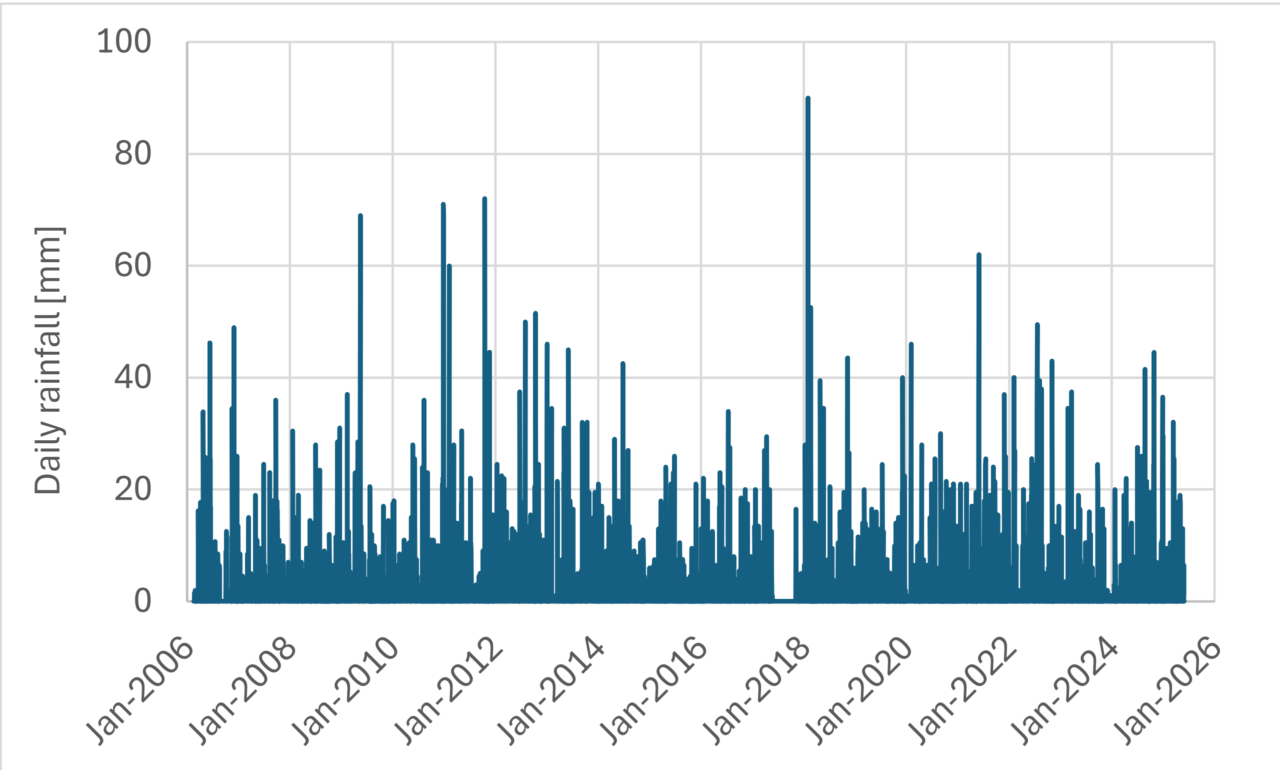


Figure 26 Daily rainfall record at Maryburn. Data supplied by Meridian

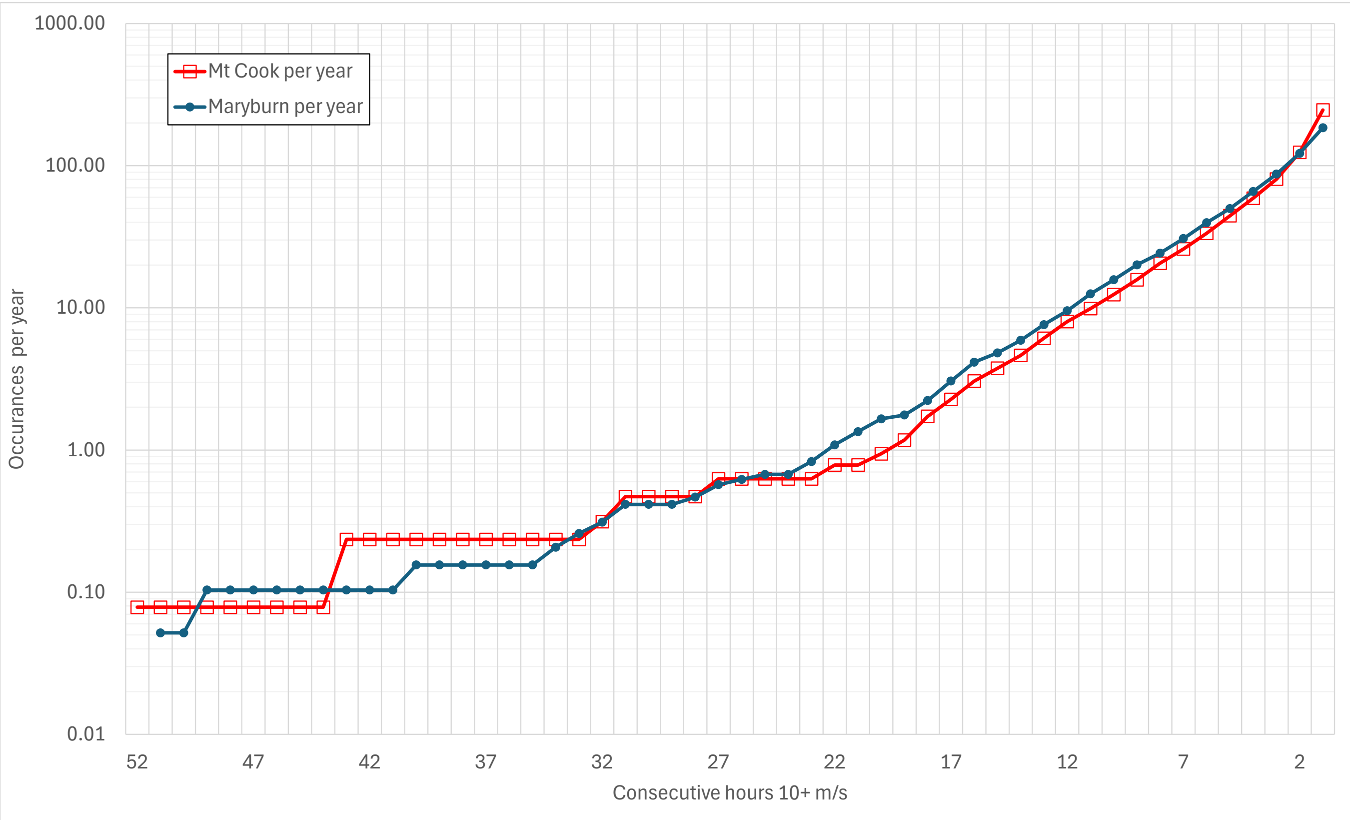
7.5 Potential dust storm event frequency analysis

As part of the ranked multi-criteria analysis, with detailed ranking tables shown in Appendix B, an analysis of the number of consecutive hours with a wind speed greater than 10 m/s was undertaken. A comparative analysis was performed between Mt Cook and Maryburn site data, adjusted to a per year basis as six years (approx.) of additional data was available for the Maryburn site, from 2006 where data for Mt Cook was available from 2012. A frequency plot is shown in Figure 27.

From Figure 27:

- At Maryburn, one period of 51 consecutive hours of 10+ m/s wind was observed. This is exceeded by one hour at Mt Cook.
- The general frequency trends between the two locations are similar. Maryburn has slightly more frequent periods of up to about 24 hours of consistent high winds, but Mt Cook has more frequent periods of between 34 to 43 hours of consecutive high winds.
- Over the assessed periods, there is on average approximately 500 times per year when a wind speed greater than 10 m/s will occur for 2 hours or more,[7] corresponding to the wind speed dust storm criteria as defined by Bluett (2012). This is a probability of 5.9 percent that any hour will be a potential dust storm wind event.

A probability analysis of the annual distribution of 10+m/s wind events for 2+ consecutive hours was undertaken. A probability distribution graph is shown in Figure 28. The months of May to October have an average probability of approximately 0.4 percent of any hour having dust storm potential, corresponding to the most likely times of below 518 m lake level, consistent with Figure 8.



[7] An integration under the curve shown in Figure 27. For Maryburn there were 10,016 occurrences of 10+m/s for 2 or more consecutive hours in 169,009 hours of observations, equating to 5.9 percent. 8760x0.059 = 517 hours.

Figure 27 Wind frequency analysis at Maryburn and Mt Cook for consecutive hours of wind 10+m/s.

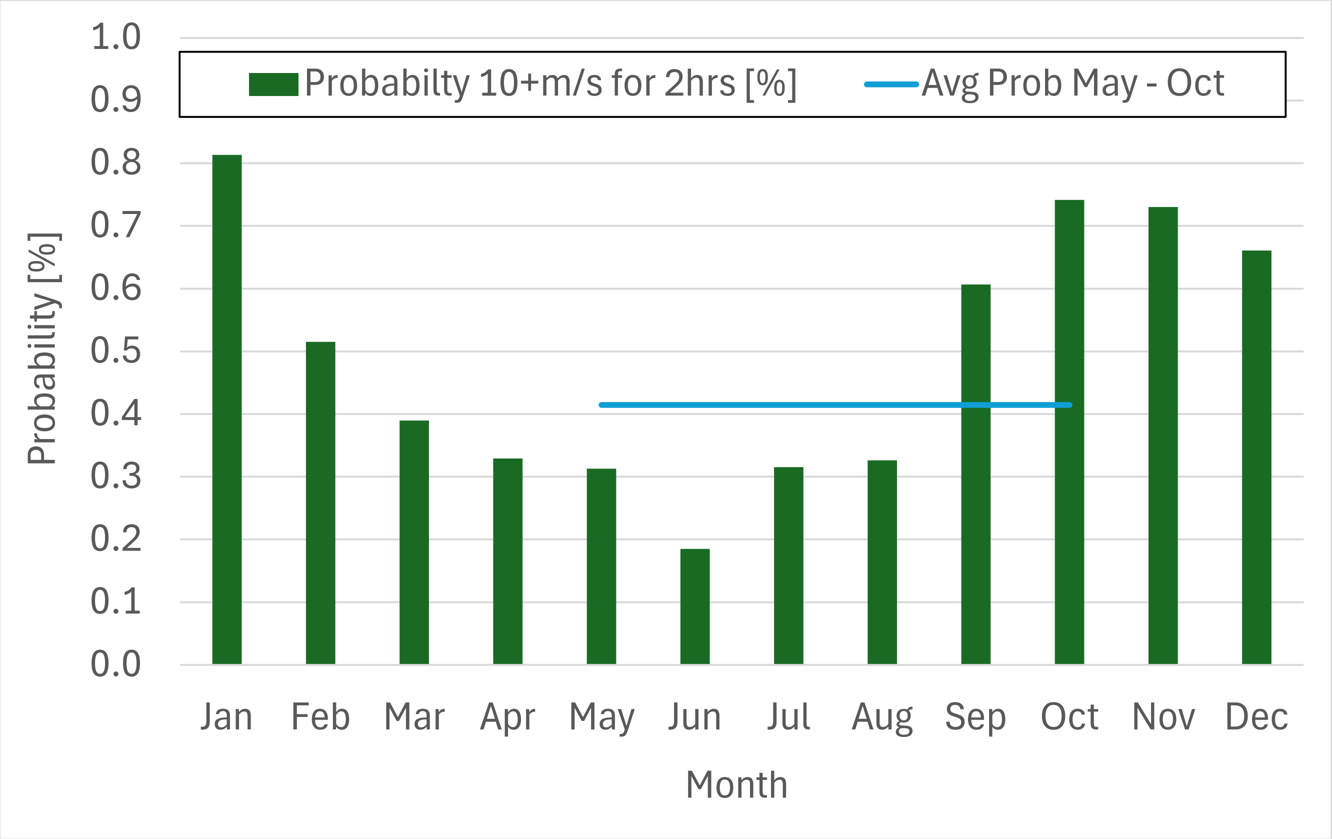


Figure 28 Dust storm wind speed criteria probability estimates for all months and May to October (lake level below 518 m) average. Based on Maryburn observations.

8. Sensitive receptors

8.1 Definition

The 2016 New Zealand Good Practice Guide for Assessing and Managing Dust (MFE 2016) provides guidelines on the classification of sensitive receptors and their sensitivity ratings, as shown in Table 7. Lookouts, which are frequently found around Lake Pūkaki, have been designated as “open space recreational”.

Note: Lake Pūkaki itself can be considered as a sensitive receptor. In general, glacial till is more likely to be hydrophilic and therefore dust is likely to become suspended in the water and eventually settle at the bottom of the lake. However, if the till is hydrophobic, a layer of fine dust may settle on the water surface, dependent on wave and wind actions.

Table 7 Classification and sensitivity of sensitive receptors (MFE, 2016)

Land use	Sensitivity
Hospitals, schools, childcare facilities, rest homes, marae	High
Residential	High
Open space recreational	Moderate to high
Tourist, cultural, conservation	High
Commercial, retail, business	Moderate to high
Rural residential/countryside living	Moderate to high
Rural	Low for rural activities; moderate or high for other activities
Heavy industrial	Low
Light industrial	Moderate
Public roads	Low

8.2 General description

In general, the identified sensitive receptors around Lake Pūkaki are classified as “tourist, cultural, and conservation”, “open space recreational”, “commercial, retail and business”, “rural” and “residential” . A total of 66 sensitive receptors were identified by GHD, with their location and distance from the shoreline detailed in Figure 29 and Table 8.

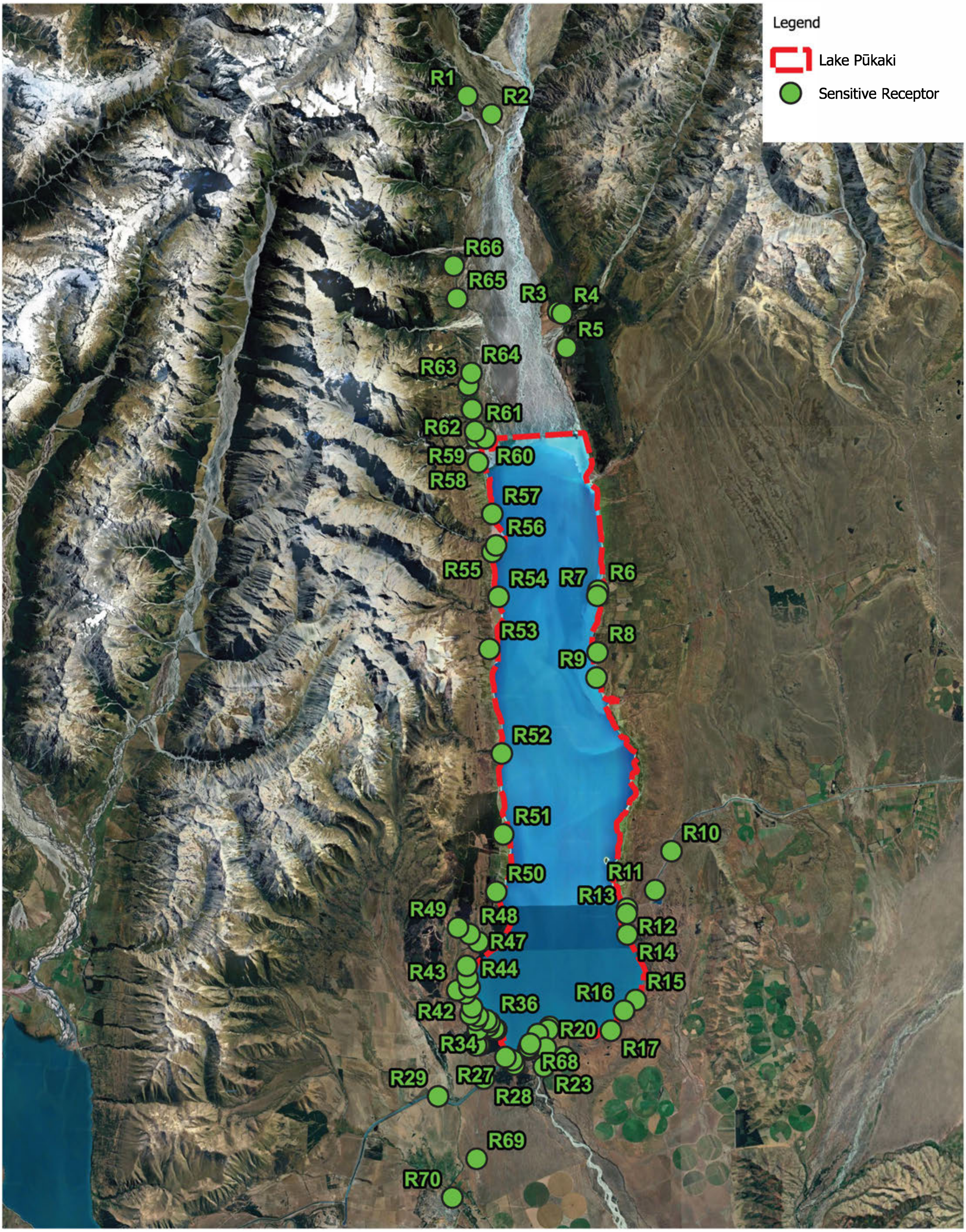
The median distance of a receptor from the lake shoreline, as defined in Figure 29 is approximately 340 m, noting that the shoreline will change with lake level. Nevertheless, a large majority of receptors are 1.) close to the lake and 2.) located on the western edge of the lake.

