Lower Fraser Valley Visual Air Quality Pilot Study: Synthesis of Findings

Prepared by: Bianca Ravani Cecato,

UBC Sustainability Scholar, 2019

Prepared for: Julie Saxton, PhD P. Chem.,

Air Quality Planner, Air Quality and Climate Change, Metro Vancouver

August 23, 2019

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability across the region.

This project was conducted under the mentorship of Metro Vancouver staff. The opinions and recommendations in this report and any errors are those of the author and not necessarily reflect the views of Metro Vancouver and the University of British Columbia.

Contents

List of Figures

List of Tables

List of Terms

ANO_3 - Ammonium nitrate

AQBAT - Air Quality Benefits Assessment Tool

ASO_4 - Ammonium sulfate

AURAMS - Environment Canada's Photochemical Model

BCVCC - British Columbia Visibility Coordinating Committee

b_{ext} - Light extinction

b_{scat} - Light scattering

CO - Carbon monoxide

CC - Contingent choice

CM - Coarse mass

CV - Contingent valuation

dv - Deciviews

EC - Elemental carbon

ECCC - Environment and Climate Change Canada

FS - Fine soil

FVRD - Fraser Valley Regional District

IAQGGMP - Integrated Air Quality and Greenhouse Gas Management Plan

LFV - Lower Fraser Valley

ENV - British Columbia Ministry of Environment and Climate Change Strategy

MVRD - Metro Vancouver Regional District

NO_2 - Nitrogen dioxide

$PM_{2.5}$ - Particulate matter with aerodynamic diameter less than 2.5 microns

PM_{10} - Particulate matter with aerodynamic diameter less than 10 microns

OM - Organic matter

RH - Relative humidity

SO_2 - Sulfur dioxide

SS - Sea salt

VAQ - Visual air quality

VAQR - Visual air quality rating

VOC - Volatile organic compounds

Executive Summary

This report synthesizes the outcomes of the various elements of the Lower Fraser Valley (LFV) visual air quality (VAQ) pilot study and, where possible, identifies the key features of the study that could be relevant to developing recommendations for a visual air quality program. Regional work on VAQ has been coordinated by BC Visibility Coordinating Committee (BCVCC). Results, findings and recommendations arising from the pilot study inform the development of actions for improving visual air quality.

This report is divided into three parts. Part I provides the background to the development of the pilot study and describes the policies targeting VAQ, the agencies involved, and its achievements. Part II provides an introduction to visibility science, its monitoring, modelling and data analysis; the description of the VAQ metric that has been developed for the LFV; models of economic and health valuation of VAQ, as well as economic impacts by sector; and finally, how stakeholders have been informed and engaged in various aspects of the pilot study, including their role in establishing the main goals for VAQ improvements.

Part III describes the main results and findings of the elements of the pilot plan. It synthesizes the results of the various visibility measuring and modelling techniques described in Part I; the applications of the VAQ index developed for the region, as well as what has been established in terms of goals based on the index, and the communication of its progress with the public; the results of health and economic models that attempt to estimate the economic benefits of improving VAQ; and finally how aligned the progress of the pilot project is to the stakeholder's opinion and expectations.

Part I: Background to the Lower Fraser Valley visual air quality pilot study

1 Introduction and Policy Goals

The LFV is a densely populated region in British Columbia, as well as being a region of intense scenic beauty. Most residents agree that the physical setting of the region and the ability to see landscapes improves their quality of life (Pryor, 1996). Visibility has a strong link to air quality, and the LFV has air quality standards based on health considerations. However, visibility measure are more related to human perception, which allows policy goals targeting air quality improvement to be aligned with the preferences of local residents.

Visibility in this report refers to the impact of air contaminants on the ability to see distant objects. Visual air quality (VAQ) refers to that visual impact of air pollution. The terms visibility and visual air quality are used interchangeably throughout this report.

1.1 Action on visibility

The management of air quality in the Lower Fraser Valley (LFV) is a collaborative effort shared by a number of jurisdictions, including not only air quality, but also health, climate change, and transportation authorities at the regional, provincial, federal, and international levels. (Sonoma, 2017).

1.1.1 B.C. Ministry of Environment and Climate Change Strategy

The BC Ministry of Environment and Climate Change Strategy (ENV) supports Metro Vancouver (MVRD) and the Fraser Valley Regional District (FVRD) in developing a VAQ goal for the LFV region. The development of visibility goals is aligned with policy directions to reduce levels of particulate matter, and hence the Ministry aims to achieve an understanding of how visibility considerations can be incorporated into its policy development and decision-making. If a specific goal is endorsed, that will be taken into account in the Ministry's decision-making processes (for instance, emission sources regulated by the ENV) within the LFV.

1.1.2 Metro Vancouver

MVRD manages and regulates air quality in the region, under the authority delegated under the BC Environmental Management Act.

In 2011 Metro Vancouver adopted an Integrated Air Quality and Greenhouse Gas Management Plan (IAQGGMP), as part of ongoing air quality planning. One of the strategies for action in the plan is to develop a VAQ management program for the LFV airshed in partnership with other government agencies.

1.1.3 Fraser Valley Regional District

FVRD has planning authority in the FVRD region, and the ENV has regulatory authority for air emissions in the FVRD. The FVRD included visual air quality monitoring studies in its 1998 Air Quality Management Plan, which is currently being revised to include actions related to visual air quality.

1.1.4 Environment and Climate Change Canada

ECCC works with Metro Vancouver to maintain specialist visibility monitoring capacity in the LFV, which provides near real-time reporting of VAQ conditions. ECCC has also been responsible for leading and supporting studies to help understand the origins of visibility impairment in the region.

1.2 British Columbia Visibility Coordinating Committee

The BC Visibility Coordinating Committee (BCVCC) was formed to develop visual air quality management tools and options, and its commitment is achieving clean air and clear visibility for the health and quality of life of current and future generations. Members agencies of the BCVCC include ECCC, Health Canada, ENV, FVRD and MVRD.

The structure of the BCVCC currently comprises a steering group and three workgroups with the following responsibilities[1]:

(1) Steering group: responsible for coordinating activities and communication between the other workgroups.

(2) Goal and Index workgroup: responsible for developing a perception based VAQ metric and for developing recommendations for VAQ goals.

(3) Science workgroup: responsible for VAQ monitoring instrumentation, modelling and data analysis to produce assessments of visibility science.

(4) Strategic Outreach workgroup: responsible for raising awareness of air quality impacts on visibility.

[1] See BCVCC, 2017.

