4.0 Design Recommendations

Our recommendations, and rationale, are summarised below and presented visually in **Figure 6** with technical detail in Appendix I. NB: In order to preserve the privacy of the residents who have kindly permitted us to use their properties, the exact locations of the monitoring sites will remain confidential for the duration of monitoring. Locations in **Figure 6** are therefore, indicative only.

In brief, we propose five things:

(i) Monitor RCS over 12 months at five locations around the quarries;

a. One location only (reference site) to have continuous and wind directional monitoring (i.e. three filters and two pumps sampling in tandem)

b. Majority (three) of locations to be representative of residential exposure

c. All five locations to be co-located with nephelometer (PM_{10})

The purpose of this monitoring is to fulfil the primary objective of measuring long-term ambient levels of RCS around a quarry with a focus on residential exposure.

(ii) Monitor fine and coarse particles over 12 months around the quarries;

a. Five PM_{10} and two $PM_{2.5}$ nephelometers to be collocated with RCS monitoring

b. One location only (reference site) to have PM_{10} beta attenuation monitor operating in tandem

c. Four transect PM_{10} nephelometers (i.e. at increasing distance downwind of quarries) for three months

The purpose of the PM_{10} (nephelometer) monitoring is to provide temporal and spatial data to inform the RCS monitoring and provide backup (to warn of filter blinding). The reference PM_{10} monitoring will further provide indicative daily and long-term levels of PM_{10} around a quarry as representative of residential exposure.

The purpose of the $PM_{2.5}$ monitoring is to fulfil the second objective in the terms of reference of characterising the nature of particulate.

(iii) Monitor meteorology at the reference site for 12 months. This will support both the RCS and particulate monitoring.

(iv) Background monitoring for RCS, PM_{10} (nephelometer and reference method), $PM_{2.5}$ (nephelometer) and meteorology at a location representative of rural Canterbury for 12 months. This will support both the RCS and particulate monitoring.

(v) Report publicly

These are discussed in Sections 4.1 – 4.5, with a discussion of design limitations in Section 4.6.

Figure 6 **Indicative (only) Monitoring Locations (NB: Transect and background monitoring not shown)**

4.1 Monitor Respirable Crystalline Silica (RCS)

We propose to undertake long-term monitoring for RCS at five separate locations around the quarries and one background location. Specifically, sampling will be conducted over a month, for a period of 12-months to establish an annual average at each site. This will enable direct comparison with the OEHHA guideline for silica as required by the primary purpose (health) in the terms of reference.

We consider five locations, three of which represent residential exposure, and two represent other downwind locations, to be sufficiently robust to withstand legal and scientific scrutiny.

Details of our chosen monitoring method (modified occupational exposure sampling method) are provided in our response to the quarry peer review (refer Appendix H) and Appendix I.

We also propose to undertake wind directional RCS monitoring at one (only) of these locations as follows:

- One RCS monitor will sample continuously;
- One RCS monitor will sample only when the wind direction is from the quarries; and
- One RCS monitor will sample only when the wind is blowing in other directions (i.e. not from the quarries).

We gave serious consideration to setting the directional monitors to only sample when the wind speed is above 0.5 metres per second. However, we are concerned that katabatic drainage flow[1] may significantly influence local meteorology (i.e. a high predominance of low wind speeds) and are uncertain of potential recirculation effects of fine particulate originating from the quarries. Therefore, to increase certainty, it is more straightforward to sample continuously.

Changes from Proposal in Consultation

We previously proposed[2] to undertake wind directional monitoring at all RCS monitoring sites. However, we are concerned that the wind-directional data:

(i) Will not provide an annual average value for comparison with the OEHHA guideline; and

(ii) May overly complicate matters in terms of data interpretation (i.e. trying to be too clever with our programme design).

We are also sensitive to criticism that weight of the monitoring should focus on establishing ambient levels of silica, rather than source investigation. Therefore, to maximise the available budget we have assigned the RCS samplers to additional locations (rather than undertake wind directional monitoring).

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[1] Katabatic winds (from the Greek word *katabasis* which means descending) carry high density air from a higher elevation down a slope under the force of gravity

[2] Refer Table 1 in Section 1.4

In addition to the above long-term RCS monitoring, we also propose co-located monitoring for PM_{10} at each of these five locations with $PM_{2.5}$ monitoring also in two locations. This is discussed in more detail in Section 4.2 and Section 4.3.