Table 8 Identified sensitive receptors

Name	Classification of land use	Labels	Easting [m]	Northing [m]	Distance [m]
NZ Alpine Club Unwin Lodge (Private Club)	Rural	R1	429018	5154558	17,065
Mount Cook airport	Tourist, cultural, conservation	R2	430229	5153642	16,072
Mount Cook station huts	Rural residential/countryside living	R3	433537	5143839	6,082
Mount Cook station shearers quarters lodge	Rural residential/countryside living	R4	433726	5143751	5,982
Mount Cook Station Camp	Tourist, cultural, conservation	R5	433944	5142059	4,279
Park	Open space recreational	R6	435522	5129977	71

Name	Classification of land use	Labels	Easting [m]	Northing [m]	Distance [m]
Braemar Station	Tourist, cultural, conservation, rural	R7	435478	5129728	82
Tasman Downs station	Tourist, cultural, conservation, rural	R8	435495	5126912	250
Pūkaki Swing photography area	Tourist, cultural, conservation	R9	435440	5125662	50
Mt Cook Alpine salmon limited	Commercial, retail, business	R10	439166	5117040	2,603
Fish Farm Yard	Light industrial	R11	438351	5115106	1,492
Tekapo B power station	Light industrial	R12	436962	5114185	39
Substation	Light industrial	R13	436939	5113932	155
The Pines lake Pūkaki freedom camping	Tourist, cultural, conservation	R14	436972	5112899	115
Picnic spot	Open space recreational	R15	437387	5109643	90
Lake Pūkaki Viewpoint	Tourist, cultural, conservation	R16	436807	5109110	105
Viewing spot	Tourist, cultural, conservation	R17	436155	5108115	257
House	Residential	R18	433862	5106822	62
Viewing spot	Tourist, cultural, conservation	R19	433111	5108304	205
Lakestone lodge	Rural residential/countryside living	R20	433037	5108159	41
walk photo spot	Tourist, cultural, conservation	R21	432525	5107951	607
House	Residential	R22	432922	5107266	46
House	Residential	R23	432819	5106344	63
Lake Pūkaki photo point	Tourist, cultural, conservation	R24	432047	5107188	1,543
House	Residential	R25	431356	5106446	1,077
Mt Cook alpine salmon shop	Commercial, retail, business	R26	431265	5106660	1,215
Lake Pūkaki outlet	Light industrial	R27	430910	5106810	722
Lake wardel campside	Tourist, cultural, conservation	R28	429840	5105749	96
Lake Poaka Campsite	Tourist, cultural, conservation	R29	427569	5104864	258
The moraine fine dining restaurant	Commercial, retail, business	R30	429601	5107402	371
Mt Cook lakeside retreat, high country	Rural	R31	430459	5108183	584
House	Residential	R32	429463	5107393	318
House	Residential	R33	430357	5108209	726
House	Residential	R34	430067	5108352	128
The moraine- luxury wedding and events venue	Commercial, retail, business	R35	429548	5108174	244
House	Residential	R36	430125	5108544	436
House	Residential	R37	429972	5108644	755
House	Residential	R38	429455	5108645	1,959
House	Residential	R39	429545	5108836	272
House	Residential	R40	429171	5108932	17
Karaerea Lakehouse	Residential	R41	429255	5109280	34
House	Residential	R42	428933	5109967	265
Pūkaki adventures	Tourist, cultural, conservation	R43	428519	5110125	94
Pūkaki lakeside getaway	Rural	R44	429136	5110286	371
House	Residential	R45	429032	5110763	650
Pūkaki boulder	Tourist, cultural, conservation	R46	428984	5111342	508

Name	Classification of land use	Labels	Easting [m]	Northing [m]	Distance [m]
NZ Alpine Lavender	Tourist, cultural, conservation	R47	429568	5112531	992
House	Residential	R48	429132	5112920	1,859
House	Residential	R49	428553	5113245	2,963
Reflecting Mountain View	Tourist, cultural, conservation	R50	430457	5115019	3,469
Tapataia Mahaka Peter's lookout	Tourist, cultural, conservation	R51	430802	5117877	7,203
Lake Pūkaki lookout	Tourist, cultural, conservation	R52	430732	5121895	8,821
House	Residential	R53	430113	5127082	156
Aoraki Mt Cook Scenic Lookout	Tourist, cultural, conservation	R54	430572	5129672	222
Ferintosh Station	Residential, Rural	R55	430261	5131908	411
House/Ferintosh Station P2	Residential, Rural	R56	430448	5132231	1,335
Lake Pūkaki and Mount Cook View Point	Tourist, cultural, conservation	R57	430262	5133794	417
Harlan's Gate View	Tourist, cultural, conservation	R58	429548	5136353	247
Glentanner Park Centre (Mount Cook)	Open space recreational	R59	429477	5137570	50
Glentanner Aerodrome	Commercial, retail, business	R60	429915	5137560	164
Residential Area	Residential	R61	429401	5137907	214
House	Residential	R62	429255	5138996	42
Glentanner Stream photography area	Tourist, cultural, conservation	R63	429069	5140186	233
Glentanner lookout	Tourist, cultural, conservation	R64	429226	5140806	971
Mount Cook and Tasman River lookout	Tourist, cultural, conservation	R65	428507	5144494	1,506
Acland Lagoon Lookout	Tourist, cultural, conservation	R66	428344	5146123	3,863



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

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Meridian Energy
WPS Pūkaki FTC

Identified Sensitive Receptors around Lake Pūkaki

Project No. 12656630
Revision No. B
Date 24/10/2025

FIGURE 29

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 24/10/2025

Data Source:Google Earth Imagery 2025.
Created By: rwilson3

9. FIDOL assessment

According to the *Canterbury Regional Air Plan Schedule 2*, the Canterbury Regional Council:

"for the purposes of assessing compliance with permitted activity conditions, resource consent conditions, or sections 17(3)(a), 314(1)(a)(ii) of the RMA, and resource consent applicants carrying out assessments pursuant to this Schedule, will have regard to the following matters when determining whether or not a dust discharge has caused objectionable or offensive effect:

1. *The frequency of dust events; and*
2. *The intensity of dust events, as indicated by dust quantity and degree of effect; and*
3. *The duration of each dust event; and*
4. *The offensiveness of the discharge having regard to the nature of the dust, including soiling of materials or structures and any potential health effects; and*
5. *The location of the dust, having regard to the sensitivity of the receiving environment, including taking into account the relevant zone(s) and provisions in the relevant District Plan."*

The above-listed metrics are captured in a FIDOL assessment. FIDOL assessment for dust and discussions of the indicators are presented in the section below. The table with the FIDOL indicators presents a description of the activities and conditions and give an indication of the impacts as high, medium, or low. It should be noted that the condition impacts are given relative to the size of the site and are not compared, for instance, to a large, long-term construction project. Thus, "high" impacts may specify high frequency, occurring most days of the year, or encompassing most of the lake area. In contrast, "low" impacts refer to infrequent activities with a short duration and/or a small footprint.

9.1 Dust FIDOL

Dust storms already occur at this site, and their intensity may increase due to the impacts of lake lowering. The dust FIDOL is presented in Table 9 below.

Table 9 Dust FIDOL

FIDOL Indicator	Activities
Frequency	Frequency relates to how often dust impacts will be experienced at off-site receptor locations. The frequency that off-site receptors could experience dust nuisance is dependent on numerous factors which typically need to coincide. These factors include: - flooding events depositing new fine sediments or, - lowered lake level exposing fine sediments, - dry weather immediately following fine sediment exposure for more than one day and - wind speeds exceeding 10 m/s for at least 2-hours, Bluett (2012) note the frequency of a lake-lowering event is conservatively estimated as 1 event every 15-30 years (see section 5.11), which translates to an Annual Exceedance Probability (AEP) of 3.3% - 6.7%. The Meridian modelling (see Section 2) for the proposed three years of eased restrictions indicates that approximately 23% of the 91 years of data indicates lake levels falling below 518mRL, with the majority of these lowering events (i.e. 18 of 21 events) limited to no more than two metres below 518 mRL. Only one of the 91 hydrological records modelled indicated lake levels below 515mRL. In any given week the probability of lake levels being below 518 mRL is approximately three percent. Further to this, if lake lowering occurs, it is likely to occur in late winter or early spring (August-September/October). This is when snowmelt may also start to re-fill the lake. However, in a particularly dry year, the lake may not re-fill before February, resulting in lake levels below 518 m for a period of up to 6 months. Meridian modelling estimates that a 4-month duration of lake levels below 518 m is 1 %, therefore, a 6-month duration has an extremely low probability. As discussed in Section 5.12.1, there are approximately 8 high risk dust days per spring. Thus, the likelihood of a high risk dust day occurring during a lake lowering event is 100%.

FIDOL Indicator	Activities
	The remaining ingredients for a dust storm (source-to-receiver winds and sufficiently dry lake shores) are determined by meteorology and the level of the lake has no impact on this factor. In conclusion, the overall chance of a dust storm does not change due to lake lowering, and thus, there is no net change to the overall risk faced by residents.
Intensity	The intensity of dust storms may increase compared to current conditions during periods when the lake level is below 518 m. However, the impacts of this increased intensity is expected to be uneven in distribution. That is, the above conditions must be met (lowered lake level), plus meteorologically favourable conditions, plus a lack of rainfall (leading to a dry lake shore). Dust intensity will be dependent upon the direction of the winds, where receptors located in the source-to-receiver pathway will experience more intense dust concentrations than upwind or obliquely-located receptors.
Duration	As discussed in section 5.12.1, meteorological conditions conducive to dust storms typically have a relatively short duration (two hours). Longer events (≥4 hours) occur approximately four days/year, two of which are in spring. Because the dust storms are driven by meteorological phenomena, the duration of a dust storm is not expected to change when the lake level drops below 518 m.
Offensiveness	Dust material from the lake should not be considered offensive or objectionable by members of the general public. Natural dust storms generated by winds lifting silt from the shore of the lake are part of the natural geomorphic processes of the region. The dust material could be considered as offensive when it deposits on built structures (dwellings) or within the fleece of nearby sheep, or during the event when air quality (and visual quality) is low. When a dust storm event is occurring, it is likely to be considered offensive, but this is unchanged from the current conditions. It is possible that a more intense storm would translate into a higher level of perceived offensiveness. Management measures in Appendix D focussing on communications of low lake level times and expected duration should enable surrounding communities to prepare for possible dust storms.
Location	To a large extent, the location of the sources in proximity to sensitive receptors is possibly the most important of the FIDOL factors. With increased distance, dust has greater time to disperse, therefore becoming lower in intensity as it travels from source to receptor. The site is located in a rural setting in an area that expects a dust storm from time-to-time. The majority of sensitive receptors are located on the western edge of the lake, and the median distance of the receptor to the lake shore is ~340 m. Winds are predominantly from the north-west quadrant; thus, most receptors are upwind of the lake. However, the spatio-temporally localised nature of dust storms mean that individual receptors or small groups may be subject to higher intensity dust loads than other locations during the same event. It is not possible to change the lake location, areas where dust storms may originate or the location of the surrounding communities.
FIDOL conclusion	Overall, GHD considers that the frequency of dust storm conditions *coinciding with* the lake being lowered below 518m or a flooding event *and* lake shores being sufficiently dry enough to create a more intense dust storm than a resident may currently experience (where the lake level is ≤518 m) to be low. This is primarily due to the low likelihood of lake lowering activities being undertaken over the course of the 3-year permit window in conjunction with the localised impacts of more intense dust concentrations should a storm occur while the lake is lowered.

10. Lake wind erosion qualitative assessment

A relative qualitative assessment of wind eroded dust generation due to the lake water level lowering was undertaken. Details regarding the methodology used for this assessment are provided in Sections 10.1 to 10.10. Results of the qualitative assessment are provided in Section 10.11.

10.1 Dust quantification

Dust wind erosion potential was estimated using the AP-42 wind erosion potential metric as shown in Section 5.5.

10.2 Assessed sites

Fifteen sites were assessed for wind erosion potential. These sites, detailed in Section 7.3, are located around the lake.

The sites are not meant to represent all the dust, i.e., cumulative impact, that could be generated from the lake shoreline at any corresponding time period. The site locations were selected as many correspond with the locations identified by Bluett (2012), shown in Section 5.9 (Figure 17).

As identified by Bluett (2012) and in discussions with Meridian personnel (*per.coms. Eddie Stead 29 May 2025*), single dust storm events can be generated by as little as a 1 ha area of unevenly drying or especially fine sediment from a recent flooding event.

10.3 Meteorology

CALMET derived meteorology for each of the sites was extracted and used to inform the assessment, as shown in Section 7.3 (Table 6) and Appendix C.

10.4 Surface roughness

To estimate the friction velocity from the wind velocity as estimated by CALMET, a surface roughness height value of 0.1 m has been applied to all sites.

10.5 Friction velocity

The wind velocity, friction velocity and surface roughness (Z_0) are related to each other by the equation:

$$U(z) = \frac{u^*}{k} \ln\left(\frac{z + z_0}{z_0}\right)$$

where k (kappa) = von Karman's constant (0.42) and z is the vertical distance above the ground.

10.6 Rainfall suppression

Rainfall data, as measured at Maryburn (Section 7.4), was used to inform the assessment with regards to the potential for natural – rainfall – dust suppression.

A threshold value of 3 mm of rain within the last 24 hour period was used to determine if wind erosion potential would be suppressed (eliminated). That is, if rainfall was equal to or greater than 3 mm in the previous 24 hours, no wind eroded dust would occur.

The following items were considered in selecting this value.

– There are no specific experimentally measured values for this Project.
– A detailed heat and mass transfer analysis for each location was considered to be too much detail for this qualitative study, that would unlikely be supported with onsite empirical observations.

– A single value representative for all sites was sought. It is identified that rainfall does vary significantly across the north-south length of the lake.
– With reference to Section 11, 2 L/m²/hr is considered to give 50 percent dust suppression on mining stockpiles and haul roads. This is equal to 2 mm/hr of water application.
– With reference to observed rainfall (Section 7.4.3), the median daily rainfall quantity is 3 mm/day.
– Fine glacial till "crusting" due to water/rain addition and time required for any crust to break up. Crust formation breaking after 24 hours without sufficient rainfall.

10.7 Wind speed and dust storms

Wind speed was used in the estimation of wind erosion, as per Section 5.5. However, for the assessment of dust storm potential, the criterion suggested by Bluett (Section 4.5.2.1) was adopted whereby the average wind had to be greater than 10 m/s for two or more consecutive hours.

If there was sufficient rainfall, as detailed above, a wind storm event would be estimated to be unlikely. Therefore, a dust storm event could only occur when rainfall was low for the preceding 24 hours and winds were high.

10.8 Exposure area scaling

As the water level in the lake drops, the amount of additional exposed shoreline is dependent on its gradient. The slope of the lake at the Tasman delta end is very gradual (i.e. has a shallow gradient) compared to that of the east, south and west sides of the lake.

The Bluett (2012) approach indicated that the ratio of exposed additional shoreline is approximately 2:1 for Tasman delta to the remaining lake shore. This area ratio has been adopted for this assessment, with a summary of the values for each assessment location shown in Table 10. Those locations at the upper end of the Tasman River delta that are going to be unaffected by the lake level have had a scaling factor of unity applied. The two most northerly catchment river deltas, (i.e., at Glentanner), have been included as the lake level may lower enough for these to become part of an expanded Tasman River delta.

The scaling factors[8] in Table 10 represent a proportional increase in potential dust emissions, either through general wind erosion or via a dust storm event.

Table 10 Dust area scaling factor for each location

Location	Dust intensity area scale factors
Delta 1	1.37
Glentanner 2	1.63
Tasman delta 3	1.63
Delta 4	1.00
Delta 5	1.00
Delta 6	1.63
Shore dust 1	1.37
Shore dust 2	1.37
Shore dust 3	1.37
Maryburn	1.00
Shore dust 4	1.37
Shore dust 5	1.37
Shore dust 6	1.37

[8] Total additional exposed area = 9.5 km². Tasman Delta additional area = 6 km². Shoreline additional area = 3.5 km².
Tasman delta additional area factor = 1 + 6/9.5 = 1.63
Shoreline additional area factor = 1 + 3.5/9.5 = 1.37

Location	Dust intensity area scale factors
Shore dust 7	1.37
Dam site	1.37

10.9 Wind directional adjustment

The potential dust emissions that could affect the landscape to the south and east of the lake were the focus of this assessment. Each of the 15 locations were adjusted for wind directions that would have the potential to generate dust in a storm event that had a greater chance of significantly impacting a person or landscape. Wind directions that would blow dust across the lake from east to west were discounted.

A summary of the wind directions used in this assessment for each of the site is provided in Table 11.

In general, the applied wind directions for the assessment correspond to the prevailing "*norwesters*".

Table 11 Applicable wind directions for the dust assessment

Location	Wind directions (degrees)
Delta 1	180 – 360
Glentanner 2	0 – 22 and 270 – 360
Tasman delta 3	0 – 22 and 270 – 360
Delta 4	0 – 22 and 270 – 360
Delta 5	0 – 45 and 337 to 360
Delta 6	0 – 22 and 270 – 360
Shore dust 1	180 – 360
Shore dust 2	180 – 360
Shore dust 3	150 – 338
Maryburn	0 – 360
Shore dust 4	0 – 22 and 202 – 360
Shore dust 5	180 – 360
Shore dust 6	0 – 60 and 180 – 360
Shore dust 7	0 – 30 and 225 – 360
Dam site	0 – 45 and 203 – 360

10.10 Normalised results

The results presented in this assessment are normalised, (i.e., scaled based on the maximum result for all scenarios as a fraction of unity). A linear scaling has been applied.

10.11 Dust assessment results

10.11.1 Existing lake level

The relative estimates of total dust and dust likely due to a dust storm event for the existing lake levels, i.e., no lower than 518 m, are shown graphically in Figure 30.

Locations Delta 5, Delta 6 and Shore 1 are estimated to be the largest sources of existing potential dust emissions, both during all winds and during dust storm events. These sites all have estimated annual average wind speeds near or greater than 7 m/s. Consistent with the meteorology, locations closer to the southern end of the lake have less wind eroded dust generation potential.

10.11.2 Lowered lake level

The relative estimates of total dust and dust likely due to a dust storm event for an eased access scenario, (i.e., lake levels lowered to 513 m RL for six months), are shown graphically in Figure 31.

Location Delta 6 is identified as having the greatest potential to generate wind eroded dust and dust storm emissions. This is due to the high winds estimated at the location (by the CALMET modelling) and a larger area of shoreline being exposed due to the receding water. It is estimated to have about 20 percent more dust emissions than the next highest location (i.e. 20% greater dust potential than Shore dust site 1, shown in Figure 31).

Locations upstream in the Tasman River delta, such as location Delta 5, are estimated to have no change to their current dust emissions due to the fact that the amount of exposed glacial till remains unchanged. This is clearly shown graphically in Figure 32, which shows the change in the potential dust wind erosion emissions between the base case and the eased access scenario (i.e. the difference between the two models). Location Delta 6 is estimated to have about 30 percent more dust potential than any other assessed location when considering the difference between base case and eased access scenarios.

10.12 Summary

A relative qualitative assessment of potential dust emissions was constructed with appropriate modelling assumptions that are consistent to dust and dust storm events and dust suppression.

A graphical representation of the location and relative magnitude of potential dust emissions is shown in Figure 33.

It was found that location Delta 6 had the highest potential for increased dust and dust storm event emissions. Given that this location corresponds to a delta, where flooding events will deposit glacial till sediments, this general area should be considered as a higher risk area.

Note that changing the values used in the model assumptions may change the output values of the assessment, however, the outcomes do not seem unreasonable based on the general physics of dust emissions – generation and suppression – and other studies undertaken by Bluett (2012), refer to Sections 5.9, 5.10, 5.11 and 5.12.

