Good practice guide for monitoring and management of visibility in New Zealand

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Ministry for the
Environment
Manatū Mō Te Taiao

Ministerial Foreword

Unlike many countries around the world, New Zealand is fortunate in having excellent visibility, most of the time. I want to make sure it stays that way. Unfortunately, increasing levels of pollution mean we can no longer take for granted that the breathtaking views we currently enjoy will always appear vibrant and unspoilt. In some major cities visibility is already degrading to unacceptable levels and affecting the enjoyment of some of our best scenic vistas.

Visibility degradation is the haze that obscures the clarity, colour and texture of the air around us. Protecting visibility in New Zealand is important, not only to maintain air quality but also to protect and enhance our enjoyment of our natural environment. Visibility degradation is therefore a key environmental issue that should be investigated, monitored and managed. Quite simply, it is more effective to protect the current high quality than wait for the situation to deteriorate and end up with a problem to fix.

This document provides guidance on the benefits of clear visibility, the contaminants and factors affecting visibility, suitable monitoring methods, potential indicators of visibility degradation, and how emissions causing visibility can be managed in New Zealand.

Clear atmospheric visibility, unaffected by air pollution is one of New Zealand's assets. It needs to be maintained and, where necessary, improved. We want to ensure the sustainability of our air resource by maintaining the existing levels of good visibility. This will allow us to continue to enjoy our environment and protect New Zealand's reputation as having one of the cleanest environments in the world.

Marian L. Hobbs

Hon Marian L Hobbs
MINISTER FOR THE ENVIRONMENT

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1 Introduction

Chapter 1 briefly describes the nature of visibility, how visibility is degraded by air pollution, and why efforts should be made to preserve and maintain the good visibility conditions generally experienced throughout most of New Zealand. It provides an introduction to concepts related to visibility that are discussed in more detail in Chapters 2 to 7.

The rest of the report is structured as follows.

Chapter 2	discusses the nature of visibility in New Zealand, and the value the community places on it.
Chapter 3	provides a description of the contaminants that degrade visibility, identifies typical sources, and describes tools to identify sources and activities in areas suffering visibility problems.
Chapter 4	describes the advantages and disadvantages of different monitoring methods and recommends methods for particular air quality situations.
Chapter 5	describes processes for visibility management and the legislative framework for implementing management measures.
Chapter 6	outlines ways in which visibility can be improved and protected, including the types of goals that might be appropriate regionally and nationally.
Chapter 7	gives an overall summary of the points discussed, and provides conclusions.

1.1 What is visibility degradation?

Visibility degradation is most simply described as *the formation of haze that obscures the clarity, colour, texture, and form of what is seen through the atmosphere*. It is a complex phenomenon influenced by a number of emissions and air pollutants, and affected by a number of natural factors such as temperature, humidity, meteorology, time and sunlight. The focus of this document is visibility degradation caused primarily by tiny particles suspended in the air, and by gases such as nitrogen dioxide. These particles and gases scatter or absorb light, thereby reducing visibility and causing haze. The pollutants responsible for reducing visibility are emitted from a variety of sources, both natural and human.

Internationally, visibility degradation caused by human pollution is seen as a major air quality problem, with most of the world's major urban areas being affected to some extent. For example, Los Angeles is well known for the haze that hangs over the city, restricting views in all directions.

New Zealand is fortunate in having excellent visibility in many areas for most of the time. However, this situation may not last, and indeed is perceived as already degrading to unacceptable levels in the major cities, and noticeably in some scenic vistas. Protecting visibility in New Zealand is important for maintaining environmental quality, and for enhancing the amenity value of the environment for the community and tourists. The major aim of this discussion document is to detail the reasons for this, and to propose methods to achieve it.

It is quite simply more effective and appropriate to protect the current high quality, than to try to fix problems once they occur.

Although *visibility* is a common enough term, people use it in a variety of ways. For the purposes of this report it means the degree to which the atmosphere is transparent to visible light. It is often described quantitatively using *visual range* or the *light extinction* coefficient.

The term *turbidity* may also be associated with visibility. However, turbidity is a specific property of the atmosphere related to the transmission of sunlight, and is not directly associated with visibility.

Reduced visibility in the atmosphere is caused by light scattering and/or light absorption. Light scattering is usually associated with small particles or certain gases, and can occur at night or during the day. During the night, light from street lamps and houses is reflected by particles in the air above a city and can cause the sky to appear brownish and prevent a clear view of the stars. During the day, reduced visibility prevents objects at a distance from being seen clearly. It is this daytime visibility reduction that is more commonly used to judge air quality, and is the focus in this document.

Other factors that cause poor visibility include naturally occurring atmospheric conditions such as fog and low cloud. Where such atmospheric conditions occur at the same time as high pollution incidents, their impacts on visibility will be considered, but only incidentally.

The visual appearance of a single plume of contaminants discharged from a stack and its effects on amenity values in an area is not covered either. However, the report does consider the extent to which industrial and other point discharges contribute to regional-scale degraded visibility.

1.2 Visibility as an indicator of environmental quality

The benefits of clear air and good visibility are obvious – no one would deliberately agree that poor air quality is desirable. But since there are always likely to be costs associated with maintaining good visibility, the reasons for doing so must be clearly identified.

- Visibility is a primary and highly obvious indicator of general air quality: *If the air looks dirty then it probably is!*
- The type of visual degradation is perceived to be an indicator of more serious health impacts: *Surely something that looks that bad is not healthy.*
- Visibility is relatively easy to understand by most people: *I can see that air pollution is occurring!*
- Many people regard good air quality and good visibility as a defining factor for the quality of outdoor life: *You can see all the way to the mountains on a clear day!*
- New Zealand benefits substantially from tourism (a recent survey has shown it is now the number one export earner for the country), and part of this is due to the cleanliness of the air: *New Zealand's air is much clearer than that of almost any other industrialised country.*
- Because visibility is the most noticed effect of air pollution, the community may judge the effectiveness of management options to improve health by the transparency of the air*. The pollution looks as bad as ever. Clearly all those rules imposed to clean it up haven't worked.*

1.3 Assessing visibility degradation

Visual range, or the distance at which objects can be clearly seen, has been widely used to quantify visibility. The range is usually derived by measuring the light extinction by various optical means. The *light extinction* coefficient is a quantifiable factor that can be used to monitor visibility. It is the sum of light scattering and absorption by various particulate and gaseous species.

However, the perception of visibility can be affected by a number of factors other than just the simple extinction of light, including:

- ***colour***, particularly if any part of the sky looks dirty, or brown, or any other colour that might be perceived as 'unnatural'
- ***fuzziness of edges***, for instance, if objects cannot be seen clearly due to some visual obscuration
- ***position of the sun***, which might create circumstances such that even a modest amount of visual degradation is more obvious than usual
- ***presence of moisture in the air***, particularly leading to haze formation (this is a very common event, which may be purely 'natural' or may exacerbate the effect of pollution, due to condensation on pollution particles)
- ***amount and location of cloud cover***, which can affect how an observer perceives a distant object, and can differ depending on where cloud cover is in relation to the observer and object
- ***presence of rain, fog and cloud***, which are by far the most common factors obscuring visibility, and which can sometimes be very difficult to distinguish from pollution effects.

So visibility cannot always be easily quantified or defined. Simply monitoring one indicator, such as visual range, may not be sufficient to understand the impact of degraded visibility. One objective of visibility monitoring is to understand the effect that various types of particles and lighting conditions have on the appearance of a scene. Another is to understand the causes of visibility degradation, which can be complex and not always obvious from simple monitoring.[1]

Effective visibility monitoring programmes sometimes involve taking photographs of the appearance of a scene under various levels of visibility. Because it is difficult to extract quantitative information from photographs, instruments to record optical characteristics of the atmosphere and the composition of visibility-reducing particles are also used. Optical instruments are the usual measure of the scattering or extinction coefficient. Particulate monitoring determines the composition of visibility-reducing particles to help identify the type and strength of the source of the particles and gaseous precursors to secondary particles.[2]

1.4 Summary

What is visibility?

- Visibility is a fundamental property of the atmosphere.
- It is often used as an indicator of general air quality.
- Causes of visibility degradation are many and complex.
- Assessing visibility is not easy.

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[1] Pryor S. 1996. Assessing public perception of visibility for standard setting exercises. *Atmospheric Environment* 30: 2705–16.

[2] United States Environmental Protection Agency. *Information Pertaining to the 1994 Air Quality Trends Report*. http://www.epa.gov/oar/overview.html.

2 The Value of Visibility in New Zealand

2.1 Sustainable air quality

The Government has identified a key goal for public sector policy and performance relating to the environment. It is to:

> *Protect and enhance the environment – treasure and nurture our environment with protection for eco-systems so that New Zealand maintains a clean, green environment and rebuilds our reputation as a world leader in environmental issues.*

More specific to air quality is the *Environment 2010 Strategy* (E2010) (1995) goal, which is:

> *To maintain air quality in parts of New Zealand that enjoy clean air and improve air quality in places where it has deteriorated.*

These policy statements send a clear message that air quality, its improvement and maintenance is a Government priority for the environment.

The provision of clean air is usually considered to be a requirement for protecting human health. Many decisions about managing air pollution are made on the basis of its potential or actual effects on human health. However, under the Resource Management Act 1991 (RMA), which establishes the legislative framework for air quality management, amenity values and the overall quality of the environment are also key environmental issues that must be taken into account.

Visibility is primarily an amenity issue that significantly affects the ability of people to enjoy the environment. It is also widely used by people to judge the quality of the air and to indicate potential adverse health effects. Visual pollution signals that air contaminant concentrations are likely to be high (particularly particle concentrations) and that the day's air quality may be unhealthy, particularly for those with existing respiratory problems. Based on sensitivity to air pollution and awareness of the effects of air pollution, a person may alter their behaviour to avoid inhaling outdoor air. For example, they may choose to stay indoors, drive to work instead of walking or biking (which causes a higher exposure to air pollutants), and avoid exercising or spending time outside.

The goal of the RMA is to promote the sustainable management of natural and physical resources. The air is a vital resource for life and therefore must be managed in a sustainable manner. Because visibility of the air is a key indicator of air quality, and its clarity is an important amenity value, it too must be managed in a sustainable manner. This means ensuring it is improved where degraded, and maintained where the quality is presently good.

To do this we need to know the causes of visibility degradation, what the current levels are in New Zealand, the benefits of good visibility, what policies will achieve improvements, and how much these policies will cost.

2.2 An amenity value for New Zealanders

Many New Zealanders take for granted the ability to travel to almost any part of the country and view breathtaking landscapes which appear crystal clear, lush in colour and 'untouched' in appearance. Also, the New Zealand lifestyle is strongly influenced by outdoor sports and recreational activities. Maintaining good visibility allows us the freedom to enjoy such activities in the backyard, rather than having to travel to remote regions as millions of people overseas do each year to enjoy 'the good life' and 'fresh air'.

While New Zealanders value clean air highly, their perceptions of visibility as an amenity value are generally not well known. Most people are familiar with international concerns, such as localised smog in Los Angeles or London, or the effects of forest burning in Indonesia. However, a community survey conducted by National Institute for Water and Atmospheric Research (NIWA)[3] revealed that while the general public view maintaining good air quality to be extremely important, they believe that their own activities have little effect on air quality. The study also showed that the general public attribute major air pollution problems to industrial activities and, to some extent, vehicle emissions.

2.3 Tourism and business

To most overseas tourists, New Zealand is a clean, green country with intensely blue skies, lush forests, diverse ecosystems and crystal clear waters. New Zealand also boasts amazing scenic vistas that rival those around the world. This image of New Zealand is a powerful product-marketing tool utilised by both the tourism and export industries. Brochures depicting clean, clear landscapes are often used in product packaging and in promotional travel videos and magazines. While clear visibility is not the only trait drawing visitors, it is important to protect these scenic vistas from degraded visibility, and we need to be aware of the pressures on air quality in sensitive areas.

Tourism in New Zealand generates in excess of $20 million per day, and an estimated $8.2 billion per year from international and domestic tourism combined. A survey by Statistics NZ (June 1999) has shown that tourism is now the top single earner of overseas revenue for the country. New Zealand's unique environment, scenic variety and unquestionable beauty are a major attraction for many overseas visitors.

A visitor study carried out by the New Zealand Tourism Board[4,5] highlighted a number of characteristics that tourists identify with New Zealand, including the:

- clarity, vivid colours, lush undergrowth and untouched and youthful appearance of the environment
- active nature of the landscape
- variety of activities available to tourists
- distinctive wildlife, flora and fauna

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[3] Petersen J, Stevens S, Fisher GW. 1997. *Auckland Trial Community Visibility Survey: Preliminary results.*

[4] NZ Tourism Board. 1998. *Product Development Opportunities for Asian Markets*.

[5] NZ Tourism Board. 1998. *Product Development Opportunities for European and American Markets*.

- constantly changing terrain over short distances – beaches, rivers, lakes, forests, mountains and glaciers
- vibrant, contrasting and unspoilt landscapes.

More than 1.3 million tourists visit at least one New Zealand national park each year. Fortunately for New Zealand, these areas are unlikely to currently suffer from degraded visibility caused by air pollution. However, it is important to monitor the situation and to consider the potential adverse impacts that a decline in visibility might have, especially for the tourism industry, which relies on the amenity value of many of the national parks, mountains, and coastal recreational areas. In the US, degraded visibility significantly reduces the ability of people to enjoy some of their most popular scenic areas, including the Grand Canyon. This situation must be avoided in New Zealand.

2.4 Maori perception of air quality

The traditional Maori view of air is encapsulated by Ranginui (sky father) and Tawhirimatea (guardian of the wind). The expression "Ko Ranginui e tu iho nei, Ko Papatuanuku" is heard throughout the country on marae and at hui. This classical expression denotes the creation genealogy, and depicts how Maori see the world as being contained within Ranginui and Papatuanuku (Te Puni Kokiri, 1993). Concepts such as tihei mauriora (the breath of life), nga hau e wha (the four winds) and te hau o Tawhirimatea (the wind Tawhirimatea) are also tohu (indicators) within Maori society to signify the importance of air for Maori.[6]

Maori view the protection of air resources in terms of the effects of activities both inside and outside Maori tribal rohe (boundaries). Activities that may impact on Maori boundaries include airports, industry, buildings, rock concerts and telecommunications.

Health concerns may also be included in the impacts of these activities on the domain of Ranginui, a protected taonga (treasure) under the Treaty of Waitangi.[7]

In an informal survey on visibility issues, one Maori group responded that they considered the effects of air quality on human health to be of concern, and the settling of air pollutants on food-gathering areas, rivers and streams to be having an impact on Maori people. They also noted that Maori always refer to their mountain ranges, rivers and areas of special significance and that therefore visibility protection in all national parks is a high priority.

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[6] Ministry for the Environment. 1997. Environmental Performance Indicators: Proposals for air, fresh water and land. *Signposts for Sustainability*. Wellington: Ministry for the Environment.

[7] Ministry for the Environment. 1997. Environmental Performance Indicators: Proposals for air, fresh water and land. *Signposts for Sustainability*. Wellington: Ministry for the Environment.

2.5 Visibility and human health

The particles responsible for causing visibility degradation can also cause adverse health effects. Along with other countries, New Zealand has tended to consider the health effects of PM_{10}, which includes finer particles (such as $PM_{2.5}$) that contribute substantially to visibility degradation.

Health effects identified as being associated with fine particles include:

- premature death and increased hospital admissions and emergency room visits (primarily the elderly and individuals with cardiopulmonary disease)
- increased respiratory symptoms and disease (children and individuals with cardiopulmonary disease such as asthma)
- decreased lung function (particularly in children and individuals with asthma)
- alterations in lung tissue and structure and in respiratory tract defence mechanisms.

Overseas human health impact studies have shown that humans with underlying respiratory disease such as asthma are likely to be more susceptible to the adverse effects of air pollution.[8] The inhalation of these particles has also been linked with causing other human respiratory illnesses to develop, such as bronchitis.[9]

The current United States Environmental Protection Agency (USEPA) standards for particles have been revised as a result of new studies on health effects, focusing on fine particles ($PM_{2.5}$). These studies showed that adverse health effects, such as premature deaths and increased morbidity in children and other sensitive populations, are associated with exposure to particle levels well below those allowed by the previous USEPA standard.

The new standard for PM_{10} has remained essentially unchanged, but a new standard for fine particles ($PM_{2.5}$) has been set at an annual limit of 15 micrograms per cubic metre and a 24-hour limit of 65 micrograms per cubic metre. The USEPA has been charged with reviewing these new standards within the next three years.

A similar review of the particulate health guideline values is underway in many countries, including one by the Ministry for the Environment in New Zealand. It is likely that most standards and guidelines will be tightened, and new ones introduced. In the longer term, it is also likely that standards and guidelines will be developed for ultra-fine particles ($PM_{1.0}$), which also have a large impact on visibility.

The relationship between levels of visibility degradation and the concentration of fine particles in the air is complex and varies with particle size and composition. Thus it is not possible to use visibility monitoring techniques (for example, survey methods, light scattering or people's perception) to assess particle concentrations and therefore potential adverse health effects. It is also unlikely that a guideline set to protect human health from particles would be as low as one required to protect visibility.

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[8] Higgins BG, Francis HC, Yates CJ, *et al*. 1995. Effects of Air Pollution on Symptoms and Peak Expiratory Flow Measurements in Subjects with Obstructive Airways Disease. *Thorax* 50: 149–55.

[9] Reichhardt T. 1995. Weighing the Health Risks of Airborne Particulates. *Environmental Science & Technology* 29(8).

It is therefore appropriate to keep visibility assessment separate from the health effects of particulates (or gases). Any guidelines or indicators for visibility should specifically address the visibility issue, independent of other air quality issues.

2.6 Regional government perspective

Although visibility degradation is evident in selected areas of New Zealand, comments from a survey indicate that all councils place a high value on maintaining good visibility, particularly in regions where there are areas of high landscape significance and natural beauty.

