Visibility Perception in the Lower Fraser Valley, BC

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Abstract

A survey was conducted during the spring of 2011 in the Metro Vancouver region of British Columbia (BC) to assess public perceptions of visual air quality (VAQ) in different air pollution conditions. The survey was conducted live in a group setting to 17 different groups. Participants were asked to view and rate the VAQ depicted in 30 digital photos of a scene from Chilliwack, BC. Results show that averaged subjective ratings of VAQ have an approximately linear relationship to deciview, which is a measure of atmospheric haziness obtained from instrumentation. Results are similar for the different survey groups and different demographic categories. Age is the only demographic factor that shows statistically significant differences between categories, with young respondents displaying a tendency to rate the images more favourably than two of the older age groups. Based on analysis of acceptability ratings from Part 2 of the survey, the results of this study appear similar to those of two previous Lower Fraser Valley VAQ studies from the 1990s, indicating that public perception of VAQ in the region has not changed substantially in the intervening years. However, when asked directly for their opinion on the region's VAQ trend over the most recent five years, long-term residents were ten times more likely to respond that it had deteriorated than to indicate that it had improved.

Table of Contents

1. Rationale for study

The Lower Fraser Valley (LFV) is the most densely populated region of British Columbia, containing approximately 60% of the province's total population (Statistics Canada, 2011). It is also a region of renowned scenic beauty where the Fraser River meets the ocean against a backdrop of evergreen forests and the rugged Coast Mountains. Most residents would likely agree that the physical setting of the LFV contributes substantially to their quality of life. The geography and scenic vistas of the area also help draw visitors from around the world, bolstering a tourism sector that adds billions of dollars to the region's economy each year (McNeill and Roberge, 2000). The high value attributed to scenery means that visual air quality should be considered an important asset for the region.

For this study, visual air quality (VAQ) has been defined as the visibility effect caused solely by air quality conditions, excluding those associated with weather conditions such as fog and rain (U.S. EPA, 2010). VAQ embodies a subjective quality that most other measures related to visibility lack; it is considered to be an aesthetic judgment (Middleton et al., 1984) in which scene elements such as colour and texture may be equally as important as the visual range (the distance at which landmarks can be discerned). Unlike more objective air quality variables, VAQ is fundamentally linked to the individual and his or her interpretation of the scene.

Existing air quality standards for the LFV are based on health considerations, with a focus on fine particulate matter ($PM_{2.5}$) and various trace gases that are known to be harmful to human health. For the most part, such health-based standards are weak in terms of visibility protection (Hyslop, 2009). It is not uncommon to have substantially degraded visibility conditions in an air mass that is well within national and provincial standards that have been established for health concerns. Therefore, visibility considerations merit separate study in accordance with the value placed upon the quality of the region’s scenic views.

The subjective nature of VAQ means that the setting of a standard or development of an index for visibility conditions requires input from persons residing in the relevant area. Data representing residents’ evaluations of various VAQ conditions – known as public perception data – can be used to define a scale and/or standard among more objective measures of visibility. This approach has been employed in several previous studies of VAQ, which have been reviewed by the U.S. EPA (2010) and are briefly summarized in Section 3.1 of this report. In British Columbia, three previous studies of visibility perception in the LFV have been conducted. The first was a pilot study by Pryor and Steyn (1994) in which students at the University of British Columbia (UBC) were surveyed for their input on a visibility standard for the region. A similar follow-up study (Pryor et al., 1995) surveyed groups outside of UBC, primarily in the eastern half of the LFV. A separate study by McNeill and Roberge (2000) focused on the potential impacts of poor visibility on the tourism industry. These earlier studies provide a methodological model and points of comparison for the current visibility perception study.

2. Study objectives

The current study arises from the interest amongst air quality specialists in BC in developing a perception-based visibility index and visibility goals for the LFV. These air quality researchers and planners are represented by the BC Visibility Coordinating Committee (BCVCC), which has members from Environment Canada, BC Ministry of Environment, Metro Vancouver, Fraser Valley Regional District, and Health Canada. According to the Statement of Work for the project, this study was meant to expand and update the previous work of Pryor (1994, 1995) by way of the following three objectives:

1) Obtain a larger set of data relating public perception of visibility to measured atmospheric parameters.
2) Investigate whether visibility perception has changed over time as air quality in the LFV has changed.
3) Investigate whether the techniques of Pryor (1994, 1995) will work in a broader range of atmospheric conditions (humidity, partial cloud cover).