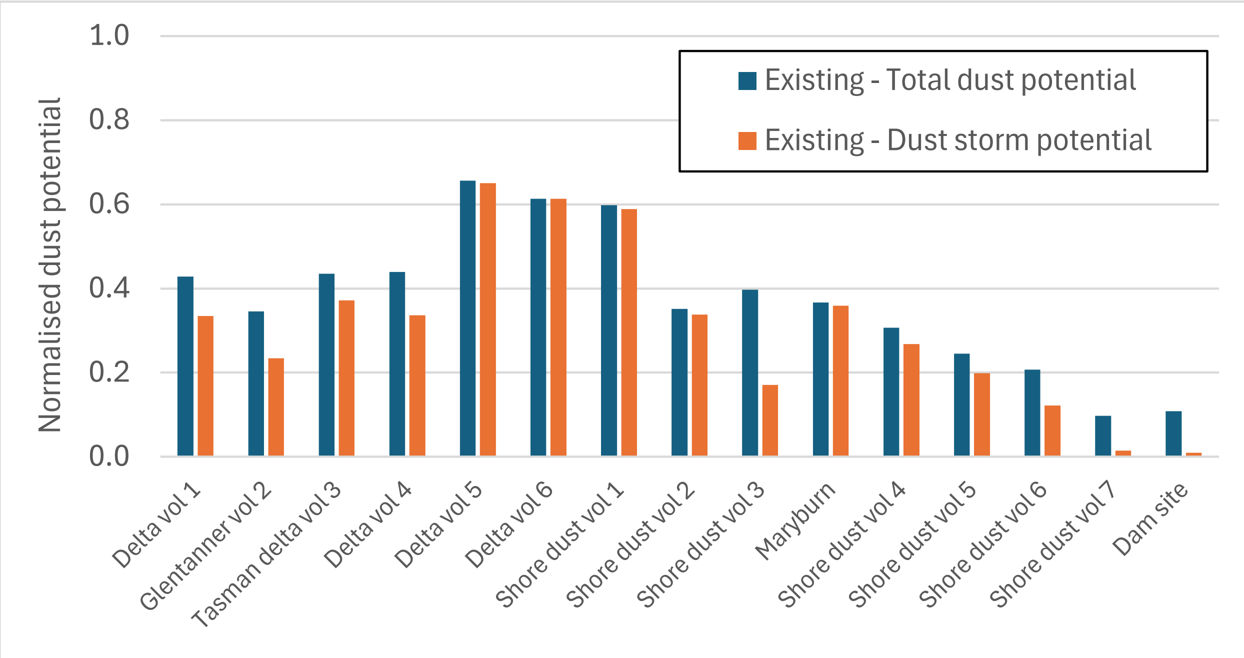


Figure 30 ***Existing potential total dust and dust storm event relative emissions with lake at 518 m.***

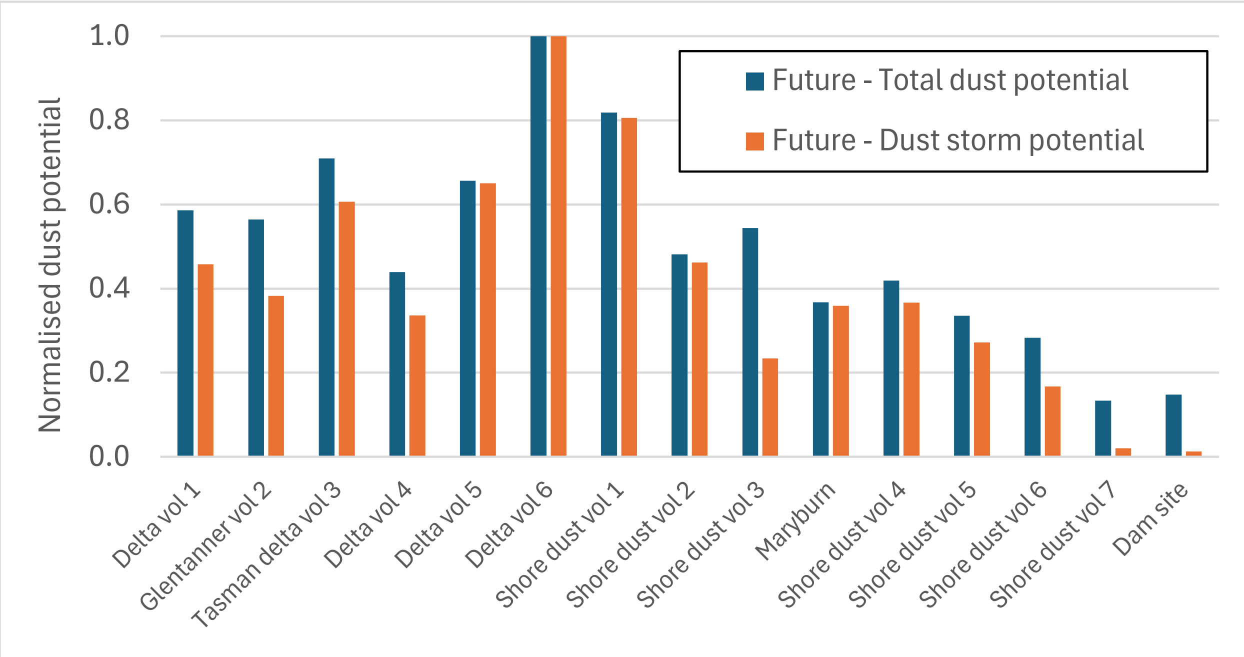


Figure 31 ***Future potential total dust and dust storm event relative emissions due to lake lowering to 513 m.***

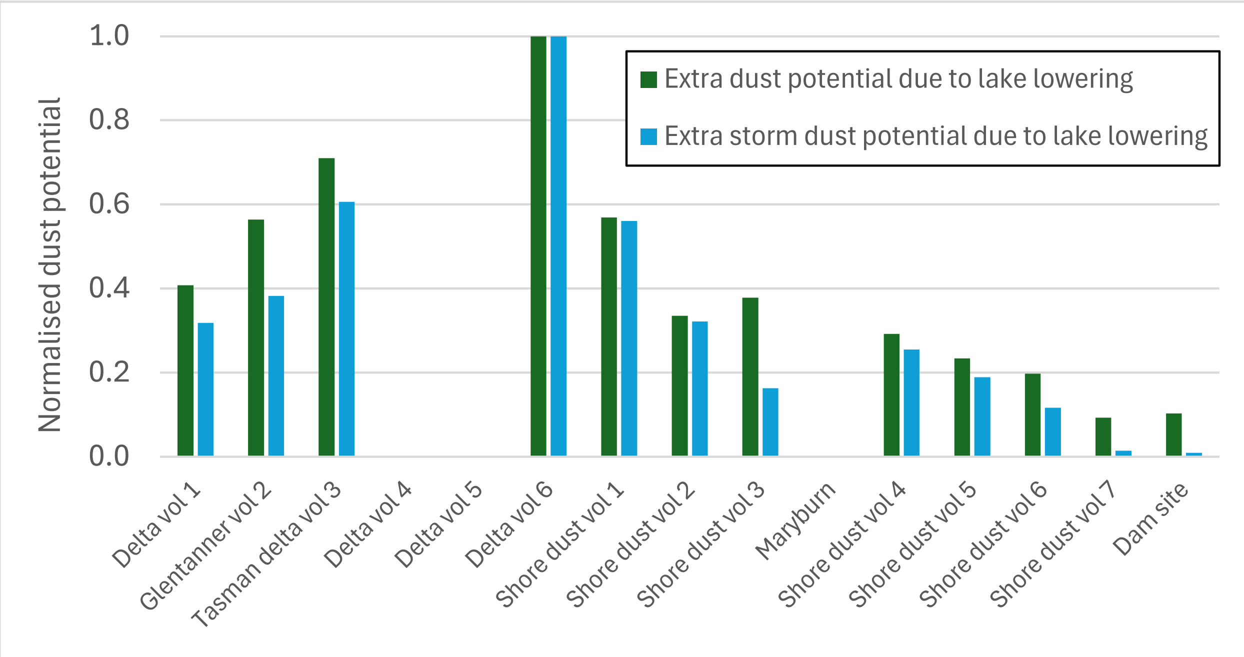
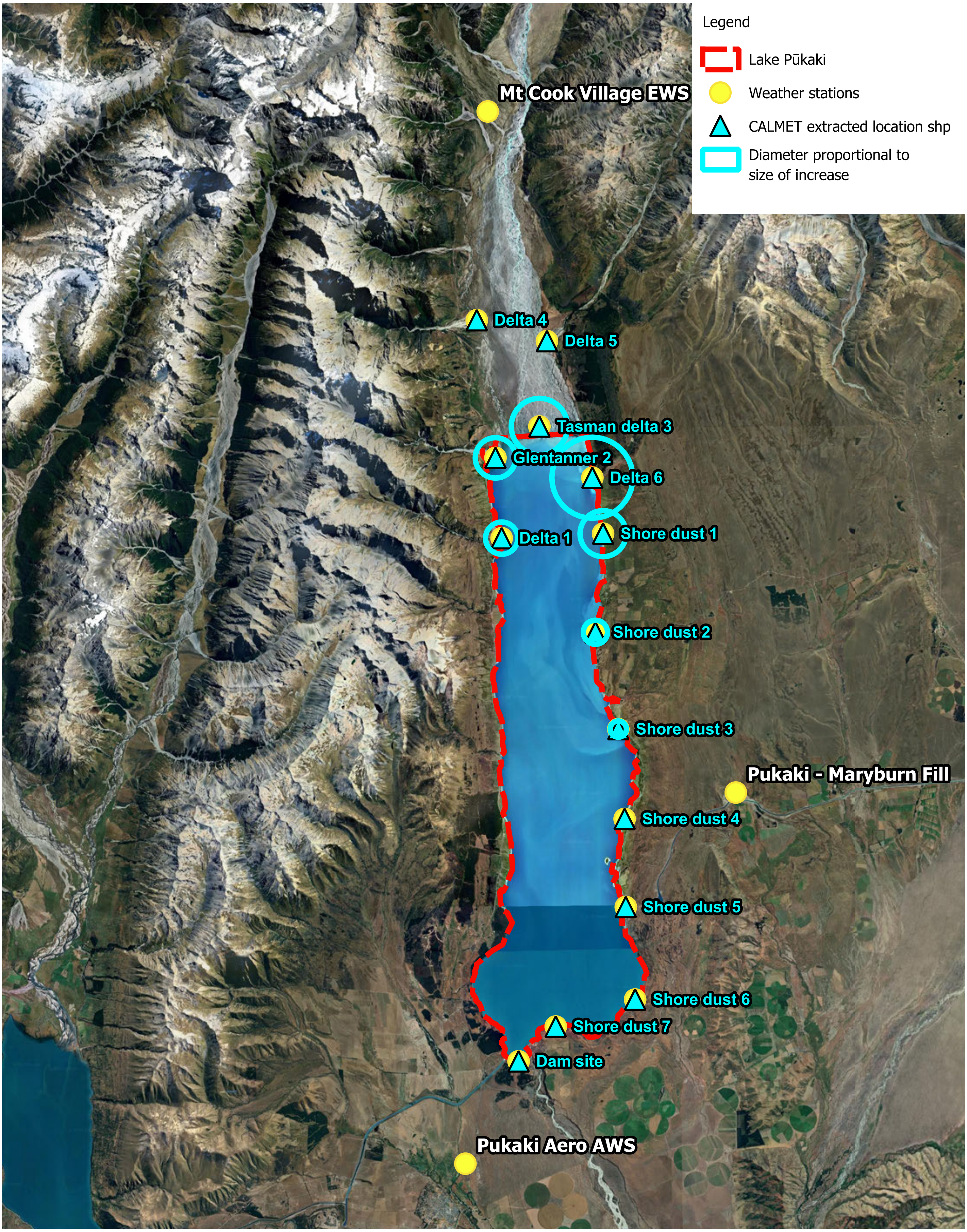


Figure 32 ***Future potential increase to dust and dust storm event relative emissions with lake lowered to 513 m.***



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

N

Meridian Energy
WPS Pūkaki FTC

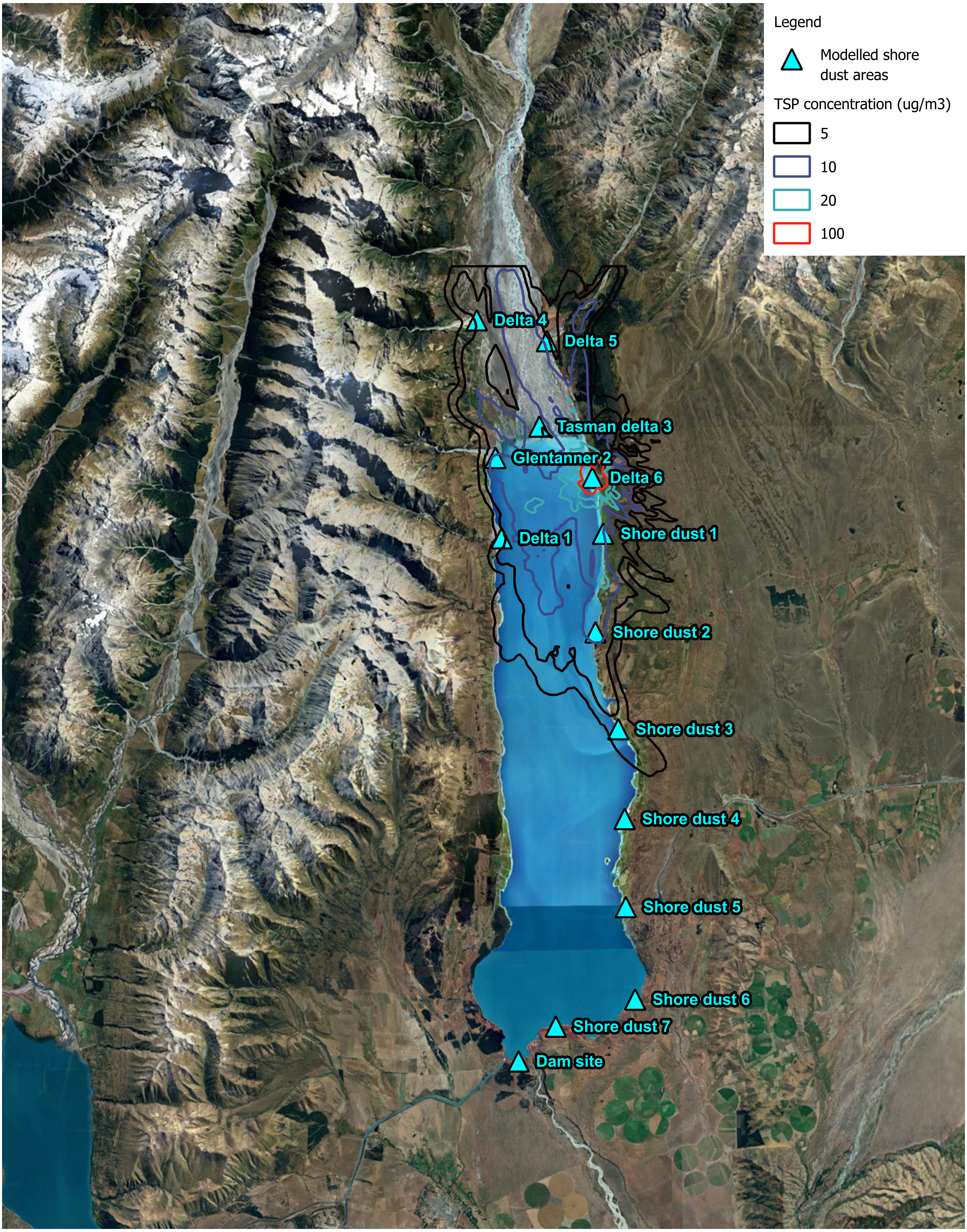
Future potential increase to relative dust emissions with lake lowered to 513 m.

Project No. 12656630
Revision No. A
Date 04/11/2025

FIGURE 33

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 04/11/2025

Data Source:Google Earth Imagery 2025.
Created By: bfraser4



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

N

Meridian Energy
WPS Pūkaki FTC

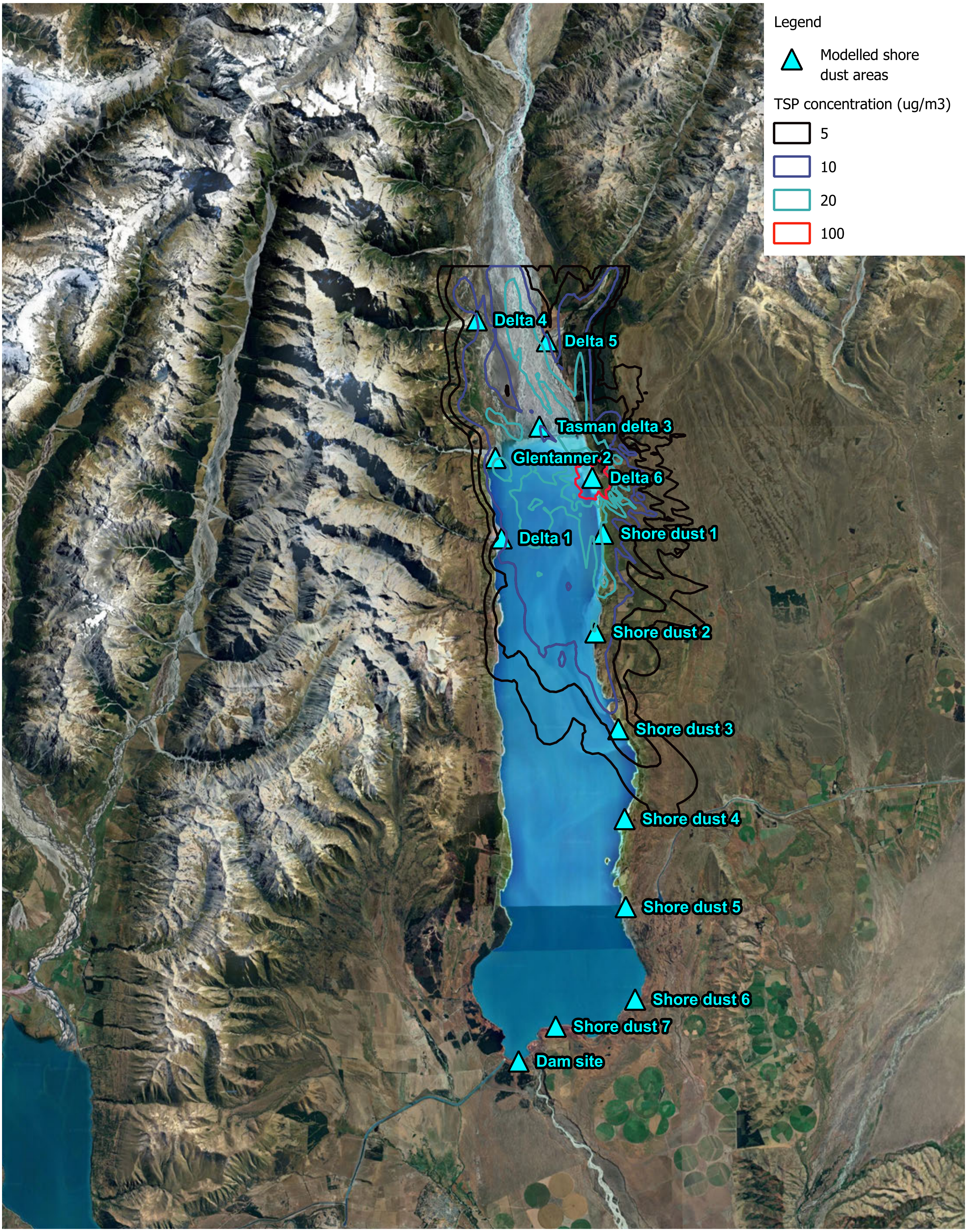
Delta 6 lake wind erosion
1-hour averaged maximum
TSP GLC (ug/m3)

Project No. 12656630
Revision No. A
Date 24/10/2025

FIGURE 34

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 24/10/2025

Data Source:Google Earth Imagery 2025.
Created By: rwilson3



Paper Size ISO A4

0 5 10 km

Map Projection: Universal Transverse Mercator
Horizontal Datum: WGS 84
Grid: UTM Zone 59 South

N

GHD

Meridian Energy
WPS Pūkaki FTC

Delta 6 lake wind erosion
3-minute averaged maximum
TSP GLC (ug/m3)

Project No. 12656630
Revision No. A
Date 24/10/2025

FIGURE 35

Document Path: \\ghdnet\ghd\NZ\Christchurch\Projects\51\12656630\GIS\Maps\Working\Lake_Pukaki_James_D.qgz
Print Date: 24/10/2025

Data Source:Google Earth Imagery 2025.
Created By: rwilson3

11. Dust management

A dust management plan (draft) is provided in D.

11.1 Dust suppression

There are many different possible methods of dust suppression however, a detailed analysis of them all is beyond the scope of this assessment.

A common technique used to prevent dust generation via wind erosion is to treat a particulate surface with a wetting agent such as a chemical or water.