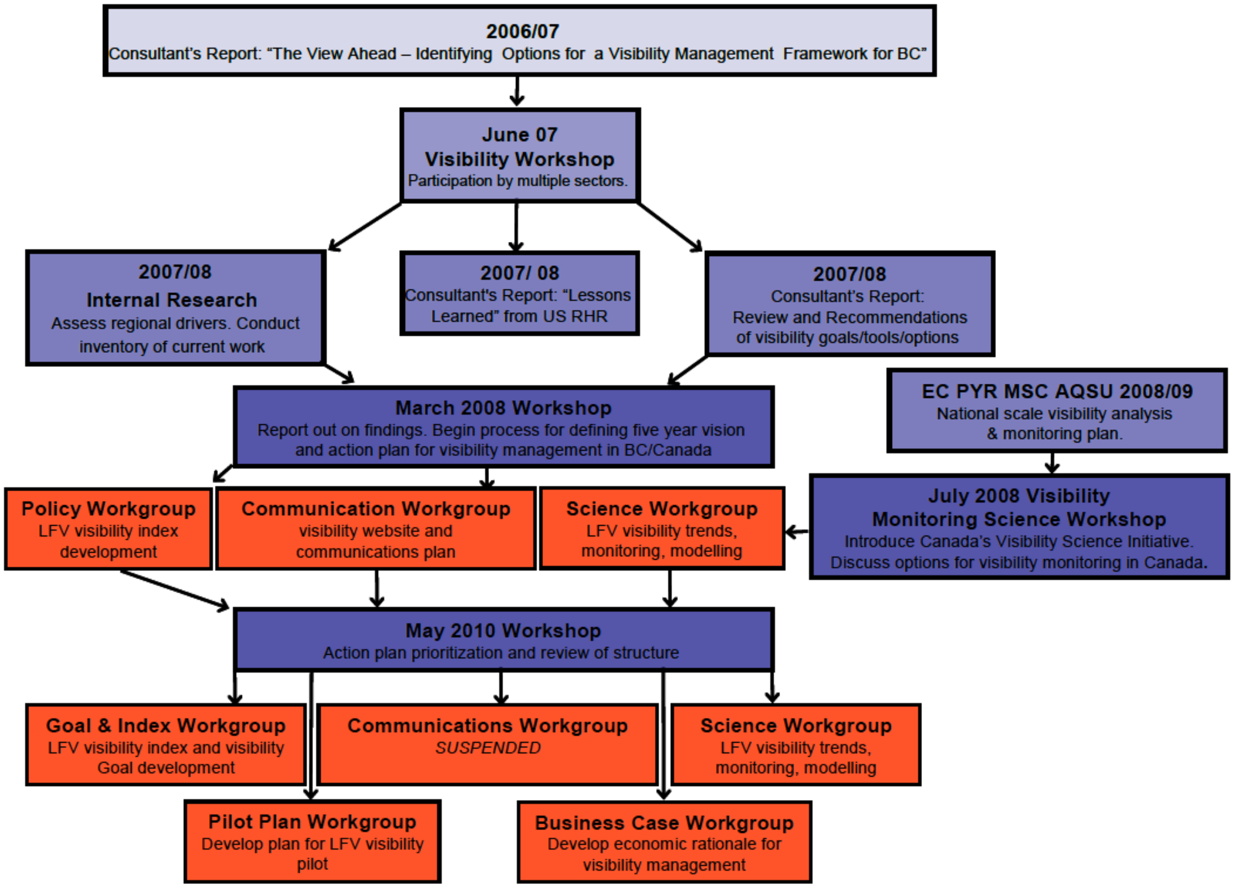
1.3 The origins of the LFV pilot

The BCVCC was establish in 2006 as a collaborative effort of the agencies it comprises. During the initial work, the BCVCC committed to understanding VAQ conditions in the LFV. As part of this process, in June 2007 a workshop was held by ECCC, ENV, MVRD and FVRD to discuss possible directions for managing visibility in LFV, with possible extension to other impacted areas in BC.

The 2007 workshop culminated in the report "The View Ahead – Managing Visibility in B.C.". This was an important first step in establishing policies and goals towards improving visibility. It was recognized that visibility is an important means by which the public perceives air quality, thus impacting residents and various sectors that are economically relevant for the region, including tourism and film industries. Several policy options were discussed in the workshop, including the development of a visibility management program, and the establishment of a regulatory framework for visibility in important areas.

Since 2007, other workshops have been held. They paid special attention to understanding what had been done in other regions, what technology for monitoring VAQ would be most appropriate, and what the ideal metric for measuring it would be. The various discussions and reports culminated in the creation of task-focused workgroups, to work on three main components to inform policy development: visibility index development, development of a visibility website and communications plan, monitoring and modelling VAQ and its trends. At a subsequent workshop in 2010, the pilot project was initiated and tasks divided between five workgroups. The organizational developments of the BCVCC from its formation to the beginning of the pilot study are described in Figure 1.

Figure 1: Key BCVCC organizational developments to 2010



Note: This figure was taken from BCVCC (2011) and describes the BCVCC developments from its formation in 2006 to the start of the pilot plan.

1.3.1 Pilot study and policy development timeline

The pilot project was initiated by the BCVCC in 2010 to devise proposals for a VAQ management strategy for the LFV. Workgroups were responsible for conducting different elements of the pilot study. The tools and findings developed by these workgroups were intended to be compiled into a comprehensive approach for visibility management.

Each workgroup and the agencies involved in the development of the pilot project made progress in terms of monitoring, measuring and tracking visibility, as well as in communicating it to the public. There were also important advances in terms of establishing goals and implementing policies targeting visibility improvements. Some of the key achievements are summarized below[2]:

- 2010 - 2011

  (1) Science: Monitoring, modelling and data analysis

  - Visibility monitoring upgraded and expanded.
  - Recommendations were made for targeting emissions reductions.
  - Measurements of real-time light extinction[3] began.
  - Link between air pollution and visibility, including the development of a model that relates $PM_{2.5}$ and VAQ investigated.
  - Relative contributions of pollutants to visibility degradation investigated.

  (2) Goal and index development

  - A visibility index that is easily trackable and communicated to the public was proposed.
  - A visibility goal was proposed, based on a visibility index supported by measurement data.

  (3) Economic benefits

  - A summary of visibility benefits was completed, including health, economic and environmental benefits.

[2]For more details on what has been achieved since the pilot study started, refer to the BCVCC annual reports: BCVCC (2011), BCVCC (2012), BCVCC (2013), BCVCC (2015), BCVCC (2017)

[3]For a description of light extinction refer to Section 2.1

(4) Pilot Plan workgroup

- Study on aboriginal perspectives was completed (Carlson, 2009).
- Workplan developed for pilot study.
- Strategic Outreach workgroup identified.

(5) Communications

- The website (cleanairbc.ca) was completed, providing an important tool of communication to the public.
- The workgroup was suspended until further communications activities required.

• 2011 - 2012:

(1) Science: Monitoring, modelling and data analysis

- New visibility monitoring site was established in Burnaby[4].
- Image metrics methodology developed by ECCC.
- Speciation extinction calculations were updated to include seasonality, and emissions sources contributing to visibility impairment.

(2) Goal and index development

- A near final index called the Visual Air Quality Rating (VAQR)[5] was developed.
- Visibility perception studies in Metro Vancouver and LFV were completed[6].
- A real time test site for the VAQR was developed.

(3) Economic benefits

[4] For more details on the monitoring sites refer to Section 2.2.
[5] For more details on the VAQR refer to Section 3.
[6] For more details on the visibility perception studies refer to Sections 4.2 and 8.2.

  - Assessed the health and economic benefits of improved visibility using the Air Quality Benefits Assessment Tool - AQBAT[7].

(4) Pilot Plan

  - Steering group was established to oversee the progress of the pilot project.

(5) Strategic outreach

  - The preliminary web interface to show real-time visual air quality rating was completed.
  - Strategy to engage different key audiences was developed.

- 2012 - 2013:

(1) Science: Monitoring, modelling and data analysis

  - The visibility monitoring site was re-established in Abbotsford.
  - Statistical models were developed to estimate light extinction from $PM_{2.5}$ measures, and for estimating $PM_{2.5}$ reductions necessary to achieve visibility goals[8].

(2) Goal and index development

  - Testing and preparations for public launch of the VAQR.

(3) Economic benefits

  - A report was prepared on the evaluation of the health and economics benefits of air quality improvements targeting visibility goals[9].

[7] For more details on the AQBAT refer to Sections 4.4 and 8.5.
[8] For more details on statistical modelling refer to Section 2.3
[9] For more details on the results of the study ENVIRON EC (2013) refer to Section 8.5.

(3) Strategic outreach

- Real-time display of VAQR was made publicly available on the clearairbc website.
- Development of fact sheets providing background information on VAQ, including health and economic benefits of visibility improvements.
- Visibility was rebranded "visual air quality" throughout clearairbc website to distinguish BCVCC project from other similar programs.

- 2013 - 2015:

(1) Science: Monitoring, modelling and data analysis

- All VAQ cameras in the monitoring network were upgraded.
- New VAQ-capable sites were established in Richmond and Pitt Meadows[10].
- A statistical VAQ model that provides near real-time estimates of time-resolved extinction was developed and published[11].
- The potential impacts of future emissions changes on visibility were investigated using the Environment Canada's photochemical model (AURAMS)[12].

(2) Goal and index development

- The development of the VAQR was completed, and it was tested through a public survey.

(3) Strategic outreach

- A stakeholder workshop was held with representatives from local governments.

[10]For more details on monitoring techniques refer to Section 2.2.
[11]For more details on the study by So et al. (2015) refer to Sections 2.3 and 6.1.
[12]For more details on modelling techniques and its results refer to Sections 2.3 and 6.2.

- Clearairbc website improved to enhance usability on mobile devices.
- Use of social media for public engagement was explored.

- 2015 - 2017:

  (1) Science: Monitoring, modelling and data analysis

  - Potential VAQ forecasting method were developed and tested.
  - Model-based investigations of effects on VAQ improvements of emissions reductions for specific species and sectors was completed[13].

  (2) Goal and index development

  - A study conducted to investigate VAQ goals (Sonoma, 2017[14]) was commissioned and prepared for the BCVCC. The report confirmed the use of VAQR for goal determination, and identified a possible need for assessing cold season and warm season VAQ separated.

  (3) Strategic outreach

  - An educational brochure providing information on pollution sources, how visibility can be affected by $PM_{2.5}$, and how pollution can impact health and ecosystems was developed and distributed.
  - A stakeholders workshop was held, with representatives from the health, tourism and real state sectors.
  - Visual air quality interpretive signs were installed in Metro Vancouver regional parks locations.

[13]For more details on modelling techniques and its results refer to Sections 2.3 and 6.1.
[14]For more details on the report refer to Section 3.