A VAQ survey was developed using earlier studies as a model. The survey was conducted at UBC and various other sites in Metro Vancouver from 16 March to 11 May 2011. Results are presented in Section 5 of this report.

3. Background and Definitions

3.1 Previous VAQ studies

Awareness of the human health impacts of air pollution dates back at least to the Industrial Revolution, and regulation of emissions in both Great Britain and North America began in the middle of the 20th century (Boubel et al., 1994). Although the visual effects of air pollution have likely been cited as an additional negative impact all along, the deliberate study of visibility issues has been initiated relatively recently. In North America, official recognition of visibility as an important air quality parameter was made by the United States Congress as part of the 1977 Clean Air Act Amendments (Latimer et al., 1981). The emphasis at that time was on protection of scenic views in U.S. National Parks and Wilderness Areas. This led to some of the first studies on human perception of VAQ (e.g. Latimer et al., 1981; Malm et al., 1981) and to the establishment in 1985 of the Interagency Monitoring of Protected Visual Environment (IMPROVE) program, which is an ongoing effort aimed at monitoring, studying and improving visibility in protected areas.

One of the first urban VAQ studies was that of Ely et al. (1991), which was prompted by the Metro Denver Brown Cloud Study of the late 1980s. The Ely study used public perception data as a basis for formulating a visibility standard for the Denver area. This study established a methodology for obtaining public perception data that has been followed to a large degree by most of the more recent VAQ studies. Specifically, the survey methods of collecting VAQ ratings based on a 1-7 scale and the subsequent acceptability judgments of a series of photographs have been employed in numerous studies since, including the present study.

The visibility standard proposed by Ely et al. (1991) was based on a “50% acceptability” criterion, which was defined as the level of an objective visibility variable (total light extinction) above which a majority of survey respondents judged the VAQ to be unacceptable. While other methods of applying the survey data may be just as reasonable, the main idea employed in this and other public perception studies was to relate the subjective VAQ ratings from surveys to a more objective measure of visibility conditions that can be automated.

A later urban VAQ study in Phoenix (BBC Research & Consulting, 2003) used images generated by a software application called WinHaze, which degrades a pristine view in linear increments. This technique removed some of the variables aside from pollutant concentrations that affect VAQ, such as sun angle and cloud cover. As with the Denver study, participants' VAQ ratings were generally found to be well correlated to measured indicators of atmospheric haziness.

The two previous VAQ studies that involved residents of the LFV (Pryor and Steyn, 1994; Pryor et al., 1995) included analysis of both the numeric VAQ ratings and the acceptability ratings from the surveys. An approximate 50% acceptability criterion was determined separately for each site. In the 1994 study, photos from Abbotsford and Chilliwack were used in the survey and in the 1995 study a third site at Matsqui was also included. A comparison of results from the current study with those of the two earlier studies is included in Section 5.4.4 of this report.

3.2 Perception of visibility and VAQ

The term visibility most often refers to visual range, which is simply the distance to which one can discern landmarks. More precise definitions of visual range exist for the purpose of recording visibility in aviation weather observations. Furthermore, the Koschmieder equation shows that visual range (VR) is inversely proportional to the total light extinction:

$VR = 3.912/b_{ext}$ (for a perfectly black object, where b_{ext} is the light extinction coefficient).

The extinction coefficient, b_{ext}, accounts for the total amount of light that is attenuated from a sight path via scattering and absorption by both particles and gases in the air:

$$b_{ext} = b_{sp} + b_{sg} + b_{ap} + b_{ag}$$

where b_{sp} = scattering by particles, b_{sg} = scattering by gases, b_{ap} = absorption by particles and b_{ag} = absorption by gases.