4.2 Monitor Particulate Matter

We propose to co-locate nephelometers at all long-term RCS monitoring sites. This is to assist with improving our understanding of how ambient particulate levels vary at different locations, and over different time periods (RCS monitors will only give one value for an entire month) around the quarries. This should further provide a measure of the frequency and magnitude of nuisance dust events.

However, we are also now proposing to include $PM_{2.5}$ nephelometers to fulfil the second objective in the terms of reference of characterising the nature of particulate.

PM_{10}

We propose to undertake long-term monitoring for PM_{10} at five locations around the quarries and one background location – as collocated with the long-term RCS monitoring sites. Specifically, monitoring will be undertaken using nephelometers to provide precise (down to 1-minute) data on how particulate varies both spatially and temporally around the quarries. It will further provide backup particulate loading information to prevent RCS filter blinding as well as *indicative*[3] PM_{10} for comparison with good practice guidelines for nuisance dust:

- 1-hour average trigger threshold of 150 µg/m^3 for dust nuisance (MfE, 2016);

We further propose to undertake long-term monitoring for PM_{10} at one location (reference site) using a beta attenuation monitor, which is a reference method. A reference method is compliant with Schedule 2 of the *Resource Management (National Environmental Standards for Air Quality) Regulations 2004*. Our intent is that over one year, this will permit two outcomes:

- Calibration of the nephelometer measuring PM_{10} (also at the reference site location) to improve accuracy to reference level (for this location); and
- Establishment of a relationship between PM_{10} and RCS (for this location).

This will further permit, *at the reference site only*, direct comparison of measured ambient (reference) PM_{10} levels with.

- 1-hour average trigger threshold of 150 µg/m^3 for dust nuisance (MfE, 2016);
- 24-hour average national PM_{10} standard of 50 µg/m^3 for "guaranteed level of public health protection" (MfE, 2011); and
- Annual average national PM_{10} guideline of 20 µg/m^3 for "minimum requirement that outdoor air quality should meet to protect human health and the environment" (MfE, 2002).

[3] Non-reference methods are not accurate (unless calibrated)

$PM_{2.5}$ (New)

We propose to undertake long-term monitoring for $PM_{2.5}$ at two locations around the quarries and one background location – as collocated with long-term RCS monitoring sites. This will provide new information on the nature of particles in the vicinity of the quarry as compared with background rural Canterbury.

Transect PM_{10}

We propose four PM_{10} nephelometers in a line extending at increasing intervals up to 1,000 metres from the quarry boundary. This monitoring will be timed to coincide with a three month period of dry weather. The purpose of this monitoring is to fulfil a specific request from Environment Canterbury to determine the decrease in PM_{10} concentration with distance from quarrying operations (i.e. the drop off).

The predominance of northwest, northeast and southwest winds means that (opposite) these directions are the most useful for transect monitoring. However, other considerations and practical limitations are:

- A southeast transect is downwind of the prevailing northwest winds. This would maximise the time the monitors are downwind to collect data and is our preferred option. However, this land is all owned by the prison and the increased number of monitors (albeit only for three months) increases the risk of tampering and/or equipment theft.
- A southwest transect is downwind of the prevailing northeast winds. This is the preferred option of the quarries and some of the residents. However, this land is all owned by the prison and the increased number of monitors (albeit only for three months) increases the risk of tampering and/or equipment theft. There is also a piggery located in this area which may increase and/or invalidate ambient levels of particulate measured in this location. We witnessed visible dust from wind pick-up over the piggery during only light wind conditions.[4]
- A northern transect is downwind of some prevailing winds at speeds above 5.5 m/s (the level at which dust pick-up occurs). Whilst less frequent, a northern transect would be representative of worst-case winds for dust emissions – but not necessarily dust dispersion (as the higher winds will increase dispersion downwind). We understand land to the north of the quarries is owned by Environment Canterbury and may be suitable for monitoring.

We are waiting to hear from the prisons regarding the viability of our preferred location.