Part II: Pilot study activity

2 VAQ Science

2.1 Introduction to visibility

The atmosphere is composed of gases and suspended particulate matter (PM). Visibility degradation is the result of particulate matter and gases in the atmosphere interacting with light. Light scattering and absorption by those particles and gases determines the level of visibility impairment, and hence our ability to see the various landscapes, and distant hills and mountains. Monitoring, modelling and analysing VAQ data helps us manage our air resource.

Light scattering is an interaction of a light wave with an object that causes the light to be redirected in its path. Light absorption is the light absorbed by particles and gases. The can be tied together into what is called light extinction, which is the attenuation of light due to the scattering and absorption as it passes through the air[15]. The total light extinction is defined as:

$$b_{ext} = b_{scat,p} + b_{scat,g} + b_{abs,p} + b_{abs,g}$$

Where $b_{scat,p}$ and $b_{scat,g}$ are the light scattering by particles and gases, respectively, and $b_{abs,p}$ and $b_{abs,g}$ are the light absorption by particles and gases, respectively. The main factors that affect visibility when the air is polluted are the light scattering by particles, hence PM is responsible for most of the visibility impairment.

[15] For more details refer to CIRA (1999) and Hyslop (2009).

The haziness index measures of the amount of visibility impairment. It is measured in *deciview* units, and it has a more linear relationship to the perceived visibility than the light extinction. More specifically, one deciview is approximately the minimum change in visibility that is perceptible to a human observer:

$HazeIndex(dv) = 10 * ln(b_{ext}/10)$

Although this measure is more directly related to the human perception of visibility, it is still hard to associate the perceived VAQ to the light extinction or deciview measure.

Visual range (VR) is measured in distance units, typically kilometres, and it is the greatest distance at which a large black object can be seen on the horizon:

$VR(km) = 3910/b_{ext}(Mm^{-1})$

This measure is more relatable to the perceived VAQ, and more understandable for the general public than extinction and deciview.

The calculation of VAQ measures requires visibility monitoring instrumentation and air quality monitoring data, as well as reliable statistical and numerical modelling to provide analysis of the data. The next sections describe how each of these steps could be performed and its relevance to the LFV pilot study for assessing VAQ and its impacts.

2.2 Monitoring

VAQ cannot be defined by a single parameter, hence there isn't a single well-defined monitoring methodology. In general, there are three classes of monitoring methods that aim to quantify VAQ: view, optical, and aerosol monitoring.

2.2.1 Monitoring techniques

The simplest and most direct way to assess visibility impairment is with a photograph of the landscape, and relating the effects PM has on the appearance of the landscape. This is view monitoring, which consists of a systematic photography program that records images of the landscape under different concentrations of aerosol and different lighting conditions. Because this doesn't provide a direct measure of VAQ, this methodology is combined with some optical measure of either: (1) light scattering; or (2) atmospheric extinction.

Optical measurements are generally made in conjunction with particle measurements, or aerosol monitoring. They help infer the causes of visibility impairment, and to estimate the sources of the aerosols. Most visibility monitoring programs record size and composition as the two main dimensions to characterize these particles.

There are two main techniques used for optical monitoring[16]: nephelometry and transmissometry. Nephelometry captures light scattering by illuminating a chamber filled with a "sample" of the ambient air. This is a point-monitoring technique, so the location of the monitor must be chosen such that the air collected as a sample is representative of an area.

Transmissometry captures the attenuation of light over a range of up to 10 km, measured by the ability of the air to transmit light, and it can be converted to quantitative visibility measures such as light extinction. Here lies one of the main advantages of the transmissometers over the nephelometers; the former can capture the total light extinction, rather than just a component of it. Another advantage is that it provides a measure of visibility over a certain path instead of one point, which potentially makes the VAQ measurement more representative of a given area.

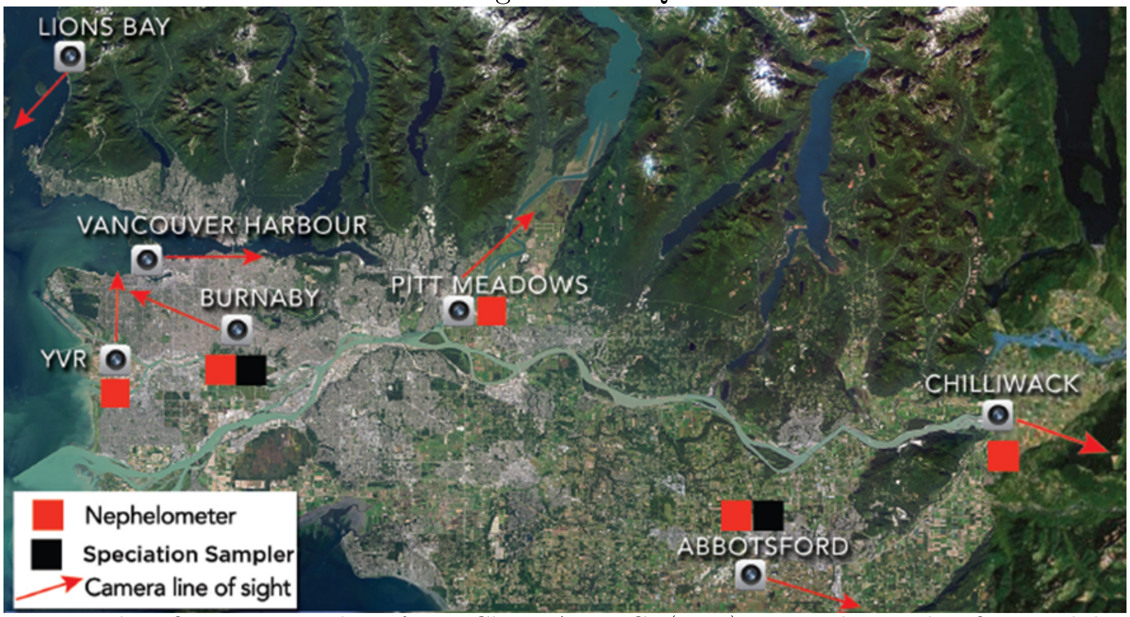
[16] For more details refer to Ministry for the Environment (2001)

Another monitoring technique worth mentioning is manual surveys. This involves asking individuals to evaluate visibility on a daily basis. Surveys conducted in the LFV region were used to develop the VAQR (see section 3). These involved rating photographs of views rather than daily observations. They provided important data for policy targeting visibility improvement since VAQ is mainly a phenomenon derived from human perception.

2.2.2 Monitoring sites

In the LFV visual air quality monitoring instrumentation is located at five sites. A nephelometer is used to measure light scattering, and light absorption is calculated using nitrogen dioxide (NO_2) and black carbon data. Besides the optical point measurements, these sites also include digital camera imagery, and visibility-related aerosol speciation measurements. It was established and maintained in order to obtain reliable real-time data for the calculation of the VAQR (see Section 3). The visibility monitoring sites (Vancouver Airport, Burnaby South, Abbotsford, Chilliwack and Pitt Meadows) and the additional camera sites (Lions Bay and Vancouver Harbor) located within the LFV are shown in Figure 2.

Figure 2: VAQ network



Note: This figure was taken from Clear Air BC (2015). It shows the five visibility monitoring sites in the LFV region: Vancouver Airport, Burnaby South, Abbotsford, Chilliwack and Pitt Meadows. It also shows camera locations in Lions Bay and Vancouver Harbor. For more information about the monitoring stations see *http://www.metrovancouver.org/services/air-quality/emissions-monitoring/monitoring/network/Pages/default.aspx*.

The monitoring stations capture measurements of various gases (such as NO_2 and Ozone), as well as PM_{10} and $PM_{2.5}$, and meteorological factors such as wind speed, wind direction and relative humidity (RH). The next section describes the importance of the statistical and numerical models alongside with monitoring data to examine VAQ in the LFV.

2.3 Modelling and Data Analysis

The different types of modelling used over the course of the pilot study aim to address three areas: (1) which pollutants/sources contribute to light extinction in the LFV; (2) how VAQ responds to changes in emissions and pollutants concentrations; and (3) what the health and economic impacts of changes in VAQ are[17].

[17] These last two models are described in Sections 4.4 and 4.1, respectively

The statistical and numerical modelling of light extinction alongside with source appointment analysis aims to predict VAQ based on air contaminants concentrations, and which pollutants contribute the most to visibility impairment. $PM_{2.5}$ is found to be the main contributor to visibility impairment in the LFV. So et al. (2015) describes a method that estimates 1-hour light extinction in real time, based on the measurements of PM collected by air quality instruments. This modelling is important given a limited number of existing VAQ stations, which doesn't allow for a fine-grained analysis of VAQ using only data collected by them.

In order to estimate the 1 hour light extinction in real time the model uses a linear algorithm from the Hybrid Method[18]. Besides the $PM_{2.5}$ the model's inputs include NO_2, RH measurements, and historical monthly-averaged aerosol composition. Although hourly concentrations of $PM_{2.5}$ are within moderate levels (less than $40\mu/m^{3}$[19]), the visibility becomes significantly affected with concentrations as low as $10 - 20\mu/m^3$.