In most cases of degraded visibility, particles are much more effective than gases in reducing visual range and scattering is more important than absorption; from this, it can be assumed that b_{sp} is the dominant term in the above equation for b_{ext}. Field studies have confirmed this to be the case in the LFV (Pryor et al., 1995). However, absorption can also be important in the presence of dark particles such as soot from forest fires; such particles can darken the view and significantly reduce the visual range.

In addition to the type and concentrations of particle and gases in the atmosphere, other physical qualities can affect the perceived visibility. Illumination conditions and characteristics of the visual targets are two examples that incorporate factors such as sun angle, amount of cloud cover, and the colour and size of scenic elements (Latimer, 1981). Visual range as determined by a human observer will also depend on the eyesight and visual processing capabilities of the individual.

VAQ varies with all the above factors that affect VR, but is also contingent upon other, more subjective factors. These include the perceived scenic beauty of the view's physical features as well as the observer's values and expectations (Latimer, 1981). As VAQ is considered to be an aesthetic judgment, its ratings in surveys largely reduce to a matter of opinion.

Another characteristic of VAQ, in this and other studies, that distinguishes it from VR is the emphasis on visibility outcomes that arise from varying air quality (pollution) conditions. Cases of visibility reduction due to fog and precipitation are usually excluded from the dataset when evaluation of VAQ is the objective. This point is perhaps especially important for a coastal location such as the LFV, and has implications for how a VAQ index or standard might be applied in places with a high frequency of precipitation and mist.

3.3 Measurement of visibility

As previously mentioned, VR is often determined by a human observer as part of a surface weather observation. The reportable range of VR for a given location depends on the availability of landmarks of known distance from the observation point. Remarks can be added to the observation when the VR varies by direction.

There are also instruments that enable automation of visibility observations. A transmissometer measures the total light extinction, b_{ext}, from which a version of the Koschmieder equation can be used to calculate VR. The transmissometer is an active sensor that normally operates at a wavelength near the midpoint of the visible light spectrum.

Another kind of active sensor that employs both a light beam and light detector is the nephelometer, which is designed to detect aerosols (particulate matter suspended in the atmosphere). Rather than measuring the total light extinction, a nephelometer measures the scattering component ($b_{scat} = b_{sp} + b_{sg}$). By making some assumptions about the other terms in the equation for b_{ext}, or by using additional instruments to measure the absorption terms, an approximate VR can also be derived from nephelometer readings.

A limitation of instrument-derived VR values is that the sampled air mass is very local to the observing location. Conditions of spatially non-uniform visibility impairment will not be handled well by an instrument in a fixed location. While a human observer has the ability to see for a considerable distance in every direction, an instrument only "sees" its immediate air sample. For this reason, VAQ studies tend to be limited to situations of apparently uniform haze.

4. Methods

4.1 Study area

The Lower Fraser Valley of British Columbia refers to a region of southwestern BC that lies between the Strait of Georgia in the west and the Fraser Canyon in the east. The east-west length of the LFV between Vancouver and Hope is approximately 100 km and the north-south distance between the U.S.A. border and the Coast Mountains averages approximately 20 km. A smaller portion of the LFV airshed extends across the border into northern Washington State. Some principal communities of the LFV are labeled on Figure 1. This map was included in the survey questionnaire to help clarify the study area to participants.

The survey for this study was conducted at various locations within Metro Vancouver, which is a regional district comprised of the municipalities in the western portion of the LFV (as far east as Maple Ridge and Langley). The UBC Point Grey campus and adjacent University Endowment Lands, which are located on unincorporated land, are also considered part of Metro Vancouver (Electoral Area A).