The Australian National Pollution Inventory Estimation Manual for Mining (NPI Mining, 2012, Table 4) specifies that water sprays onto stockpiles and haul roads, at a rate of 2 L/m²/h will result in wind erosion suppression by 50 percent. The MfE (2016) indicates that for New Zealand conditions 1 L/m²/h would provide a similar level of dust control. This implies continual water application where cohesive forces between particles is maintained.

Given that the estimated area of newly exposed glacial till is in units of square kilometres, i.e., very large, applying water suppression is not considered as a feasible control method.

Active dust suppression is not practicable for newly exposed shoreline and Tasman/river delta areas.

11.2 Communication

Communication of lake levels to the surrounding communities and local signage in areas prone to dust storm activity are things that Meridian can control. Such items are included in the attached (draft) dust management plan (Appendix D).

12. Assessment of environmental effects

The assessment of environmental effects presented here focuses on the impacts of the proposed activity on air quality associated with the lowering of lake levels. This assessment does not include the construction works associated with the dam armouring – this is addressed in a separate report.

The process undertaken to assess the potential effects of a lowered lake level was based on the assessment criteria and methodology for assessing dust impacts in New Zealand (MfE, 2016) for health and amenity.

This report provides a detailed description of the processes for dust generation and suppression, the meteorological data that is relevant to the site, and identification of potential receptors and their likely sensitivity to dust.

12.1 FIDOL

A FIDOL assessment has been undertaken and is provided in Section 9.

From the FIDOL assessment, only a possible increase in dust storm intensity was identified, due to a larger area of fine sediments being exposed to the wind.

There is no expected change to the composition of the dust or the frequency of the storm events that are driven the meteorological and hydrological factors.

Control of dust around the entire perimeter of the lake is not feasible, however, increased communications to surrounding communities regarding lake level has been identified as a practical measure that can be implemented by Meridian to ameliorate any potential increase in dust storm intensity.

12.2 Dust dispersion modelling

A review of meteorological data using a multi-criteria analysis process (as described in Section 7.2.2) was undertaken to identify a representative worst-case year to use for modelling dust dispersion. The year 2015 was selected as it was assessed as the most appropriate for a high number and severity of dust storm and wind erosion events.

A total of 15 representative dust storm origin locations were created around the eastern and southern lake perimeter and on the Tasman River delta to understand the change in potential for dust events to be generated between the current and eased restriction scenarios. These selected locations were selected based on information that indicates dust storm events can be generated at highly localised areas surrounding the Tasman River delta due to natural irregularities with flooding events and sediment deposition and drying.

The qualitative assessment indicated that the risk of dust storm impact reduces with distance from the Tasman delta and with distance from the lake shoreline, with the modelled location with the greatest increased risk (identified as Delta 6) located in the vicinity of the Tasman delta and the Landslip Creek delta.

The modelling indicated that all sites had the potential for dust events to be generated under existing conditions. For sites located downstream of the Tasman delta where a lower lake level would potentially exposure more shoreline and sediments, there was an increase in potential dust emission rates during a storm event under the eased scenario when compared to the status quo (i.e. compared to the average lake level assessment).

Areas immediately adjacent to the eastern shoreline of the lake and closer to the Tasman Delta are expected to be more exposed to dust due to the prevailing meteorological conditions.

12.3 Amenity

In terms of amenity, the MfE identifies a dust deposition rate of greater than 2 g/m²/30-days above background levels (for high sensitive areas) as being applicable (MFE, 2016, Section 3.1.4, para.2). The rate of dust accumulation was not modelled. However, the modelling did indicate that the lateral extent of dust being generated from the current and eased restrictions scenario was most pronounced near the lake and Tasman delta. For those landowners who operate farms and businesses in close proximity to the lake and delta, it would be difficult to determine if dust accumulation rates under an eased scenario were significantly different to current conditions without a lot of baseline monitoring under a range of climatic conditions. As the time proposed for the eased access is over the next three winters, it is considered impracticable to obtain the necessary data to determine the scale of any effect associated with amenity.

12.4 Dust mitigation

It is noted that there are no practicable mitigation measures that could be adopted in an eased scenario, as dust suppression measures are not practicable to apply over the exposed Tasman delta. In addition, the short duration of the proposed eased access means that there is unlikely to be benefit from installing monitoring equipment as an early warning system for those landowners and visitors to the lake margins.

The dust management plan, refer to **Appendix D**, emphasises lake level operation communications with local communities and investigation of dust issues via a complaints/incidents register.

12.5 Comparison to PC1

The assessment undertaken in connection with PC1 by Bluett (2012) concluded that:

– There were no adverse effects on people and the environment associated with a proposed lower lake level of 513 m RL.
– Increased dust storm activity would be unlikely to affect the lungs or eyes of stock within the area.
– During a dust storm event, with a lower lake and potentially a more intense storm, visual amenity would be degraded more than currently occurs.
– There was likely to be greater nuisance dust deposited into the wool of sheep around Lake Pūkaki due to a lower lake level, however, this was not quantified.

The assessment presented in PC1 also identified that the lowest lake levels will tend to occur during the end of winter to early spring, with lake refilling during spring/summer and peaking in March/April.

The assessment undertaken in this report is consistent with those findings prepared by Bluett (2012) for the PC1 hearings, with the following exception:

– This report does not make an assessment on the health implication on stock that occupy the grazing lands surrounding the lake.

The quantitative assessment indicates that there are unlikely to be any adverse effects on people and the environment. Whilst there is a likelihood of increased potential for dust events, the lateral extent and intensity of these events is expected to be limited to those areas along the lake and near the delta.

12.6 Summary

The qualitative dust assessment, including a FIDOL assessment, found that lowering the lake water level has the potential to increase the intensity of dust storms in the vicinity of Lake Pukaki, and in particular at the river delta regions that enter the lake at its northern end. The qualitative modelling also showed that current dust storm origin and intensity is estimated to be greatest from the Tasman River delta. Changes to the lake levels under an eased access scenario indicate that there is expected to be an increase in dust potential for wind and dust storm events, but the relative change between the existing and eased scenarios is focused around the northern end of the lake and exposed delta and diminishes with distance along the lake to the south.

The assessment indicated that the dust impacts are more pronounced to the northern end of the lake and adjacent to the shoreline, reducing with distance along the lake towards the south. Those sensitive receptors that have been identified as most likely to be affected are Braemar Station and Tasman Downs Station. The public accessing and using the eastern shoreline of the lake for recreational activities may also be exposed to more intense dust events.

As noted in a number of locations through this report, Meridian's modelling indicates the lowering of the lake below 518.0 m RL is likely to be infrequent and for short duration limiting the potential for an increase in effects. Given the short duration of the eased restrictions (i.e., lower lake levels for no more than three years), the assessment that has been undertaken is deemed to be conservative and precautionary in its approach.

In terms of mitigation, there is no practicable measures for the active management of newly exposed areas of the lakebed to the risk of dust generation, given the short duration of increased risk – measured in weeks to months – and the potentially large areas for which dust suppression would have to be applied across.

A dust management plan emphasises communications with local communities regarding lake level activity and the establishment of a formalised complaints/incident register so that Meridian can undertake investigations and implement corrective actions were practicable.

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Appendices

Appendix A

Curriculum vitae

Rebecca Wilson PHD

Senior Air Quality Consultant

Location

Brisbane, QLD

Experience

11 years

Qualifications/Accreditations

- Certified Air Quality Practitioner (CAQP), Clean Air Society of Australia/New Zealand, 2025
- PhD in Env Science and Atmospheric & Env Science, Macquarie & Edinburgh Universities, 2018
- Master of Science of Public Health in Env Sciences and Engineering, University of North Carolina-Chapel Hill, 2008
- Bachelor of Science in Meteorology, Texas A&M University, 2004

Key technical skills

- Atmospheric models: CALPUFF, AERMOD, TAPM, WRF, MLC-CHEM
- Programming languages: Python, SQL, R, FORTRAN

Memberships

- CASANZ: GHD is a member firm

Relevant experience summary

Dr Rebecca Wilson is an atmospheric chemist and meteorologist with a background in measuring, monitoring, and modelling of aerosols and other gaseous and particulate emissions to air. Her PhD research examined the emission of isoprene, a response to and protection from warming temperatures, from Australia's tropical forests. Her Masters research developed a method of dilute mixing of reactants in an outdoor smog chamber and applied it to a dark α-pinene-ozone system, with implications for human and environmental health.

Rebecca combines her atmospheric and meteorological training with scripting and data visualisation skills to understand and communicate climate risk and air quality issues for a range of Australian industries and organisations. She applies atmospheric dispersion models including CALMET/CALPUFF, AERMOD, and TAPM, with coding and spatial Geographic Information System (GIS) modelling to address and manage air quality for human and environmental health.

Project experience

Technical advice and guidance recommendations – Middle Arm Sustainable Development Precinct

Senior Consultant | Department of Logistics and Infrastructure | Darwin, NT

Rebecca provided a range of peer review and technical advice relating to air quality for the Middle Arm Sustainable Development Precinct (MASDP).The project included several elements: technical advice regarding the suitability of the MASDP Air Quality Model, recommendations for the location of a Precinct air quality monitoring station and periodic monitoring, and guidance documentation for the approach to establishing air quality targets for the Precinct in the context of the larger Darwin airshed.

Risk Assessment of Extreme Meteorological Events

Senior Consultant | Confidential – Defence | Australia

Conducted an assessment to determine the frequency of extreme meteorological events (high straight line winds, severe storms, cyclones, dust storms and precipitation events) and relative risk of such events to a defence site. The study used publicly available data and historical records from the Bureau of Meteorology and the study methodology followed an international safety standard suitable for use at the site.

Air Quality Assessment – Renewable Energy

Senior Consultant | Confidential | Gladstone Region, QLD

Conducted an air quality assessment for a first-of-its-kind renewable energy facility in the Gladstone region of Queensland. Emergency and routine flare modelling was undertaken as part of this work. This assessment required additional support in the form of an academic literature review to assist the client and regulatory professionals with understanding the potential implications of the proposed activities.

Operation Expansion - Granite Quarry

Technical Lead | Joyful View | Cherrabah, QLD

Rebecca led an air quality impact assessment for a proposed expansion of a previously approved but not constructed granite quarry using the CALPUFF dispersion model. Predicted dust deposition was modelled and the potential impacts of Respirable Crystalline Silica (RCS) were considered. This assessment was undertaken as part of a larger Environmental Impact Statement (EIS).

Proposed Coal Seam Gas (CSG) Project

Senior Consultant | Epic Environmental and Comet Ridge Mahalo North | Emerald, QLD

Rebecca led an air quality assessment for a proposed CSG Project in the Bowen Basin. The Project comprises up to 68 wells (34 lateral, 34 vertical), gas gathering lines, a petroleum pipeline, and a gas compression facility. Dispersion modelling was undertaken using CALPUFF and ground-level concentrations of NOx and CO were determined at nearby sensitive receptors and across a Cartesian grid of the region. This project formed part of an application for Environmental Authority (EA).

Proposed LNG compressor stations

Senior Consultant | APA | Tibooburra, NSW

Rebecca conducted an air quality assessment of a proposed series of compressor stations using the CALPUFF dispersion model. Predicted concentrations were used to ensure that the neighbouring and on-site work camps were located appropriately within the project site. The work further contributed to a larger EIS of the proposed work.

Air Quality Management Plan – Mount Morgan Mine

Technical Lead | Heritage Minerals | Mount Morgan, QLD

Rebecca reviewed planned operations at the historic Mount Morgan Mine and drafted an Air Quality Management Plan to support operations and minimise impacts to the surrounding community. The plan included activities to be maintain compliance with the air quality-related conditions of the site's Environmental Authority (EA), identified activities that were likely to produce atmospheric emissions, and provided employees and contractors with clear roles and responsibilities in relation to air quality management. A monitoring plan and advice for continuous improvement was also included in the plan. This project contributed to an EA Amendment for the client.

Dust Assessment – Landfill

Senior Consultant | Liverpool Plains Shire Council | Willow Tree, NSW

Rebecca undertook an air quality assessment to consider the impacts of a planned expansion of an existing landfill. In this project, CALPUFF was used to undertake a risk-based assessment of dust and odour on nearby receptors throughout both the construction and operational phases. This assessment formed part of the larger EIS work undertaken by GHD for the client.

Air Quality Advice and CFD modelling

Senior Consultant | Valmont Coatings | Carole Park, QLD

Rebecca conducted a records review of stack maintenance and site visit for a zinc galvanizing facility as part of a larger body of work to locate and identify sources contributing to groundwater contamination. A computational fluid dynamics study was further undertaken to test the hypothesis and role of roof condensation as a potential source

Remediation of Waitakere Landfill

Senior Consultant | Auckland Council | Auckland, New Zealand

Rebecca undertook an air quality assessment that considered the impact of remediation works on a landfill near sensitive areas in a regional area outside Auckland, New Zealand. In this assessment, particular care was taken to work with the design engineering team to ensure that the proposed remediation plan minimised impacts to nearby residential areas. Care was also taken to ensure that the proposed remediation would have the least impact on the climate compared to alternative methods.

Mine Expansion Project

Lead | Bowen Basin Coal | Moranbah, QLD

An air quality assessment was undertaken to assess a proposed expansion of Lake Vermont mine. The proposed expansion is to develop an underground mining project and a satellite open-cut mine. CALPUFF software was used to model particulate dust impacts of the proposed project. Predicted concentrations were paired with modelled outputs from existing mine operations and locally relevant background monitoring data to form a cumulative impact assessment of the proposed project.

Haul Road Investigation

Lead | Epic Environmental and Glencore | Western QLD

Lead the air quality modelling to quantify heavy metal deposition and accumulation due to haulage activities along the road connecting Mt. Isa Mine and George Fisher Mine in western Queensland. Soil sampling indicated elevated soil concentrations of heavy metals in proximity to the road, which, left untreated, may contaminate nearby waterways and be ingested by grazing livestock. Atmospheric dispersion models were used to identify locations most likely to be affected by haulage activities and estimate a schedule for commencing soil monitoring and remediation.

Bimonthly, Quarterly and Annual Reporting

Senior Consultant | Port Hedland Industries Council | Port Hedland, WA

Conducted regular analysis and reporting of air quality conditions in Port Hedland. Analysis was undertaken using custom R scripts. The reporting included monitoring data capture rates, calculation of 24-hour averages and exceedance analysis to determine if exceedances were due to industrial activities or larger regional events. A meteorological discussion was also included in the reports to provide context and a basis for any dust events that may have occurred in the reporting period.

Data Centre Expansion

Senior Consultant | iSeek | Eagle Farm, QLD

An air quality assessment was undertaken for an expansion of an existing data centre located near Brisbane Airport. Atmospheric dispersion modelling was undertaken using AERMOD, and built upon previously undertaken research to determine the safest emissions protocols, given the CASA requirements for the site.

Proposed Data Centre

Air Quality Scientist | AirTrunk | Blacktown, NSW

An air quality assessment was undertaken for a proposed large data centre near Blacktown, NSW. Atmospheric dispersion modelling was undertaken for normal operations, a variety of backup generator testing regimes, and emergency conditions. Consideration was required for the staging of installation of pollution control technology throughout the Project’s staged development and its evolving testing regime.

Review of Net Zero Business Cases

Senior Consultant | NSW Department of Environment, Climate Change and Water | Sydney, NSW

Rebecca conducted a global review of the methodologies used to calculate the cost of air pollution and the benefits of Net Zero policies. The review included methodologies derived in New Zealand, the United States, Canada, the United Kingdom, and the European Union. The survey considered the pollutants included, health endpoints, and various methods of determining cost, both to the individual and larger society. From this survey, she determined which approaches form best practices for calculating costs and worked with DECCW to form connections with other departments and lay the groundwork to develop an approach suitable for use in New South Wales.

Proposed Residential Development

Lead | Gorman Property Group | Ipswich, QLD

An air quality assessment was undertaken for a proposed residential subdivision located adjacent to a historic neighbourhood and a cleared area which had formerly been quarried and carried a current mining lease. CALPUFF software was used to model particulate matter impacts of both the proposed and the historic residential developments should quarrying re-commence, and a relative risk assessment was undertaken to characterise the potential exposure risk of each development.

Technical Advice of Odour at LMWQCC

Technical Lead | Icon Water | Ginninderry, ACT

Rebecca provided technical advice and undertook a peer review of modelling and monitoring works of a wastewater treatment plant outside Canberra prepared by a 3rd party. The outcomes of the review process highlighted areas of improvement for the 3rd party and helped Icon Water identify areas where their odour control efforts would be the most impactful.

Climate Risk Assessment for Space Launch Facility

Senior Consultant | Equatorial Launch Australia | Arnhem Land, NT

Rebecca assisted Equatorial Launch Australia (ELA) with a climate risk assessment for their rocket launch facility in Arnhem Land, Northern Territory. The assessment considered current and future temperature, rainfall, wind patterns, storms, and forest fire danger impact (FFDI) days, with particular attention to the impacts of these elements on the health and safety of employees, clients, and the nearby Aboriginal community, and the operational impacts on the company. In addition, Rebecca developed four future climate scenarios for consideration by the client. Scenarios were selected based on their likelihood of occurrence and severity of health and/or operational impacts. The scenarios were used to assist ELA with the development of their safety protocols and emergency response plans.

Nationwide Climate Risk Assessment for Equipment Hire Facilities

Senior Consultant | Seven Group Holdings | Various

A physical climate risk assessment was undertaken to assist Seven Group Holdings with their Task Force on Climate-related Financial Disclosures (TCFD) reporting. The assessment, conducted for 200+ Coates and WestTrac sites across the country, considered temperature, extreme rainfall, sea level rise, forest fire danger index (FFDI).

Air Quality Assessments – Brisbane City Council

Senior Consultant | Various clients | Brisbane region

The list below comprises a selection of air quality assessments undertaken for various clients proposing developments within Brisbane City Council.

- Service station | Citimark Properties | Kedron
- Data centre | Smart Capital Property & Investment | Tenerife
- VJ manufacturing | Easycraft | Wynnum West
- AQ Traffic Assessment – Proposed residential | confidential | Sandgate
- AQ Traffic Assessment – Proposed residential | City Developments Limited | Toowong
- Service station | McAndrew Property Group | Bridgeman Downs
- Childcare centre | Explorers Early Learning | Cannon Hill
- Blast Shed | confidential | Carole Park
- Residential development | Steffan Town Planning | Kedron
- Pilot Pyrolysis Plant | confidential | Rocklea
- Microbrewery | West End Craft Brewery | West End
- Aquamation facility (cremation) | Pure Souls | Virginia, QLD
- Smallgoods manufacturing | confidential | Coopers Plains

Air Quality Assessments – beyond Brisbane

Consultant | Various clients | Various locations

The list below comprises a selection of air quality assessments undertaken for various clients proposing developments elsewhere in Australia and beyond.

- Spray booth | confidential | Ipswich, QLD
- Concrete batching plant | Holcim | Lithgow, NSW
- Proposed generator | Newcrest | Lihir Island
- Burnie Chip Loading Facility | TasPorts | Burnie, TAS
- Proposed chicken farm | Coominya Chooks | Coominya, QLD

Career history

2023 - present	GHD, Senior Air Quality Consultant
2021 - 2023	Katestone Environmental, Senior Air Quality Consultant
2019 - 2021	Trinity Consultants Australia/Air Noise Environment, Environmental Consultant

Appendix B

CALMET-CALPUFF modelling

Modelling

Emissions and meteorology for the project were assessed using the CALPUFF modelling system, a transport and dispersion model that tracks “puffs” of material from emission sources, accounting for their dispersion and transformation over time. The model utilises meteorological data generated by the CALMET pre-processor, which incorporates temporal and spatial variations in weather conditions.