Many councils have addressed the importance of preserving visibility for the tourism industry, particularly in areas that are frequently visited by tourists and rely on maintaining the 'clean, green' image as a marketing tool. Visibility is also given a priority in most councils' air plans, reflecting both their responsibilities under the RMA and the wishes of the community.

2.7 Summary

Why should visibility be protected or improved?

- To enhance our living environment: New Zealanders place a high value on having a clean environment and excellent air quality. Improved visibility enhances feelings of well being and enjoyment of the environment.
- For the purposes of tourism: New Zealand's image is that of a clean, unpolluted environment. To continue to have this image in the future, the excellent visibility we have should be maintained.
- To provide for human health: research studies have identified a link between inhaling air contaminants (which can also impair visibility) and the incidence of human respiratory diseases such as bronchitis. These contaminants can also lead to an increase in asthma attacks for those with underlying respiratory problems.
- To maintain and enhance the amenity value of our environment as outlined in the Resource Management Act (RMA): amenity value is defined in section 7 of the RMA as "those natural or physical qualities and characteristic of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes".
- To provide sustainable air quality for future generations and to provide for living ecosystems.
- To meet New Zealand government and regional council policy objectives such as those stated in regional policy statements, regional plans and the *Environment 2010 Strategy*.

3 Factors Affecting Visibility

3.1 Introduction

If we are to minimise visibility degradation by reducing air pollution we need to know the major sources of pollutants responsible and how they affect visibility. These sources, and other factors that might affect visibility conditions, are discussed in this section.

Contaminants contributing directly to visibility degradation include various forms of particulate matter or particles, and nitrogen dioxide gas (NO_2). Other contaminants, including nitrogen oxides (NO_x), sulphur dioxide gas (SO_2) and volatile organic compounds, contribute by reacting under certain conditions to form fine particles. These contaminants are emitted into the atmosphere from both natural and human activities.

Air contaminants are often classified as either primary pollutants or secondary pollutants.

Primary pollutants are emitted directly into the atmosphere by natural or human sources; for example, SO_2 emitted from a volcanic eruption, or a coal-fired power plant. Other examples include carbon monoxide gas (from vehicle exhausts during combustion), wind-blown dust, and pollen.

Secondary pollutants are produced by gaseous–gaseous or gaseous–particulate interactions (typically referred to as secondary reactions) in the atmosphere. For example, NO_2 can react with sea salt in the atmosphere to form nitrate particles (a secondary particulate). The chemical and physical processes of secondary pollutant production are extremely complex, and are difficult to measure. However, secondary particulate formation is known to contribute significantly to haze problems experienced overseas.

The different contaminants and atmospheric conditions affecting visibility are discussed below.

3.2 Contaminants

3.2.1 Particles

Suspended particles in the atmosphere exist in a wide range of shapes and sizes and are made up of a variety of chemical species (for example, heavy metals, salts, carbon) or combinations of chemicals (for example, polyaromatic hydrocarbons absorbed onto the surface of carbon particles).

Particles are typically classified as *total suspended particulate* (TSP: comprising all particle sizes), *medium to fine particulate* (PM_{10}: particles less than 10 µm in diameter), *fine particulate* ($PM_{2.5}$: particles less than 2.5 µm in diameter), and ultra fine particulate ($PM_{1.0}$ and smaller).[10]

Fine particles, or $PM_{2.5}$, are the most significant contaminant influencing visibility conditions because their specific size allows them to scatter or absorb visible light.[11] It also allows them to remain airborne for long periods of time, and under favourable climatic conditions they may be transported over long distances. This is one reason why locations distant from the main pollution sources can experience degraded visibility.

Secondary reactions are influenced by a wide range of factors, such as temperature, sunlight, the mixture of gases present, and time. Secondary formation of particles from gaseous pollutants can take some time to occur and will be exacerbated under conditions of low wind speed and poor dispersion.

Particles larger than $PM_{2.5}$ and up to PM_{10} can scatter visible light and do adversely affect long-range visibility when present in high concentrations.[12] However, coarse particles (larger than PM_{10}) in the air are usually deposited on the ground quickly due to gravity or collision with other suspended particles, or are washed out of the atmosphere during precipitation. Larger dust particles can cause visibility problems and nuisance effects during high wind conditions, but these effects are not the focus of this document.

Particles are discharged into the air from a variety of sources. Some are emitted directly from sources such as chimneys and vehicles. Coarse particles generally come from sources such as dust generated by vehicles travelling on unpaved roads, soil tilling and quarrying operations, materials handling, crushing and grinding operations (such as cement manufacturing), and combustion sources. Fine particles commonly result from fuel combustion in motor vehicles, power plants and industrial facilities, residential fireplaces, wood burners, wildfires and agricultural burn-off. Fine particles may also be formed by secondary reactions, and primarily include sulphates, nitrates, elemental carbon, organics and biogenic organics.[13]

3.2.2 Gases

SO_2 and NO_2 are primary pollutants and may be emitted from both natural and human sources. Both of these gases can undergo secondary reactions to form secondary pollutants, including sulphate and nitrate particles, which contribute to degraded visibility. The conversion of these gases to secondary particulates is climate dependent, requiring warm temperatures. Thus while secondary particles may be a significant contributor in Auckland, they are unlikely to be responsible for visibility degradation in Christchurch, particularly during the winter months.

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[10] United States Environmental Protection Agency. *Information Pertaining to the 1994 Air Quality Trends Report*. http://www.epa.gov/oar/overview.html

[11] Mathai CV. 1995. The Grand Canyon Visibility. *Environmental Manager* 1(Dec): 20–31. Arizona Public Service Company.

[12] White JS, *et al*. 1994. Size Resolved Measurements of Light Scattering by Ambient Particles in the Southwestern USA. *Atmospheric Environment* 28: 909–21.

[13] United States Environmental Protection Agency. *Information Pertaining to the 1994 Air Quality Trends Report*. http://www.epa.gov/oar/overview.html

Also, NO_2, unlike any other gaseous pollutants, can directly affect visibility due to its ability to absorb visible and ultraviolet light.

The presence of NO_2 is indicated by a brownish colouration of a haze, such as has been observed in the atmosphere around Auckland. But the brown appearance of haze is not only attributable to NO_2. It can also occur when the sizes of the particles that scatter light vary. This results in the scattering of light across a range of wavelengths in the visible spectra; for example, blue and red, resulting in a brown tinge.

The major human source of NO_2 emissions in most urban locations is motor vehicles. SO_2 is predominantly emitted from coal-fired power plants and smelters and domestic coal fires, but may also be emitted naturally by oceanic processes and during volcanic eruptions.

Volatile hydrocarbon concentrations can also be a significant factor in visibility degradation, through their role in chemical reactions in urban air leading to secondary particulates, and through direct emissions, both industrial and biogenic. Direct biogenic emissions of volatile hydrocarbons such as terpenes in an otherwise clear airshed can result in a blue haze. The blue colour occurs because the particles are of a similar size and scatter light in the blue wavelength fraction of the visible spectrum.

3.2.3 Major sources of contaminants

Contaminants that cause visibility degradation may be emitted from a variety of natural and human sources, so identifying their source is often difficult. A number of other factors must also be considered when assessing visibility, including meteorological variables (rain, fog, cloud, wind speed and direction, humidity, temperature), the presence of temperature inversions, and the geographical characteristics of a region.

Natural sources

Natural sources of primary particles in New Zealand include wind-blown dust and soil particles, coastal processes, and volcanic eruptions.

Sea-salt particles released into the air from coastal processes, particularly during high winds or surf, may contribute significant quantities of fine particles. These can play an important role in exacerbating haze problems in cities located near coasts. Chloride in the sea salt can react with anthropogenic pollutants such as NO_2, resulting in a greater formation of particles.

Other contaminants contributing to secondary particle formation and released from natural sources include SO_2 from volcanic eruptions and volatile hydrocarbons from biogenic sources such as pine forests.

In most areas natural sources of emissions are the largest contributor to regional visibility degradation. There are no practical management strategies that can – or should – be applied to the natural emissions that contribute to reduced visibility.

Industrial sources

Industrial processes can influence visibility in two ways: they can generate significant quantities of fine particles (SO_2 and NO_2), which contribute to air pollution and visibility across the city; or they can emit a visible plume, which on its own may degrade a scenic landscape.

Most large industrial discharges are managed by councils in accordance with the purpose and principles of the RMA on the basis of their effects. Regional councils and unitary authorities have the ability to develop regional air quality plans in which they can specify those discharges to air that require consents and those that are permitted or subject to conditions.

In this way, emission limits can be imposed on industrial discharges either through consents or the plan. Emission limits for discharges such as PM_{10}, SO_2 and NO_x are likely to be based on their potential for causing health effects at ground level or contributing to overall ambient concentrations of these contaminants. The *Ambient Air Quality Guidelines* combined with data on background concentrations can be used to determine whether a particular concentration at ground level is likely to cause adverse effects. However, it is unlikely that this approach would be appropriate for managing the effects of visibility degradation, as the maximum ground level concentration is unlikely to be a good indicator of overall contribution to visibility impairment. At this stage there is insufficient information available to manage discharges of these types of contaminants in order to address secondary particulate formation or degraded visibility.

Domestic sources

Residential domestic activities that contribute to visibility degradation include domestic home heating and outdoor burning. Combustion of coal, oil, wood and gas in domestic fires and the burning of waste such as garden clippings or cardboard releases contaminants into the air.

These discharges can be managed under section 15(2) of the Act through the preparation of an air quality plan. Adverse 'nuisance' effects caused by discharges from these sources can also be addressed under section 17 on a case-by-case basis. However, some councils have included rules and conditions relating to nuisance effects of domestic activities in their plans.

A number of councils have introduced bans on outdoor burning to minimise the effects of these activities on the environment, particularly during winter when pollutants can be trapped below inversion layers, or contained within stable layers close to the ground. They have also stipulated that each model of solid-fuel burning equipment installed into houses must have passed an emissions test, with a limit on the amount of particulate matter discharged from the appliance.

In their *Draft Air Quality Plan*,[14] Environment Canterbury proposes to ban residential outdoor burning, use of coal on domestic fires, and, over time, the use of open fires and old solid fuel burners in homes. The aim of these rules is to reduce the concentration of wintertime PM_{10} to levels that will protect people from adverse health effects. Currently, PM_{10} concentrations exceed not only the Ministry for the Environment's *Ambient Air Quality Guidelines* but also the proposed council guideline. Although the measures to reduce PM_{10} may also improve visibility to some extent, visibility has not been a significant driving factor in this policy development.

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[14] Canterbury Regional Council. 1993. *Let's Clear the Air: Issues and options for air quality management in Canterbury and background information*. Report 93(35).

Emissions from burn-offs in agricultural areas, particularly during still wind conditions or under temperature inversions, contribute to visibility degradation in a number of regions throughout New Zealand. Agricultural burn-off is not usually regulated for its effects on air quality, and the extent to which regulation is required needs further attention.

Transport sources

The combustion of hydrocarbon fuels in vehicles emits a variety of contaminants into the atmosphere. These include water vapour and carbon dioxide, and under incomplete combustion conditions CO, NO_x, volatile organics and particles are also emitted. Higher emissions of particles, particularly elemental carbon, occur from diesel-operated vehicles and poorly maintained petrol engines. Statistics for registered vehicles in New Zealand for 1997 show that diesel-operated vehicles constitute about 13% of total licensed vehicles.

The effect of vehicle emissions on visibility is typically worse in heavily populated areas or city regions, but may also be exacerbated under certain geographical and climatic conditions. The potential for transport sources to contribute significantly towards visibility degradation in New Zealand is of a growing concern, particularly in the Auckland region, which currently has more than a million vehicles on its roads.

The Ministry of Transport is currently investigating the effects of vehicle emissions on the environment in the *Vehicle Fleet Emission Control Strategy* (VFECS). It has been recognised that vehicle emissions are major contributors of visibility-degrading contaminants. The recommendations and subsequent policies outlined in the VFECS are expected to benefit visibility. However, because the VFECS is focusing on the health effects of contaminants such as CO, visibility is unlikely to be a key factor in current policy decisions.

The development of transport policies to reduce the effects of contaminants from vehicles should improve visibility over time. However, visibility must be monitored and more research into the causes of contaminants responsible for degrading visibility is required. This information can then be used to review, and if necessary modify, transport policies.

3.3 Other factors affecting visibility

There are several other factors, mainly meteorological and geographical, that have a strong influence on air quality and regional visibility. In most cases these have the biggest influence on visibility, compared to anthropogenic sources of pollution.

3.3.1 Atmospheric conditions

Warm, dry weather conditions favour secondary particle formation. They also provide suitable conditions for long-distance transportation of air contaminants.

Rain washes out suspended particles, which are quickly deposited on the earth’s surface. While rainfall thus acts to remedy the effects of particles on visibility, it can act as a transport mechanism for water-soluble components to enter waterways and biological processes.

For example, sulphuric acid particles (formed by the secondary reactions involving SO_2 gas and moisture in the atmosphere) may enter biological pathways during precipitation (referred to as 'acid rain'). This can cause irreversible damage to valuable ecosystems. Acid rain is typically associated with countries that have high SO_2 gas emission levels, such as the US and Germany. It is not generally a concern in New Zealand, and indeed in many parts of the country most of the anthropogenic acidity in rainfall comes from Australian emissions.[15]

While sulphates may not be as important in New Zealand as in many other places, the situation may be reversed for nitrates and chlorides. These are thought to play a relatively greater role in the atmospheric chemistry over New Zealand's urban areas, although more research is needed before this can be confirmed.

3.3.2 Geographical influences

The geographical characteristics of a region also influence the dispersion of contaminants once they are released into the air. The effects of emissions may be modified in regions that are sheltered from wind, since wind acts to dilute pollutant concentrations. One significant feature for many regions is the trapping of contaminants by a layer of cool air in the lower atmosphere (referred to as a 'temperature inversion'). These layers of air can be complex in structure, occurring at the surface or in narrow layers above the surface, and are often seen over urban areas such as Auckland.

3.3.3 Temperature

Visibility may be observed to worsen during cooler temperature conditions. A drop in temperature combined with other supporting factors increases the likelihood for temperature inversions to occur. This often coincides with an increase in emissions through an increase in heating requirements. The Christchurch area frequently experiences temperature inversions during the winter months due to its geographical characteristics, and under low wind conditions high concentrations of air contaminants are common.

3.3.4 Relative humidity

The amount of water vapour in the atmosphere, typically indicated by the relative humidity, has a strong effect on visibility. Although relative humidity does not by itself cause visibility to be degraded, research studies have linked high humidity conditions with an increase in secondary particulate formation, particularly for hydroscopic particles such as sulphates, nitrates and sodium chloride. An increase in moisture in the atmosphere associated with high humidity causes these particles to accumulate water and grow to just the right size to be very efficient at scattering light, causing visibility to be degraded in the form of a highly distinctive haze.

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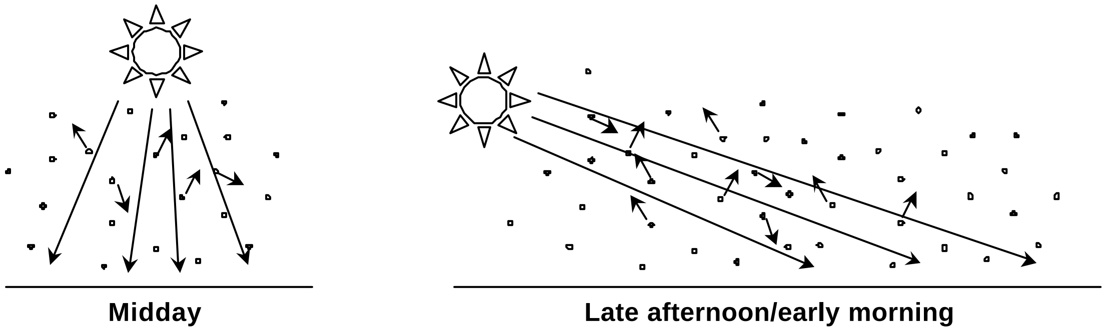
[15] Holden R, Clarkson TS. 1985. Acid Rain in New Zealand: Is it a problem? *Chemistry in New Zealand* (December).

3.3.5 Sun angle and cloud cover

The effect of sun angle and clouds on visibility is complex. An object is visible if the difference in brightness between it and the background (the contrast) is more than about 2%. For example, when the sun is above and behind the observer, the sun shines on the object, making it brighter, so that it contrasts less with the background. This makes it less visible, but more detail can be seen. When the sun is behind the object, however, the object will be in shadow (relative to the observer). In this situation, the object contrasts more strongly with the background and is hence more easily visible, but the detail in the object is less visible because it is in shadow.

This example shows that the direction of sunlight will influence how an object is perceived, in terms of both contrast and detail. Different conclusions could be reached on how visible an object is depending on which method is chosen as a measure of visibility.

Figure 1: Effect of sun angle on visibility



In addition, even without the effect of other influences, visibility may be perceived to change during the day.[16] In the morning and evening, haze may appear to be worse. This is partly due to the sun being lower in the sky and light having further to travel through the particles in the haze, causing more light scattering to occur (see Figure 1). An observer's position will also affect their perception of visibility, depending on whether a haze is being viewed in the forward scatter (sun in the observer's field of view) or back scatter (sun behind the observer) mode. Particles mainly scatter light in the forward scatter direction, and therefore haze viewed in the forward scatter mode will appear brighter than haze viewed in the back scatter mode. Particle concentrations, and hence the amount of light scatter, will also vary during the day due to meteorological conditions and those times of day when contaminants are emitted into the air.