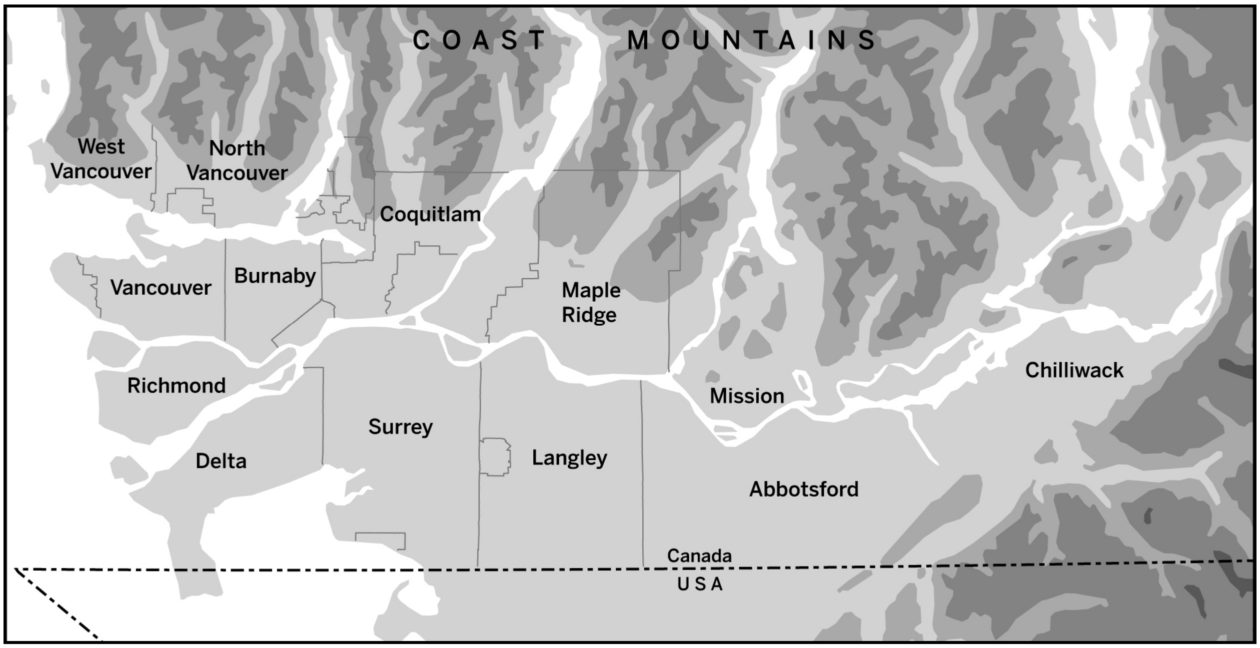

Figure 1: Map of the Lower Fraser Valley.

4.2 Instrumentation

The camera, optical instruments and meteorological sensors used for this study were all co-located on an observing platform at the Chilliwack airport. The Olympus C-8080WZ digital camera produced images with a resolution of 2288 x 1712 pixels. The camera's focal length was 30 mm and settings such as exposure time, ISO speed and F-number were automated.

Light scattering was measured by an Optec NGN-2A open-air integrating nephelometer. Light absorption was derived from measurements of NO_2 and black carbon by a Thermo Scientific 17C analyzer and a Magee Scientific AE22 Aethalometer, respectively. Fine particulate matter ($PM_{2.5}$) was monitored with a Thermo Scientific TEOM 1400ab. Temperature and relative humidity were measured by a Vaisala HMP45A sensor housed in an unaspirated radiation shield.

4.3 Survey procedures

The basic procedure for collection of public perception data in this study closely followed the methods of previous VAQ studies, particularly the earlier LFV studies, which in turn were modeled after the Denver VAQ study by Ely et al. (1991). The survey was conducted live in a group setting. Participants were asked to view and rate a series of projected photographs depicting a scene from the LFV in various air quality conditions. They were instructed to rate each picture based solely on how the air looked, without trying to assess the potential health impacts of the apparent air quality conditions.

The survey consisted of two parts; for each part four warm-up slides and 30 study slides were shown. (*Note:* the term "slide" is used here and in the survey script to mean the projected image of a digital photograph.) The 30 study slides consisted of 26 unique images and four repeated slides to check consistency of rating. In Part 1, participants were asked to rate each slide using a 1-7 VAQ scale in which a "1" represents very poor visual air quality and a "7" indicates excellent VAQ. For Part 2, the slides were shown again and participants were instructed to rate the visibility condition of each one as either acceptable or unacceptable based on their own visibility standard. The same four warm-up slides were presented in the same order as for Part 1. The study slides for Part 2 were the same slides that were used in Part 1, but they were presented in a different order. However, the slide order used in each part was kept consistent for all survey groups. Appendices A and B contain the survey questionnaire and script that were used for all groups. The script consists of the verbal introduction and instructions that were used in the survey. In order to provide consistent information to the different survey groups, only the survey director (J. Gallagher) led survey sessions and the script was used each time. Participants were invited to ask questions about the instructions prior to the start of each part, but other questions regarding the survey's purpose and methods were deferred until the end of the session.