Changes from Proposal in Consultation

In an attempt to be innovative, we had previously proposed[5] to use the reference site to establish a relationship between PM_{10} measured by nephelometer and PM_{10} measured by reference method (beta attenuation monitor). In this way, the cheaper and more mobile PM_{10} nephelometers could provide 'proxy PM_{10}' levels at a number of locations.

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[4] Site visit 24 November 2017; north east winds 2-3 m/s

[5] Refer Table 1 at Section 1.4

However, following peer reviews we accept that this relationship – at least in the early months of monitoring – may not be sufficiently certain to establish a robust, defensible calibration factor for all other locations. We have removed all references to ‘proxy PM_{10}’ from our proposal until such time as we see what the data reveals.

We further previously proposed to use the reference site to investigate a relationship between PM_{10} measured by the reference method and RCS. We similarly accept that this may not be sufficiently robust and will wait to see what the data reveals.

The inclusion of a (preferred) southeast transect is in response to consultation with the quarries and residents.

We previously proposed to distribute dust diaries with the residents to assist with data interpretation. However, we are wary of imposing unduly onerous requirements on residents who are already cooperating by letting us use their property for monitoring purposes. This has been removed from our proposal.

4.3 Monitor Meteorology

We propose to undertake meteorological monitoring at the reference site to assist with data interpretation. This will consist of:

- wind speed (average, wind gust)
- wind direction
- temperature
- relative humidity
- air pressure

We intend to request rainfall data from Christchurch airport.

In addition to this, wind direction and wind speed will be measured at all long-term RCS (and nephelometer) monitoring sites using ultrasonic wind speed and direction sensors. These sensors are intended to be representative of local rather than synoptic airflow movements and will therefore be mounted at heights 1 metre above the adjacent nephelometers.

4.4 Background Monitoring

We anticipate that our proposal will fulfil the primary objective of the terms of reference which is to determine if long-term levels of RCS at residences in close proximity to the quarries in Yaldhurst exceed the annual guideline (for RCS). However, it would also be helpful to understand what typical levels of annual RCS are in areas without any quarries nearby. In this way it may be possible to determine the impact that quarries are having on annual levels, by subtracting typical background levels from annual levels measured in the vicinity of Yaldhurst quarries.

This raises the question of what constitutes a ‘typical’ background level. During consultation the partner agencies and the quarries highlighted to us that ‘background’ levels of RCS in Canterbury may also be impacted by natural sources (e.g. riverbed dust and dust from exposed soils). The Yaldhurst area is around six kilometres southwest, south and southeast of the Waimakariri River – a known source of elevated levels of particulate likely to contain natural sources of silica.

We therefore, sought to locate our background site in a location that is not unduly influenced by the Waimakariri River so as not to *underestimate* the potential quarry contribution to annual levels of RCS in Yaldhurst.

Our proposed background location is shown in **Figure 7**.