Cloud cover affects the amount of light shining on the horizon, the foreground and any objects in the view of the observer. The particular location of the clouds also affects how objects can be seen. For example, if there are clouds behind an object being viewed, then the horizon may appear darker and the contrast between the object and the horizon less, so the object is less visible. For cities with high levels of particulate, clouds in the field of view between the object and horizon can cast a shadow over particles that would normally scatter light, and the light from the object will be easier to see.[17]

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[16] Horvath H. 1981. Atmospheric Visibility. *Atmospheric Environment* 15(10/11): 1785–96.

[17] Horvath H. 1981. Atmospheric Visibility. *Atmospheric Environment* 15(10/11): 1785–96.

3.4 Quantifying emissions

A key first step in any attempt to manage visibility, or air quality, is to be able to identify what the contributing emissions are, where they are coming from, and how they might be changing.

3.4.1 Emission inventories

Emission inventories are used to quantify emissions of contaminants from various sources in an area. They are an integral part of developing management strategies to reduce or maintain pollutant levels at an acceptable level. Emission inventories also assist in the development of longer-term control strategies and in predicting future air quality conditions. The information obtained from emission inventories and data modelling is used to assess the effectiveness of implementing various policy options, and to determine whether the required reductions in emissions will be achieved by implementing such options.

The use of a home heating, industry and motor vehicle emission inventory has been part of a strategy adopted by Environment Canterbury (EC) to determine the major sources of PM_{10} emissions in Christchurch,[18] and has been integral to the development of measures proposed in a draft air quality plan to reduce 24-hour average PM_{10} concentrations to meet health guidelines. Comprehensive inventories have been developed by several councils (Auckland, Canterbury, Waikato, Gisborne, Otago and Wellington).

Although emission inventories are used extensively for determining the sources of emissions of contaminants, further analysis and modelling is required to determine the effects of meteorology on the resulting contaminant concentrations

Emission inventories are of limited use in assessing factors contributing to visibility degradation because they rarely provide information about the key factors that contribute to visibility degradation, namely:

- information about particle size and composition
- estimates of secondary particulates
- emissions from natural sources such as sea spray.

3.4.2 Air quality indicators

Measurement of air quality indicators is the basis on which regional air quality is determined, and also provides information about the rate of use, or production, of a substance that discharges contaminants into the air. As part of the *Environment 2010 Strategy* objectives and the Environmental Performance Indicators (EPI) programme, environmental indicators have been selected to assess air quality. Visibility is one of the key Stage 2 indicators of air quality in the EPI programme and potential indicators for visibility are discussed in Chapter 4.

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[18] Canterbury Regional Council. 1997. *Christchurch Inventory of Home Heating and Motor Vehicle Emissions*. NIWA Report R97/5.

3.4.3 Modelling and source apportionment

Modelling can be used to determine the potential effects of an air pollutant on regional air quality; for example, the potential effect on neighbouring areas of SO_2 from a point source with a known rate of discharge. Such dispersion modelling can be very sophisticated, involving many sources and movement over tens of kilometres. Mass trajectory models are commonly used to track the transportation pathways of atmospheric pollutants when emitted from a point source. These use meteorological data such as wind speed and direction, and precipitation. Cumulative effects of pollutants may also be determined using full-scale airshed models.

Receptor modelling uses elemental composition data collected at a receptor site to characterise and quantify the effects of emission sources, followed by the fingerprinting of data to specific sources – referred to as 'source apportionment'. There are two types of receptor models: multivariate models, which are based on principle component analysis (PCA) or factor analysis, and chemical mass balance (CMB) models. PCA models generate a hypothesis of the number of sources and their physical and chemical fingerprints, and may also be used to perform source apportionment (known as absolute principal component analysis, or APCA). The effect of individual sources on a receptor site may be calculated from inputting the number of active sources and their chemical fingerprints.[19]

Finally, full urban airshed modelling is being applied in New Zealand to attempt to understand the complex relationships between emissions, meteorology and ambient contaminant concentrations over an entire region, or airshed. These models require very detailed information, usually on a grid basis down to 1 km x 1 km resolution. At present only the Auckland and Christchurch regions have sufficiently detailed information.

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[19] Thompson A. 1996. *Visibility Degradation in New Zealand: Elemental fingerprints of particulates for source apportionment.* NIWA (Draft) Report AK 96094, prepared for the Ministry for the Environment Sustainable Management Fund.

3.5 Summary

What factors affect visibility?

- Particulates are the main contaminant affecting visibility. Different-sized particles have different effects, with fine particles ($PM_{2.5}$) having the greatest effect at visible wavelengths.
- Gases can also affect visibility, the most common being oxides of nitrogen and hydrocarbons.
- Sources of pollution affecting visibility fall into four main categories:
  - natural emissions (from geothermal sources, forests, sea spray, etc.)
  - industrial emissions (from stacks, waste disposal, and a variety of manufacturing processes)
  - domestic emissions (from the day-to-day activities of people, including burning rubbish, cooking, heating and painting)
  - transport emissions (from the operation of vehicles, fuel usage, road wear, etc.).
- Visibility degradation is also strongly influenced by weather factors and geographical location.
- Tools for assessing sources of degradation include air pollution emission inventories, modelling, and the use of indicators.

4 Visibility Monitoring and Potential Indicators

4.1 Introduction

This chapter provides guidance on how to measure and monitor visibility in New Zealand and recommends the methods that should be used in particular air quality situations. It also explores whether an indicator can be developed for visibility, based on particular monitoring methods.

As discussed in Chapter 3, atmospheric visibility is influenced by a large number of factors. This makes visibility difficult to monitor, and its measurement is often complicated by the subjective nature of its effects. There is no single ideal measurement method. However, there are several techniques that can be applied effectively, and this chapter explains when these different methods should be used.

4.2 Measuring visibility degradation

Fortunately, in most areas in New Zealand visibility is generally excellent. Impaired visibility is usually only experienced in larger regional centres such as Auckland, Christchurch and Hamilton, and in towns where air contaminants can be trapped by surrounding hills under an inversion layer, typically in winter. Therefore, unlike other countries in the world, where the objectives of visibility monitoring are often to ensure visibility is improving as a result of policy measures, the objectives for visibility monitoring in New Zealand are normally to maintain the existing levels of good visibility.

There are several methods that can be used to measure visibility.

- Make ***manual observations*** of the visual range (the distance to objects that can be clearly seen in the distance) or contrast and colour. Sometimes black-and-white disks placed at various distances are used to make a comparison.
- Measure the ***optical characteristics*** of the air: typically these include light scattering or the light extinction coefficient. This can be carried out either over an open path or by point monitoring.
- Take ***photographs or video images***, and make visual or manual comparisons of visibility, or measurements of contrast.
- Acquire and ***process digital images***. This is largely experimental at this stage.

Visual range has been widely used to quantify visibility. However, because visibility is not just about how far one can see, using visual range as an indicator may not be enough to determine whether human activities are affecting visibility in New Zealand.

Effective visibility monitoring programmes often involve a combination of the methods listed above. Photographs of the appearance of the scene under various levels of visibility can be used as a baseline for judging visibility on different days. However, because it is difficult to extract quantitative information from photographs, instruments to record optical characteristics of the atmosphere and the composition of visibility-reducing aerosols are also used. In addition, measuring the composition of visibility-reducing aerosols can help to identify the sources of particles and gaseous precursors to secondary particles and their relative contributions to poor visibility.[20]

4.3 Measurement methods

There is no single 'right' way to monitor visibility, because visibility and its degradation are still very much a matter of human perception. Although some quantitative assessment techniques are available, reduced visibility can assume differing levels of importance depending on the circumstances. A good example might be the difference between Taranaki, Southland and Auckland.

In Taranaki visibility can be impaired quite often, but this is due to the action of wind on the sea, producing haziness, and reduced visual range. However, this is rarely seen as 'bad' and is simply an unalterable characteristic of the region.

In Southland visibility can be reduced over very large areas at times during the year when agricultural burn-offs occur. Again, although this is not too nice for some people, it is often accepted as a consequence of life in the region.

In Auckland the visibility degradation caused by the appearance of the 'brown haze' over the city is quantitatively nowhere near as bad as in Taranaki and Southland, but is seen as 'very bad' because it makes the city look dirty and polluted.

These examples highlight the difficulty with using just a single visibility measure: a recording of sea-salt concentrations in Taranaki's air might indicate that it is worse than Auckland's brown haze when it clearly is not.

This document details some of the more common and appropriate methods, and recommends that one or more of these methods be used. Although it is not appropriate to recommend a single method, some consistency throughout New Zealand is desirable.

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[20] United States Environmental Protection Agency. *Information Pertaining to the 1994 Air Quality Trends Report*. http://www.epa.gov/oar/overview.html

4.4 Deciding on which method to use

The choice of monitoring method will be influenced by:

- the objectives of the monitoring programme
- the resources available
- guidelines or standards to be used for monitoring
- limitations of the methods.

Recommendations on the type of monitoring that could be used on the basis of the type of region or city being monitored and the extent of any visibility degradation are given later in this report.

4.4.1 Objectives

Monitoring objectives may range from a simple short-term assessment of the visibility effects in a small area, through to large multi-year programmes to track visibility within a whole region. They might be aligned to examining a particular effect from an identified source, or establishing the acceptability of degraded visibility, or testing the effect of a specific policy, or examining long-term trends due to effects from a wide variety of sources.

4.4.2 Resources

In general, the major limiting factor in any visibility monitoring programme will be the resources available. These include the capital costs, the running costs, and the skill levels of staff. It is beyond the scope of this discussion document to address these factors in detail, but the following general points can be made.

- Capital costs for new equipment can be very high, and need to include not only the monitor, but data logging and, in some instances, housing facilities.
- Running costs can also be high, as most equipment (such as nephelometers, particulate monitors and optical instruments) requires a high degree of maintenance and calibration.
- Skill levels required to install and maintain equipment should not be underestimated; nor should the effort needed to understand and interpret what is being measured.

4.4.3 Standard methods

Most people undertaking new monitoring programmes would prefer to use a standardised or accepted method. Unfortunately, such standardisation is not available for visibility measurements. There are some quantified guidelines for nephelometry, and there are international standards for many types of particulate measurements, but nothing universal for the assessment of visibility degradation due to air pollution.

Some countries have established 'criteria' that are used for assessing overall effects. For instance, Australia has used a criterion of 20 km as an indicator of good/bad visibility (although in the recent *National Environmental Protection Measure* (NEPM) review, the visibility criterion was dropped for reasons of complexity). The US has recently developed a 'deciview' concept, which may be useful for New Zealand but is not proposed at this stage. Some related meteorological standards for assessing visibility are widely used, but these invariably focus on rain and fog, not on air pollution. There is little hope of a standardised methodology appearing in the near future, as the problems in developing a robust, consistent method have not been solved.

4.4.4 Limitations

It should also be noted that not all methods can be used in all circumstances.

- Nephelometers rely on having enough air pollution (in the form of particles or gases) to produce at least some measurable backscattering. In clean locations – which would be the case for much of New Zealand for much of the time – there will be insufficient scattering to produce a usable signal. In other words, the instrument would be measuring nothing useful for much of the time.
- Community surveys rely on having a community. In some locations, such as national parks, the community might be difficult to identify and use.
- Digital cameras do not work very well at night (or in rain, fog, etc.). Although visibility is not often an issue at night, this can provide a biased record.
- Particulate measurements, which are invariably obtained at a single point near the ground, will not always be representative of conditions above the ground, where visibility degradation occurs. They can sometimes over-estimate visibility degradation by measuring much higher particulate loadings due to local sources, or underestimate degradation due to a build up of pollution in the air above a city, which might not be evident in ground-based measurements.

These limitations all need to be accounted for when determining the programme objectives and methods selected.

4.5 Nephelometry

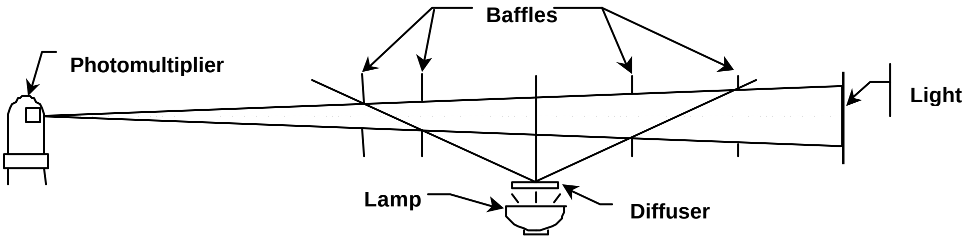
4.5.1 Background to the technique

One of the main factors affecting visibility in polluted air is light scattering due to fine particles in the air. A nephelometer operates on the basis of this light scattering.

Air passes through two stages in the nephelometer. It is usually first pumped through a heated inlet and then through an optical chamber (Figure 2), to remove most of the water vapour in the sample, which can affect the measurements due to light scattering by the water droplets. The air is then passed through an enclosed optical chamber (Figure 2), where it is illuminated by a diffuse light source. Particles in the sample air cause some of this light to scatter and a photomultiplier tube at the end of the optical chamber measures the amount of scattered light.

The light extinction coefficient for scattered light due to particles (b_{sp}) is then calculated by applying the Beer-Lambert Law.[21,22]

Figure 2: Schematic showing optical chamber in the nephelometer



Source: Reproduced from MRI Model 1590 Series Manual[23]

Light absorption is not measured by the nephelometer. However, in polluted urban air, light scattering from particles is usually the main component of the extinction coefficient (between 50 and 80% in urban areas and 80 to 95% in non-urban areas).[24] Hence the particle light scattering coefficient b_{sp} may be a good indicator of light attenuation in urban air.[25]

The particle light-scattering coefficient (b_{sp}) is dependent on a number of factors, such as particle concentration and size, and light distribution and wavelength (λ). It can be used to estimate the visual range (using the Koschmeider relation), although this should be treated with caution as different model nephelometers may yield differing results for b_{sp} depending on the construction of the optical chamber and the wavelength of the light. In addition, the nephelometer takes no account of light absorption due to particles or gas in the air, or the light scattering due to gas in the air (which in some circumstances can contribute up to 50% of total light extinction).[26] In general it is preferable to report on the particle light-scattering coefficient measured by the nephelometer,[27] unless it is necessary to make comparisons with other visibility-monitoring techniques.

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[21] Standards Association of Australia. 1987. *Ambient Air – Particulate Matter; Part 4: Determination of Light Scattering – Integrating Nephelometer Method.* AS 2724.4.

[22] Belfort Instruments. 1992. *Installation, Operation and Maintenance Manual; Model 1590 Series Integrating Nephelometer.*

[23] Belfort Instruments. 1992. *Installation, Operation and Maintenance Manual; Model 1590 Series Integrating Nephelometer.*

[24] Seinfield J, Pandis S. 1998. *Atmospheric Chemistry and Physics: From air pollution to climate change.* John Wiley and Sons, New York.

[25] Seinfield J, Pandis S. 1998. *Atmospheric Chemistry and Physics: From air pollution to climate change.* John Wiley and Sons, New York.

[26] Seinfield J, Pandis S. 1998. *Atmospheric Chemistry and Physics: From air pollution to climate change.* John Wiley and Sons, New York.

[27] Standards Association of Australia. 1987. *Ambient Air – Particulate Matter; Part 4: Determination of Light Scattering – Integrating Nephelometer Method.* AS 2724.4.

4.5.2 Guidelines for using the nephelometer

Some of the information provided here is based on the Australian Standard AS 2724.4-1987 *Ambient Air Particulate Matter: Part 4: Determination of Light Scattering – Integrating Nephelometer Method*. Readers should also refer to this standard and to the manufacturer's instructions for the nephelometer.

Equipment specification

The equipment required for monitoring includes the following.

- An integrating ***nephelometer*** (includes optical chamber, air pump and heated inlet). There are several models available. These include Belfort Instruments Model 1550, 1560 and 1590 series nephelometers (each series has a slightly different optical chamber and each model has a different measurement range), Radiance Research M903 integrating nephelometers, and the Optec NGN-2 and NGN-3 integrating nephelometers. Other suppliers may also exist.
- A ***data logger***, to record the signal output of the nephelometer. The output will be in volts DC.
- Weather-proof ***housing***, preferably air-conditioned, to contain the nephelometer. A mains power supply will also be required.
- An air ***inlet*** with rain shield to prevent water from entering the sampler. The inlet should be at a height of between 2 and 5 m.
- ***Calibration gas*** – FM-200 (a 4 kg bottle should be sufficient for several calibrations).[28]

Siting criteria

The nephelometer should be situated in a background site well away from any major sources of emissions such as vehicles, home heating or industry (a background station is defined in AS 2922-1987).[29] The main factors to consider in siting a nephelometer are:

- ensure that the local topography is as representative as possible of the area you want to sample and that there are no features (ridges or dips) that will tend to concentrate any local pollutants (for example, from inversion layers or similar)
- avoid having buildings or trees near to the site (within 20 m)
- ensure a minimum clear sky angle of 120° above the sampling inlet
- availability of power supply

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[28] Previously, the recommended gas for calibrations has been dichlorodifluoromethane (also known as DCDFM or Freon R12). This is one of the gases being phased out under the Montreal Protocol. From testing carried out in Australia, FM-200 (1,1,1,2,3,3,3-heptafluoropropane) has been recommended as a suitable alternative as it gives similar results to Freon R12 in the calibration. Possible sources of this gas include companies that supply fire-fighting equipment. Currently in New Zealand Chubb Building Services is the only company that supplies FM-200.

[29] Standards Association of Australia. 1987. *Australian Standard for Ambient Air: The siting of sampling units*. AS 2922.

- ease of access for vehicles
- security (to minimise the likelihood of vandalism)
- ensure the inlet is at least 1m away from any building or structure, and for ground level stations between 2 and 5 m in height. Rooftop measurements would be appropriate for visibility monitoring (but ensure that there are no nearby incinerator flues or air-conditioning vents).

It will sometimes be difficult to achieve all of these criteria, and compromises will generally have to be made in order to establish a site.