The survey procedure for this study was developed by the UBC researchers (Gallagher and McKendry) in consultation with members of the BCVCC. The survey questionnaire and script by Pryor et al. (1995) were used as a starting point for the current survey. Listed below are the changes that were made to the 1995 questionnaire in the development of the latest (2011) version.

- The introductory information on page 1 of the questionnaire was re-worded in an attempt to increase clarity and to reflect procedural changes.
- A map of the study area was included on page 1.
- The written instructions for Part 1 were expanded.
- Four warm-up slides were used instead of nine. This change is related to the decision to use photos from only one scenic view rather than three (see section on slide selection).
- Check-boxes were provided for recording responses in Part 1 and in the demographic questions rather than having respondents write down their numeric ratings.
- The written instructions for Part 2 were re-worded for clarity and to reflect procedural changes. Wording in the earlier survey which emphasized that the visibility standard is for an urban/suburban area rather than a pristine mountain area was omitted.
- The instructions for recording responses in Part 2 were changed. In the previous survey, respondents were instructed to circle a “Y” for yes when the depicted scene violated their VAQ standard and an “N” for no when their standard was not violated. This was changed in the updated questionnaire so that “Y” was for acceptable VAQ and “N” was for not acceptable.
- The demographic question about household income was updated to include larger ranges and higher categories of income.
- The demographic question on political affiliation was eliminated.
- The “yes” or “no” question asking if the respondent’s primary residence was in the LFV was changed to a question asking for the name of the city in which the respondent lived.
- The question which had asked long-term LFV residents (more than 5 years) if they thought the VAQ in the valley had changed over the preceding 5 years was updated to collect more specific information regarding their opinions of the region’s VAQ trend.
- A question asking, “Are you a permanent resident of Canada?” was eliminated.

- For the question asking in what kind of environment the respondent spent their formative years, the second category representing “a city or town of more than 20,000 people but less than 250,000 people” was changed from “Urban” to “Urban/suburban.”
- A question asking, “Have you ever participated in a visibility study of any kind before?” was added.

The survey script was also updated to reflect procedural changes and to clarify some of the instructions. The most substantial change here was to provide an explicit definition of VAQ.

The amount of time that each slide was displayed was increased from six seconds to ten seconds. No clear evidence supporting a preferred display time was found in the literature, but it was thought that ten seconds may give participants a better opportunity to take in the whole scene and then carefully record their rating in the correct place on the questionnaire sheet.

4.3.1 Logistical considerations

The survey was conducted to 17 distinct groups: eight groups were undergraduate classes at UBC and Langara College, and the other nine sessions involved groups of adults from various organizations within Metro Vancouver. (See Section 5.1 for more information about the survey groups.)

This study did not have the resources required to perform a random sampling of the LFV population. Instead, existing groups were recruited in an attempt to sample a reasonably representative cross-section of the population (evaluated through the questionnaire’s demographic section). In statistical terms, these groups are regarded as convenience samples.

Recruitment was performed by contacting prospective groups via email or phone with an invitation to participate in the survey. A synopsis of the study and its purpose was provided at this stage. Prospective groups were identified through personal contacts and Internet searches. No material incentives – other than light refreshments that were available at most of the non-student sessions – were offered for participation. Therefore, recruitment tended to be successful for groups of persons who had some pre-existing interest in air quality issues. This is recognized as a possible source of bias in the survey results. It is also recognized that convenience sampling by its nature excludes portions of the population from having the opportunity to participate in the study.