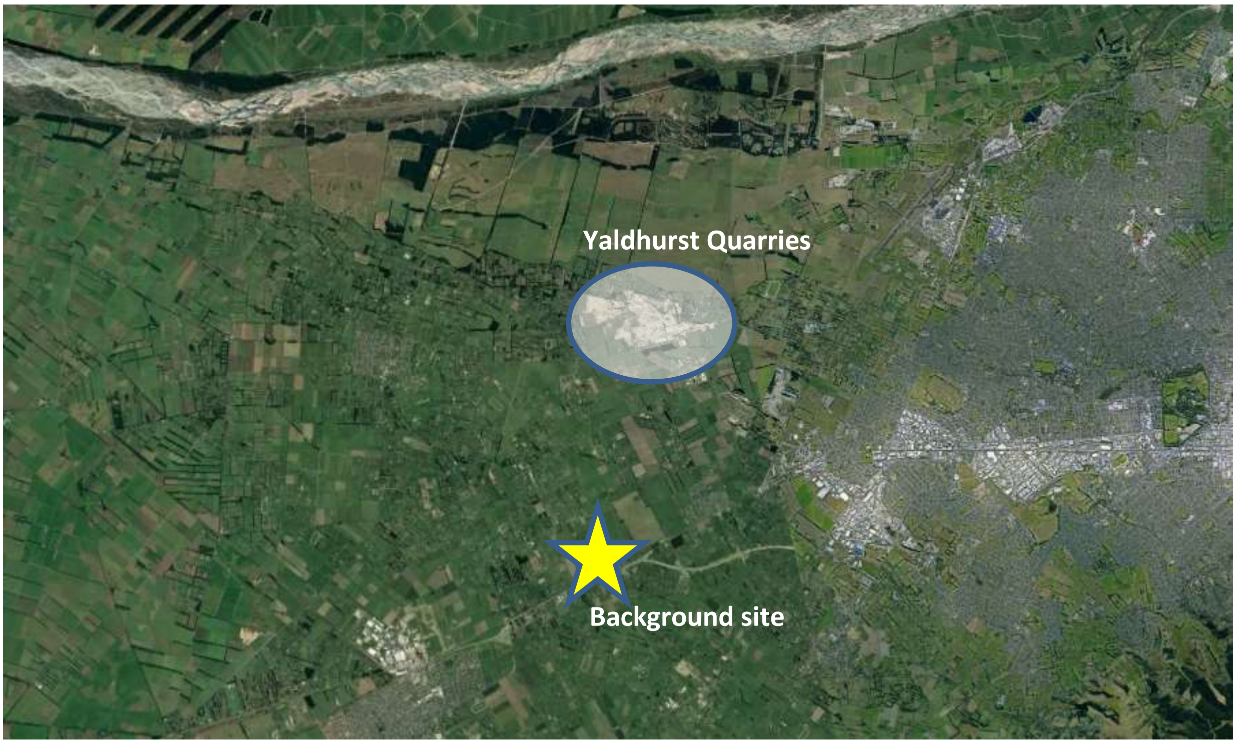

Figure 7 Indicative location of background monitoring site

This proposed background location is a rural site near Templeton that to our knowledge is <u>not</u> impacted by:

- quarrying;[6]
- significant earthworks;
- residential wood burners; and or
- coal boilers or industry;

It <u>will</u> be impacted by the following identified sources:

- Natural sources including;
  - dust from exposed soils and riverbeds; and
  - sea salt aerosols;
- Surrounding agricultural activities.

The land owner for this property has agreed to inform us when tilling and/or grass mowing is being carried out on the property in the vicinity of the background monitoring site.

[6] Background site is around 5 km south of Yaldhurst quarries (i.e. out of prevailing ENE winds) and 5 km south west of another quarry (i.e. also out of prevailing ENE winds)

4.5 Report Publicly

Dust from the quarries in Yaldhurst has been a highly controversial topic for a number of years for all parties; residents, quarries and partner agencies. We consider that full transparency over the monitoring programme is essential to build trust and clarify expectations over what the data will, and won't, provide.

In addition to providing this finalised design recommendations report therefore, we propose to make all monitoring data publicly available in real time. We already anticipate that, pending a short period of time for review for feedback, Environment Canterbury will similarly make our reports publicly available.

4.6 Limitations

The proposed locations in **Figure 6** build upon Environment Canterbury's previous study (ECan, 2016) and seek to capitalise on Winstone Quarry's PM_{10} monitoring to assist with greater spatial and temporal representation.

Nephelometers measure the light scattering *effect* of particulate matter. As such, nephelometry is subject to interference by particle size and particle composition. Put simply, the smaller the particle and more uniform the particle composition, the more accurate the measurement using a nephelometer.

We are therefore, proposing to co-locate a nephelometer with a PM_{10} reference method to calibrate the nephelometer in one location. We will use the relationship, established over a year of monitoring together, to determine a calibration factor for PM_{10} (nephelometer) based on PM_{10} (reference method). This affords a high level of confidence in the accuracy of this nephelometer for the PM_{10} measured - *at this site*.

However, this does not address the issue of particle composition – which will vary from site to site. This will necessarily limit the confidence we can have with the *accuracy* of PM_{10} levels measured using nephelometers at different locations to the reference site.

Based on Environment Canterbury, (2016) we anticipate that the nephelometer at the southeast site will typically measure higher levels of PM_{10} than the nephelometer at the northeast site. This means that if the particles at the southeast site are dominated by coarse particles (from quarrying) we may be under-reading the true PM_{10} level at this site using a calibration factor developed from the northeast site.