CALPUFF produces hourly concentration outputs at specified receptor locations, which are further processed using the CALPOST post-processor to summarise results over user-defined averaging periods.

CALPUFF is a more advanced dispersion modelling package than a Gaussian plume model such as AERMOD or AUSPLUME. It takes into consideration three-dimensional atmospheric wind affects.

For the meteorology around Lake Pūkaki, the CALPUFF system has been selected due to the following complexities that were identified prior to and subsequently following initial meteorological modelling.

– Large body of water – Lake Pūkaki
– High mountains immediately adjacent to Lake Pūkaki with steep sides resulting in terrain elevation rises of about 1500 m.
– Steep valley winds, particularly at the Tasman delta end of Lake Pūkaki.
– Large relative flat plains consisting of grasslands and glacial riverbeds extending kilometres from Lake Pūkaki.
– Dust sources located at the edge of the lake.

Given the above identified complexities, and after reviewing the *Good Practice Guide for Atmospheric Dispersion Modelling* (2004) the CALPUFF modelling package was identified as the most appropriate model for quantitatively assessing dust emissions from the proposed project.

The CALPUFF modelling package was accessed using the Lakes Environmental Calpuff View software that provides a user-friendly GUI interface for model set up and results analysis.

Meteorological modelling

Meteorological processes significantly influence the dispersion, transformation, and removal of pollutants in the atmosphere. Vertical dispersion depends on atmospheric stability and surface mixing layer depth, while horizontal dispersion is driven by wind speed and direction. Wind speed affects pollutant transport and dilution, with mechanical turbulence, influenced by surface roughness, further aiding dispersion. Wind direction determines pollutant pathways and crosswind spreading, causing concentrations to fluctuate with changes in stability, mixing depth, and wind patterns. (Oke, 2002).

For this project, a site-specific three-dimensional meteorological dataset was developed using TAPM, surface observational data and CALMET, as detailed in the following sections.

Selection of meteorological year

The single year for the modelling was selected based on a multi-criteria analysis, as described in Section 7.2.2 and repeated here for convenience.

A multi-criteria assessment was used of all the available data, which included the following parameters.

– Annual rainfall
  - A drier year is generally associated with more frequent dust storms, i.e., dust wind erosion.
– July to December rainfall
  - Dust storms tend to occur during the later half of the year.
– Annual average relative humidity

- Lower RH is generally favourable for exposed surfaces to lose moisture.

– Annual average wind speed
  - Wind erosion and dust storms increase in intensity with wind speed.

– Number of hourly observations with wind speed 10+ m/s
  - Highest wind speeds are associated with dust storms, consistent with Bluett (2012).

– Number of periods where the wind speed exceeded 10 m/s for longer than 24 consecutive hours.
  - Long duration high wind events are more likely to result in dust storms and exposed surface drying.

– Number of missing hours
  - Validity of the analysis needs to be maintained.
  - Used to exclude 2017 as a usable year given 52.5 percent of data was missing from the Maryburn site.

More weighting was given the observations from Maryburn and Pūkaki Aero rather than Mt Cook Village given their better proximity to the dam wall construction site and representation of winds across the plains east of Lake Pūkaki.

A ranked multi-criteria analysis was applied for each of the sites with ranking tables shown below.

The year 2015 was selected as it ranked highest (lower number) than the other years. Although 2015 was ranked poorly for the number of consecutive hours greater than 10 m/s, it had a very large number (rank 2) of total hours greater than 10 m/s.

The annual wind rose for the year 2015 for Maryburn and Pūkaki Aero are shown below.

Table B.1 Maryburn site multi-criteria assessment for modelling year selection

Year	Total Rainfall	RH avg	WS Avg	24hr consect 10+m/s	10+m/s	missing data	Rain last 6months of year	Total Rainfall	RH avg	WS Avg	24hr consect 10+m/s	10+m/s	Rain last 6months of year	rank sum
								Rankings						
2007	436.5	67.8	4.2	5	710	170	258	1	16	7	7	11	5	47
2008	595	67.0	4.0	4	700	75	370.5	5	13	10	9	12	10	59
2009	637	65.8	4.4	0	896	47	223.5	8	6	3	11	4	3	35
2010	750.5	66.8	4.3	8	827	7	428.5	13	11	5	6	5	14	54
2011	732	66.9	4.1	4	726	0	379.5	12	12	9	9	10	11	63
2012	731	68.4	3.9	0	692	4	407	11	17	12	11	13	13	77
2013	686.5	66.4	4.2	9	752	2	282	10	9	6	5	8	6	44
2014	612	67.1	4.3	11	914	12	241	7	14	4	4	3	4	36
2015	**488**	**64.4**	**4.5**	**0**	**936**	**30**	**176.5**	**2**	**4**	**2**	**11**	**2**	**1**	**22**
2016	602	65.9	4.6	5	965	0	309	6	7	1	7	1	8	30
2017						4606								
2018	847	66.4	3.8	0	533	71	346.5	16	10	16	11	16	9	78
2019	672.5	63.0	4.1	0	774	4	392.5	9	1	8	11	6	12	47
2020	547	64.1	4.0	34	739	80	303	4	3	11	1	9	7	35
2021	809.5	65.0	3.9	28	652	0	457.5	15	5	13	2	14	15	64
2022	847	67.1	3.5	0	443	51	491.5	16	15	17	11	17	16	92
2023	521.5	66.0	3.8	17	620	46	202	3	8	15	3	15	2	46
2024	767.5	63.8	3.9	0	761	32	565	14	2	14	11	7	17	65

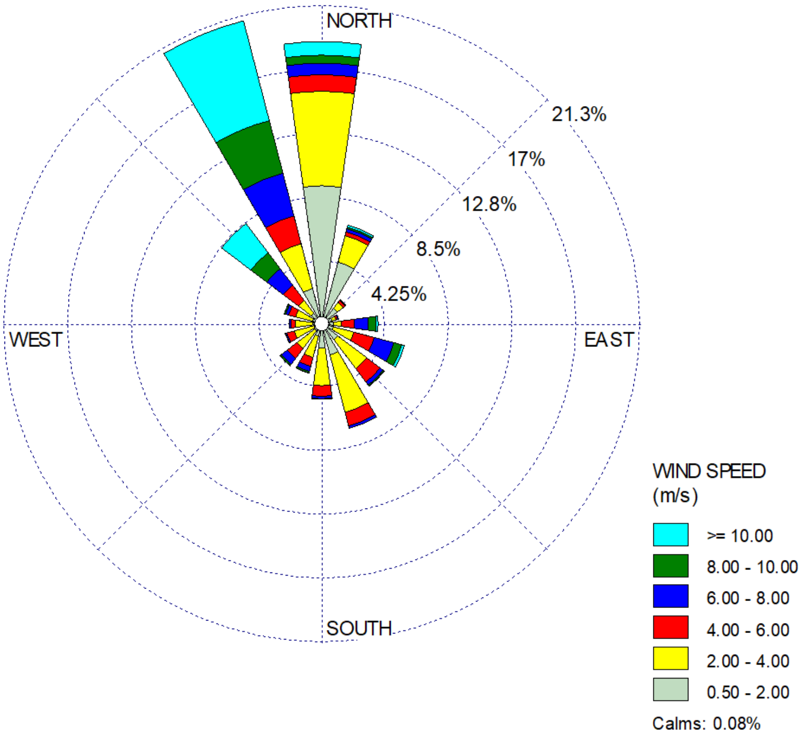
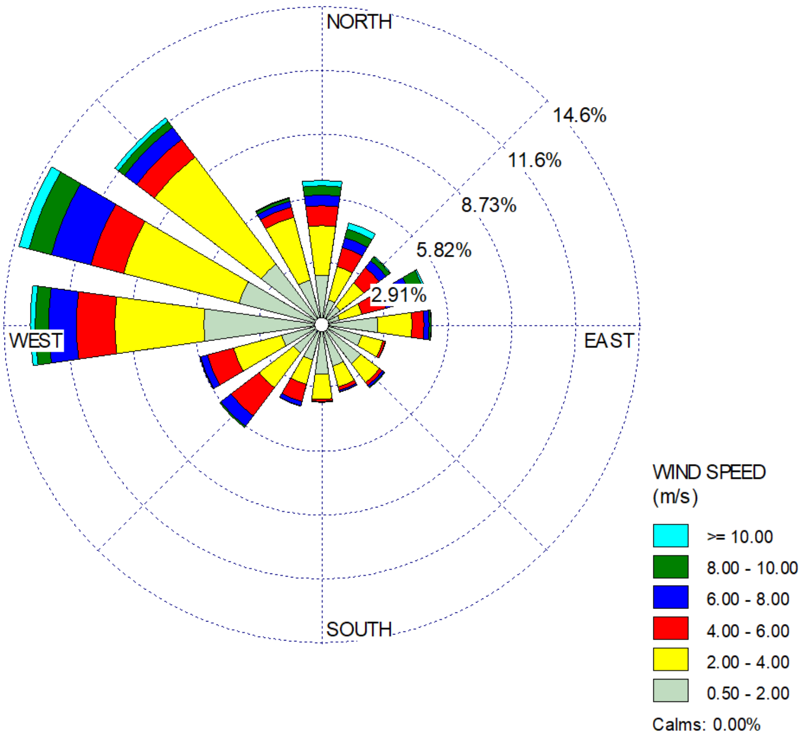
Table B.2 Pūkaki Aero site multi-criteria assessment for modelling year selection

Year	Total Rainfall	RH avg	WS Avg	10+m/s	missing data	Rain last 6months of year	Total Rainfall	RH avg	WS Avg	10+m/s	Rain last 6months of year	rank sum
							Ranking					
2009	648.2	68.9	3.0	139	104	232.2	8	2	2	2	3	17
2010	698.2	69.6	2.9	126	71	353.2	12	4	5	4	9	34
2011	661.6	69.8	2.9	113	39	358.8	10	6	6	6	10	38
2012	727.4	71.8	2.7	87	77	367.6	13	12	13	9	12	59
2013	636.6	71.6	2.8	102	97	271.6	6	11	9	7	5	38
2014	599.2	70.7	3.0	122	54	244.8	5	8	3	5	4	25
2015	**477.6**	**65.9**	**3.1**	**141**	**90**	**152.6**	**2**	**1**	**1**	**1**	**1**	**6**
2016	578.6	70.1	2.9	130	61	318.8	4	7	4	3	7	25
2017	661	71.9	2.7	62	15	362.4	9	13	11	14	11	58
2018	876.2	73.9	2.6	41	76	349	16	15	14	16	8	69
2019	689	70.7	2.9	68	8	393.8	11	9	7	13	14	54
2020	550	69.2	2.8	84	10	291.4	3	3	10	10	6	32
2021	737.8	72.6	2.6	79	26	470	14	14	15	11	16	70
2022	753.2	75.2	2.5	53	40	389.8	15	16	16	15	13	75
2023	422.8	71.2	2.7	76	27	176.8	1	10	12	12	2	37
2024	647.8	69.7	2.8	89	21	445	7	5	8	8	15	43

Table B.3 Mt Cook Village site multi-criteria assessment for modelling year selection

Year	Total Rainfall	RH avg	WS Avg	10+m/s	missing data	Rain last 6months of year	Total Rainfall	RH avg	WS Avg	10+m/s	Rain last 6months of year	rank sum
							Ranking					
2013	2861.6	62.5	4.8	608	198	1510.2	11	2	8	10	10	41
2014	2551.4	65.4	4.8	697	454	1219.2	8	8	9	7	6	38
2015	**2224**	**62.0**	**5.1**	**789**	**916**	**1057.8**	**4**	**1**	**3**	**4**	**2**	**14**
2016	2581.2	65.0	4.7	650	737	1275.8	10	7	10	8	7	42
2017	2202.4	67.6	4.6	584	359	1097	3	10	12	11	3	39
2018	1972.8	66.8	5.0	632	111	949	1	9	6	9	1	26
2019	3334.6	64.3	5.3	868	76	1867.2	12	3	1	2	12	30
2020	**2132.2**	**64.6**	**5.2**	**912**	**112**	**1137.6**	**2**	**5**	**2**	**1**	**4**	**14**
2021	2558.8	67.8	5.0	779	90	1492.6	9	11	4	5	9	38
2022	2485.4	68.6	4.7	572	200	1456.4	6	12	11	12	8	49
2023	2263	64.5	4.9	721	38	1151.8	5	4	7	6	5	27
2024	2545.4	64.8	5.0	811	44	1611	7	6	5	3	11	32

Table B.4 Annual wind roses for 2015, used in CALMET modelling

Site	Annual wind rose
Maryburn Avg WS = 4.5 m/s	
Pūkaki Aero Avg WS = 3.1 m/s	

TAPM Meteorological Modelling

TAPM (v4.0.4), developed by CSIRO Australia, was used to generate meteorological data for input into CALMET modelling. This model predicts parameters such as wind, temperature, and turbulence using input from terrain, vegetation, and synoptic meteorological data. TAPM observational assimilation ability was not used in this assessment.

TAPM modelling at smaller spatial resolution scales of 1 km or smaller was attempted however, numerical instabilities occurred that prevented solutions for the entire modelled period of time. For the purposes obtaining three-dimensional coarse grid meteorology as an initial guess filed in CALMET, 3 km resolution was considered to be adequate.

TAPM parameters used for this study are presented in Table B.5**Error! Reference source not found.**.

Table B.5 Meteorological modelling parameters - TAPM v 4.0.4

Parameter	Model Configuration
Modelling Period	01 January 2015 to 31 December 2015
Centre of analysis	433,244 mE 5,122,236 mS (UTM Coordinates) -44°3'0", 170°10'0" (Latitude, Longitude)
Number of grid points	48 × 48 × 20
Number of grids (spacing)	3 (30 km, 10 km, 3 km)
Data Assimilation	None

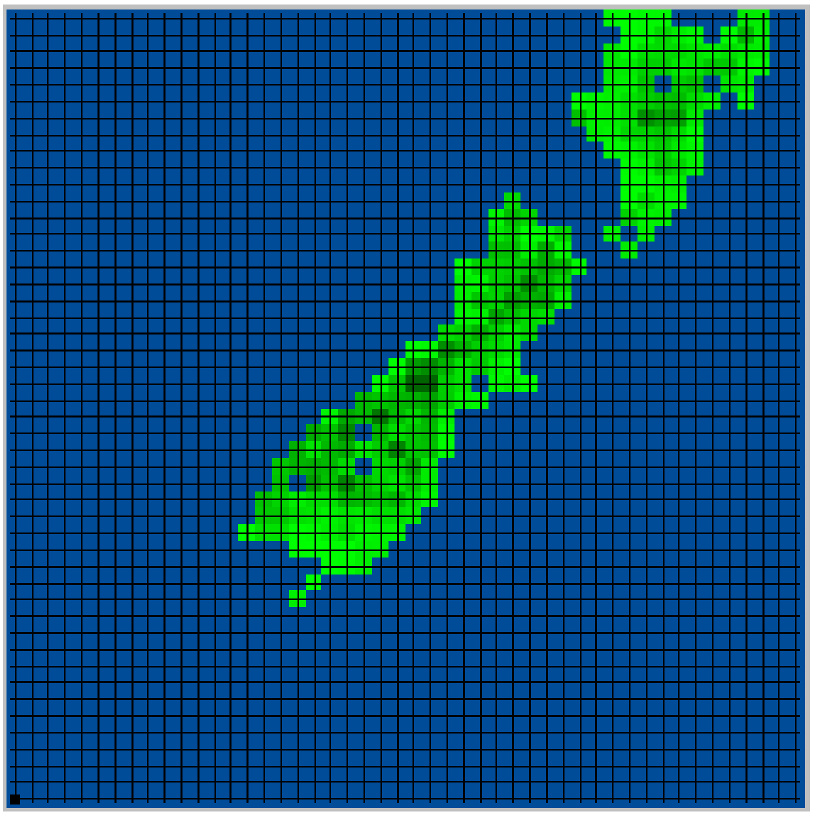


Figure B.1 TAPM model grid 1 – 30 km

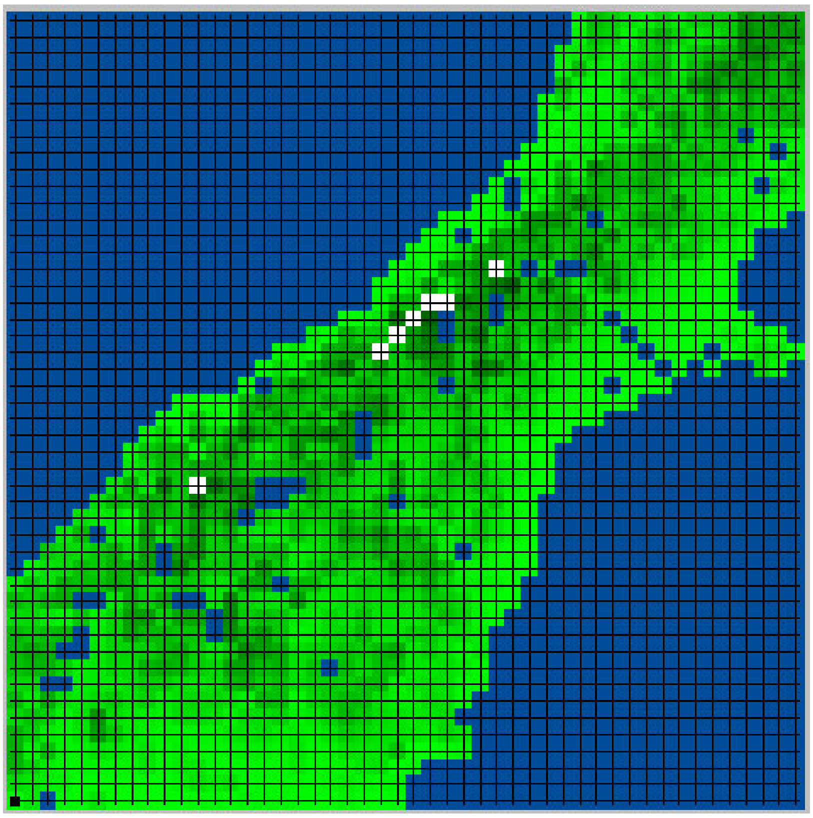


Figure B.2 TAPM model grid 2 – 10 km

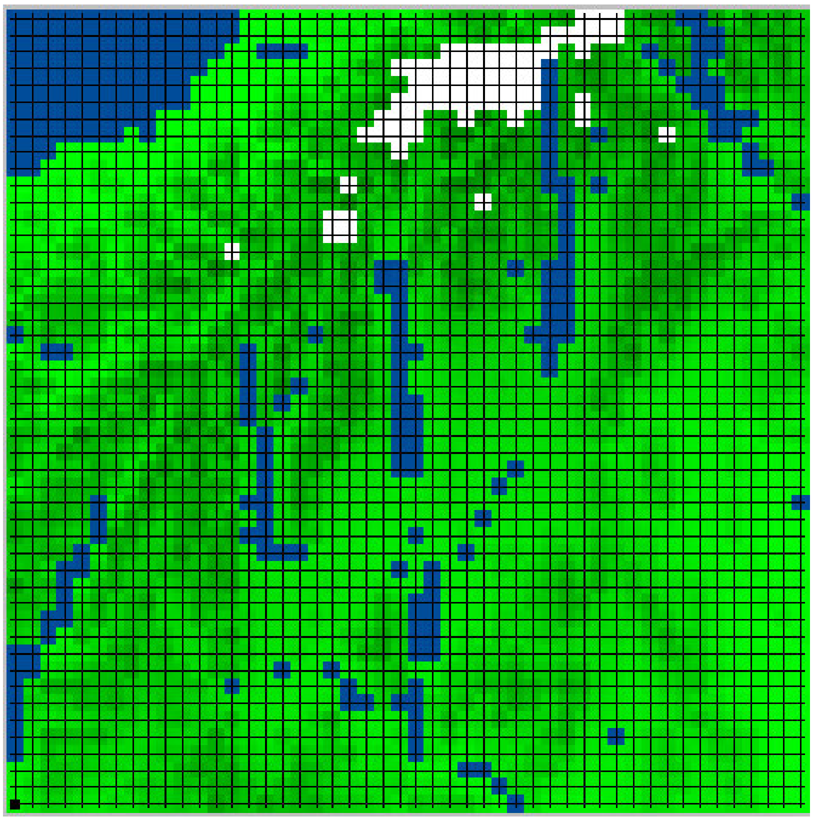


Figure B.3 TAPM model grid 3 – 3 km

CALMET

CALMET is a meteorological modelling tool that generates hourly wind and other meteorological fields within a three-dimensional gridded domain, which serve as inputs for the CALPUFF dispersion model. The output from CALMET also includes associated two-dimensional fields, such as mixing height, surface characteristics, and dispersion properties.