Although each group was shown the same sequence of photos, viewing conditions inevitably varied amongst survey sessions. This variation was minimized to the extent that was practical. Rooms were darkened so that the images could be seen clearly, but with enough ambient light retained for participants to mark their answers on the questionnaire. There was also variation in the projectors and screens used to display the images. For surveys conducted in classrooms, the fixed projectors and screens of each room were used; these were all liquid crystal display (LCD) projectors and pull-down white screens. For most of the survey sessions conducted in other locations around Metro Vancouver, the same portable LCD projector was used with in-house white screens or a portable white screen. The typical setting for a session was a either a boardroom with participants seated around a rectangular table or a meeting room in which participants sat in rows of folding chairs. Details of projection conditions for each survey group are provided in Appendix D.

The effect of different projector types is noteworthy as an unwelcome source of potential variability in VAQ studies that use digital images as a basis for collecting perception data. A side-by-side comparison of images was made using two different projectors, one being an LCD projector while the other used digital light processing (DLP) technology. The DLP machine also projected a brighter image. Subjective evaluation of photos displayed by both projectors simultaneously found that the images appeared “less hazy” in the DLP projection than in the LCD version. This brings into question how to best represent the original scene as an in-situ observer would have encountered and highlights the fact that technological factors will come into play whenever digital photographs are used for VAQ studies. In this case, rather than trying to assemble an ideal set-up (as this would be very difficult to define), the survey director worked to maintain a reasonable level of consistency in viewing conditions. The logistics of presenting the survey in a variety of locations over a period of several weeks meant that the equipment and lighting conditions could not always be the same.

In addition to statistical analysis of results by demographic groups, comparisons between the different survey groups were made to determine if variations such as those associated with viewing conditions and pre-existing interests could have substantially affected the ratings. Details of this analysis are presented in the Section 5.2.

4.4 Image selection

As with the questionnaire development, the image selection process was a collaborative effort between the UBC researchers and members of the BCVCC. An automated camera located at the site of interest provided twice-hourly images from which to select suitable examples of varying air quality conditions. Previous studies have found that VAQ ratings from photographs correlate well with in-situ observations of the same scene in identical or very similar conditions (Malm et al, 1981). This finding is assumed to be valid for the current study, i.e., it is assumed that digital photographs of the scene are an appropriate substitute for in-situ viewings.

The previous LFV study by Pryor et al. (1995) used images from three different locations in order to assess the influence of scene characteristics on VAQ ratings, which has been found to be an important factor in earlier studies (e.g. Latimer et al., 1981). In this study, preference was given to simplifying the analysis by reducing the number of factors affecting VAQ. Thus, images from just one location were used in the survey. The selected location is the Chilliwack airport, where a camera maintained by Environment Canada recorded a photograph every half hour. The view is toward the southeast, with a number of visual targets (mostly mountains) located at a considerable range of distances from the camera. Details of the viewscape are provided in Appendix C.

Pryor et al. (1995) listed four slide selection criteria that were applied to their study: i) there had to be a valid corresponding hourly average b_{sp} or b_{ext} value; ii) days when the relative humidity (RH) exceeded 75% anytime during the 1000-1600 PST period were excluded; iii) photos showing between 4/10 and 8/10 cloud cover were not used; and iv) only photos taken at or near 1200-1300 and 1600 PST were used. The first requirement was so that an objective measure of visibility was available for comparison to the VAQ ratings. The RH standard was meant to exclude instances of visibility reduction by rain and/or fog. The third and fourth requirements were meant to limit the range of illumination conditions, which are considered important to perceived VAQ (Latimer et al., 1981).

For the current study, similar principles were applied to arrive at the following selection criteria:

- Valid hourly-average extinction data (b_{sp} and b_{ext}) corresponding to the photo time had to available.
- Meteorological data also had to be available for the relevant times (at least RH and temperature readings).
- Images were selected from a date range of 27 July 2010 (when a high resolution camera was installed at the site) to 30 September 2010.
- The time of day was constrained to 1130-1600 PST; most images were from either 1230 or 1530. Photos from earlier in the morning were found to be overly affected by forward scattering as the camera faced toward the sun at that time of day.
- For any images from a particular day to be included, the hourly RH readings from 1000-1600 PST had to be below 75% for at least four of the seven hours. Additionally, the RH was required to be below 75% at the time of the photo (based on the nearest hourly mean).