We are also proposing to co-locate $PM_{2.5}$ nephelometer at two sites to the north and south of quarrying operations as well as the background location. This should provide new and valuable information on the coarse/fine split at these locations.

The exact locations of the transect PM_{10} monitoring are yet to be finalised.

APPENDIX I RECOMMENDED MONITORING INSTRUMENTS

I-1 Respirable Crystalline Silica monitoring

Our sampling methodology is based on the NIOSH 7500 (Issue 4) method for assessing respirable crystalline silica concentrations in the workplace. This method pumps a known volume of air through a cyclone in order to separate out particles with an aerodynamic diameter of 4 microns or less. The resulting particles are deemed to be “respirable” and are collected onto a PVC filter for subsequent analysis.

It is important to note that the NIOSH 7500 method assesses workplace exposure and therefore operates over a typical 6 to 12 hour day in extremely dusty environments. We have adapted this method for ambient monitoring primarily by extending the operating period from 1 day to 1 month. This increases the volume of air sampled using this method and in doing so substantially reduces the detection limit.

However, it is important to note that the NIOSH 7500 method stipulates a maximum sample volume of 1000 litres. In discussions with NIOSH, this limit was primarily set in order to prevent filter blockage and to ensure that the flow through the cyclone stayed at the correct flow rate. As will be seen below, we intend including several additional features in the monitoring equipment to ensure the flow remains at the set point throughout the sample period. Importantly, we anticipate that ambient concentrations of PM_4 to be considerably lower than those experienced by workers performing abrasive blasting and inside mines and therefore much less likely to result in filter blockage.

Our recommended method involves sampling the air through aluminium cyclones that meet the requirements of NIOSH 7500. We will attach a small ceramic heater with a microcontroller to the side of the cyclone, which will heat the cyclone to 40 degrees Celsius. This will prevent moisture from affecting cyclone efficiency. Normally we would regulate the temperature to be approximately 5 degrees higher than ambient to minimise volatile loss, but as the filters are solely for RCS monitoring, volatile loss is inconsequential.

Our numbered, pre-weighed 37mm PVC filters are loaded inside filter cassettes in an accredited laboratory before being couriered to Mote. The cyclones form an airtight seal with the numbered filter cassettes and the leakage across the seal must meet the standard requirement in order for sampling to commence.

A flow sensor continuously measures the volume of air passing through the cyclone and checks that the flow is 2.5 litres per minute. If the flow changes by more than 0.05 litres per minute, the control circuit will modulate the voltage to the pump using a pulse wave modulator (PWM) to maintain the flow at 2.5 litres per minute.

Figure I-1, which follows, depicts the standard layout of an RCS monitor.

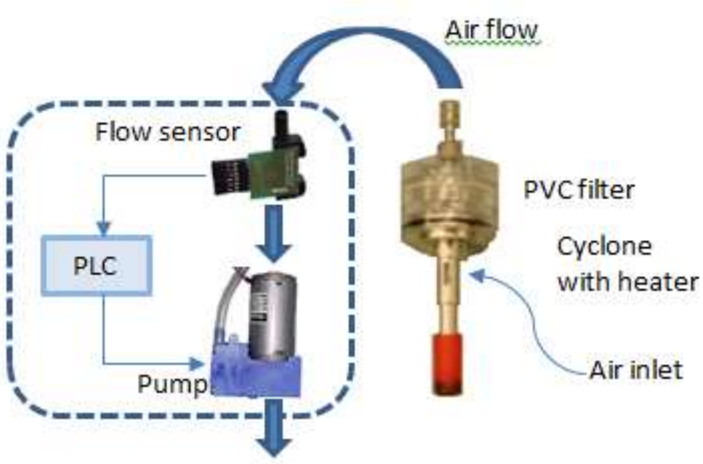

Figure I-1: Primary features of the RCS monitoring system

At the reference site, we intend to deploy a modification of the standard RCS monitor shown above. During consultation with the partner agencies and local residents, concerns were raised about the contribution of dust and potentially RCS that could be sourced from the Waimakariri river bed during dry, windy conditions. For this reason, we propose to include wind directional monitoring at the reference station in addition to the standard RCS monitor deployed at other sites.