Within CALMET, the interpolated wind field is adjusted to incorporate the effects of topography, sea/lake breezes, and variations in heating and surface roughness due to diverse land uses throughout the modelling domain, most notably the high mountains immediately to the west of Lake Pūkaki. These adjustments are applied at each grid point to produce a final wind field that accurately reflects local influences.

The CALMET modelling was conducted using the ‘Hybrid’ approach across a 48 km by 48 km domain with a 300 m resolution. TAPM-generated three-dimensional meteorological data served as the initial wind field for the domain. Two surface stations observations were incorporated into the CALMET model as surface observations. Local topographical and land use data were manually updated to enhance the wind field calculation down to the meteorological resolution of 300 m.

Observational data

The observational stations of Maryburn and Pūkaki Aero were incorporated into the CALMET as surface observations. As per the input requirements of CALMET, all hours of the year had at least one observation. The Pūkaki station was used for cloud cover and cloud height information. Missing data were filled using recognised US EPA hierarchy of methods, namely persistence, interpolation and substitution. Where substitution was used, information from an alternate observational station of the three detailed in this assessment was incorporated. Repetition of previous days data, possible for Gaussian plume models was not done was observational time consistency especially with the TAPM initial guess field was maintained as best as possible.

The Mt Cook Village site was not incorporated into the CALMET modelling as this is located inside the Tasman River delta valley and would therefore require detailed surface station barrier information to be included in the modelling otherwise its observations could adversely affect wind in an adjacent mountain valley.

No upper air observation station was used. TAPM incorporated results through the initial guess field was used for the upper air information.

Some preliminary test runs of shorter time periods – 48 hours – were undertaken to investigate the most appropriate settings for terrain and observational station radius input parameters (TERRAD, R1MAX, R1, etc.). A TERRAD value of 8 km corresponds to the approximate width of the Tasman River delta valley.

Table B.6 outlines the parameters employed in the meteorological modelling to drive the CALMET model.

Table B.6 Meteorological modelling parameters – CALMET

Parameter	Model Configuration
Version	6.5
Modelling period	01 January 2015 to 31 December 2015
Meteorological grid resolution	300 m 160 x 160 cells
Grid southwest corner coordinates	409,244 mE 5,098,236 mS UTM Coordinates
Land use	Manually adjusted using satellite imagery
Initial guess filed	TAPM output
Surface stations	Maryburn (442,494 mE, 5,120,112 mS) Pūkaki Aerodrome (429,498 mE, 5,100,535 mS)
Vertical resolution (cell heights)	10 (0 m, 20 m, 40 m, 80 m, 160 m, 320 m, 640 m, 1200 m, 2000 m, 3000 m, 4000 m)
TERRAD parameter	8 km

Parameter	Model Configuration
Surface station radius of influence	RMAX1 = 12 km RMAX2 = 8 km R1 = 8 km R2 = 6 km

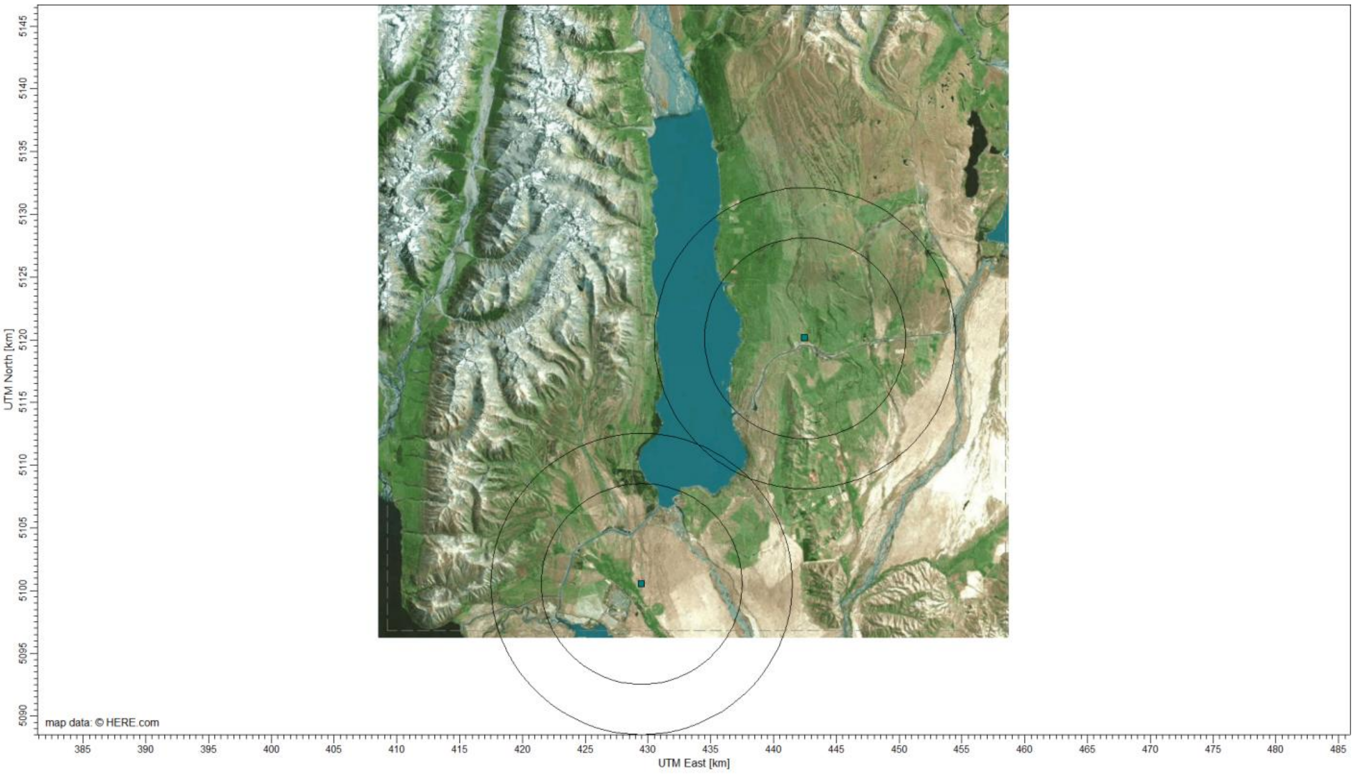


Figure B.4 CALMET satellite terrain with surface observation station location shown, with R1MAX and R1 distances shown

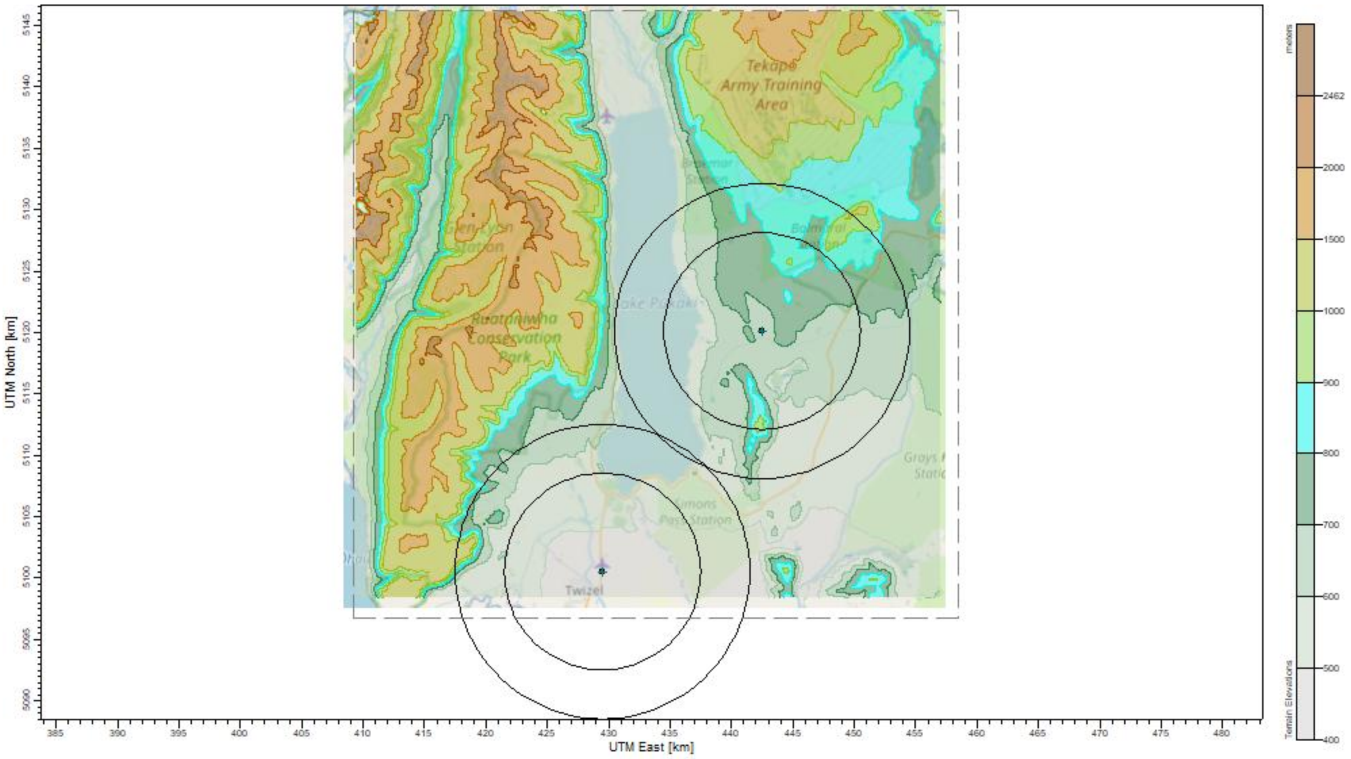


Figure B.5 ***CALMET terrain elevation with surface observation station location shown, with R1MAX and R1 distances shown***

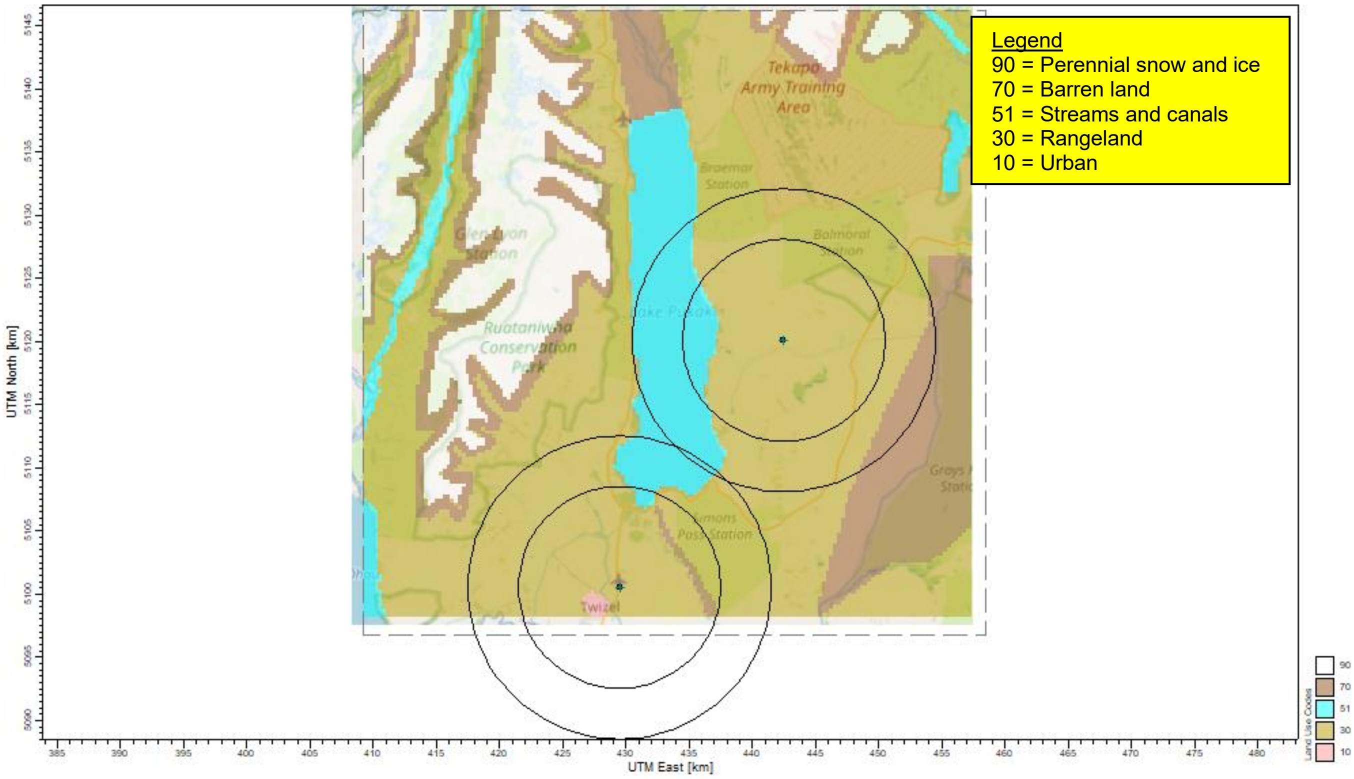


Figure B.6 ***CALMET landuse with surface observation station location shown, with R1MAX and R1 distances shown. Coloured by CALMET land use codes***

Source characteristics

Wind erosion

CALPUFF modelled source characteristics for the wind erosion sources are provided in Table B.7.

Wind erosion emissions rates were modelled using a variable emissions file via the VOLEMARB.DAT input file method. An extract of the variable emission rate file for source Delta 6 is shown in Figure B.7.

Table B.7 CALPUFF source characteristics for lake and river delta wind erosion sources.

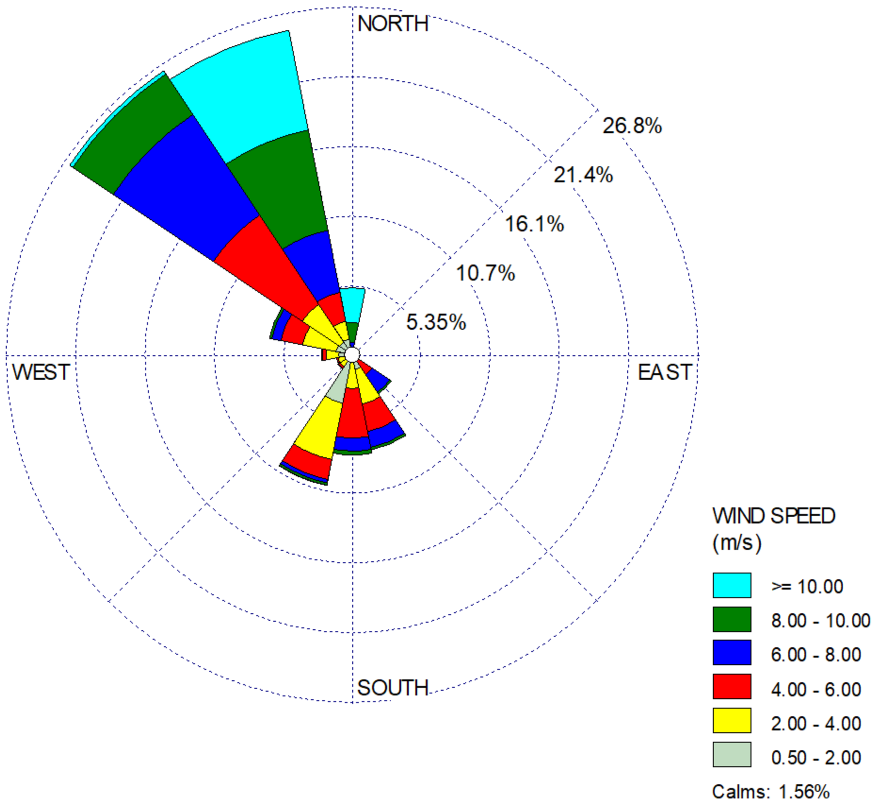
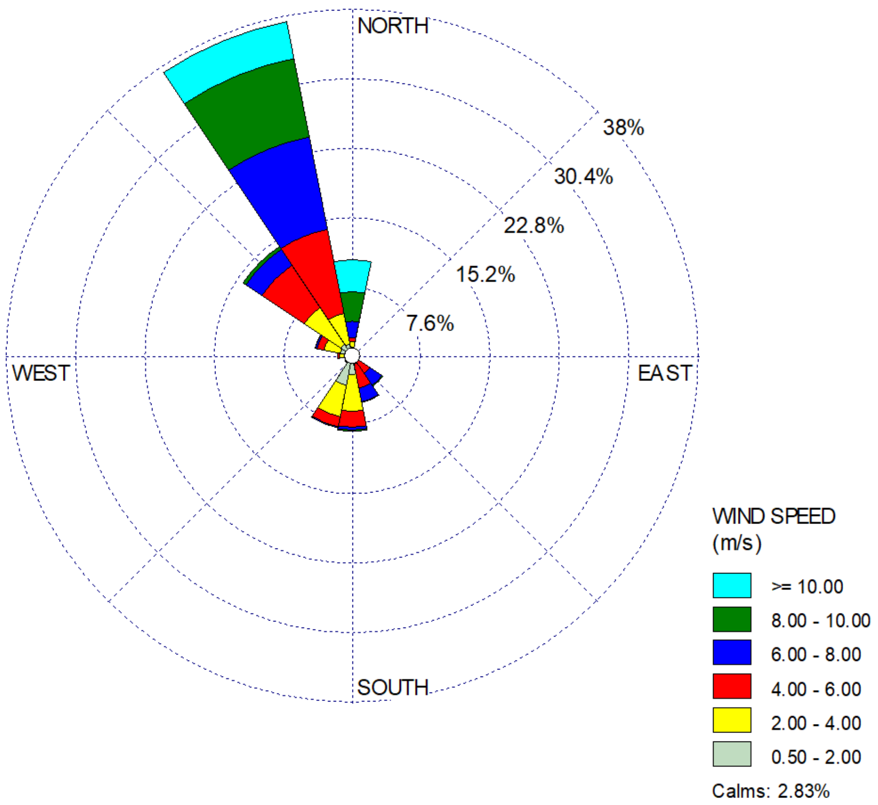
Source name/ID	Type	Easting [km]	Northing [km]	Elevation [m]	Release height [m]	Initial lateral spread (sigma-y) [m]	Initial vertical spread (sigma-z) [m]	Emission rate
Delta 1	Volume	430.694	5132.586	537.4	1.0	23.26	0.47	VOLEMARB
Glentanner 2	Volume	430.387	5136.573	536.0	1.0	23.26	0.47	VOLEMARB
Tasman delta 3	Volume	432.566	5138.131	534.0	1.0	23.26	0.47	VOLEMARB
Delta 4	Volume	429.458	5143.406	568.3	1.0	23.26	0.47	VOLEMARB
Delta 5	Volume	432.940	5142.370	557.1	1.0	23.26	0.47	VOLEMARB
Delta 6	Volume	435.194	5135.586	542.1	1.0	23.26	0.47	VOLEMARB
Shore dust 1	Volume	435.725	5132.810	549.3	1.0	23.26	0.47	VOLEMARB
Shore dust 2	Volume	435.346	5127.914	540.8	1.0	23.26	0.47	VOLEMARB
Shore dust 3	Volume	436.481	5123.107	539.4	1.0	23.26	0.47	VOLEMARB
Shore dust 4	Volume	436.794	5118.648	539.0	1.0	23.26	0.47	VOLEMARB
Shore dust 5	Volume	436.851	5114.276	539.1	1.0	23.26	0.47	VOLEMARB
Shore dust 6	Volume	437.315	5109.684	536.9	1.0	23.26	0.47	VOLEMARB
Shore dust 7	Volume	433.377	5108.342	541.5	1.0	23.26	0.47	VOLEMARB
Maryburn	Volume	442.492	5120.111	653.6	1.0	23.26	0.47	VOLEMARB
Dam site	Volume	431.534	5106.615	531.3	1.0	23.26	0.47	VOLEMARB