The ECCC's photochemical model (AURAMS) also uses extinction calculations to predict the impact of possible future changes in emissions on local VAQ. The model uses historical data of VAQ and emissions, and the results were compared to the actual observations of visibility. According to the 2015 BCVCC annual report, *AURAMS was generally responsive to the large scale changes in emissions that have occurred within the region over the last 25 years, but it did have problems reproducing observed particulate nitrate concentrations*, systematically underestimating it.

The AURAMS model was used to examine the impacts of emissions reductions in nitrogen oxides, $PM_{2.5}$, SO_2 and VOC on local VAQ conditions. Scenarios with emissions changes by sector such as on-road vehicles, marine vessels, agriculture and industrial point sources were also modelled to predict its impact on VAQ.

[18] See Pitchford (2010).
[19] μ/m^3: micrograms per cubic meter.

These modelling work has a few limitations. One of them is seasonality. Light extinction tends to be higher in fall and winter months than in summer hours, but the modelling looked only at summer episodes. Another caveat is that the model uses a 24-hour averaging, which introduces confounding factors like the higher relative humidity of night-time hours.

These modelling techniques are important in understanding how air contaminants affect visibility in LFV, and to predict how changes in emissions are likely to affect VAQ. The models also provided estimates of the effects of changes in visibility on health outcomes, which are known to be significantly affected by air quality. The results of the science investigations are described in Section 6.

3 Index Development

As described in Section 2.1, VAQ is determined by air quality conditions. Air quality in the LFV is good most of the time, although survey results have shown that people's perception is that the visibility in the region has been deteriorating. This affects the residents' quality of life, and VAQ impairment can also be associated with negative effects on health. However, VAQ measurements reported in terms of light extinction are not intuitively understandable to the general public.

Given the importance of visibility as a reference for air quality management, the development of an index to quantify and track changes in the VAQ was necessary. Inspired by visibility indices elsewhere and recommendations received by the BCVCC, and based on perception studies, the BCVCC and its agencies developed the Visual Air Quality Rating (VAQR).

3.1 Construction

The VAQR is the current metric for VAQ in the LFV. It is based on physical and chemical measurements and related to human perception. The perception information comes from surveys where participants rate photos of landscapes with varying degrees of visibility degradation. Having a perception-based rating rather than an exclusively quantitative one (i.e., light extinction, deciviews or VR[20]) is more meaningful for the public.

VAQR categories were defined based on people's rating of VAQ, correlated with light extinction. Light extinction was calculated based on data from the monitoring network[21]. The VAQR relates the physical measurements to help people perceive visibility.

[20] These measures are described in Section 2.1

[21] Described in Sections 2.2 and 2.3

The VAQR categories, excellent, good, fair, poor and very poor, deciviews and extinction ranges. Table 1 summarizes findings from surveys in which the participants were asked to rate the image by acceptability of the degree of visibility impairment (see Kellerhals, 2016).

Table 1: VAQR

VAQR Category	**dv range**	b_ext **(Mm^{-1})**	**VR (km)**	**% rating scene as acceptable**
Excellent	<11	<30.04	130	>99.5%
Good	11 to 16.5	52.07	75	93.5 to 99.5%
Fair	16.5 to 22	90.25	43.2	47 – 93.5%
Poor	22-27.5	156.4	24.9	5 to 47%
Very Poor	>27.5	>156.4	130	<5%

The VAQR is valid during daylight hours (from sunrise +2 hours to sunset -2 hours) and with RH at or below 75%. A survey conducted by the Environics Research Group in 2013[22] showed that the participants' ratings of VAQ were in reasonable agreement with the VAQR (as reported in Table 1), and also indicated that the individuals surveyed perceived the index as useful and understandable.

The VAQR in its current form defines a VAQ event as "at least one hour in a day at more than one station, or at least one hour on at least two consecutive days at one station"[23]. An event of visibility impairment represents light extinction that would result in a "poor" or "very poor" VAQR.

3.2 Purposes

The fact that the VAQR metric is aligned with the perceived visibility impairment helps to offer reporting of VAQ in a meaningful way for the public. This is one of the main purposes

[22] See Environics (2013)

[23] Kellerhals (2016)

of the index. The VAQR can also be directly linked to recommendations to the public through an outreach program, such as taking actions to reduce VAQ impairment (and hence air pollution).

The VAQR can be used to provide evidence that the issue of visibility impairment is being targeted; an engagement tool, so people can be informed about the issue; and a reporting and accountability tool, that allows stakeholders to keep track of the changes in VAQ.

3.3 Issues and challenges

In constructing the VAQR, RH and light scattering are the main components that must be taken into account. BC and NO_2 are also important components. Data completeness of 75% for these components is required, and analyses show a substantial amount of missing data resulting from instrument malfunction, especially for light scattering. Data substitution options have been evaluated, but that is not ideal especially for light scattering, which has a significant temporal and spatial variability.

According to a study commissioned by the BCVCC (Sonoma, 2017), some aspects of the VAQR required refinement. The use of daylight as 2 hours after sunrise and 2 hours before sunset reduces the number of daylight hours available for recording the VAQR. A related issue, also associated with the validity of the index during daylight hours, is that warm seasons are going to be overrepresented in the metric due to longer days. Because of differences in weather between the seasons affecting the composition and spatial distribution of pollutants, having one season dominating the metric can lead to biased yearly measurements. Sonoma (2017) suggested some solutions for the seasonal issue, such as considering seasons separately. Despite these issues there is still a consensus that a visibility metric should be based solely on daylight hours, because those are the most important for the public perception of visibility.

4 Economics

Visibility is not a market commodity, so it is hard to establish a value to it. At the same time, visibility degradation can impose high costs to the residents and sectors. Hence, it is important to use reliable economic methods to estimate the potential benefits of visibility improvements. Some of these methods and studies that have been done both for the LFV and other regions are described below. The results of these studies are described in Section 8.

4.1 Visibility valuation techniques

4.1.1 Contingent Valuation

Kumar et al. (2007) documents the methods and results of a visibility valuation study in the United States. The method employed to value non-market goods is contingent valuation (CV), and it estimates the willingness to pay (WTP) for visibility improvements based on surveys that ask subjects directly how much these improvements are worth to them.

The survey displays a sequence of photographs with different degrees of visibility impairment, and subjects were asked the dollar amount they were willing to pay for each visibility improvement scenario. One of the main complications of this kind of technique is that the WTP is directly linked to the budget constraints of the participants. Another caveat is that it is hard to separate the value people attribute to improvements in visibility itself from other benefits associated to it, such as health benefits.

4.1.2 Contingent Choice

Given the limitations of the CV method, an alternative is to use the contingent choice (CC) method, often referred to as Discrete Choice Experiment. The CC method is more flexible in the sense that it incorporates multiple choice sets with two or more alternative visibility scenarios, that are described in terms of several attributes. Rather than asking respondents about their WTP for a single improvement in visibility, a CC study forces respondents to repeatedly choose between various improvements at various costs.

In the study by Haider et al. (2002) this method was used in order to estimate welfare effects associated to different visibility scenarios, and hence the economic value of improved visibility in the Lower Mainland of British Columbia[24]. The attributes used in the CC method were visibility levels, health risk (measured by the Air Quality Index), and costs for the household given the visibility scenario. There were three visibility levels (poor, medium and excellent), based on visual range and deciviews[25].

These three attributes were combined to form several choice sets for air quality option. Based on the choices of the respondents the authors estimated utility functions for each attribute[26]. Then, they statistically estimated the importance of each attribute in determining the utility levels associated to different visibility scenarios using a regression model, and calculated welfare measures for changes in VAQ. The results of the study provided an estimated monetary value for visibility improvements and are described in Section 8.1.

[24]That includes the Greater Vancouver Regional District (GVRD) and much of the FVRD (FVRD)
[25]For a description of these measures, refer to Section 2.1.
[26]Refer to Haider et al. (2002) for more details.

4.2 Perception studies in the LFV

A few perception studies have been done in the LFV region. These use similar survey techniques but ask the subjects to rate images with different degrees of visibility impairment, based on the respondents' own perception.

McNeill & Roberge (2011) presented multi-day visibility scenarios to a focus group. They selected slides with varying degrees of visibility and created a 10-day visibility scenario in each location. The subjects were asked whether each of those images violated their personal standard of visibility degradation.

In Gallagher & McKendry (2011) subjects were shown photographs of scenes in the LFV under various air quality conditions and were instructed to rate each picture based solely on how the air looked (i.e., without considering any health benefits associated to improved visibility).

Although subjects are not asked to put a dollar value to each image in these studies, the results of such studies (described in Section 8.2) can provide a quantitative reference for the importance people attribute to VAQ in the LFV.