Steps involved in set-up and operations

The work involved in setting up a nephelometer includes the following:

1. equipment purchase (or lease)
2. site selection
3. site installation
4. calibrations – a zero check and adjustment should be carried out at regular intervals, preferably weekly; calibrations using the calibration gas should be carried out at least quarterly
5. monthly filter changes
6. cleaning – depending on the type of environment the nephelometer is working in, the optical assembly will need to be cleaned occasionally (for dirty environments this could be monthly and for cleaner environments six-monthly; the manufacturer's instructions will describe how to identify whether the optical assembly needs to be cleaned)
7. regular data download and quality assurance.

4.5.3 Assessment of nephelometer measurements

The output from the nephelometer is usually expressed as the coefficient of particle light scattering, b_{sp} (in m^{-1}). The results of the nephelometer readings should preferably be reported as either hourly or 24-hour average measurements of b_{sp} and visual range.

The report should include the type of nephelometer being used, the amount of valid data (and any problems experienced), location of the sampling site (and inlet), sample temperature (heated or unheated), and a graphical representation of the data. For days of poor visibility (when the value for b_{sp} is high), a further investigation into the reasons for the poor visibility may be worthwhile. This would include taking into account any meteorological data, visibility observations and particulate measurements.

In some cases, when nephelometer data is to be compared with other visibility data, it may be necessary to express results in terms of visual range (L_{vr}). In this case, the visual range can be estimated by using the Koschmeider relationship: $L_{vr} = K/b_{ext}$ (where K is the Koschmeider constant and $b_{ext} \approx b_{sp}$ is assumed for the nephelometer). Different values for the Koschmeider constant have been suggested, and when comparing visual range from different nephelometer data it is important to be aware of which value has been used. For consistency, it is recommended that a value of K = 3.9 be used. This assumes that a dark object cannot be seen in contrast with the background (is not visible) if more than 98% of the light is extinguished between the object and the observer (calculated from the Beer-Lambert Law).[30,31]

The Beer-Lambert Law

The Beer-Lambert Law represents the attenuation of light passing through the atmosphere as follows.

$$I = I_0 e^{-b_{exi}x}$$

Where:

b_{ext} = the extinction coefficient (the sum of extinction coefficients due to light scattering and absorption from particles and gases $b_{sp}+b_{sg}+b_{ap}+b_{ag}$)

I = the intensity of light at the observer

I_0 = the initial light intensity

x = the path length of light.

Light extinction occurs because either particles or gases scatter or absorb light. Scattering from particles can account for between 50 to 90% of the light extinction in air, and particle absorption (typically due to elemental carbon from combustion) can account for up to 50% of light extinction in cities (less in rural areas). Nitrogen dioxide is the main gas that absorbs light in the troposphere.[32]

From the above equation, if $b_{ext}x$ =1 then the light intensity is 37% of the initial light intensity. Therefore b_{ext} is the inverse of the distance over which 63% of the initial light intensity is lost by light scattering or absorption from particles or gases.[33,34]

4.5.4 Advantages and disadvantages

The advantage of using the nephelometer is that it is a well-known technique for automatically measuring visibility without the need for manual observations. If the heated inlet is used, the effect of poor visibility due to water droplets in the air is minimised. The disadvantage of the

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[30] Husar RB, Holloway JM. 1984. *The Properties of Climate and Atmospheric Haze*. Washington University: Center for Air Pollution Impact and Trend Analysis (CAPITA). http://www.wustl.edu/Capita/CapitaRegports/PropertiesClimateHaze

[31] The USEPA also recommend the 'deciview' (dv) as an indicator for visibility. The deciview scale is modelled on the approximately logarithmic response of human vision to light attenuation, where:

$$1\ \text{dv} = 10 \ln (b_{ext}/0.01\ \text{km}^{-1}).$$

[32] Seinfield J, Pandis S. 1998. *Atmospheric Chemistry and Physics: From air pollution to climate change*. John Wiley and Sons, New York.

[33] Standards Association of Australia. 1987. *Ambient Air – Particulate Matter; Part 4: Determination of Light Scattering – Integrating Nephelometer Method*. AS 2724.4.

[34] Belfort Instruments. 1992. *Installation, Operation and Maintenance Manual; Model 1590 Series Integrating Nephelometer*.

heated inlet, however, is that some aerosols (for example, nitrates and sulphates) have an affinity for water and their scattering characteristics will change with relative humidity.[35]

In addition, users should be aware that the nephelometer is a point-monitoring technique and monitoring sites need to be chosen very carefully to ensure that the measurement of visibility is representative for an area. Concentrations of particles affecting visibility may vary over the area, even though the visibility is determined by the overall effect of the particles. This is why the monitoring site should be a background site away from any major sources of pollution.

Depending on the internal optics of the equipment, different models of nephelometers may yield slightly different results, so results between different models should be interpreted with care.

If there is significant salt-spray (and other natural particulate) where monitoring is taking place, it will be difficult to isolate these effects from the effects of visibility-reducing particles due to human activities. Monitoring with a nephelometer should therefore preferably be regarded as a long-term option for measuring visibility so that sufficient baseline data can be obtained.

4.6 Transmissometry

4.6.1 Background to the technique

A transmissometer is a visibility-monitoring device that measures the ability of air to transmit light. It measures the attenuation of light over a long path length (r), typically ranging between 300 m and 10 km. Green light at 550 nm wavelength is emitted in pulses from the transmissometer transmitter. A corresponding transmissometer receiver, placed directly in the path of the light beam, measures the intensity of the received light. The percent light transmission (the amount of light transmitted by the atmosphere) can then be calculated. This is the ratio (transmittance, τ) of the light measured by the receiver over the known light output from the transmitter. The transmittance coefficient can be converted into visibility-related parameters such as the extinction coefficient b_{ext} (see below) and the standard visual range (using the Koschmeider relationship and b_{ext}).[36]

$$\mathrm{b}_{ext} = -\ln(\tau)/r$$

The Optec LPV-2 transmissometer has been used in visibility studies in the US, although there may be other models available.

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[35] Malm C, Molenar J, Eldred R, *et al*. 1996. Examining the Relationship Among Atmospheric Aerosols and Light Scattering and Extinction in the Grand Canyon Area. *Journal of Geophysical Research* 101(D14): 19251–65.

[36] Air Resource Specialists. *Long-Range Transmissometer System for Visibility Monitoring*. Technical Note 92–204. http://www.air-resource.com/visibility.html

4.6.2 Advantages and disadvantages

The advantage of using a transmissometer in visibility studies is that it provides a measure of total light extinction, as opposed to just the scattering component measured by the nephelometer. Another advantage is that it is an open path method – it measures transmittance between two different locations. Thus it provides a measure of visibility along a sight path of several kilometres and is more representative of what is observed than a single point-source measurement.

A disadvantage of this method is that it is resource intensive and the data collected is subject to interference.

At present no transmissometers are used for visibility studies in New Zealand.

4.7 Manual and survey methods

4.7.1 Background to the technique

Scrub burn-off near Wanaka.
Photo: Leif Pigott

Recording visual range manually has been carried out from as far back as the middle of last century. From the 1930s, trained observers were regularly taking observations of visibility for the purposes of sea and air travel. Many meteorological stations, particularly at airports, continue to make manual observations of visibility. More recently (in the 1970s, with the environmental movement) researchers have become interested in how human activities can affect visibility, and historical manual observations have provided useful baseline data.[37]

In this guideline, community visibility surveys are proposed as being a valuable method of relating visibility directly to human perception. They are essentially long-term surveys in which observers are asked to judge visibility on a daily basis. An alternative is to use just one (or a few) trained observers, the advantage being that this is a more direct and traceable method.

The human eye is very sensitive to changes in visibility, particularly when there are small changes in areas where visibility is normally excellent. Other techniques may not be sensitive enough in the clean air environment of New Zealand. Therefore, as the visibility in New Zealand is generally excellent, taking manual observations of visual air quality is an appropriate method for measuring air visibility.[38]

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[37] Husar RB, Holloway JM. 1984. *The Properties of Climate and Atmospheric Haze*. Washington University, Center for Air Pollution Impact and Trend Analysis (CAPITA). http://www.wustl.edu/Capita/CapitaRegports/PropertiesClimateHaze

[38] Sloane CS, White WH. 1986. Visibility: An evolving issue. *Environmental Science and Technology* 20(8).

4.7.2 Guidelines for conducting surveys

Survey design

The main steps in conducting a survey are as follows.

1. ***Prepare survey forms:*** the survey forms should include questions on the type of weather conditions, the observer's impression of the visibility, and notes on any unusual events at the time of the survey. A sample survey form is provided in Appendix 1. Observations taken by each participant could include:
   - how well they can see their chosen landmark
   - how far they can see
   - their impression of visibility overall
   - percentage cloud cover and wind speed
   - whether there is any fog, rain, haze, smoke or brown colour in the sky
   - general comments, such as observations on open burning nearby or a heavy storm.
2. ***Advertise***, or contact specific community groups that may have an interest in carrying out observations. Community groups with a specific interest could include meteorological observers or members of a meteorological society. Advertising can elicit a varied response depending on the area, and several attempts may be required before sufficient observers are found.
3. If possible, ***visit survey participants*** to ensure their locations are suitable for the visibility observations, and that they understand the purpose of the study and how the forms should be filled in. As an alternative, a seminar for the survey participants to explain these issues would be sensible. Important issues to be discussed include:
   - the reason you are carrying out the survey
   - a description of how to estimate visible distance
   - the importance of taking observations in the middle of the day
   - what the difference between fog and haze is
   - how to select landmarks (one should be at least 20 km away)
   - how to judge wind speed
   - how to estimate cloud cover
   - what is meant by the proportion of human-impaired visibility (although this is very subjective, it has been included to give an indication on whether there is a possibility that visibility has been influenced by human activities on a particular day).
4. Provide survey forms, information and location maps to observers. Observers can mark their location and observation points on the location maps, which will make it easier for the analysis to be carried out later.
5. Once the survey is complete the ***results should be collated*** and reported.

Survey analysis

For the community surveys the following recommendations apply.[39]

- At least 15 observers should take part to avoid one observer skewing the results.
- A period of three months or more is the preferred length for a survey.
- Complementary summer and winter surveys are ideal, because visibility is affected by different factors between the seasons and at different locations. For example, visibility may be affected by the formation of photochemical smog in the summer in larger cities and a combination of fog and emissions from domestic home heating in winter.
- The observer should include at least two landmarks that are far into the distance (more than 20 km away). A good view of the horizon, a variety of landmarks, and landmark distances and size (they should be large) are important. In addition, darker coloured landmarks or ones that contrast strongly against the background are preferable.
- Observers can be in different locations, although multiple observers from one location may be useful.
- Observations should be taken around the same time each day. It should be stressed to observers that the observations are to be taken in the middle of the day because sun angle can affect observations in varying ways during the day.
- Each observer should consistently take observations from the same location.
- If possible, visibility observations should be supplemented by other techniques of monitoring, including nephelometry, particulate measurements or source apportionment. The results of this additional monitoring would give a better picture of the causes of poor visibility in a particular area. However, the type of detailed analysis that could be carried out can be complex and is beyond the scope of this document.[40]

4.7.3 Assessment of visual data

Once the survey is complete the data can be presented in a variety of ways, depending on the intended uses and the region involved. Possibilities include:

- A graph showing the ***average clarity ratings*** indicating how well landmarks can be seen each day, with landmarks grouped by distance from the observers. Suggested groupings are 0–2 km, 2–10 km, 10–25 km, 25–50 km and over 50 km.

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[39] Ministry for the Environment. 1998. *Visibility Monitoring as an Environmental Indicator.* Joint project carried out by Manawatu-Wanganui Regional Council, Environment Waikato, Taranaki Regional Council, Hawke's Bay Regional Council and NIWA. June.

[40] Eldering A, Cass G, Moon K. An Air Monitoring Network Using Continuous Particle Size Distribution Monitors: Connecting particle size distribution properties to visibility via Mie scattering calculations. *Atmospheric Environment* 28(16): 2733–49.

- Graphs showing the ***average visibility rating*** each day compared to observations on:
    - whether there was a brown colour or haze in the sky
    - the average estimated contribution of human activities to poor visibility
    - the amount of cloud cover and wind
    - rain, storm or low cloud.

  For data where respondents are required to give a yes/no answer, bar charts would be appropriate.
- A graph of the ***average visual range*** given by observers each day (including error bars as the scatter of observations can be quite large). This will give an indication on how good visibility is on each day. However, generally poor visibility will usually be attributable to poor weather rather than human influences. To isolate the influence of human activities, responses on whether there was any haze or brown colour in the sky and the estimated human contribution to poor visibility should also be investigated.

4.7.4 Advantages and disadvantages

The advantages of carrying out community visibility surveys are that they are easy to understand and set up and involve little capital expenditure. The main cost is related to the time involved in entering the results into a database and assessing the trends, and any advertising costs. Importantly, the observations are a direct assessment of what is visible to the eye rather than an analogue (where the measurements 'represent' visibility).

Some of the limitations of using a single trained observer can be overcome by using a wider community perception survey, but this also introduces additional complications:

- results can be subject to bias by poorly trained observers or vexatious observations
- results can show trends that are due to observer conditioning
- it is very difficult to correlate survey results with other measures
- it requires a population (not feasible in remote regions)
- it is difficult to distinguish between 'natural' and 'pollution' events
- problems may arise when observers go on holiday, are sleeping, etc.
- there is a considerable management overhead in running networks and surveys.

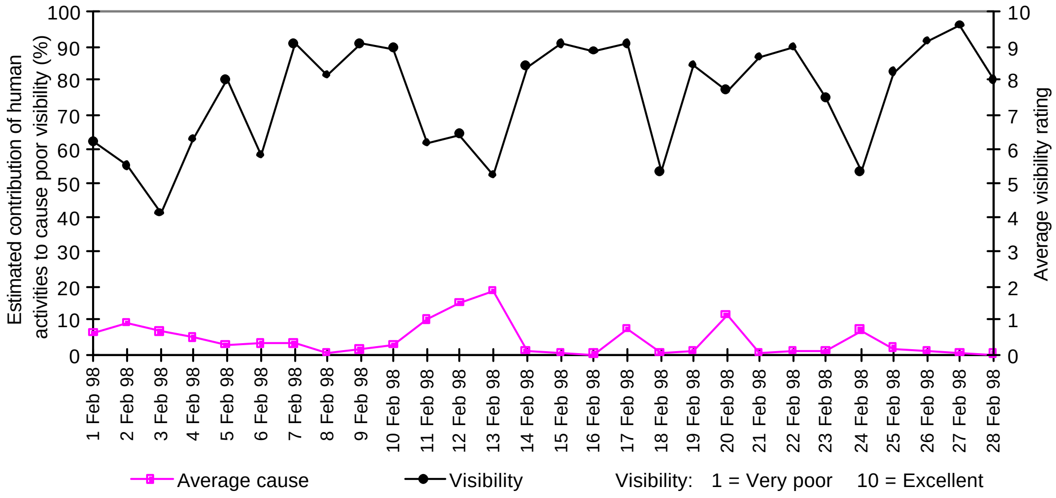
Despite these disadvantages, the technique has been shown to be very useful, and can provide valuable information in circumstances where other methods might not be practical.

Case study: Visibility in the Hawke's Bay

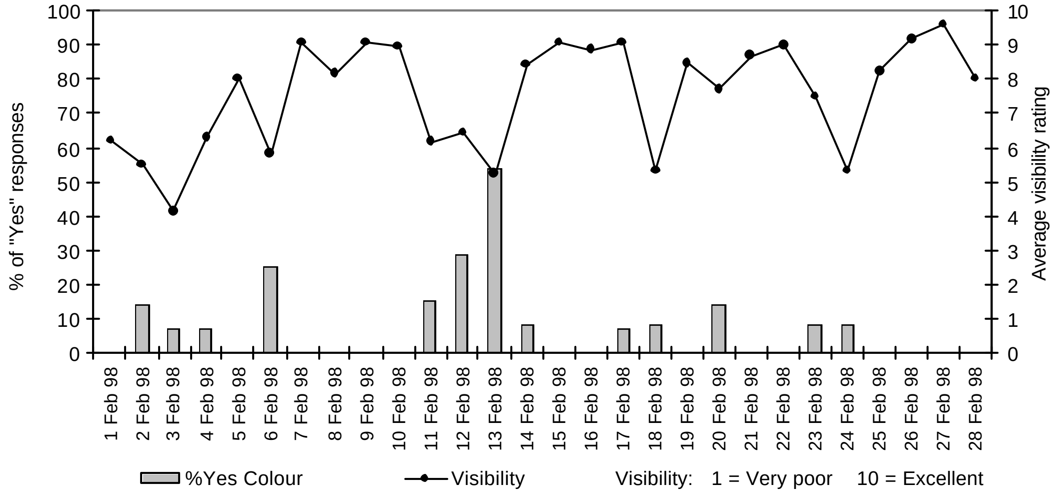
An example of the type of graphical data that could be presented is shown in Figure 3. A low visibility rating was given on 13 February 1998. In addition, a brown colour was observed by around half of the respondents and the poor visibility was partly attributed to human causes. From the corresponding particulate data collected at the time, high particulate concentrations were also recorded on 13 February, and as there had been no rain on several preceding days the poor visibility may have been caused by wind-blown dust (possibly due to farming practices).

Figure 3: Examples of graphical data that can be presented from visibility surveys

a) Cause of poor visibility



b) Brown colour events



4.8 Digital camera

4.8.1 Background to the technique

Source: www.kodak.com/US/en/digital/GenInfo/dc120.shtml

Over the years, numerous studies have been carried out to investigate the suitability of using still camera images to judge visibility. These images have been analysed using a technique known as photographic densitometric measurement, where the contrast between target and sky are measured quantitatively using a microdensitometer. This was found to be an effective and economical method for measuring visibility.[41] The physical record makes it possible to go back to the images and investigate the effects of clouds or lighting, which would not be readily identified using other measurement techniques.