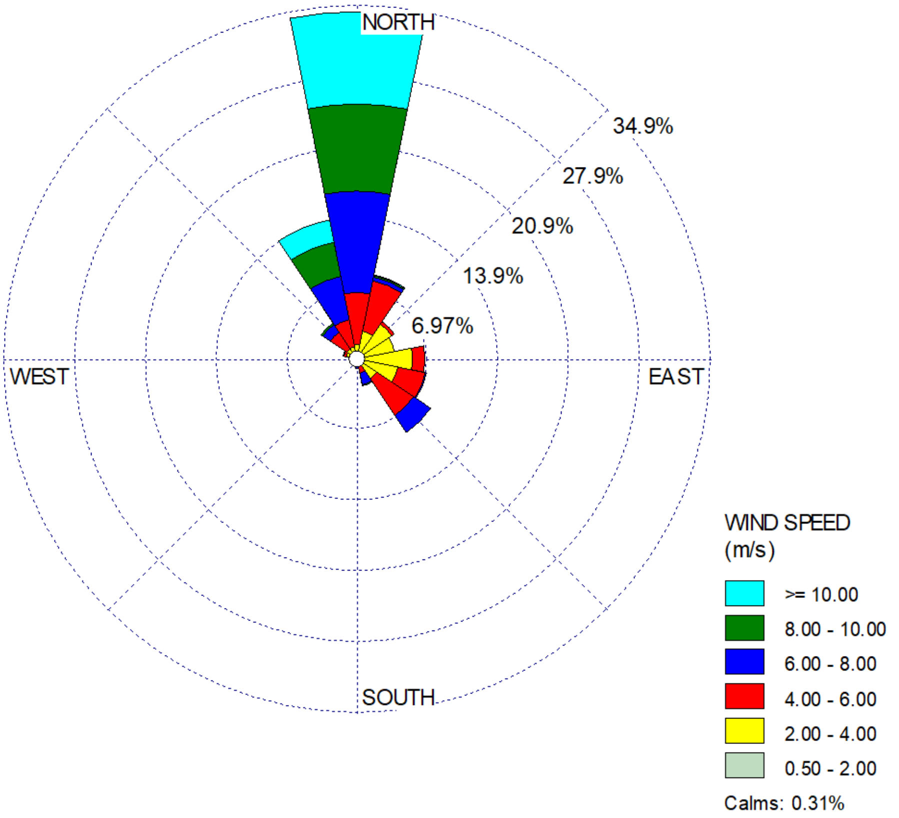
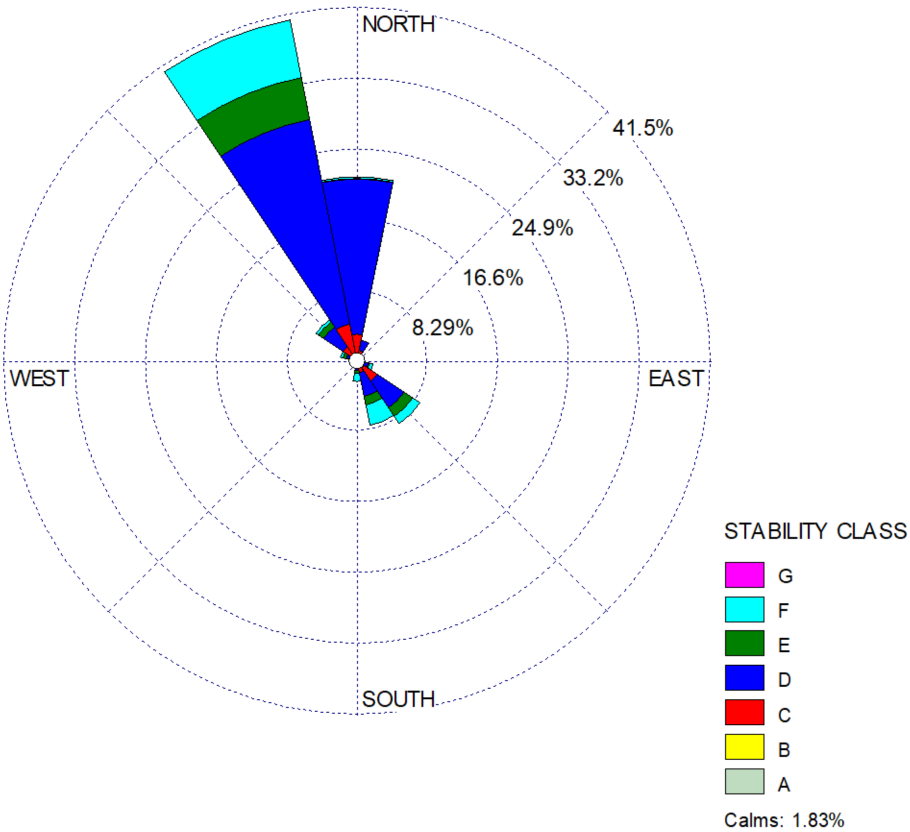
```
VOLEMARB.DAT    2.1            Comments, times with seconds, time zone, coord info
1
Example using Lambert Conformal coordinates
UTM
  59S
WGS-84  02-21-2003
  KM
UTC+1200
2015 001 00 0000 2015 365 22 3600
   1  1
'TXS'
28.8
'Delta6'  0
2015   001   00   0000   2015   001   00  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.1137
2015   001   01   0000   2015   001   01  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0761
2015   001   02   0000   2015   001   02  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0664
2015   001   03   0000   2015   001   03  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0664
2015   001   04   0000   2015   001   04  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0635
2015   001   05   0000   2015   001   05  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0525
2015   001   06   0000   2015   001   06  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0025
2015   001   07   0000   2015   001   07  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   08   0000   2015   001   08  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   09   0000   2015   001   09  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   10   0000   2015   001   10  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   11   0000   2015   001   11  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   12   0000   2015   001   12  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0000
2015   001   13   0000   2015   001   13  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0152
2015   001   14   0000   2015   001   14  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0544
2015   001   15   0000   2015   001   15  3600
'Delta6'     435.190     5135.590    1.0     542.1    23.26    0.47   0.0773
```

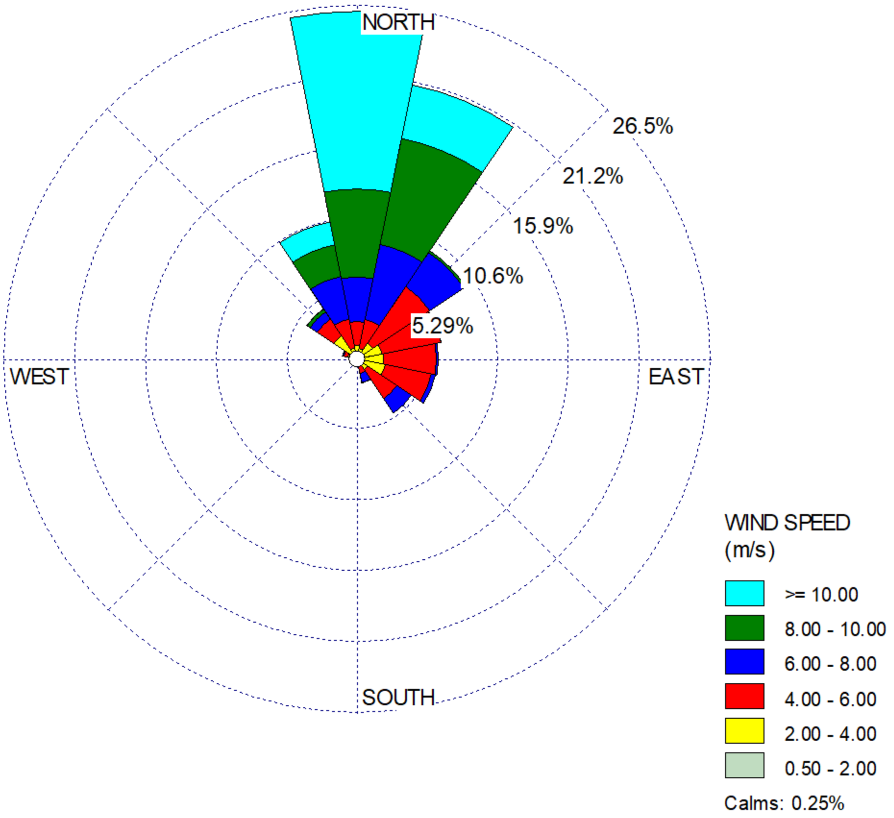
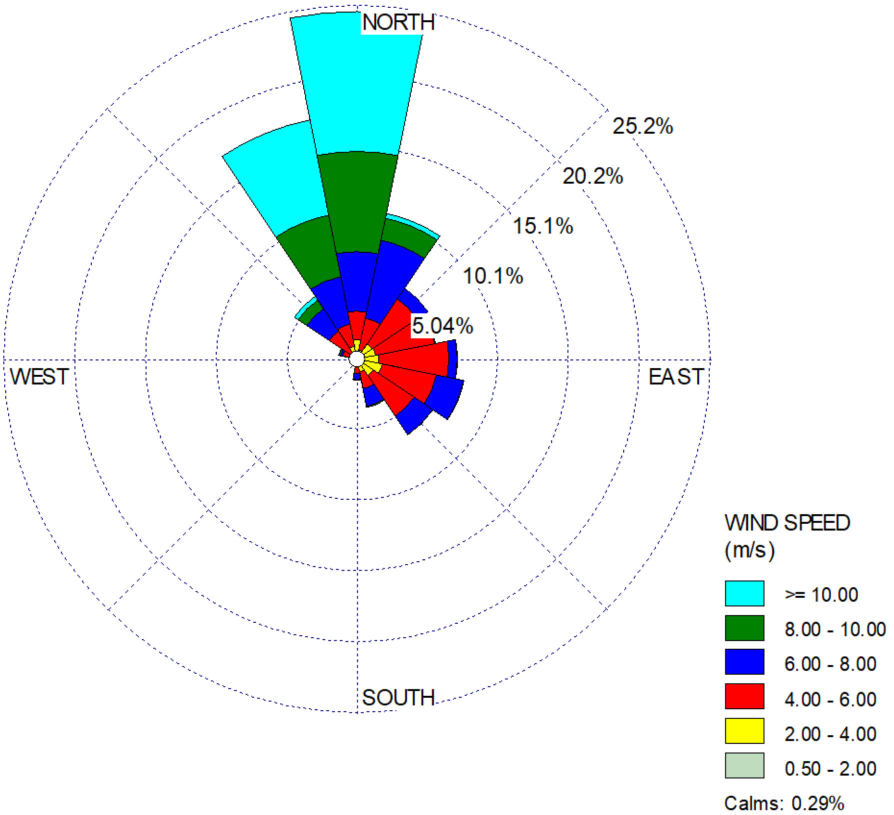
Figure B.7 Extract of Delta 6 wind erosion source variable emission file.

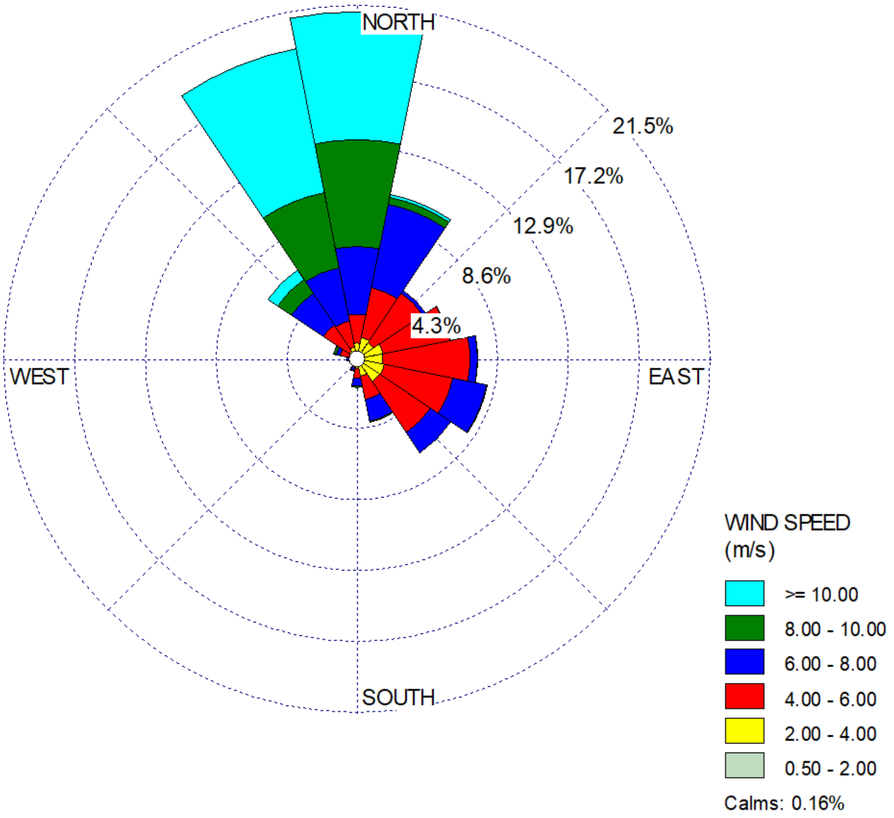
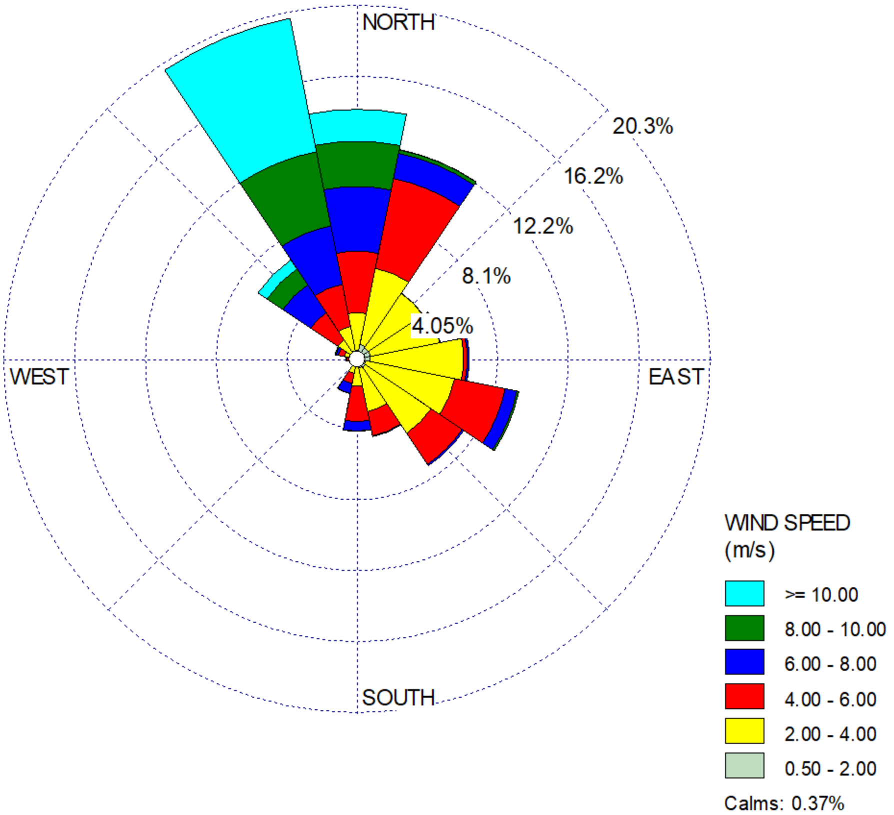
Appendix C

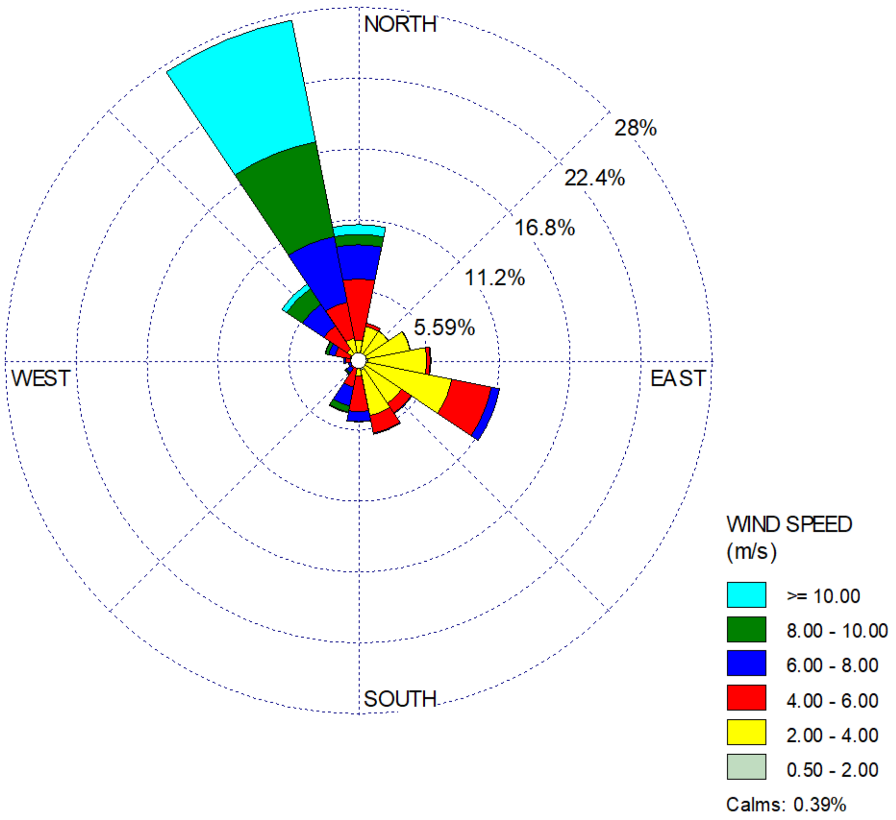
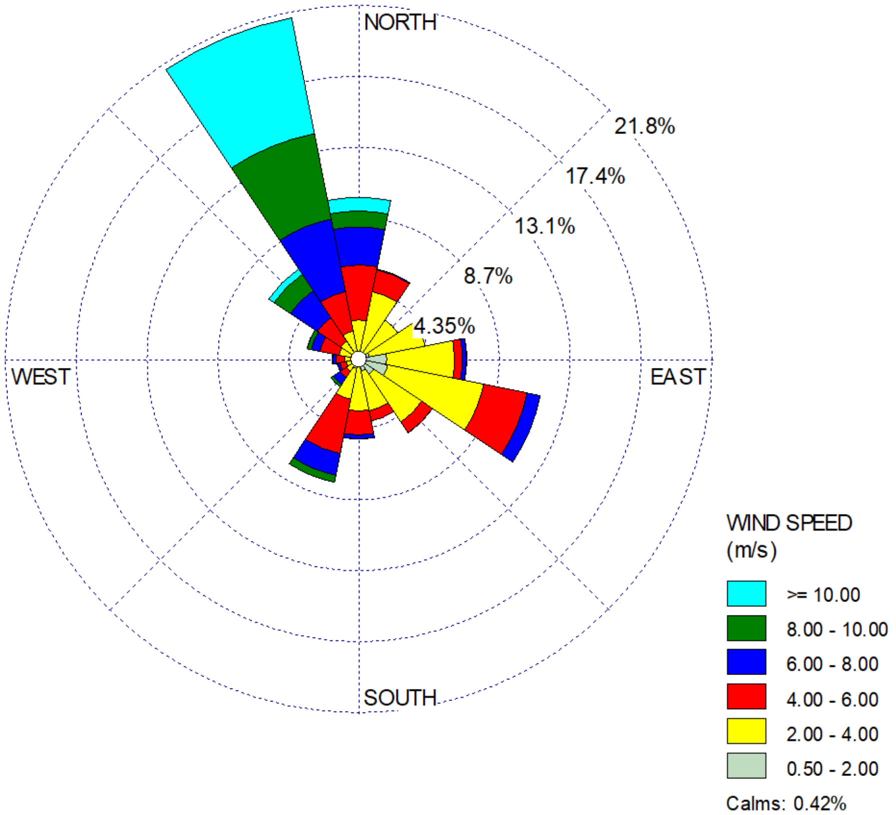
Lake wind roses – CALMET generated