4.3 Valuation for tourism

Visibility is important for the tourism industry, especially in the LFV where the ability to view landscapes and vistas are important tourist attractions. With that in mind, a study by McNeill and Roberge (2000) estimated the impact of poor visibility episodes on tourist revenue in the LFV.

The first stage of the study was a survey where tourists were asked to rate images of from four camera locations in the LFV, including Vancouver, during the summer of 1999. The subjects rated the images as acceptable or unacceptable. In the second stage, they performed a statistical analysis with the acceptability rates as a function of visibility (measured by light scattering), cloud cover and socioeconomic variables. In other words, the estimated violation rate equations were used to predict the total number of tourists whose visibility standards would be violated for a given level of visibility impairment. In the third stage, an economic model incorporated the estimated relationships from the second stage to predict losses in future tourist revenues from poor visibility episodes. These estimated tourism revenue losses were calculated based on changes in return visits and new visits generated by "word of mouth" advertising. The results of this model are described in Section 8.4.

4.4 Valuation for health

The statistical model outputs (described in Section 6) were used as input into the Health Canada's model Health Canada's AQBAT[27]. The goal of the model is to predict the impact of changes in concentrations of $PM_{2.5}$ on health outcomes, and to estimate the value of health benefits under different scenarios of $PM_{2.5}$ concentration reductions in the LFV as a result of achieving specific visibility improvement goals.

The first step was to develop scenarios of different ambient $PM_{2.5}$ concentrations over the 2015-2035 period. The AQBAT establishes a relationship between health endpoints (for example, respiratory hospital admissions, adult and child chronic bronchitis cases, cardiac hospital admissions, among others) and changes in air pollution and visibility using concentration response functions (CRFs). Ten different visibility change scenarios were modelled for the defined period, each using changes in $PM_{2.5}$ associated to VAQ improvements. The

[27]See ENVIRON EC (2013), prepared for Metro Vancouver.

scenarios considered were both quantitative[28] and perception-based[29].

More than estimating the impact of air pollution itself on health, the use of AQBAT combined with statistical modelling provides a means to estimate the direct impact of visibility on health outcomes. The values for most of the endpoints are determined from willingness to pay studies endorsed by Health Canada. The results are described in Section 8.5.

[28]Scenarios 1-4 considered changes ranging from 0.45-3 dv.

[29]Scenarios 5-10 considered changes in the amount of poor to excellent visibility hours.

5 Strategic Outreach

5.1 Is VAQ important to stakeholders?

VAQ metrics are a potentially effective way of communicating to general audiences about air quality. Section 8.1 describes the results of visibility valuation studies that have been done in the region and elsewhere. Not only are people aware that visibility impairment exists and that it is closely related to air quality, but it also seems that they attribute a value to having it improved. As shown in Haider et al. (2002), an economic model predicted that there are significant welfare improvements associated to achieving better VAQ, and that people are willing to pay for it. Visibility also has the potential to affect some business sectors in the LFV, especially the tourism industry, as well as having impacts on health[30].

Hence, it is important to inform and engage interested parties - namely, residents, First Nations, and sectors affected by it - about VAQ and the policies targeting it. One of the aspects of the pilot study is the creation of communication and engagement tools for public audiences.

An important way to reach out to stakeholders after the start of the pilot project was the creation of the strategic outreach workgroup. According to BCVCC (2012), its main goals were to *identify and establish engagement mechanisms to reach potential partners and stakeholder groups, to determine the appropriate timing of visual air quality outreach and communication activities, and to develop proactive communication strategies specific to different groups of stakeholders.*

[30] See McNeill and Anne (2010) and ENVIRON EC (2013).

5.2 Informing stakeholders

One of its first important accomplishments of the strategic outreach workgroup was the creation of a web interface (clearairbc.ca) to show near real-time visual air quality rating, inform the public about the benefits of improving VAQ, and provide information on how people can help improve visibility. Another communication tool developed by this workgroup was factsheets, which provided background information about VAQ. Findings from studies that evaluate health and economic benefits of VAQ improvements were integrated in the factsheets. The strategic outreach group also provided support for the science and goal, and index workgroups in terms of publicly launching the VAQR and sharing science findings.

The strategic outreach workgroup also made other advances in terms of communicating VAQ to the public. One of them was the development of a clear air brochure that provides information on pollution sources and how scenic views can be obscured by $PM_{2.5}$. A second initiative was to install clear air signs in regional parks in the Metro Vancouver region. The signs provide similar information to the brochure, but are specific to each location where a sign is installed.

A social media based outreach campaign was developed to share information about VAQ, but could not be implemented during the pilot study.

5.3 Engaging stakeholders

The agencies involved in the pilot study have undertaken some stakeholder engagement activities. The workshop held in 2007, which culminated in the report "The View Ahead" (Workshop Report, 2007), had various representatives of local sectors participating. Participants were introduced to background on the issues, visibility science and management regimes in other jurisdictions[31]. A few workshops had also been held before the pilot study started with participants from multiple sectors (see Figure 1).

Workshops held during the pilot study reached out to local government staff and representatives from the health, tourism and real estate sectors[32]. The major concerns expressed by the participants were the negative impacts that VAQ might have on health, and on the attractiveness of the region as a tourist destination. The policy recommendations and topics discussed are presented in Section 9.

[31] For more details on the workshop refer to Section 1.3.

[32] See BCVCC(2017)

Part III : Findings of the pilot study

6 Key Science Results

According to BCVCC (2015) the BCVCC science workgroup made significant progress in expanding air quality monitoring and measuring capacity, as well as in understanding the determinants of VAQ degradation during the pilot study. As described in Section 2.2, there are currently five visibility monitoring sites in the region, and the data collected by them combined with modelling techniques provided an understanding of the relationships between air pollution and visibility and the effects of emissions reductions on VAQ.

6.1 Pollution and visibility

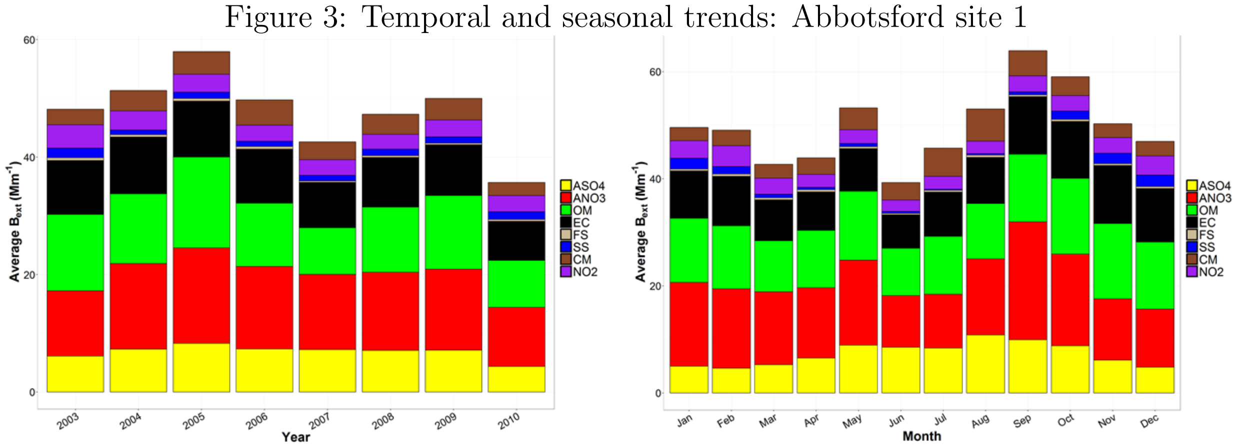
As described in the 2017 BCVCC annual report, numerical modelling indicated that reducing primary $PM_{2.5}$ emissions is the most effective way of improving visibility in the LFV. The results of the model developed by So et al. (2015), described in Section 2.3, suggest that to achieve a reduction of 1 deciview (which is an improvement perceptible to the human eye) on average visibility levels in the LFV airshed, average ambient $PM_{2.5}$ levels would have to decrease by 17%. In terms of VAQR, in order to increase the number of "excellent" visibility hours by 20% the ambient levels of $PM_{2.5}$ would have to be reduced by 30%. A reduction of 10% in average $PM_{2.5}$ concentrations would decrease the amount of "very poor" (> 27.5 deciviews) visibility daylight hours by 50%.

The results presented by So et al. (2015) also suggest that it is less costly (in terms of emissions reductions) to decrease the number of "poor" visibility days than to increase the number of "excellent" visibility days.

The results from statistical trend analyses and retrospective modelling (that looks at historical visibility events) found that significant emissions reductions in the LFV since 1993 have resulted mostly in a decrease of "Poor" and "Very Poor" visibility hours, as measured by the VAQR. Based on photochemical modelling, according to ECCC and U.S. EPA (2014) the improvement in visibility under different scenarios estimated by the AURAMS has been largely driven by emission reductions in electricity generation and base-metal smelting sectors.