The wind directional sampling will contain two sample filter cassettes. The first filter will collect dust when the wind is blowing from the direction of the Yaldhurst quarry. The second filter will collect dust when the wind is blowing from any other location. While there will be some overlap between these two filters under very light winds due to recirculation, we are hopeful that this method will permit differentiation between the quarry and other sources during synoptic events. The elements of the directional RCS monitor are shown in **Figure I-2**.

NIOSH method 7500 allows up to 2 milligrams of crystalline silica to be collected on the filter. The aluminium cyclones we will use require a flow rate of 2.5 litres per minute. This equates to 3.6 cubic metres per day. We anticipate that the average PM_4 concentration over a month is likely to be approximately 20 micrograms per cubic metre. At this concentration, we anticipate collecting approximately 72 micrograms of PM_4 per day. Over a 31 day sampling period, this equates to a total mass of 2.2 milligrams of PM_4. However not all of this sample will consist of crystalline silica, if we conservatively estimate that 50% of the PM_4 consists of RCS, then a 31 day sample will consist of approximately 1.1 milligrams of RCS which is within the limit specified by the method.

Each RCS monitor will be co-located with a PM_{10} nephelometer, which provides continuous real-time data. We intend to use the accumulated PM_{10} data from the nephelometer to predict the total filter loading. In the event that filter loadings are higher than expected, we will initiate an early filter change to ensure we do not exceed the 2 milligram RCS limit.

At the conclusion of sampling, each sample has a cap inserted into the inlet and outlet respectively. Samples are then sealed and couriered to an accredited laboratory for analysis. Each batch of samples will include one field blank and one laboratory blank to assist with data interpretation and analysis.

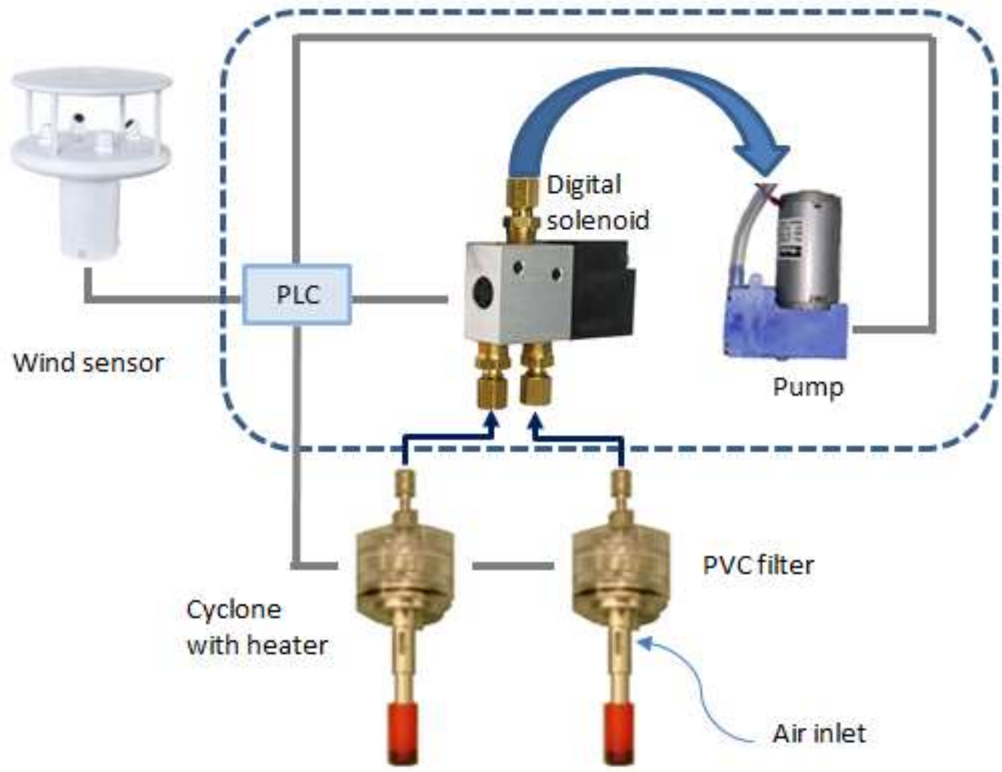

Figure I-2: Primary features of the wind directional RCS monitoring system

I-2 Nephelometer monitoring

An air quality nephelometer is an optical sensor that uses light scattering from particulate matter to provide a continuous real-time measurement of airborne particle mass. The light source is a visible laser diode and scattered light is measured in the near forward angle using focusing optics and a photo diode. The nephelometer has an on-board temperature sensor, which corrects for thermal drift, sheath air filter to keep the optics clean, automatic baseline drift correction and a fibre optic span system to provide a check of the optical components.