With the recent advent of the digital camera, the microdensitometer technique will probably be superseded by digital image processing. Photographic images can now be captured directly from a camera into digital format suitable for the computer (without the extra processing step required previously). It should soon be possible, using similar concepts to the microdensitometer, to analyse visual air quality by techniques of digital image processing. Therefore, digital cameras have been recommended, in this guide as another method for measuring visual air quality. The captured images can be stored and analysed or viewed later, which will give an excellent long-term record of visibility.

4.8.2 Guidelines for using a digital camera

Equipment specification

There are a variety of digital cameras on the market that are suitable for recording digital images for visibility. At the time of writing, a reasonable cost-effective camera is the Kodak DC290, which has a 1901 x 1212 pixel size CCD, or the Kodak DC120 with a 1280 x 960 pixel size CCD. The DC120 camera also has software available which enables the images to be directly uploaded on to the Internet. Additional equipment required with a camera would include a suitable power supply, an RS232 cable and a host computer on which the images can be stored.

Other cameras with a slightly lower resolution (640 x 480 pixel CCD), such as the Fuji DX-5, Casio QV 100 and Olympus Camedia G-400L, may also be suitable (although not ideal). However, as technology improves, further improvements will be made with the type of digital camera available.

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[41] Dietrich DL, Klitch MA, Cismoski DS, *et al*. 1989. CV Mathai (ed) *An Assessment of the Accuracy and Precision of Photographic Densitometric Measurements for Monitoring Visual Air Quality*. *Transactions – Visibility and Fine Particles*. AWMA/EPA International Specialty Conference.

Overall, choose a camera that has:

- a reasonable depth of field (so that the resolution of objects is good both in the near field and in the distance)
- high resolution (1280 x 960 or more pixel size CCD)
- a good angle of view (to obtain as much information as possible).

The first two criteria are the most important.

When the camera has been set up, each image being collected and viewed should be constant (the image should not be zoomed in or out, although adjustments for focus may occasionally be necessary). This ensures that images taken at different times can be easily compared. If you choose to have a camera with a zoom, optical zoom is preferable to digital zoom. As mentioned, it is possible to purchase cameras for which software is available for loading images onto the Internet. But there is also a choice between a web camera, a digital camera with limited processing, or a digital video with direct link to a computer.[42]

Siting criteria

For still-camera or video surveying, the following recommendations apply.

- A good view of the horizon and a variety of landmarks and landmark distances are important. Objects that contrast strongly with the horizon are good choices for landmarks.
- Mount the camera externally to avoid effects from window reflection.
- Direct the camera away from the sun to avoid sunlight dominating the image or affecting the operation of the camera.
- Direct the camera away from reflecting objects in the field of vision (for example, shiny roofs, water).

4.8.3 Interpretation of camera data

Images from a digital camera can be interpreted manually (possibly by using a form of the visibility survey outlined in Appendix 1) or by using digital image processing. Preliminary software (ICARUS), which estimates the visible distance from digital camera images, has been developed by researchers at Auckland University. This software is available from the Ministry for the Environment via their home page on the Internet (www.mfe.govt.nz under Sustainable Management Fund projects) and can be used for the image analysis. However, users should be aware that the software is regarded as preliminary at this stage and further research is required for the analysis to account for factors such as image contrast and colour. In future, more sophisticated software is likely to be available. For example, the colour frequency response from an image could be used as a possible indicator of the cause of visibility degradation.

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[42] Technical information on digital cameras can be found on the Internet at the following addresses: www.kodak.com, www.olympusamerica.com, www.casio.com, www.fujifilm.com. Other web sites may have information on the best cameras to buy (e.g. www.dcresource.com/reviews/reviews-static.sthml) and webcam software (e.g. www.webx.co.uk). With technology advances this information is constantly changing.

4.8.4 Advantages and disadvantages

The main advantage of using a digital camera is that a database of digital images can be collected and stored without the need for additional steps such as scanning the images. This can create a permanent visual record of visibility. Comparisons can be made to determine whether visibility has changed over time. The images can also be processed using digital image-processing software. In addition, if quantitative data is available from another instrument, camera images can be used to supplement this data if the instrumentation indicates times of poor visibility.

The disadvantages are that factors such as sun angle and camera position can influence results from a digital camera. For example, if the sun is shining directly into the camera lens (as at sunrise or sunset), the image could be over-exposed, in which case it would not be possible to assess visibility. Droplets or dirt on the lens can also affect the results.

If the images were to be digitally processed for visibility monitoring, a database of images would be required along with a set of calibrated images that can be used to judge the images. These images would be site-specific, and moving the camera to a new site would require a new set of images to be generated. Finally, the results of image processing give an indication of perceived visibility and may not be directly related to other methods of visibility measurement (such as particulate monitoring or nephelometry).

4.9 Other techniques related to visibility measurement

4.9.1 Fine particulate

As we have seen, fine particulate has a significant influence on visibility so a correlation can be made between particulate concentrations and reduced visibility. It may be possible, therefore, to use fine particulate monitoring as a surrogate for visibility monitoring for locations where this relationship is known. However, there are limitations to this approach:

- If the composition or size distribution of the particles changes with time, or if NO_2 concentrations change with time, the relationship between visibility and particulate concentrations will also change.
- It is not possible to extrapolate a relationship from one location to another as the composition and size of particles, both of which influence visibility, will generally be unique to each location.

The type of equipment (from least to most expensive) that can be used to measure fine particulate includes:

- gravimetric samples: pumps fitted with filters and either cyclone or impactor $PM_{2.5}$ heads to measure $PM_{2.5}$; the change in weight of the filter can be used to calculate the concentration of particles
- particle counters, such as the Grimm sampler, which counts the particles of differing sizes and calculates concentrations of the particles continuously

- continuous particulate monitoring (for example, the TEOM, which measures particle concentrations by continuously measuring the change in weight of a filter)
- staged impactors, which can segregate particles of differing sizes on to filters, which can then be weighed later to determine concentrations (for example, MOUDI and Graseby Anderson samplers).

For some of the samplers above it is possible to analyse the filters for the composition of the particulates, depending on the type of filter being used.

4.9.2 Emissions inventories

Although not a direct measurement technique, emissions inventories can be used, in conjunction with other monitoring, to estimate the main contaminants contributing to visibility impairment in a particular area. An air emission inventory involves identifying all possible sources of air emissions for a particular contaminant and estimating the total emissions from these sources. The results of the emissions inventory can also be used as input into medium-scale modelling of visibility.

A lot of effort is often involved in obtaining all the information required for an emissions inventory and it is important to define the scope of the inventory before starting. The type of decisions that should be made at the outset include which contaminants are of interest, what timeframes should be considered (base year, time of day, season), and what area you are interested in (local or regional). Emissions are often grouped into area sources (for example, home heating, motor mowers), transport sources (for example, vehicles, rail transport), point sources (such as industry) and natural sources. The types of pollutants that may be of interest for the emissions inventory in relation to visibility are particulates, NO_2, SO_2 and hydrocarbons.

4.9.4 Other optical techniques

Nephelometry and transmissometry are two optical techniques (discussed earlier) which can be used to measure visibility. Other techniques include teleradiometry and photoacoustic spectrometry.

Teleradiometry is carried out using telescopes and photodetectors. The ratio of light emitted from the horizon to the light emitted from the adjacent sky is calculated. This ratio is used as a measure of visibility.[43]

The advantage of the technique is that it measures visibility over a long path length, as does a transmissometer. However, during poor weather such as low cloud or fog, both a teleradiometer and a transmissometer would record poor visibility. This is not particularly useful if the intention of monitoring is to identify impaired visibility due to human causes. Taking measurements of relative humidity and rain (and perhaps solar radiation) can isolate these effects.

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[43] Sloane CS, White WH. 1986. Visibility: An evolving issue. *Environmental Science and Technology* 20(8).

Another method is the *photoacoustic spectrometer*. In this method, a sample of air is exposed to pulses of electromagnetic radiation. This causes the particles in the air to heat up as they absorb the radiation and this heat is transferred to the surrounding air. As the air heats up its volume, or pressure, increases. At the same time it is also exposed to a standing acoustic wave (in an acoustic resonator). The increase in volume/pressure as the air heats up amplifies the standing acoustic wave. The sound pressure associated with the aerosol light absorption can then be calculated, and hence an estimate of the elemental carbon concentration in the sample can be calculated.[44]

4.9.4 Source determination

Sources of air contamination can have a typical 'fingerprint' where certain elements and compounds are associated with a particular source. For example, silicon is a key indicator of soil sources, potassium of wood and coal burning, and sulphur of coal combustion and diesel vehicles. Different-sized particles often indicate differing sources of pollution. Source determination methods involve collecting particulate samples and analysing their composition to identify the types of sources that may be implicated. Provided enough samples are collected (several hundred), it is sometimes possible using statistical methods to identify the relative contribution by various sources to the overall air quality.

Using the 'fingerprint' method of source determination will help to identify the sources of particles. However, because not all particles contribute equally to poor visibility this method does not necessarily identify sources having the greatest impact on visibility. Used in conjunction with other visibility monitoring methods, source determination can be used to assess the contribution of different sources to visibility. This combination of methods, referred to as extinction budget analysis, is resource intensive and requires the measurement of all components of the extinction budget.

Carrying out fieldwork for source determination can be a complex and expensive activity, and careful planning is required from the outset to avoid problems later on. Consideration should be given to:

- ***compounds to be analysed*** – this affects the analysis methods to be used, the filter type (and size) and cleaning procedures
- ***analysis method*** – different analysis methods can have differing sensitivities; more sensitive (and hence expensive) methods may be required if it is not possible to sample for long periods of time
- ***sampling head*** – will the sampling be for $PM_{2.5}$, PM_{10}, TSP or some other size fraction?
- ***flow rate*** through pump and total ***volume*** to be collected – this will be determined by the sampling head (for example, $PM_{2.5}$ heads are usually designed for a specific flow rate) and the environment where sampling is being undertaken (high flow-rate pumps are often noisy and not acceptable for residential areas)
- ***cleaning procedures*** and sample ***transport*** (do the samples need to be kept cold?)
- field ***blanks***, laboratory blanks and data quality assurance procedures.

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[44] Arnott PW, Moosmüller H, Rogers CF, *et al*. 1999. Photoacoustic Spectrometer for Measuring Light Absorption by Aerosol: Instrument description. *Atmospheric Environment* 33: 2845–52.

Analysis techniques that could be used for source determination include gas chromatography (GC), ion chromatography (IC) or accelerator-based ion beam analysis (IBA) techniques, including proton-induced x-ray emission (PIXE) and particle-induced gamma ray emission (PIGME). The former two techniques are available in New Zealand and the IBA techniques can be carried out by ANSTO in Australia and are currently under development by the Institute of Geological and Nuclear Science Limited (GNS) in New Zealand.

4.9.5 Videos and still cameras

Video cameras and still cameras are alternatives to a digital camera for recording images of visibility. The advantage of a still camera over a video camera is that far better quality images can be obtained. However, this should be weighed against the amount of time required to set up the still camera and the fact that a video camera can give a continuous record. When purchasing a video camera the following aspects should be considered:

- quality of camera and lens
- quality of video tape
- quality of playback head.

When purchasing a still camera the following aspects should be considered:

- better quality is obtained from slides rather than prints, and scanned images from the negatives can be very good if digital information is required
- prime lenses are preferable (a 50 mm lens should be suitable and not as expensive)
- a fixed focal length, which should consistently give the same image
- film type.

There have been concerns about the accuracy of video and photographic methods for observing visibility conditions. Although these methods provide a consistent and visual record of visibility, they do require human judgement before the final analysis is made. Photographic and video monitoring require the user to select instrument settings such as image focus and exposure. In addition, photographic development involves the selection of a variety of colour and contrast settings by the film processor, which in turn are used as the base variables for quantifying human judgement of visibility. If these techniques are to be used, then the procedures should be carefully defined to ensure that a consistent approach is taken for every image collected (hence minimising the influence of human judgement in setting up or developing the images). At present, still cameras give better-quality images than digital cameras, although digital cameras are likely to improve considerably in the future.

4.9.6 Meteorology

For any visibility measurements it is important to have a record of meteorological conditions at the time of measurement, as the local conditions strongly influence ambient contaminant levels and the rate at which secondary reactions occur in the atmosphere. Meteorological conditions that can affect visibility include wind speed, wind direction, temperature, rainfall and humidity. In many locations, particularly for regional towns, this information will already be available from local automatic weather stations (run by local airports, the Meteorological Service and other organisations). Information can also be obtained (for a nominal fee) from the national climate database (CLIDB), which is operated and maintained by NIWA.

In some cases it will be possible to obtain information on manual (or occasionally automated) cloud cover observations, usually from local airports. The cloud cover is important if manual visibility observations have been taken because it directly affects the amount of light shining on objects, which in turn affects their contrast with the background and how visible they are.

4.10 Relating different visibility measurements

As we have seen, there are many ways of measuring or assessing visibility, and there is not always a direct, or even understandable, relationship between them.

4.10.1 Visual observations

The most common quantitative measure has been visual range, usually expressed in kilometres. Correlations between manual observations of visual range and other more quantitative techniques are possible, but complex. Typically, a relationship can be established for a particular circumstance, but it will be approximate and subject to change if the causes of the visibility degradation change (for example, through changes in emissions sources). The relationship is based on empirical observations, and attempts to produce a more generalised model have not been successful.

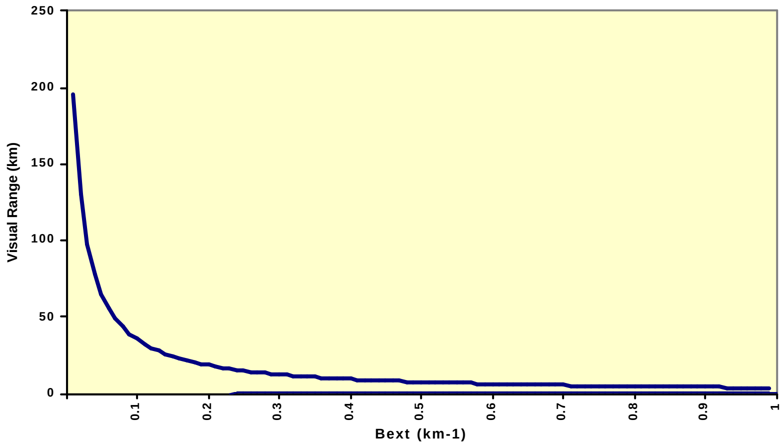
4.10.2 Optical methods

The most quantitative measure of visibility is a description of the optical transmission properties of the atmosphere, expressed either as backscatter and/or transmittance. Backscatter measures the light scattering component of transmittance and is relatively easily measured by nephelometry. Transmittance is less commonly used, and is more difficult to measure, requiring a source and detector over a long path.

While neither backscatter nor transmittance measure visual range, there is a reasonably direct relationship between transmittance (total light extinction) and visual range (Koschmeider's Law). This is illustrated in Figure 4.

Often data outputs from a nephelometer are converted into kilometres to provide an indication of visual range. This is calculated by multiplying the inverse of the measured backscatter by the Koschmeider coefficient. The relationship is often used to report nephelometer measurements in kilometres. However, the nephelometer is not designed to measure total light extinction. Thus the accuracy of converting nephelometer data into a visual range estimate will vary depending on the amount of visibility degradation being caused by optical properties other than light scattering. For example if there is a significant proportion of elemental carbon causing visibility degradation by absorbing light, using a nephelometer could significantly over-predict the actual visual range.

Figure 4: The relationship between visual range and light extinction, as described by Koschmeider (1925)



Clearly total light extinction (transmittance) is the preferable optical measurement if data is to be expressed as visual range. This is because it does not require the assumption that all visibility degradation is caused by light scattering. However, as indicated previously it is more difficult to measure and nephelometry is more common.

4.10.3 Camera methods

Various camera methods (still frames, digital frame images, analogue video, digital video) are used either (a) to replace a human observer, or (b) to try to quantify the observation by digital processing of the images. The method has only recently been developed, and is still undergoing refinements, but it shows considerable promise and is being more widely adopted as a valid monitoring technique. Still or analogue images can provide a replacement for direct visual observations, but become tedious to analyse and can lack other clues to visibility assessment that are available to manual observers.

A more exciting prospect is the use of advanced image processing on digital pictures. This has shown a degree of correlation with other monitoring methods. Further improvements are expected, especially by using colour analysis. However, the problem of identifying 'natural' events, such as rain, fog and haze, has not yet been overcome.

4.10.4 Particulate methods

Directly measuring various properties of the particulates in the air causing visibility degradation offers the best chance to understand and explain the sources, but it is also very resource-intensive. One method, referred to as the extinction budget analysis method, requires measurements of particulate mass and size distribution, chemical properties (which can be different for different sizes), optical properties, and identification of many related quantities (such as meteorological variables, precursor gases for secondary particulates, and source inventories).

A full description of the analysis method options is extremely complex. In some simple circumstances, where the sources and particulate composition are well understood, it is possible to develop a model of visibility and get good correlation between the particulate measurement and other methods. But usually this will not be the case. Often it is not just particulates causing visibility degradation, but gases as well. A good example is over cities, such as Auckland, where the brownish colour of the air over the city is probably caused more by nitrogen dioxide than by the particulates present. Indeed, it may be possible to have a very poor visibility day due to high nitrogen oxide concentration but low particulate concentration (and vice versa).

4.10.5 Correlation matrix

In summary, a correlation matrix has been constructed, highlighting the possible relationships between the various methods described previously.