Figures 3, 4 and 5 show the yearly average extinction by component and the average by month of the light extinction by component for three visibility monitoring sites, namely, Abbotsford 1, Abbotsford 2[33] and Burnaby, respectively. In other words, they show which components for these two locations contributed on average for the local visibility conditions. As we can see, in both sites it seems that ASO_4, ANO_3, OM and EC are the main contributors, on average. The seasonal trends show that the visibility conditions change throughout the year, but the relative contribution of each component is relatively constant.

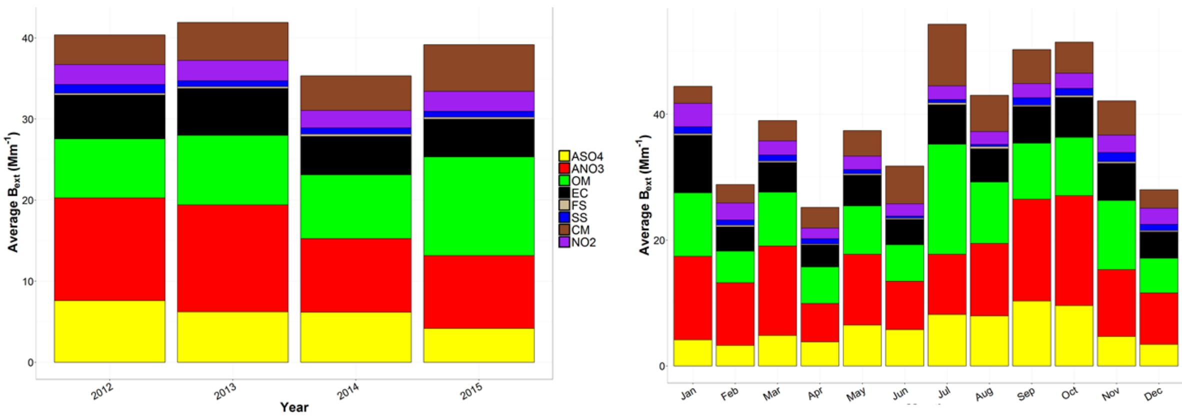
Figure 3: Temporal and seasonal trends: Abbotsford site 1



Note: This figure was taken from Jones (2017). The first graph on the left plots the yearly average extinction by component at the Abbotsford site 1 (ABB1), from 2003 to 2010. The second graph plots the average by month of the extinction by component across 2003-2010 at the Abbotsford site 1 (ABB1). The graphs are not on the same scale.

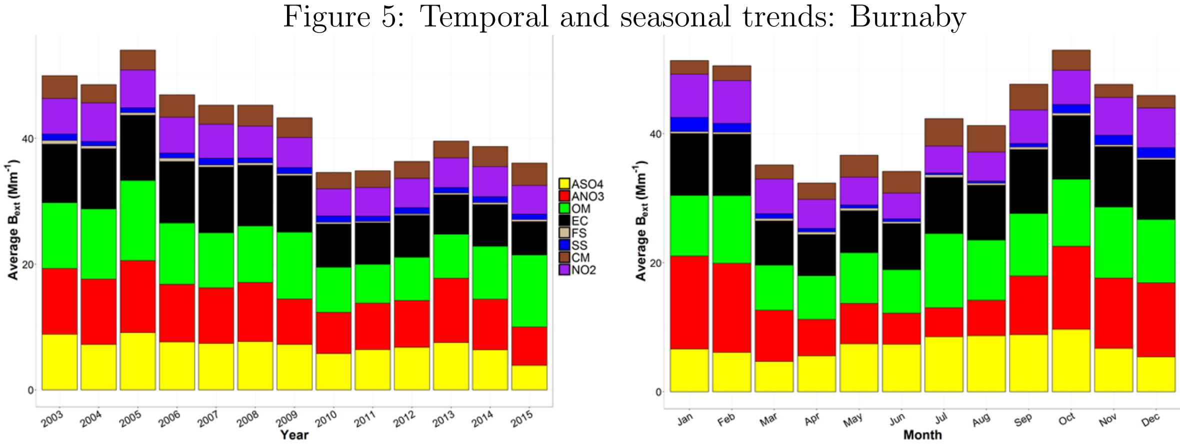
[33] The Abbotsford monitoring site was updated in 2012.

Figure 4: Temporal and seasonal trends: Abbotsford site 2



Note: This figure was taken from Jones (2017). The first graph on the left plots the yearly average extinction by component at the Abbotsford site 2 (ABB2), from 2012 to 2015. The second graph plots the average by month of the extinction by component across 2012-2015 at the Abbotsford site 2 (ABB2). The graphs are not on the same scale.

Figure 5: Temporal and seasonal trends: Burnaby



Note: This figure was taken from Jones (2017). The first graph on the left plots the yearly average extinction by component at the Burnaby site (BBY), from 2003 to 2015. The second graph plots the average by month of the extinction by component across 2003-2015 at the Burnaby site (BBY). The graphs are not on the same scale.

6.2 Determinants of visibility

Another important aspect targeted by the numerical and statistical modelling conducted by ECCC was to estimate which pollutants contribute most significantly to local visibility impairment. Results showed that the highest contributors to light extinction on days with the worst visibility (bottom 20%) were particulate nitrate and organic matter. Emission reductions of nitrogen oxides (NO_x) are also effective, and together with volatile organic compounds (VOCs)[34] appear to be more effective during high ozone days. SO_2 reductions seem to be more effective during daytime than at night.

One of the main sources of emissions of PM was found to be associated with combustion processes and transportation. Fifty percent of on-road sector emission reductions resulted in moderate visibility improvements, but only at certain hours. Agricultural emissions reductions separately caused only moderate visibility improvements.

Jones et al. (2012) analyzed ammonia emissions from poultry and dairy farm production. They took advantage of a natural experiment that resulted in a reduction of production due to the outbreak of influenza in poultry, centered in the Abbotsford area of the LFV in Feb 2004. They found that ammonia emissions reductions alone don't seem to play a huge role in improving visibility, and it is most effective only under certain meteorological conditions, as shown by scenario modelling.

[34] Examples of VOCs: benzene, methylene chloride, toluene.

7 Using the VAQR

7.1 Reporting

The data collected at VAQ monitoring stations in the LFV (described in Section 2.2) were used to track the state of visibility impairment through the VAQR. New sites (Pitt Meadows) and new equipment were installed (refer to Section 2.2 for details on monitoring progress), including cameras and measurements of light scattering, to help quantify and report the VAQR.

7.2 Public communication

An online platform[35] is maintained to serve as a guide to visual air quality in the region. In addition to showing real-time VAQR and rated images of each community near the monitors, it also displays information about the main sources of visibility impairment. The online platform also has useful information on how the public can play a part in improving VAQ by making choices that reduce emissions, and how these choices might also contribute to the improvement of health and life quality in general.

As mentioned in Section 3.1, the VAQR is linked to perception testing studies in order to facilitate the communication of its progress to the general public. With the public perception aligned to the metric, individuals can be actively engaged in contributing to the improvement of VAQ when visibility is impaired. The VAQR is reported publicly on the BCVCC online VAQ platform (see Section 5.2)

[35] See www.clearairbc.ca.

7.3 Performance metrics and goal progress

The VAQR serves as a reference metric for the development of visibility goals in the LFV. The possible goals that could be adopted for the next 5 to 15 years include reducing the number of days/hours of very poor visibility to one a year; reducing the number of days/hours of poor visibility by 50%; increasing the number of excellent days/hours by 10% or more. This last goal has to be coupled with emissions reductions, given the relationship between air quality and visibility impairment described in Sections 2.3 and 6.

Vingarzan et al. (2016) summarized the analysis of the VAQR progress and concluded that there were visibility improvements of about 3 dv from 2003 to 2012. Additionally, emissions reductions since the 1990's resulted in substantial decrease in hours with poor and very poor visibility according to the VAQR. However, increasing the number of excellent visibility days requires greater emissions reductions than reducing the amount of very poor and poor visibility days.

Table 2 shows the number of days with at least one hour of visibility impairment, which means 'poor' or 'very poor' VAQ, at one or more sites (Abbotsford, Burnaby, Chilliwack and Richmond) over the period 2011 to 2015. Over the period 2011-2015, most of the days with poor or very poor VAQ had only one site that reported so (about 60% of such days), which might be a sign that impaired visibility events are isolated. During the summer, the effect of wildfires could mask improvements being made in VAQ, and this is an issue for using the metric as an indicator of tracking progress on visibility.