The near-forward nephelometers used in this study are more accurate that comparable side scattering nephelometers. However, as the near-forward scattering is less sensitive to particle size, they require a particle size inlet or sharp cut cyclone to provide a mechanical means of separating the size fraction prior to measurement. For this study, we intend to deployment a PM_{10} sharp-cut cyclone for all deployments and co-locate these instruments at all RCS monitoring sites. We will also couple the PM_{10} cyclone with a $PM_{2.5}$ sharp cut cyclone at three sites (reference station, background station and the southern site). This will better characterise the nature of emissions from the quarry and provide the opportunity to determine whether PM_{10} or $PM_{2.5}$ measurements correlate best with RCS measurements.

One of the disadvantages of collecting monthly RCS data is that there is limited information on the variability in RCS emissions during the month. The primary reason for deploying the nephelometers is to determine whether there is a relationship between the monthly optical mass and the monthly RCS concentration. If we are able to develop a sufficiently robust relationship between optical mass and RCS concentration then:

- We have can use PM_{10} data as a proxy for RCS exposure. PM_{10} data is considerably easier and cheaper to obtain than RCS monitoring data.
- We can estimate ambient residential RCS exposure over shorter temporal periods (within uncertainty bounds). While the annual (chronic) guideline is presently applicable, future research may identify guidelines for shorter (acute) periods of ambient exposure – this relationship could provide a method of assessing short-term exposure.

Our nephelometers take a reading once per second, we use a small single board computer to record these readings and calculate the average concentration each minute. The same single board computer uses a GPS to determine the local time very accurately – this way we can time stamp the data. Every 10 minutes, we transmit the previous data to our server using a cellular modem. We take the data and plot this on our website. Interested persons can access this data through a secure web-portal.

We will install the nephelometers on poles and tripods at heights of between 1.5 and 2 metres above ground level. Most nephelometers will be powered using a 12 volt battery which itself will be charged using solar panels. To assist with data interpretation, we will mount ultrasonic wind sensors on poles alongside the nephelometers.

The nephelometer utilises a heating control system based on relative humidity concentrations. When the relative humidity exceeds the set point (30%RH), the inlet heater switches on. This reduces the relative humidity down to below the set point at which point the heater switches off.

While precise, the nephelometers we intend to deploy are not reference instruments. For this reason, we will be co-locating a Beta Attenuation Monitor at both the reference site and the background site. This will enable us to establish a relationship between the reference method instrumentation and establish if the relationship is sufficiently robust to enable us to estimate exposure using nephelometer data. **Figure I-3**, which follows, illustrates the nephelometers we intend to deploy around the Yaldhurst quarry.

Figure I-3: Typical nephelometer installations. The unit on the left is mains powered, while the unit in the centre is battery powered. The unit on the right provides a close up.

I-3 Beta Attenuation Monitoring

A Beta Attenuation Monitor or BAM is a widely used air monitoring technique employing the absorption of beta radiation by solid particles extracted from airflow. We intend using Thermo FH52 C14 beta attenuation monitors inside temperature controlled enclosures at two sites. One of these will be the reference site immediately to the North of the quarry area, while the second site will be the background site.

We intend to operate the FH62 BAM in accordance with the good practice guide for air quality monitoring and data management 2009 and in accordance with the standard method specified in the Resource Management National Environmental Standards for air quality) regulations 2004:

Australian/New Zealand Standard AS/NZS 3580.9.11:2008, Methods for sampling and analysis of ambient air—Determination of suspended particulate matter—PM_{10} beta attenuation monitors

Due to the power requirements of both the instrument and the temperature controlled enclosure we intend to operate both sites using mains power. A typical BAM installation is shown in Figure 4 below:

Figure I-4: An example of a temperature controlled BAM enclosure with the doors open to illustrate the BAM inside.