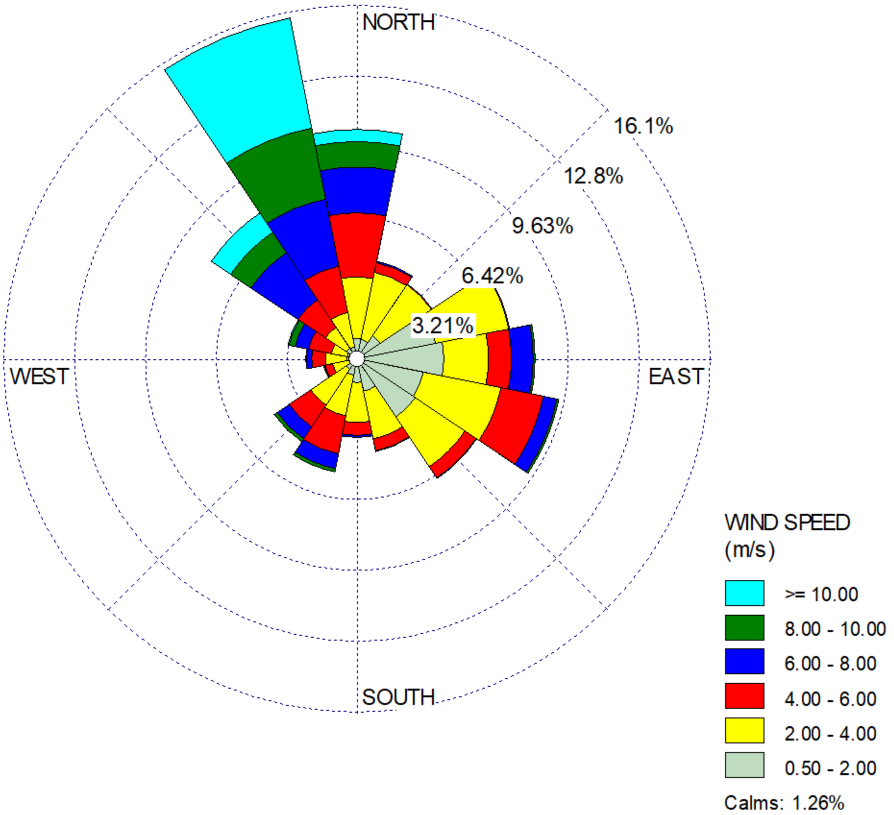
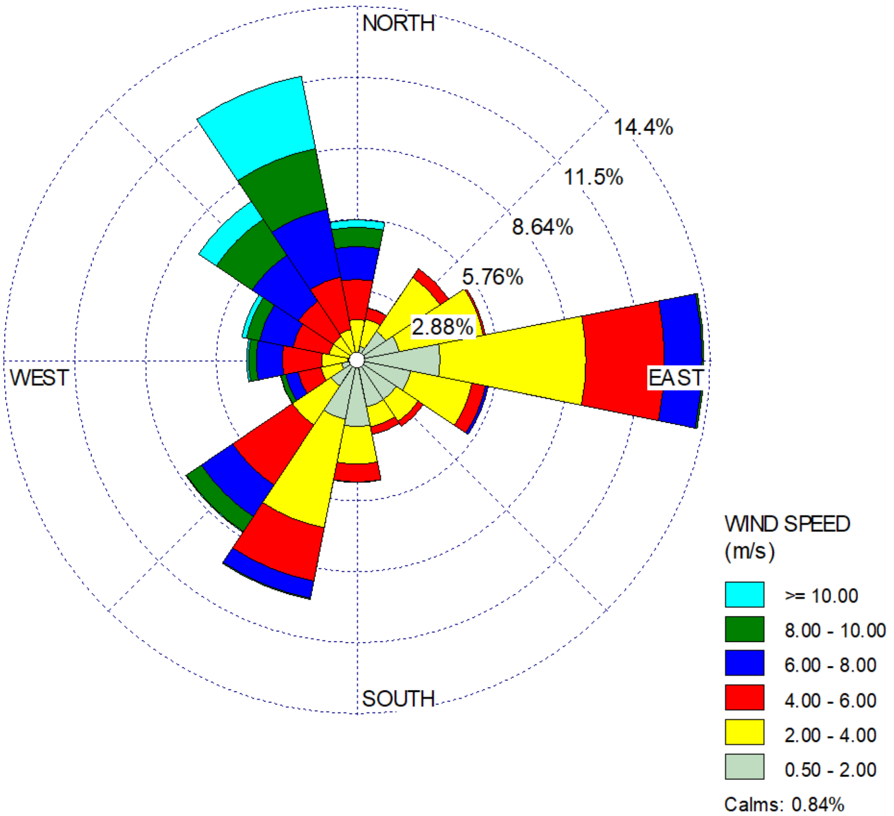
Site	Annual wind rose
Delta 1 Avg WS = 5.7 m/s	
Glentanner 2 Avg WS = 5.3 m/s	

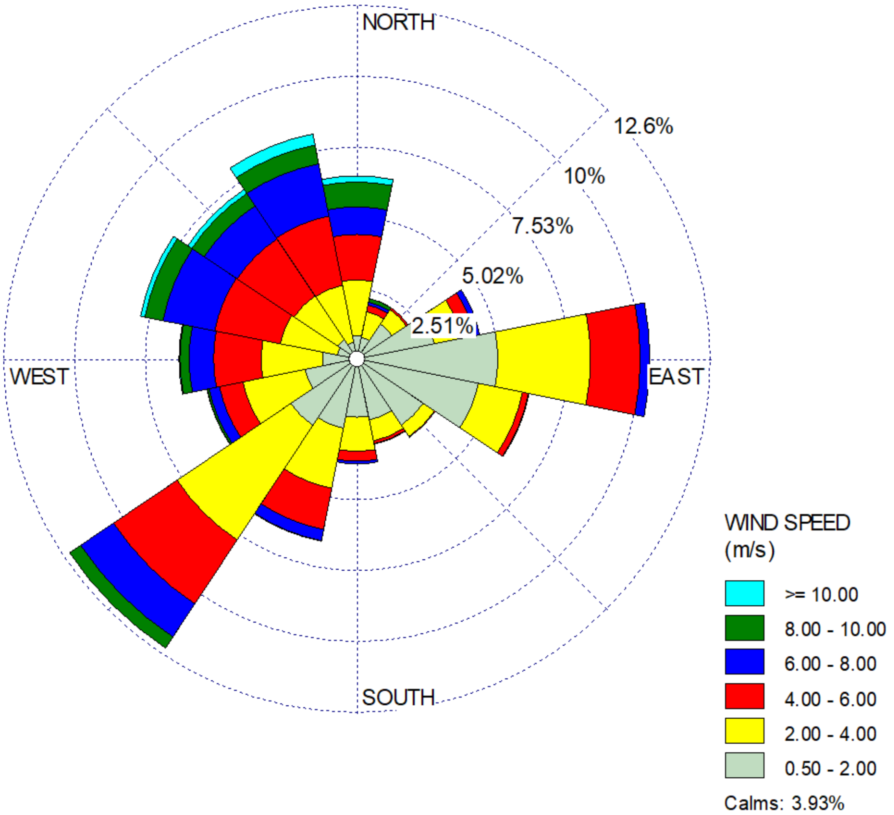
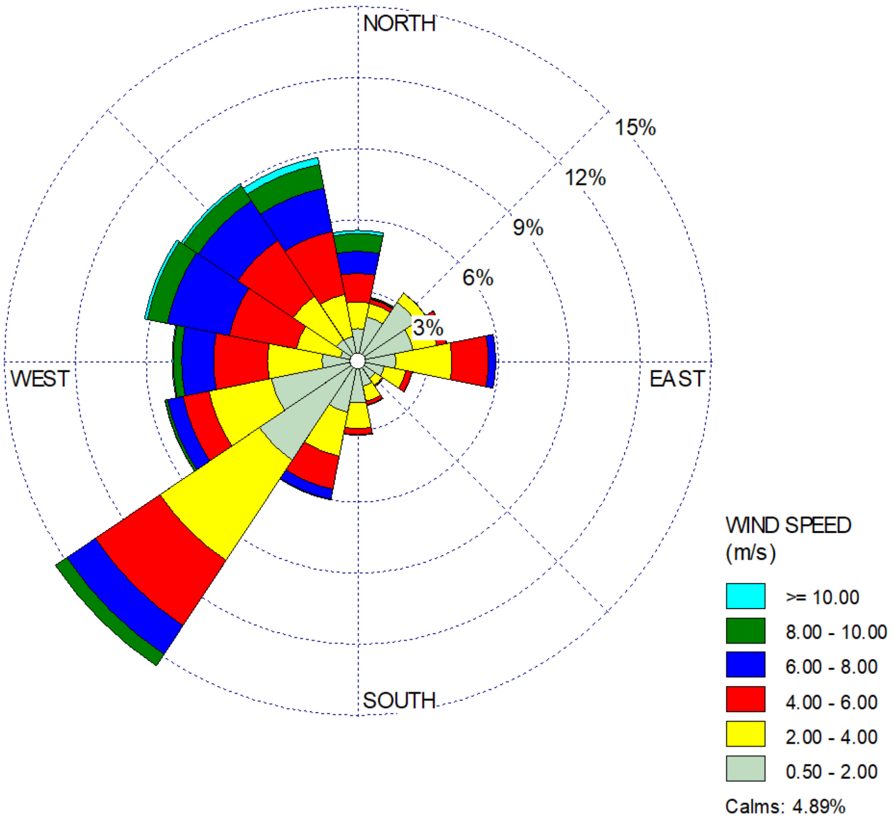
Site	Annual wind rose
Tasman delta 3 Avg WS = 5.9 m/s	
Delta 4 Avg WS = 5.7 m/s	

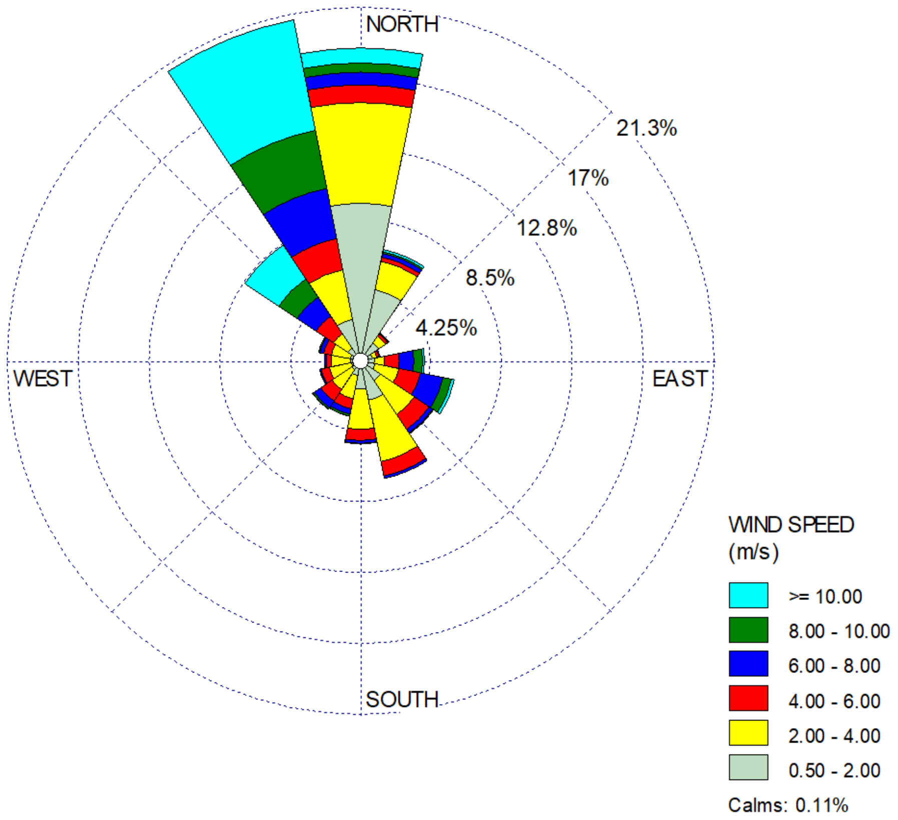
Site	Annual wind rose
Delta 5 Avg WS = 7.1 m/s	
Delta 6 Avg WS = 6.9 m/s	

Site	Annual wind rose
Shore 1 Avg WS = 6.8 m/s	
Shore 2 Avg WS = 5.2 m/s	

Site	Annual wind rose
Shore 3 Avg WS = 5.5 m/s	
Shore 4 Avg WS = 4.9 m/s	

Site	Annual wind rose
Shore 5 Avg WS = 4.3 m/	
Shore 6 Avg WS = 4.3 m/s	

Site	Annual wind rose
Shore 7 Avg WS = 3.9 m/s	
Dam site Avg WS = 3.4 m/s	

Site	Annual wind rose
Maryburn Avg WS = 4.1 m/s	

Appendix D

Dust Management Plan (DRAFT)

Introduction

The Dust Management Plan presented in this section is guided by information provided in Chapter 5 of the Good Practice Guide for Assessing and Managing Dust (MFE, 2016), which outlines management options for dust emitting sites.

Management options include prevention, mitigation and communication measures. Prevention measures around the entire perimeter of Lake Pūkaki are limited. No action can reasonably be taken to lower the threat of dust exposure as a result of adverse meteorological or hydrological conditions. Likewise, mitigation measures are difficult and very expensive to implement. Dust suppression methods, such as wetting agents which would typically be applied to control dust liftoff are not well suited for this environment, particularly given the sizable area and sensitivity of the lakeshore. The management plan primarily addresses the required steps to facilitate proactive communication and engagement between Meridian and people surrounding Lake Pūkaki.

This purpose of this document is to:

– Provide a description of the measures to be implemented by Meridian to manage and mitigate dust impacts associated with lake level operations.
– Provide Meridian and its employees with clear descriptions of their responsibilities in relation to dust management during the operations of the lake.
– Provide a process for responding to feedback and complaints from the public.

Assumptions

This management plan will only take effect in the event that the lake is lowered below the current consent level of 518 masl.

Residents around Lake Pūkaki currently experience occasional impacts due to dust storms, which may become more intense if the lake is lowered.

The frequency and duration of dust storms, however, will not be affected.

Under a scenario where the lake is not lowered, there will be no changes to the emission source and therefore no changes to dust impacts at nearby sensitive receptors.

The emission sources are defined as exposed areas of the lakeshore and river deltas where dust liftoff is more likely to occur as a result of wind erosion.

Management measures and controls

The following management measures should be undertaken:

– Contacting Braemar Station and Tasman Downs Station via phone call, text or email when the lake will be lowered below 518m and when it is expected to be back above 518 m.
– Maintaining a complaints register for Meridian, requiring Meridian to identify any cause and impact of an alleged dust nuisance, and corrective and/or mitigation action taken where reasonable and practical.
– Braemar Station and Tasman Downs should also be encouraged to record details of dust nuisance events in a dust diary. Details would include date and time of event, weather conditions at the time of the event, a description of the type and amount of dust detected, and the duration of the event. Meridian should provide clear instructions to residents on how to document information and what to include, to ensure consistency.

Recording of complaints and incidents

Meridian should record the following information, when receiving dust complaints or incidents:

– Details of any complaints or incidents including the complainant’s name, address and contact number.
– A summary of the complaint including the complainant’s location, and further information regarding the dust event including time of day, duration, frequency (if occurring multiple times), and weather conditions.

– Details of response to the complaint including any post-event actions undertaken by Meridian Energy to remedy the localised impact.
– Recorded details of all complaints should be maintained in an up-to-date logbook.

Corrective actions

Corrective actions are to be undertaken to a level proportional to the severity of complaint or incident. In response to a valid complaint, the following tasks will be undertaken:

– Identify reasons contributing to off-site impacts. This includes:
    - Undertaking a visual inspection of the lakeshore, Tasman River delta and broader setting to the extent relevant to ascertain the source of dust emissions relevant to the complaint.
    - Assessing weather data during the time-period for which the complaint was made.
– Upon identification and attribution of the likely source area responsible for the complaint, a decision will be made as to the suitability of employing dust suppression. Given dust storms typically occur over short timeframes, this may only be necessary during more extreme conditions where heightened levels of dust linger, coinciding with a lengthy period without rainfall. Whilst wetting agents in general are not suitable, the use of water as a dust suppressant may be feasible over a short-term period for a localised emission area. This will need to be determined on a case-by-case basis.

Existing Landowner agreements

It is noted that Meridian has agreements in place from Plan Change 1, with six landowners along the eastern side of Lake Pūkaki. These agreements include dust mitigation measures. Meridian will continue to honour these agreements if lake levels drop below 518.0 m RL over the duration of this temporary consent.

Communication strategy

Meridian is to develop and implement a communications strategy that includes stakeholder engagement procedures. The communications strategy should include providing avenues of communication for affected parties (Braemar Station and Tasman Downs Station) to ask questions and lodge complaints regarding the operations of the site.

Continual improvement

The DMP will be viewed as a working document and updated as necessary. Reasons for updating the DMP may include:

– If improvements to management measures are required.
– If more appropriate dust suppression measures, methods or technologies become feasible for the Project.
– If repeat complaints are lodged, without an agreeable resolution.