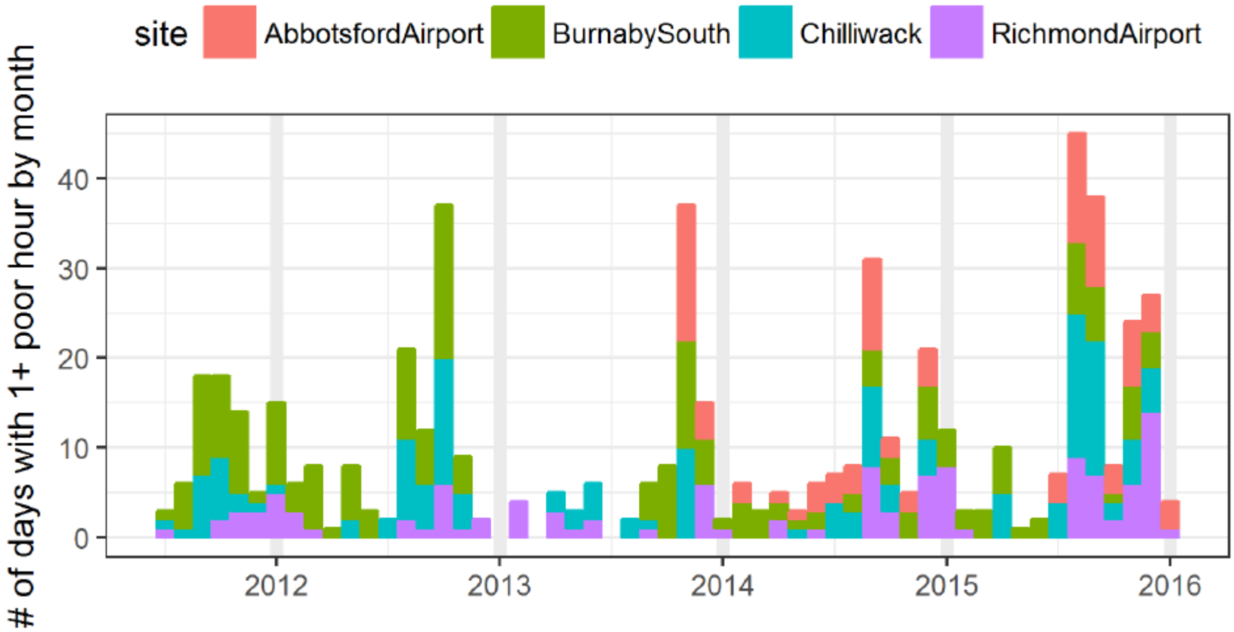
Table 2: Impaired Visibility Days: 2011-2015

No. of Sites with Poor Visual Air Quality	No. of Active Sites	Count of Days	Percent of Poor Visual Air Quality Days
1	4	49	60.4% (one site only)
1	3	86	
1	2	54	
2	4	22	39.6% (multiple sites)
2	3	40	
2	2	18	
3	4	10	
3	3	18	
4	4	16	

Note: The table reports the counts of days with at least one hour of poor or very poor visual air quality at one or more sites over the period 2011 to 2015. The figure was taken from Sonoma (2017).

Figure 6 shows the number of days with at least one hour of impaired visibility by month at each of the four stations over the period 2011 to 2016. Abbotsford Airport data were not available until late 2013, so the inclusion of this site led to an increase in the number of 'poor' and 'very poor' visibility days. There was a increase in the number of impaired visibility days from 2015 to 2016, but the data reports that there were very few 'very poor' visibility hours. The Chilliwack and Richmond sites are the ones that reported the biggest increase in the number of impaired visibility days from 2015 to 2016.

Figure 6: Impaired Visibility Days by Month and Station: 2011-2016



Note: The graph shows the number of days with at least one poor/very poor hour at each site. Abbotsford Airport data were not available until late 2013. The figure was taken from Sonoma (2017).

8 Economic Benefits

8.1 Economic valuation results

The results of the contingent valuation (CV) in Kumar et al. (2007) (described in Section 4.1.1) suggest that the willingness to pay (WTP) for an average improvement of 1 dv in visibility is US$ 42, and the WTP for an improvement of 5 dv is US$ 56[36]. WTP for visibility improvements appears to be non-linear in the sense that after an initial improvement people don't seem to assign much value to additional ones.

It is hard to translate the dollar values attributed to visibility from a survey conducted somewhere else to the WTP for clear air in the LFV. However, if we try to relate the non-linearity in the WTP to the metric for VAQ developed for the LFV (the VAQR, described in Section 3) it would mean that people would be willing to pay more, for instance, for an improvement from a baseline 'very poor' visibility hour to a 'poor' visibility hour, rather than from 'good' to 'excellent'.

The results for the contingent choice (CC) in Haider et al. (2002) (method described in Section 4.1.2) are the most reliable estimate for valuation of VAQ improvements in the Lower Mainland BC, including the LFV. All three attributes (visibility level, health risks and costs for the households) are highly statistically significant in determining utility levels associated to visibility, meaning that they are important in determining how much people value visibility in the region. People value visibility improvements and reduced health risks, and the costs associated with having reduced visibility have a negative impact on the utility.

The welfare measure calculations use the coefficients estimated by the CC method for each

[36] In 2003 US$.

attribute to estimate a monetary value associated to visibility improvements. The estimated welfare gains per household of increasing the number of excellent visibility days (5.8 – 16.9 deciviews[37]) per year by 1.69, 3.37 and 6.74 are \$29.38, \$35.77 and \$48.55[38], respectively. There effects are lower than the ones estimated by several studies done in the US, and that is partly because the CC method allows us to separate the role of visibility effects alone from the health effects associated to air pollution.

8.2 Impacts on residents

Several visibility perception surveys have been conducted in the LFV over the years, and some of them are described in Section 4.2. The main results of those surveys are described below. They can be thought of as potential impacts that visibility changes can have on the population that is affected by it.

McNeill & Roberge (2011) created quintiles based on levels of scene degradation in each slide shown to the respondents. The results showed that slides in the worst three quintiles (i.e., the 60% worst images in terms of visibility degradation) had a significant effect on acceptability of the respondents, however they seemed to perceive very little difference within those 60%. The results also indicated that older respondents tended to have higher expectations about visibility.

An important finding in McNeill & Roberge (2011) was that respondents tended to attribute greater importance to the number of good visibility days when determining the acceptability of multi-day scenarios. Hence, the most effective policy targeting visibility improvement would be to increase the number of good visibility days, rather than to reduce the number

[37]For a description of deciview refer to Section 2.1.

[38]In 2002 C\$.

of extremely bad days by improving them only marginally.

In the survey described in Gallagher & McKendry (2011), the majority of the respondents (40%) felt that VAQ is deteriorating in the LFV, while only 4% felt that it has improved. They also found that younger survey respondents tended to give higher VAQ ratings than older respondents, suggesting that age is an important factor to be taken into account and that older residents' perception may be more affected.

8.3 Impacts on First Nations

First Nations communities are affected by visibility impairment in different ways. In particular, Carlson (2009) indicated that LFV indigenous people are concerned about the impact of VAQ on their ability to see landscapes associated with geographic orientation needed for movement; at the same time there is an important link between being able to see certain geographic features and being able to communicate knowledge about those features to members of the next generation. In general, there are specific cultural perspectives of Aboriginal people that generates specific concerns related to decreased visibility.

8.4 Impacts on tourism revenues

As described in Section 4.3, tourism is an industry that has to be taken into consideration when evaluating the economic effects of impaired visibility in the LFV region. Based on the results obtained by the survey, response functions and economic modelling in McNeill and Roberge (2000), it is possible to predict the response of the tourists to impaired visibility episodes and to estimate potential losses in tourism revenues in the region.

The economic model estimated that assuming the worst visibility impairment event, represented by a light scattering index that ranged from 0.018 to 0.126, with the worst impairment being at 0.126, the Vancouver area and the FVRD would experience a loss of revenues of about $7.45 million and $1.32 million[39], respectively. Even for a more realistic scenario (where the index is 0.09), the loss in revenue for the LFV region was predicted to be around $1 million. These are losses associated with a single visibility event. There was insufficient data available to calculate mean annual losses.

8.5 Impacts on health

It is known that air pollution has significant impacts on health. The Public Health Officer's Annual Report in 2013 concluded that air pollution results in roughly 200 premature deaths per year in Canada, and some methods estimate the number of premature deaths to be three times as high.

ENVIRON EC (2013) presented the AQBAT model (described Section 4.4) estimates of health benefits associated with reductions in $PM_{2.5}$ concentration and visibility conditions for the period 2015 to 2035, in the LFV. The model incorporated population growth forecasts, and various scenarios of visibility improvement or degradation of $PM_{2.5}$ and visibility.