Table 1: Relationship between measurement methods

	Optical	Camera	Particulate measurements
Manual/ survey	Moderate correlation – needs to be calibrated for particular circumstance	Moderate correlation – but issue of rain/fog not resolved	Very difficult to correlate – not all visual degradation is caused by particulate, few survey participants will be able to discriminate these effects
Optical		Moderate correlation possible – if rain/fog can be identified by other measurements	Good correlation possible – if causes of degradation are identified and do not vary
Camera			Moderate correlation possible – but methodology needs work, and experience identifying features in images is needed

Notes: Manual/survey – includes methods relying on trained human observers or using generalised community surveys; Optical – includes all methods using quantitative optically based sensors, such as nephelometry, telephotometry, transmissometry; Camera – includes video and single image cameras, digital or analogue; Particulate – includes any direct measurement of particulates, typically TSP, PM_{10} or $PM_{2.5}$.

It is clear from this matrix that there is no one 'best' technique, and that the various visibility-monitoring programmes used have complex and varying relationships with each other.

4.11 Recommended monitoring

As emphasised throughout this document, there is no one best method for assessing visibility. Ideally a range of complementary measurements would be used. The exact nature of the monitoring undertaken in any particular region will depend on the scale of the issue and the resources available. This discussion stops short of actually recommending precise details for each region of New Zealand, because a full assessment of the current visibility problems has not been undertaken. This requires a longer period of monitoring and assessment in many regions, a more formal recognition of the relevant council policies and plans, and a consideration of the resources councils are willing to expend on this issue.

Despite these limitations, recommendations are made for each of the methods discussed so that once any monitoring agency has decided on a method, some consistent approach is used.

4.11.1 Monitoring options

A range of monitoring options is proposed for New Zealand, and the method(s) of monitoring chosen will reflect:

- the area in which monitoring is being carried out
- the perceived extent of visibility degradation in the area
- other issues involved (objectives, resources, standards and limitations) as discussed in section 4.1.2.

A summary of the recommended monitoring options for different environments is given below. These recommendations are made with some recognition of the likely resources available and the anticipated scale of the issues. Note that it is important not only to monitor the visual quality, but also to gain some information on the likely causes of any visibility degradation. All the methods suggested can contribute to this, although the details of the analyses needed are covered elsewhere.[45]

Finally, it is essential to have concurrent meteorological information. In many cases this may already be available from, say, the national network, but if not, special arrangements should be made.

Table 2: Proposed methods for visibility monitoring

	Circumstance	**Method(s)**
1	Large urban areas, with obvious visibility problems	Perception study to determine whether the haze requires management intervention *and* digital camera (continuous) to monitor trends in visibility degradation *and* nephelometer and NO_2 analyser *and* analysis of particulates (short term study)
2	Smaller urban areas, with occasional visibility problems (If results suggest management intervention is required, then adopt additional monitoring as indicated in 1 above.)	Community survey (regular) *or* digital camera (case basis) *or* nephelometer
3	Regional areas, with a strong desire to evaluate and protect scenic vistas	Community surveys (regular) *or* digital camera
4	Regional areas, environmental quality monitoring	Community surveys (regular) *or* digital camera (regular)
5	Point sources, with localised visibility degradation	Digital camera (case basis) *or* community survey (case basis)

Notes: Continuous – operates every day, for the long term; Regular – operates at regular intervals, at least for 3–4 times per year; Case basis – operates when problems occur, or every 1–2 years.

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[45] Ministry for the Environment. 1998. *Visibility Monitoring as an Environmental Indicator.* Joint project carried out by Manawatu–Wanganui Regional Council, Environment Waikato, Taranaki Regional Council, Hawke's Bay Regional Council and NIWA. June.

4.11.2 Equipment and procedures

A summary of the recommended procedures for each type of monitoring is given in the following tables.

Table 3: Recommendations for using a nephelometer

Equipment	Currently there are three main types – MRI , Radience and Optec NGN models. MRI offer several options, related to sensitivity. A full evaluation has not been conducted in New Zealand, although the earlier MRI types can be difficult to run.
Method	Sited and run according to AS AS2724.4-1987. Should ideally be as close as possible to the anticipated location of poorest visibility, both horizontally and vertically.
Frequency	Continuous measurement, logging 10-minute data, averaged to basic one-hour periods. Any site should have at least one year of measurements before relocation is considered.
Outputs	Record and archive basic output, in units of backscatter (dimensionless). Also convert to units of km using Koschmeider relationship and co-efficient of 3.9. Calculate and record daily averages.

Table 4: Recommendations for taking manual visual observations

Equipment	Use the sampling form given, or a very close derivation (for either community survey or trained observers).
Method	Sample at least 15 people, or have one or more trained observers record information, over at least three months.
Frequency	Conduct the survey over at least the season of poorest visibility. Ideally surveys would also be at other times of the year, and running over several years to gain trend information.
Outputs	Working from information off the forms, calculate and record on a daily basis the parameters of minimum visibility, colour, and related conditions.

Table 5: Recommendations for camera use

Equipment	A good-quality digital camera is recommended. Video cameras, and conventional film have problems with resources needed for processing.
Method	Locate the camera with a good view over an affected area, avoid sunstrike, use stable mountings, and take account of misting and griming of the lens. Record images on a dedicated PC.
Frequency	Take a picture every hour, through daylight. Run the programme for at least three months, preferably continuously.
Outputs	Analyse the outputs, either using one of the methods discussed or by visual inspection. Record estimates for visual range in kilometres and colour, characterising the worst visibility conditions on each day.

Table 6: Recommendations for other monitoring being undertaken

Equipment	Any equipment being used for other air quality monitoring purposes.
Method	Acquire the information for use in visibility assessment.
Frequency	As often as is available.
Outputs	Data from other sources cannot generally be used to assess visibility directly. However, in some circumstances it may be possible to ascertain sources, or contributory factors.

4.12 Potential visibility indicators

Since the monitoring of visibility has been accepted as one of the key Stage 2 performance indicators of air quality in the Environmental Performance Indicators (EPI) programme, it is appropriate to propose quantitative indicators in this discussion. A separate document has been prepared which discusses the risk of poor visibility in New Zealand on the basis of emissions and topography, *Visibility in New Zealand: National Risk Assessment*. These potential visibility indicators (and the identified risk of poor visibility) are preliminary and very likely will need to be refined through user comment and experience gained with usage. The intention here is simply to start this process, as the concepts are new to New Zealand and relatively difficult to implement.

Both visual range and appearance are proposed as visibility indicators, since true visibility perception is a mix of these. The proposed indicators are somewhat simplified, reflecting the embryonic stage of their development.

The visual range indicator is derived from any of the following methods:

- inverse nephelometer backscatter using coefficient of 3.9
- visual observations of distance
- processed camera images (quantitative).

The appearance indicator is derived from either:

- visual observations of colour
- casual observer/public complaint
- camera image (qualitative).

These proposed indicators contain a new concept – that of assessing the appearance of the sky or vista by use of colour. This concept will need further development, but for the purposes of this exercise is defined simply as follows:

No ‘off’ colour	=	No reasonable person would detect any departure from natural conditions.
Discernible ‘off’ colour	=	A reasonable person would agree that some form of air pollution was discernible, but not necessarily affecting visual clarity significantly.
Distinct ‘off’ colour	=	A reasonable person would agree that air pollution was present, thereby decreasing amenity value.

These colour concepts are subjective and may be subject to individual bias. However, it is worth experimenting with this simple approach, since other more quantitative approaches (such as using colour charts, examples, or precise definitions) are likely to be much more complex to determine and use.

The ‘visual range’ categories are derived from the following arguments.

- 70 km has historically been taken as representing almost perfect visibility. The ultimate visibility in the atmosphere is determined by fundamental Rayleigh scattering of the natural gases making up the air, and is around 290 km.[46] However, few people would be able to distinguish between 290 km and 70 km.
- 20 km has been, and is, used by many countries as the defining line between ‘good’ and ‘degraded’ visibility. For instance, in Australia the 20 km distance has been used as a primary visibility indicator for attainment purposes.
- 8 km is based on the concept, arising from meteorology, of visibility sufficiently degraded to require special care in some activities, such as aviation (as set by ICAO).

The proposed indicators are given in Table 7. The combination of visual range and colour will define the visibility. This can be taken from anywhere in the field of view; that is, the visibility will be defined by the worst conditions at any place in the atmosphere around the monitoring location (within reason – it cannot obviously be biased by, say, a single dust cloud behind a vehicle, nor a single smoke stack). Where quantitative measures of visual range are not available, then the visual range will need to be estimated. Some emphasis has been placed on having indicators that are consistent with those already adopted, hence the use of the ‘excellent’ through to ‘action’ categories.

The period of assessment is 24 hours (but would normally be only for the hours of daylight) and only applies to conditions which are clearly not natural weather phenomena such as rain, fog, clouds or sea spray. Although some monitoring techniques (particularly nephelometry) are capable of providing data down to periods of a few minutes, most of the others are not, and it would be difficult to obtain data on shorter time periods than daily.

Table 7: Proposed visibility indicators

Category	Visual range and/or appearance
Excellent	> 70 km and no ‘off’ colour
Good	20–70 km and no ‘off’ colour
Acceptable	20–70 km and discernible ‘off’ colour
Alert	< 20 km and discernible ‘off’ colour
Action	< 8 km and/or distinct ‘off’ colour

These indicators should be assessed over two time-averaging periods, as discussed in the Ministry for the Environment’s Environmental Performance Indicators documents. These are one-hour (representing a short-term event) and eight-hour (representing a day).

Using these indicators in New Zealand it is anticipated that marine and rural areas will mostly have excellent to good visibility, with good to acceptable visibility occasionally in some smaller regional towns or in rural areas when agricultural burning is taking place. Visibility at an alert level may occur at times in major urban centres, and action levels would only be expected to occur under exceptional circumstances, such as a major fire.

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[46] Seinfield J, Pandis S. 1998. *Atmospheric Chemistry and Physics: From air pollution to climate change*. John Wiley and Sons, New York.

4.13 Summary

We need to monitor visibility in New Zealand for a number of reasons, particularly as an indicator of air quality. A reasonable-sized programme is required to meet various objectives in regional air plans and the Environmental Performance Indicators programme.

There is no one best method, nor are there accepted international standards for monitoring visibility. There are pros and cons with each of the methods currently available, and there are clear difficulties in comparing results using different methods. However, this should not be used as a reason to delay the implementation of monitoring programmes in New Zealand. Preferably these programmes should include at least one monitor in every region, and one in every area where visibility degradation occurs due to human activities.

Visibility monitoring should not be seen as a substitute for measuring specific air contaminants that can affect health. Although monitoring of other contaminants – especially particulates – can give an indication of visibility, it is generally not possible to do the converse. Visibility degradation can be due to a range of different contaminants, both particulates of various sizes and various gases.

This discussion document has been prepared to give a series of options for instigating visibility-monitoring programmes. It includes some analysis methods, and an indication of how monitoring information can be used and related to other monitoring programmes.

There are several options, varying in scope and cost. Areas of greater risk, or those with existing visibility issues, should employ sufficient resources to fully understand the nature of any visibility degradation. Medium-risk areas should have sufficient monitoring to quantify trends. Lower-risk areas should undertake some form of regular monitoring, perhaps on a case basis, every few years. Recommendations are made on the nature and frequency of a suitable range of monitoring methods and how these should be implemented.

Finally, a new quantitative indicator of visibility is proposed, allowing the monitoring to be aligned to the Environmental Performance Indicators programme, and providing the public with an understandable assessment criterion. While useful for reporting visibility levels, these indicator levels do not provide an indication of the acceptability of visibility to the community. They could, however, be used as a guide for deciding whether further assessment of the acceptability of visibility levels to the community is needed, and thus whether management intervention is required.

In theory, it would be possible to produce a map of New Zealand showing a ‘risk factor’ for potential visibility degradation in each area. For instance, all other things being equal, the risks are greater in a small enclosed valley than in an open exposed plain. Such a map could be used to identify areas where special consideration is needed for monitoring or management options.

However, in practice, such a map would be very difficult to produce for two reasons.

- The extreme complexity of the geography of New Zealand would require a map with an impracticably fine scale. For instance, the West Coast is generally a very ventilated, low-risk region, but Reefton, because of its particular situation, is a small area within the West Coast of very high risk.
- Geographical factors make it difficult to derive a valid index for risk of visibility degradation. There has been little research on this topic, and any index would be largely qualitative.

Nevertheless, such maps would be very useful if they could be produced, and a trial map has been developed as a separate exercise in a third report in this series on visibility.[47]

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[47] Ministry for the Environment. 1999. *Visibility in New Zealand: National risk assessment*. Wellington: Ministry for the Environment.

5 Managing Visibility

5.1 Introduction

This chapter outlines the current framework that exists for managing air quality in New Zealand and discusses how it relates to protecting visibility. The following topics are covered:

- provisions for managing air quality under the Resource Management Act 1991
- *Ambient Air Quality Guidelines* (1994)
- the role of central and regional government in managing air quality
- regional air plans and policy statements
- processes for managing visibility.

The discussion sets the scene for considering processes involved in managing visibility in New Zealand and the methods that could be used to implement different options.

5.2 Legislation

The legislative framework for managing natural resources in New Zealand, including air, is the RMA. This promotes an integrated effects-based approach to the management of air, land and water. It replaced several Acts, including the Clean Air Act 1972, which was designed primarily to control industrial sources of air pollution.

Regional and district councils hold the formal responsibility for managing resources in their region or district in accordance with the purpose and requirements outlined in sections 5(1) and 5(2) of the Act:

Section 5(1): *to promote the sustainable management of natural and physical resources.*

Section 5(2): *sustainable management is defined as managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while –*

> *(a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations;*
>
> *(b) safeguarding the life-supporting capacity of air, water and soil and ecosystems;*
>
> *(c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

Section 7 has direct relevance to the protection of visibility for its amenity value. It states:

> *In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing its use, development and protection of natural and physical resources, shall have particular regard to –*
>
> *(a) Kaitiakitanga*
>
> *(b) the maintenance and enhancement of amenity values*
>
> *(c) maintenance and enhancement of the quality of the environment.*

The Act allows for the development of national policy statements and national environmental standards. As yet only one for coasts, *The New Zealand National Coastal Policy Statement*, has been completed. No national environmental standards have been promulgated, although some are under development by the Ministry for the Environment.

The Ministry for the Environment produces guidelines to assist those responsible for managing the environment. These include *Water Quality Guidelines*, *Marine Bathing Water Guidelines*, *Flow Guidelines for In-stream Values* and, of most interest for this work, the *Ambient Air Quality Guidelines* (1994). Although these are not environmental standards in terms of the Act, they provide a sound basis for decision-making and have been used as such in council and Environment Court hearings.

5.3 Ambient Air Quality Guidelines

When the *Ambient Air Quality Guidelines* were released in 1994 they provided a basis for protecting public health from the adverse effects of air pollution. The values represent the maximum acceptable concentrations of contaminants in the ambient air for specified exposure times. Concentrations above the guideline values were considered likely to cause unacceptable adverse health effects.

These guidelines, based on the World Health Organisation's *Air Quality Guidelines for Europe, 1987*[48] (WHO Guidelines) are now out of date with recent research findings and international guidelines, and for some contaminants they no longer provide adequate protection for human health. The guidelines, their content and applicability were reviewed by the Ministry for the Environment during 1999/2000.

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[48] World Health Organization. 1987. *Air Quality Guidelines for Europe*. WHO Regional Publications, European Series, No. 23. Copenhagen: WHO (revised 1998).

5.4 The role of local government

5.4.1 The role of regional and district councils

Regional and district councils are responsible for ensuring that natural resources in their region are sustained in accordance with the RMA. Regional councils and unitary authorities are responsible for managing physical resources such as land, air and water, and territorial local authorities are required to manage land-use activities such as subdivisions. Regional councils and unitary authorities therefore play a more significant role in managing air quality than territorial local authorities, although the potential for reducing emissions through land-use management by territorial local authorities should not be ignored.

Regional councils must prepare regional policy statements in accordance with the RMA and can prepare regional plans. These documents guide decision-making in the region and provide an opportunity for the local community to have their say on how air quality issues are handled in their region. As of 1999, several councils have such plans adopted, or in an advanced draft state.

5.4.2 Regional policy statements

Most regional policy statements contain a section dealing with air issues. The issues identified in these statements range from the cumulative effects of discharges to vehicle emissions and odour nuisance. A number of policy statements identify the effects of emissions on visibility as a key environmental issue and specify related objectives such as “to avoid, remedy and mitigate deterioration in visibility in the region”. Regional policy statements generally specify regional air plans as a method for achieving air quality objectives.

In general, the objectives of the air policies in regional policy statements are to maintain, enhance and improve air quality for the protection of human health, flora, and fauna and aesthetic values (clarity and odour). Regional councils, therefore, have a vested interest in the preparation of guidance for monitoring visibility and the possible development of national policies or guidelines related to visibility.

5.4.2 Regional air plans

The general purpose of an air quality plan (sections 63–70 of the RMA) is to outline how air quality is to be sustainably managed by the council. The effects-based approach to air quality management (section 65 of the RMA) requires air quality monitoring, determining appropriate guidelines or targets for air quality in the region (sensitive areas may have stricter requirements than industrial areas), evaluating how the situation will change over time, and implementing policies and rules to achieve targets.

The priority given to air quality issues varies through New Zealand. This is often reflected in the number of staff involved and the budget available for different councils. Regional councils are also involved in studies into source apportionment, visibility monitoring, establishing regional emissions inventories, air pollution dispersion/trajectory models, auditing, and considering discharge permits, and public consultation.

5.4.4 Addressing visibility in plans and policy statements

Councils can address specific concerns about visibility in their regional air quality plan. These may include proposed monitoring strategies and recommended control methods to reduce emissions of air contaminants that cause visibility degradation. However, in order for councils to prepare policies and rules to improve visibility, they need to identify the contaminants and their sources that contribute to visibility degradation in their region.

Many councils may have some idea of the general causes of visibility degradation, but only a few have carried out monitoring. Very few plans specify policies and rules relating to visibility, although rules to reduce particle emissions (such as those proposed by Environment Canterbury) should have beneficial consequences for visibility.

For some time Auckland and Christchurch have been the focus of the visibility debate, but as more is being learned about the causes of visibility degradation and its relationship to fine particle concentrations, other councils are becoming increasingly concerned about visibility. There is also increasing concern over the effects of air pollution in pristine areas such as national parks.

The current legislative framework appears to provide a range of options for developing visibility protection measures, including:

- national policy statements
- national environmental standards
- guidelines (including measurement methodology and targets to be achieved)
- promoting awareness
- providing advice on the development of appropriate regional polices and rules.

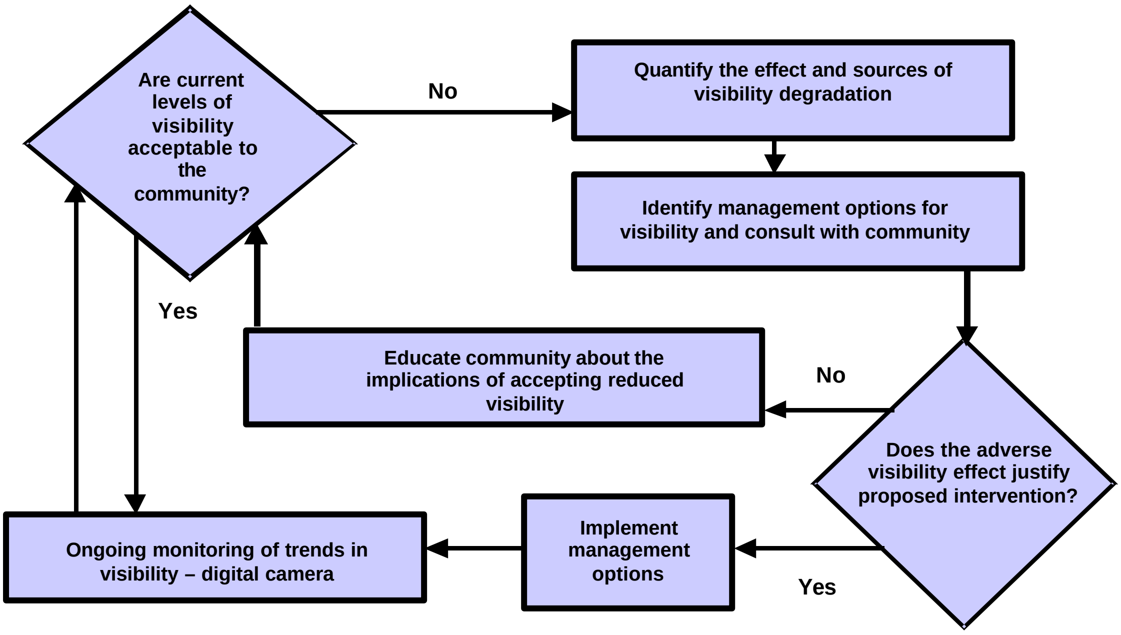
However, in most urban and in many rural areas, visibility degradation is due to a large number of sources, and it is difficult to attribute specific problems to specific sources. Techniques are available to investigate this (chemical mass balance, extinction budget analysis, elemental tracer methods), but these are complex and expensive, and do not always produce conclusive results. In addition, for many contaminant sources it may be difficult to control visibility degradation directly. Longer-term strategies are required, with roles for research and public education and possibly legislation.

5.5 Processes for managing visibility

Clearly a number of methods are available under the existing legislative framework for implementing visibility management measures should they be required. However, many of the difficulties lie not in the availability of methods for implementing management strategies, but in determining what, if any, management strategies are required to attain visibility levels that are acceptable.

Figure 5 illustrates a process for managing visibility in the absence of an air quality guideline for visibility. This process involves benchmarking current visibility levels both quantitatively, by means of monitoring, and qualitatively, in terms of the impact of existing visibility levels and the need for management intervention.

Figure 5: The process for managing visibility in New Zealand

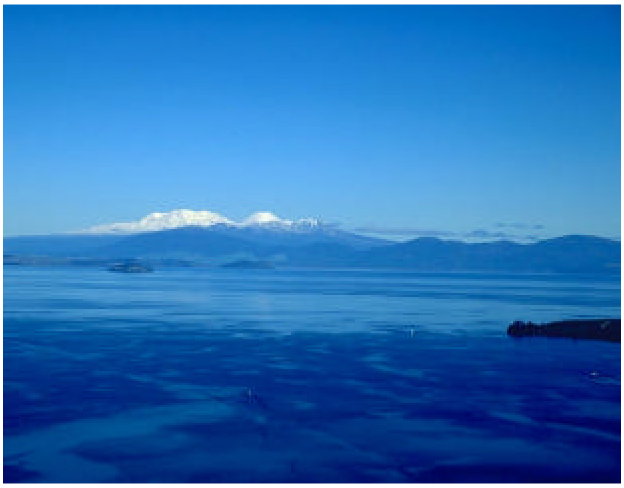


5.6 Summary

What legislative tools are available for managing visibility?

- The RMA provides a number of general and specific tools that can be used to control certain sources and effects, but not all.
- The Ministry for the Environment's *Ambient Air Quality Guidelines* are used for assessing effects. While not strictly a legislative tool, the guideline values are often adopted in policies, plans and consents.
- Regional policy statements, covering all regions, districts and cities in New Zealand, provide an overview of the management, policy and legislative intentions of local government.
- Regional air plans (in one form or another) provide specific policies pertaining to the management of air quality that have the force of local legislation.

6 Towards Visibility Protection



To ensure degraded visibility conditions are avoided and improved in New Zealand, we need to gain a better understanding of the sources of contamination and the factors that cause poor visibility We also need to develop more robust monitoring methods, suitable indicators, and appropriate goals or targets. Such goals may be quite simple; for example, no further visibility degradation is allowed in any area. Alternatively, a quantitative goal could be based on a particular measurement method. In conjunction with this, regional councils, who have the operational role of managing the air, need the tools to assess it, and guidance on how to bring about improvements or to ensure that there is no degradation from the current situation.

The introduction of a guideline for visibility would promote visibility monitoring and regional plan policies and rules that are tailor-made for visibility rather than health effects. This chapter discusses the options for immediate and long-term objectives for protecting visibility in New Zealand, and how they might be achieved.

6.1 Developing guidelines for visibility protection

The purpose of developing a guideline value for visibility is to provide a target value for councils to aim for, to quantify in plans, and to assess the nature of visibility in their regions, as well as giving a defined and understandable public indicator of visibility trends. A guideline value would allow councils to prioritise their air quality issues and put effort into those of highest priority.

Another advantage of a guideline for visibility is that it would preclude the need for councils to conduct surveys to determine the acceptability, or otherwise, of visibility levels.

The introduction of national regulation requirements, as seen in the US, to protect selected areas of New Zealand from visibility degradation would not be an effective course of action for New Zealand because it could be inconsistent with the existing framework for managing air quality under the RMA.

One difficulty in setting a national guideline for visibility is establishing the rationale on which the guideline is based. In this respect visibility differs from other air quality indicators in that it relates to amenity effects as opposed to health effects. Thus establishing a guideline for visibility involves determining a level of visibility degradation that is unacceptable to the community because of its impact on amenity values. This is complicated further by the potential for variability in levels of acceptability for different communities owing to differences in visibility perception, scenic value and the contribution of natural sources.

Put simply, on the one hand we need a target value that represents a level of visibility that is acceptable to the nation; but on the other hand, this target value could vary according to the local communities' different perceptions about the acceptability of various visibility levels. For example, where natural sources are known to be the main contributor, a national target level may be too stringent. In areas where a higher value is placed on clear air, a national value may not be stringent enough.

6.1.1 The form of a guideline

Devising a guideline value for visibility is complex, and may take the form of either:

- a guide to visibility assessment and monitoring in New Zealand; and/or
- a guideline or indicator value for visibility in New Zealand.

In essence, guidance to councils would be best achieved by using both approaches; that is, set target criteria or indicators (in the form of an ambient air quality guideline value for visibility), supplemented with information on monitoring methods, protocols and how regional visibility assessments should be approached by council staff. This approach would promote work towards a common national 'goal' or visibility target, such as those proposed in Chapter 4.

The guidelines should be designed to fulfil the *Environment 2010 Strategy* air objectives: "to maintain air quality in parts of New Zealand that enjoy clean air and improve air quality in places where it has deteriorated." However, as indicated above, they need to allow flexibility for councils to choose target levels above or below the national guidelines and the flexibility to monitor and manage visibility in a manner most appropriate to their region.

6.1.2 Moving towards a visibility guideline

Even in the absence of a visibility guideline or benchmark, some steps can be taken by councils where visibility degradation may be an issue. These include the following.

- Areas where visibility degradation has been observed need to be identified, with specific attention paid to pristine areas or areas of high landscape significance.
- Any sources of air contaminant emissions, and activities thought to contribute to visibility degradation observed in the region, should be listed.
- An integrated air quality-based monitoring strategy should be developed, which incorporates information from existing air monitoring programmes into a visibility-monitoring strategy, since many of these issues are closely linked with visibility degradation (for example, the use of NO_2 data or $PM_{2.5}$ monitoring data).
- Following identification of potential sources responsible for visibility degradation, councils should propose a control strategy for reducing emissions of air contaminants responsible for visibility degradation.

- For any control strategy proposed in the regional air plan, an assessment should be carried out to determine the potential environmental (visibility), health, social and economic impacts of implementing options outlined in the strategy. The assessment should also determine whether the control strategy would achieve the desired improved visibility through reductions in contaminant emissions where degradation has been identified.
- Data from the census and other regional plans should be used to assess trends in the region, particularly to identify new sources and new areas where emissions may contribute to reduced air quality.
- Subject to resourcing, it can be very useful to model the whole scenario. This is a complex task that is only just being developed in New Zealand. It involves having relatively detailed information on emissions, meteorology, and existing air quality. However, once set up, urban airshed models can be extremely powerful tools for investigating air quality in general.

6.2 Short-term objectives

There are number of immediate short-term objectives needed if New Zealand's visibility resource is to be adequately protected. These should be implemented immediately, and continued indefinitely.

6.2.1 Define the national goal

The purpose of setting a national goal for visibility acts in much the same way as the principles and purposes of the RMA. This is apparent, for instance, in the national goal set by the USEPA:

> *... the remedying of existing, and prevention of future, impairment of visibility in mandatory Class 1 Federal areas in which impairment results from man-made air pollution.*[49]

In the US, a Class 1 area is defined as "Any area which is classified as a highly protected natural scenic location including large national park reserves". These areas cover many of the country's tourism locations, and represent a significant fraction of the land area. The US also has Class 2 and Class 3 areas, with different levels of protection. Most cities and industrial areas are Class 3, with the remaining residential and rural areas being Class 2. Some areas remain unclassified.

New Zealand could tailor a national goal to apply different criteria to different areas, some of which may need greater protection from visibility degradation; for example, pristine areas, national parks or areas where improvement in visibility is urgently required.

Furthermore, defining a national objective may prompt councils to assess visibility in their region and address specific issues relating to visibility in their regional air plan.

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[49] USA. Clean Air Act. Section 169A (42 USC 7491), as amended 1977.

6.2.2 Raise awareness

The work being undertaken by the Ministry for the Environment, councils, universities and Crown research institutes is raising visibility as an important air quality issue. The outcomes of this current work will go forward into further projects by the Ministry for the Environment, many focusing on a better understanding and appreciation of the environment, and will become part of the promotion of the Environmental Performance Indicators programme.

The inclusion of visibility as a Stage 2 indicator has also served to raise awareness at a number of levels, including the public, political, industrial and educational sectors.

A survey undertaken as part of this work raised visibility issues with a number of interested parties, including tourism operators and industry. Further work on raising awareness is expected to occur through these communication channels.

6.2.3 Determine a visibility monitoring method

Chapter 4 of this report details different methods for monitoring visibility, and also suggests guideline indicator values for visibility. The choice of monitoring method(s) will hinge on whether New Zealand chooses to adopt an air quality guideline value for visibility, and what that value will be. Chapter 4 proposes an indicator based on visual range. Monitoring methods that provide an indication of visual range are human judgement methods and transmissometry (the measurement of light extinction). In practice, however, nephelometers are generally used instead of transmissometers.

Other techniques that could be used in conjunction with visibility monitoring to assist in source determination include:

- ***source apportionment***, which provides information on the chemical composition of the air contaminants discharged so that emissions can be traced to specific sources (for example, PIXE)
- ***meteorological monitoring***, because meteorology strongly influences ambient contaminant levels and the rate at which secondary reactions occur in the atmosphere
- ***modelling techniques***, which may be used to model physical, chemical, human observation and meteorological data so that predictions on future visibility conditions may be carried out. Modelling techniques may also be used to determine the potential impacts of implementing proposed emissions control strategies by councils.

6.2.4 Form a visibility working group

Working groups for visibility have been shown to be successful in the US in association with the implementation of visibility monitoring networks in national parks. Such a group could be formed in New Zealand to keep the information channels open on issues relating to visibility degradation. It would be beneficial to bring together scientific experts, policy and council air planners, particularly in the early stages of policy development and implementing monitoring strategies. At present, and in the near future, this role is undertaken by the national Air Quality Working Group, a semi-formal group comprising representatives from all councils, territorial local authorities with air responsibility, various ministries, and key service providers. It meets about twice a year, and usually includes an agenda item on visibility.

6.3 Long-term objectives

Apart from the short-term objectives discussed above, New Zealand should adopt some longer-term objectives for visibility management. These could include:

- developing air quality guidelines for visibility protection in New Zealand (these will include a recommended monitoring method or list of methods and a set target for councils to aim for to ensure that regional air resources are protected)
- targeting selected areas for visibility monitoring (for example, pristine areas such as national park reserves, and areas where visibility degradation has been identified by monitoring or observation, such as Auckland and Christchurch)
- modifying and/or developing policies to control sources of emissions and activities that contribute towards visibility degradation (the identification of specific sources of emissions such as outdoor residential burning will be essential in the policy development process; this will be best achieved by regional councils)
- investigating techniques such as emission inventories, source apportionment, pollutant models and any others that are used to quantify the effects of air pollutants that degrade visibility (depending on funding, the Ministry intends to continue to develop and trial assessment tools that can be used by councils).

6.4 Visibility protection in pristine areas

Currently there is no strong evidence of long-term visibility impairment in major national park areas. There are specific cases, such as the recent eruptions at Ruapehu or during agricultural burn-offs, but usually there is little that can be controlled. However, it would be optimistic to think that conditions in the future will continue as they are today, and the benefits of prevention far outweigh those associated with remedying the effects of degradation.

It may not be economically feasible to implement monitoring stations throughout New Zealand to quantify the effects of specific contaminants on visibility in all national park areas. However, to ensure that visibility is protected in these areas, it is important to provide the framework for monitoring in areas where visibility degradation by human activities is suspected, or to undertake intermittent monitoring to examine whether there has been any deterioration.

Visibility monitoring may be implemented by a two-step process:

Step 1: Set up human observation monitoring stations in a number of major national park areas to identify those areas where visibility degradation exists as the result of human activities.

Step 2: Where degradation has been identified, implement contaminant monitoring to identify specific source(s) responsible for impairment, and quantify their contribution. Such monitoring may be relatively short term, and conducted only every few years, unless a specific concern is identified at a particular location.

Step 1 could be achieved with a modest co-ordination effort of local staff and the community. Observation in national park areas might also involve general public participation, possibly through observational surveys when visiting scenic areas. This would also help to provide information on how visitors perceive visibility conditions in New Zealand, which could then be used in economic impact assessments to determine the dollar value of maintaining good visibility. Overseas studies have shown that good visibility plays an important part in visitor enjoyment, and can affect the amount of time and money tourists spend during their visit.

Step 2 involves more resources. The expenses associated with contaminant monitoring are high, and therefore such monitoring would only be implemented in selected areas. Monitoring methods and protocols used to quantify the causes and effects of visibility degradation in pristine areas could be those discussed in Chapter 4 of this report.

Given that resources are not likely to be available to implement a full national monitoring programme, some attempt to prioritise regions has been made in the companion document (*Visibility in New Zealand: National Risk Assessment*). This shows that some areas may be more susceptible to visibility degradation, due to increasing emissions or geographical conditions.

6.5 Summary of recommendations

What actions are required to protect and enhance visibility in New Zealand?

Required:

- Develop and implement guidelines and indicators for visibility protection (this report).
- Fully integrate visibility as an objective in regional air plans (already in many council plans).
- Raise awareness in the public, educational, industry and political sectors (part of the Environmental Performance Indicators programme and the Ministry's *The Air We Breathe* web pages).
- Develop and recommend monitoring methods (this report).
- Define national goals for visibility, relevant for different types of regions within New Zealand (preliminary discussion in this document, and contained in *Visibility in New Zealand: National Risk Assessment*).
- Continue research on airshed modelling, with an emphasis on understanding the key causes of visibility degradation (this is being conducted under grants from the Foundation for Research, Science and Technology – Urban Air Quality Processes).

Optional:

- Form a visibility working group, or some other forum for discussion of issues and options.
- Promote the use of additional control and mitigation measures on emissions sources.
- Undertake more in-depth research on the specific causes of visibility degradation, and on public perceptions, amenity effects, and practical mitigation and management options.

7 Concluding Remarks

There is no doubt that having good visibility is a valuable resource for New Zealand. Clear air is an excellent indicator of environmental quality, and one that most people can readily understand. The community has come to expect good visibility, and it has been identified as one of the reasons why tourists find the country attractive. This is not a trivial factor, as tourism is now New Zealand's main export-earning activity.

Visibility can be reduced, or degraded, in a number of ways. The most common are through purely natural causes, such as rain, fog, or haze caused by natural conditions such as sea spray. These causes cannot be altered or managed. Of greater concern is visibility degradation resulting from emissions of contaminants into the air. These can be particulates or gases, which can undergo relatively complex transport patterns and reactions in the atmosphere. They are becoming increasingly concentrated over urban areas, and have the potential to seriously affect visibility in areas that are currently pristine.