In terms of health benefits, the main model estimated that: (1) the total number of days with acute respiratory symptom avoided ranged from 3.8 to 19.9 million; (2) the number of premature deaths avoided due to ischemic heart disease ranged from 1,032 to 5,259. In terms of monetary values, the benefits associated to air pollution/visibility improvement from this assessment ranged from $400 million to $2.2 billion annually.

[39] In 2000 CAD$.

9 Strategic Outreach Outcomes

9.1 Information from dialogues and surveys

As mentioned in Section 5.3, stakeholders workshops about visibility conducted in the LFV are an important tool that the BCVCC and the agencies involved in air quality management have to engage and inform interested parties about VAQ.

Section 8.2 describes the results of various visibility perception studies that have been done in the region. The subjective nature of VAQ means that the setting of a standard for visibility conditions requires input from persons residing in the relevant area.

McNeill and Anne (2011) showed that the residents of Lower Mainland of B.C. are highly aware of differences in visibility impairment on hours with relatively good and bad VAQ. Gallagher and McKendry (2011) reported that the most common opinion among survey respondents was that visibility in the region has been deteriorating. Residents who were interviewed also seem to have defined personal standards on what they thought was the ideal level of visibility impairment.

First Nations people also value visibility, and besides being equally affected by it in most ways, they also have a cultural attachment to the views they are able to see.

9.2 Communication methods tested

In the 2015 workshop with stakeholders held by the strategic outreach workgroup[40], participants suggested that the agencies involved in air quality management increase efforts

[40] For more details refer to Section 5.3.

to improve air quality throughout the Lower Mainland through tighter emission standards, improved public education and managing growth.

Discussions found that stakeholders felt that the best policy should focus on increasing the number of excellent visibility days, instead of reducing the number of poor visibility days. That agrees with the most effective policy in terms of public preferences shown by the results of the survey in McNeill and Anne (2011)[41]. It also agrees to the results of statistical modelling, that suggested that an increased number of excellent visibility days is easier to achieve in terms of emissions reductions. This evidence suggests that the results from the perception studies and statistical modelling are aligned with the stakeholders preferences.

9.3 Effectiveness of the website

The web analytics data have been presented at BCVCC meetings. However, a formal report assessing web traffic was not available at the time of preparing this report.

[41]For more detail on the results of perception studies refer to Section 8.2.

Final Remarks

This report synthesized the outcomes of the various elements of the LFV visual air quality pilot study, especially features that might be relevant for the development of a visual air quality program.

Several key achievements of BCVCC and its agencies over the last few years have been described, in terms of features that are necessary for the development of a VAQ management program. Over the last decade agencies were able to implement and improve the VAQ monitoring technologies, as well as investigate modelling and data analysis techniques. Together, monitoring, modelling and data analysis of VAQ helped linking it to air pollution, and provided reliable estimates of future changes in visibility for various emissions scenarios.

Additionally, the agencies involved invested in the development of models that predict economic and health benefits of improving VAQ. The results of those models point us to the direction that impaired visibility is indeed costly for the region.

These models and findings are important for establishing policies because it gives a reference of what should be improved in terms of emissions, the costs of implementing regulations, and the benefits of improving VAQ. Having reliable estimates of the costs and benefits of each policy helps us choose the best set of regulations and goals targeting VAQ improvement. Tracking changes in VAQ is also necessary in this setting, and the agencies involved have established a reliable VAQ index that is easy to communicate to the public.

Finally, the process of developing goals and policies, which is currently in progress, has engaged the public affected by it, namely residents and stakeholders from various sectors. There is still a lot to be achieved, improving the monitoring systems, further investigating the costs and benefits of each policy, and engaging the stakeholders in every aspect of it.

References

British Columbia Visibility Coordinating Committee (2011). "2010 – 2011 Report: Working to Clear the Air in BC". BCVCC.

British Columbia Visibility Coordinating Committee (2012). "2011 – 2012 Report: Working to Clear the Air in BC". BCVCC.

British Columbia Visibility Coordinating Committee (2013). "2012 – 2013 Report: Working to Clear the Air in BC". BCVCC.

British Columbia Visibility Coordinating Committee (2015). "2013 – 2015 Report: Working to Clear the Air in BC". BCVCC.

British Columbia Visibility Coordinating Committee (2017). "2015 – 2017 Report: Working to Clear the Air in BC". BCVCC.

Carlson, Keith Thor (2009). "Mountains that See, and that Need to Be Seen: Aboriginal Perspectives on Degraded Visibility Associated with Air Pollution in the BC Lower Mainland and Fraser Valley". Prepared for Environment Canada, May 2009.

Cooperative Institute for Research in the Atmosphere - CIRA (1999). "Introduction to Visibility". Air Resources Division National Park Service: NPS Visibility Program.

Environics Research Group (2013). "Evaluation of the proposed Visual Air Quality Rating". Prepared for Greater Vancouver Regional District, July 2018.

Environment Canada and U.S. Environmental Protection Agency (2014). "Georgia Basin - Puget Sound Airshed Characterization Report". Vingarzan R., So R., Kotchenruther R., editors. Environment Canada, Pacific and Yukon Region, Vancouver (BC). U.S. Environmental Protection Agency, Region 10, Seattle (WA). ISBN 978-1-100-22695-8. Cat. No.: En84-3/2013E-PDF. EPA 910-R-14-002.

ENVIRON EC (2013). "Health and Economic Benefits of Visibility Improvements in the Lower Fraser Valley of British Columbia."

Gallagher, John, and McKendry, Ian (2011). "Visibility Perception in the Lower Fraser Valley, BC". Department of Geography - University of British Columbia, Vancouver, BC.

Haider, Wolfgang, Moore, Jeff, Knowler, Duncan, and Anderson, Don (2002). "Estimating Visibility Aesthetics Damages for AQVM". Prepared for Environmental Economics Branch, Environment Canada, August 2002.

Hyslop, Nicole Pauly (2009). "Impaired visibility: the air pollution people see". Atmospheric Environment 43.1 (2009): 182-195.

Kellerhals M. (2016). "The Visual Air Quality Rating (VAQR): a metric for visual air quality in the Lower Fraser Valley." Presented to the British Columbia Visibility Coordinating Committee, June 24.

Kumar, Naresh, Smith, Anne, and Tombach, Ivan (2007). "Economic Valuation Studies of Visibility Improvement". Air & Waste Management Association.

Jones, Keith (2017). "Visibility Analyses using LFV NAPS Speciation Data: Summary Plots". Presented to the ECCC, Jan 05.

Jones, Keith, Vingarzan, Roxanne and Zhao, Joanna (2012). "The Effect of a Large Scale Poultry Cull on Ambient Ammonia, PM2.5 and Visibility in the Lower Fraser Valley, B.C., Canada". Environment Canada.

McNeill, Roger, and Roberge, Anne (2000). "The Impact of Visual Air Quality on Tourism Revenues in Greater Vancouver and the Lower Fraser Valley". Environment Canada.

McNeill, Roger, and Roberge, Anne (2011). "Acceptability of Visual Air Quality in the Lower Fraser Valley Based on Multi-day Scenarios". Environment Canada Discussion paper.

Ministry for the Environment (2001). "Good practice guide for monitoring and management of visibility in New Zealand". Wellington: Ministry for the Environment.

Metro Vancouver (2013). "Health and Economic Benefits of Visibility Improvements in the Lower Fraser Valley of British Columbia".

Pitchford, M. 2010. "Assessment of the use of speciated PM2.5 mass-calculated light extinction as a secondary PM NAAQS indicator of visibility." Memorandum to PM NAAQS Review Docket (EPA-HQ-OAR-2007- 0492).

Pryor, S. C. (1996). "'Assessing public perception of visibility for standard setting exercises." Atmospheric Environment, 30(15), 2705-2716.

So, Rita, Roxanne Vingarzan, Keith Jones, and Marc Pitchford (2015). "Modelling of time-resolved light extinction and its applications to visibility management in the Lower Fraser Valley of British Columbia, Canada." Journal of the Air & Waste Management Association 65, no. 6 (2015): 707-720.

So, Rita, Roxanne Vingarzan, Keith Jones, and Marc Pitchford (2016). "Visibility science summary: an integration of multiple lines of analysis." Presented to the British Columbia Visibility Coordinating Committee, June 24.

Sonoma Technology, inc (2017). "Visual Air Quality Metrics and Goals for the B.C. Lower Fraser Valley". Report prepared for Metro Vancouver, Environment and Climate Change

Canada, and BC Ministry of the Environment, March 2017.

Vingarzan R., Ainslie B., So R., Jones K., and Nissen R. (2016). "Visibility science summary: an integration of multiple lines of analysis". Presented to the British Columbia Visibility Coordinating Committee, June 24.

Workshop Report (2007). "The View Ahead – Managing Visibility in B.C.". June 19, 2007 Workshop