Current environmental legislation in New Zealand puts responsibility for the management and control of air quality in the hands of regional councils and territorial local authorities. Central government has a more indirect role, through proposing new legislation, through national policies, and through providing assistance, education and project funding. The RMA has available many of the legislative tools necessary for addressing visibility concerns, such as education, advocacy and regional plans. However, assessing the relative contribution of different sources to visibility degradation is complex. Consequently, one of the biggest challenges lies in identifying management options that will be effective in improving visibility.

A number of new methods and objectives are proposed to help maintain and enhance visibility in New Zealand.

New monitoring methods and new indicators and evaluation tools are a key component. Some assessment has also been made on an overall risk assessment for various areas in New Zealand, contained in *Visibility in New Zealand: National Risk Assessment*.

Finally, one clear outcome of this investigation is the need for an integrated, long-term approach. There is no obvious single solution or simple 'fix-it' policy. The issue of visibility is tied up with factors affecting the whole of society, such as general contaminant emissions, economic development, regional environmental management, and the value that businesses and communities put on air quality. These all need continued attention from government, industry and community sectors concerned with protecting New Zealand's heritage.

Glossary

AAQG/AQG	Ambient Air Quality Guidelines/Air Quality Guidelines.
Acid rain	Harmful pollutants that are water soluble and acidic in chemical composition are deposited to the earth's surface during rainfall. Acid rain is typically observed in regions where sulphur dioxide gas emissions are high. The major component of acid rain which is harmful to the environment is sulphuric acid.
ANSTO	Australian Nuclear Science and Technology Organisation.
Anthropogenic	Arising from a human-made source or human activity, such as domestic burning.
APCA model	Absolute principal component analysis, which is capable of performing source apportionment.
AQMP	Air Quality Management Plan.
AS	Australian Standard.
Attainment areas	All areas that achieve the national requirement, or are cleaner, as shown by actual monitoring data.
ATV	Articulated vehicle.
BART	Best available retrofit technology.
CAA	Clean Air Act 1972, now replaced by the Resource Management Act 1991 (RMA).
Class 1 area	Any area classified as a highly protected natural scenic location, including large national park reserves.
CMB model	Chemical mass balance model.
Coarse particles	Particles less than 10 µm in diameter, such as, sea-salt, soil and pollen.
Elemental carbon	Elemental carbon, also referred to as *black carbon* or *soot carbon,* is considered to be a major contributor towards visibility impairment, and is produced predominantly by the combustion of fossil fuels.[50] Major sources of elemental carbon emissions include diesel-operated engines and any other activity involving the combustion of fossil fuels, such as domestic and prescribed wood- and coal-burning activities. Elemental carbon is a significant contributor to atmospheric visibility degradation for a number of reasons, including its existence in both urban and regional environments, its chemical stability in the atmosphere, and, most importantly, its strong optical-absorbing properties (attributed to its graphite microcrystalline structure). Also, elemental carbon particles are less than 1.0 µm in diameter, which potentially allows them to remain airborne for long periods of time and be transported over long distances under favourable climatic conditions. Elemental carbon emission from the combustion of wood and coal for residential heating is thought to be the major cause of wintertime visibility reduction in Christchurch. Reduction levels are also enhanced by the regular occurrence of temperature inversions, which trap chemical pollutants under certain geographical and climate conditions. Elemental carbon from vehicle emissions may also be a significant contributor towards worsening visibility conditions in the Auckland region due to high traffic volumes.
EPAV	Environmental Protection Authority of Victoria, Australia.

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[50] Kahl DJ, Hansen ADA. 1989. Determination of Regional Sources of Aerosol Black Carbon in the Arctic. *Geophysical Research Letters* 16(4): 327–30.

EPI	Environmental Performance Indicators programme.
ESR	Environmental Science and Research Ltd.
Fine particles	Particles less than 2.5 µm in diameter, which are responsible for visibility reduction and are known to cause human respiratory illness. Examples are sulphates, nitrates, elemental carbon, organic species and nitrogen dioxide.
Grimm	Portable dust monitor, which measures particle sizes continuously.
Haze	A common term for the loss of visible air quality, and may be recognised as a brownish discolouration in the atmosphere. It is formally defined as a suspension of solid particles of dust and smoke etc. reducing visibility above 1 km.
Hydrocarbon	Any organic compound that contains both carbon and hydrogen atoms in its chemical composition (for example, benzene).
IMPROVE	Interagency Monitoring of Protected Visual Environments (implemented by the National Parks Service and the USEPA).
Light extinction	A measure of the degree to which visible light is scattered and absorbed in the atmosphere.
Nitrates	Nitrates exist as fine particles, and are produced by secondary reactions involving nitrogen dioxide gas and particulate species. Nitrates may also be produced naturally from sea salt to form sodium nitrate particles.
NIWA	The National Institute of Water and Atmospheric Research Ltd.
PCA model	Principal component analysis model, which generates a hypothesis regarding the number of sources and their physical and chemical fingerprint.
PIXE	Particle induced x-ray emission analysis.
Pristine areas	Include international parks, national memorials and national parks above a certain size.
Protected areas	Include areas such as small national parks, wilderness areas, coastal zones and other areas of special (national or regional) natural, recreational, scenic or historic value.
RAP	Regional air plan.
Rayleigh scattering	Light extinction caused by particles produced naturally (for example, primary gases such as nitrogen and oxygen). Scattering by these particles gives rise to a blue appearance to the sky.
RMA	Resource Management Act 1991.
SCENES	Sub-regional Co-operative Electric Utility, Department of Defence, National Park Service, and the Environmental Protection Agency Study (November 1983 to October 1989).
Secondary reactions	Chemical reactions that occur in the atmosphere, usually involving particulate and gaseous species; for example, sulphur dioxide gas with sea-salt particles (in the form of sodium chloride), to form a secondary particle, sodium sulphate.
Sulphates	Sulphate particulates are secondary pollutants produced by the reaction of sulphur dioxide gas and other particulate species. Sulphates may be derived from a variety of sulphur dioxide sources, including oceanic processes, volcanic emissions and industrial processes such as coal-fired power plants.
Temperature inversion	The anomalous increase in temperature with height in the troposphere favoured by certain geographical and climatic conditions.
TEOM	Tapered element oscillating micro-balance.

Troposphere	The lower part of the atmosphere extending from the surface up to a height varying from about 9 km at the poles to 17 km at the equator, in which the temperature decreases fairly regularly with height.
TSP	Total suspended particulates, which includes both coarse and fine particulates combined in the sample measurement.
Turbidity	A term occasionally used to describe visibility degradation, and which quantifies the loss caused by light scattering of an observer's ability to perceive an object in the atmosphere.
Visibility	The degree to which the atmosphere is transparent to visible light. Visibility is quantified in terms of visual range and light extinction, or the maximum distance at which a black object of sufficient size can be seen and recognised in normal daylight.
Visual horizon	The junction of sea or earth with sky as seen from an observer's position; also called the 'apparent' or 'sensible' horizon.
Visual range	The farthest distance at which a large black object can be distinguished against the horizon sky.
USEPA	United States Environmental Protection Agency.
VFECS	Vehicle Fleet Emission Control Strategy.
VOC	Volatile organic compounds (VOCs) are emitted directly (for example, fuel evaporation from vehicles and service stations) and during combustion processes. Biogenic VOCs are naturally emitted by vegetation.
WHO	World Health Organisation.

Appendix 1: Background Information for Visibility Surveys

Further information for visibility surveys

Background issues to cover with survey participants

Before carrying out the visibility survey, ensure that the participants are aware of the following issues.

Distance visible

The distance visible is the greatest distance that can be seen throughout at least half the horizon circle from the observation point. In meteorological terms this is known as the prevailing visibility, and this observation is normally taken from ground level. For the purposes of the community survey it should be sufficient to be aware of the height of the observer.

Observation times

The observation times should be around the same time each day, between 10 am and 2 pm. This ensures that sun angle is not directly affecting the visibility observations (as well as very early morning fog). It also ensures that all of the observations are recorded in approximately the same time period.

Fog and haze

Fog is mainly due to water droplets in the air. Haze can be caused by sea salt or other types of particles in the air.

Landmarks

At least one landmark should be on or close to the horizon (at least 20 km away) because it is important to know how visibility is being affected far into the distance. It is best to choose a variety of landmark distances. Dark objects are preferable as landmarks because the colour of the object affects how easily visible it is (in poor visibility, light-coloured objects are more difficult to see).

Wind speed

To make observations easier, the wind speed has been classed into categories related to the Beaufort scale of wind force. The Beaufort scale classifications have been used except for higher wind speeds, because in high winds human activity is unlikely to be the principal cause of poor visibility.

Cloud cover

The amount of cloud cover in the sky has a direct effect on visibility, as clouds affect the amount of light in the sky and hence the amount shining on objects (and being reflected back or absorbed). Observers should try to view as much of the sky as possible when making this observation. Manual and automated measurements of cloud cover are taken at some airports, and this information can be useful as supplementary data for the visibility survey.

Human impaired visibility

Although this is very subjective, it has been included to give an indication of whether there is a possibility that visibility has been affected by human activities on a particular day. In a previous survey carried out in Hawke’s Bay, higher particulate levels were recorded on the days when some proportion of the poor visibility was attributed to human causes during the survey.

The following pages give examples of a community visibility survey and the associated documentation.

{date}

{address}

Dear *{observer}*

Re: Trial to measure visibility in *{town}*

Thank you for taking part in this programme to measure air visibility by taking daily observations in *{town}*. We are running this programme to help us to monitor visibility over the long term.

Visibility is a good indicator of general pollution in the air. Visibility can be degraded when light is scattered by particles or gases in the air. Monitoring visibility is important as it helps us to assess whether visibility may be changing and allows us to take action if our scenic views are being affected by human activities. In addition, if the visibility is deteriorating, then the degraded air may be causing human health problems.

Visual observations can be a reliable visibility measuring method because the eye picks up small changes in visibility. Other measurement methods can be complex and very expensive. Using the human eye is therefore a reasonable alternative to more technical methods.

I have enclosed the following to help you complete the survey:

- **Weekly worksheets**

  Please fill in your observations in the worksheet each day of the survey. The survey should take you less than three minutes a day to complete. When finished, please return the weekly observation worksheets in the enclosed self-addressed, pre-paid envelope.

  Different people will have different perceptions when they fill in the worksheets. Therefore the same person should fill out the sheets every day.

- **Map of {town}**

  Please mark your location and the location of your chosen landmarks on this map. The markings will help us measure the distance and direction between you and the landmarks. Try and choose landmarks that are a range of distances from you (with one or two at least 20 km away). If your landmark is off the map, write on the back of the map where the landmark is generally located. The landmarks do not all have to be in the same direction. View the same landmarks each time you complete observation worksheets.

- **Guide to weekly worksheets**

  This guide gives some explanatory notes about how the weekly worksheets should be filled in.

- **Example worksheet**

  The example worksheet shows how the worksheet can be filled out.

- **Questionnaire**

  This questionnaire helps give us background information for the survey. The information is used purely for statistical purposes and is strictly confidential.

Thank you for taking part in the survey. Please contact me if you need any further information.

Yours sincerely

Observation coding

Date Please write down the date that you are taking the observation. This is important as your observations may be compared with actual monitored readings.

Time Please make your observations at roughly the same time every day. Any time between 10:00 am and 2:00 pm is preferable.

Clarity What does the outline of the landmark you are observing look like? Choose a number between one and nine to indicate whether the landmark is:

1	clear and sharp
2	
3	a little hazy
4	
5	hazy
6	
7	very hazy
8	
9	so hazy you cannot see outline

Landmark These are the landmarks, numbered 1–5, which you listed in the second question of the questionnaire. Use these numbers in your observations. It is easiest for us if you list your landmarks in order from closest to furthest away.

Cloud When you make your observation, approximately how much of the sky is covered with cloud? A rough estimate will be fine (e.g. 5%, 10%, 90%).

Wind How windy is it when you make your observation?

1	calm	(smoke rises upwards or drifts slightly)
2	slight breeze	(leaves rustle)
3	gentle breeze	(leaves and twigs constantly moving)
4	moderate wind	(small branches and small trees move)
5	strong wind	(large branches moving, wind whistling)
6	gale/storm	(whole trees in motion)

From these choose one which describes what the wind is typically doing (rather than the occasional gusts).

General visibility

Using the following scale, rate your opinion on the visibility you have today.

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10

Very poor Excellent

Observation coding

Distance objects are still visible

What is the furthest you can see objects into the distance today? If it helps, you can use your map for reference. A rough estimate will be fine (e.g. 5 km, 20 km).

When you make your observations are any of the following affecting your visibility:

Y / N fog
Y / N rain
Y / N stormy weather
Y / N low cloud
Y / N haze (this could be sea salt, mist or haze due to human causes)
Y / N any brown colour (in the sky)
Y / N smoke

Cause If there is some degree of haze or poor visibility from the following categories, how much do you think is due to human activities? (An approximate percentage will be fine.)

0%	All of the haze or poor visibility is from natural causes (e.g. fog, sea mist, rain or dust).
5%	A little bit of the haze is caused by human activities (e.g. smoke or other emissions).
25%	Some of the haze is caused by human activities.
50%	About half of the haze is caused by human activities.
75%	Most of the haze is caused by human activities.
95%	Nearly all of the haze is caused by human activities.
100%	All of the haze is caused by human activities.

Comments

Is there anything that we should know that may be important for this survey? If so please write down any comments you have, such as continuous heavy rain, very foggy, smoky fire from the neighbour's, etc.

Note: there are no right or wrong answers

Perception of visibility questionnaire

Name...

Date..

General questions (this information only needs to be given once – preferably when you begin the survey.)

Q 1 What is the full address of the location where you will be recording your observations?

Floor / level ____

Street address ____

____

Suburb ____

City / town ____

Q 2 In order of distance and starting with the landmark closest to you, please write down what landmarks you can see. Please mark these landmarks on the map we have given you (this will allow us to work out the distances to your landmarks). You do not have to choose five, but the more landmarks we have, the more accurate this survey will be.

No. 1 ____

No. 2 ____

No. 3 ____

No. 4 ____

No. 5 ____

(Please try to supply at least one landmark that is near the horizon.)

Q 3 What sort of foreground do you have from your observation point? (circle one)

Urban / Suburban / Rural / Industrial / Water / Bush

Q 4 How long have you lived in this city / town ? (circle one)

Less than 1 year / 1–4 years / 5–10 years / 11–15 years / More than 16 years

Q 5 If your answer from Q 4 was less than 5 years, what type of area did you move from? (circle one)

Urban / Suburban / Rural / Industrial / Water / Bush

Perception of Visibility – Weekly Observation Sheet

Name: ____

DATE		__/____/ ____	__ /____/____	__ / ___/____	__ / ___/____	___/___ / ___	__/____/ ____	__/____/____
TIME	(between 10 am and 2 pm)	______ am/pm	______ am/pm	_______am/pm	_______am/pm	_______ am/pm	______ am/pm	______ am/pm
CLARITY	Name of landmark (fill in below)	(Scale 1 = Clear through to 9 = cannot see outline)						
Landmark 1								
Landmark 2								
Landmark 3								
Landmark 4								
Landmark 5								
CLOUD		(Percentage of the sky that is covered with cloud)						
WIND		(Scale 1 = No wind through to 6 = Storm)						
GENERAL VISIBILITY		(Scale 1 = Very poor through to 10 = Excellent)						
DISTANCE OBJECTS ARE STILL VISIBLE (use your map if this helps)		(Approximate distance in km)						
IS THERE ANY ...		(Y = Yes, N = No)						
Fog								
Rain								
Stormy weather								
Low cloud								
Haze (from sea salt, mist or human causes)								
Brown colour (in the sky)								
Smoke								
CAUSE		(0% = Natural causes only to 100% = Human causes only						
COMMENTS								

Perception of Visibility Observation Sheet – SAMPLE ONLY

WEEK 1			
DATE		Mon 22 Sep 1997	Tues 23 Sep 1997
TIME	(between 10 am and 2 pm)	11:30 [✓ am]/pm	11:50 [✓ am]/pm
CLARITY		(Scale 1 = Clear through to 9 = cannot see outline)	
Landmark 1	Motorway	1	3
Landmark 2	Grafton Bridge	3	7
Landmark 3	Container Port	3	7
Landmark 4	Rangitoto	5	7
Landmark 5			
CLOUD		(Percentage of the sky that is covered with cloud)	
		30%	100%
WIND		(Scale 1 = No wind through to 6 = Storm)	
		2	1
GENERAL VISIBILITY		(Scale 1 = Very poor through to 10 = Excellent)	
		6	2
DISTANCE OBJECTS ARE STILL VISIBLE		(Approximate distance in km)	
		10	2
IS THERE ANY ...		(Y = Yes, N = No)	
Fog		N	Y
Rain		N	N
Stormy weather		N	N
Low cloud		N	N
Haze (from sea salt, mist or human causes)		Y	N
Brown colour (in the sky)		Y	N
Smoke		N	N
CAUSE		(0% = Natural causes only to 100% = Human causes only	
		25%	0%
COMMENTS			Foggy day

This sample has been completed by a person working in a tall office building in Khyber Pass Road, Auckland. You will note that they have not only listed landmarks that are well known but they have tried to space them to give a wide range of visibility. This observation has been taken by one person looking out of their window towards the north-east. It is not necessary to move from one room to create a panorama or full circle of vision as long as there are enough landmarks or reference points from your window.

On the first day there was very little wind, but there was a little sea mist in the harbour and traffic emissions noticed in the foreground.

The second day was still quite foggy at the time the observation was recorded.

Remember this is someone's observation. You may or may not have the same opinion.

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