Low overcast conditions were also excluded. However, no criterion concerning partly cloudy conditions was applied explicitly, as one of the objectives of the study was to investigate whether the techniques of previous studies could be applied to a wider range of atmospheric conditions. However, in order to keep the participants focused primarily on air quality conditions, a majority of the images selected depict clear skies or partly cloudy conditions in which the clouds do little to obscure the view. Most of the images selected were from on the half hour (e.g. 1230 LST) to best correspond to hourly-averaged atmospheric variables.

An advantage of using photos from only one location is that the 26 images used in the survey represent a wider and more complete range of scattering and extinction coefficient values than was available from any one location in prior LFV studies. The b_{sp} values associated with the images in the current study range from 4.7 to 195.6 Mm^{-1}. In the previous LFV study

(Pryor et al., 1995), the b_{sp} values for Chilliwack ranged from 18 to 119 Mm^{-1}. Also, there was a deliberate inclusion of more images that appeared to have “good” to “excellent” visibility (low b_{sp}) compared to what was included in the earlier studies. The resulting suite of images effectively spanned the range of visibility conditions that were encountered in Chilliwack during the late summer period of 2010. Table 1 lists the study slide images and warm-up slides that were used in the survey, along with the corresponding optical data. Each image has been given an alphabetic code to enable cross-referencing between results of Parts 1 and 2 of the survey. Data from the warm-up slides were not included in the results analysis.

Table 1: The 26 images used as study slides, listed in order of increasing light extinction, and the four images used as warm-up slides, listed in the order they were presented during the survey.

Image	**Part 1 Slide #**	**Part 2 Slide #**	**Date**	**Time (LST)**	**b_{sp} Mm^{-1}**	**b_{ext} Mm^{-1}**	**Deciview (dv)**
A	16	11	9/21/2010	1600	4.7	18.3	6.0
B	9	30	9/22/2010	1330	10.6	26.6	9.8
C	3	1	9/25/2010	1530	12.6	28.7	10.5
D	19	19	8/23/2010	1530	14.5	30.5	11.1
E	4, 25	10, 28	8/24/2010	1230	16.7	32.8	11.9
F	15	5	9/3/2010	1530	17.8	35.7	12.7
G	12	14	8/24/2010	1530	23.2	42.9	14.6
H	21	17	8/25/2010	1530	32.2	51.0	16.3
I	5, 26	7, 15	7/27/2010	1530	45.4	64.0	18.6
J	30	26	8/2/2010	1530	54.1	71.2	19.6
K	10	21	8/25/2010	1230	50.6	74.3	20.1
L	27	27	7/30/2010	1530	59.4	78.3	20.6
M	14	12	8/2/2010	1200	65.4	82.7	21.1
N	7	25	8/11/2010	1330	68.3	86.6	21.6
O	1	18	8/16/2010	1530	68.8	88.2	21.8
P	17, 28	6, 20	8/16/2010	1230	79.8	102.4	23.3
Q	13	3	7/28/2010	1230	83.9	103.8	23.4
R	23	23	8/17/2010	1130	82.9	108.6	23.8
S	24	4	8/18/2010	1530	89.8	109.5	23.9
T	2	29	8/11/2010	1530	94.7	113.2	24.3
U	20	9	8/17/2010	1430	91.8	115.5	24.5
V	18	16	8/6/2010	1130	104.4	124.3	25.2
W	29	13	8/3/2010	1530	108.5	135.3	26.0
X	8, 11	8, 24	8/5/2010	1330	147.3	169.3	28.3
Y	6	2	8/4/2010	1530	177.4	202.5	30.1
Z	22	22	8/5/2010	1530	195.6	220.2	30.9
Warm-up Slides							
W-a	W-a	W-a	9/15/2010	1230	8.9	25.7	9.4
W-b	W-b	W-b	8/4/2010	1230	210.8	237.2	31.7
W-c	W-c	W-c	7/28/2010	1530	56.4	73.7	20.0
W-d	W-d	W-d	7/29/2010	1230	84.6	103.4	23.4

5. Results

5.1 Participant demographics

The survey was conducted to 17 groups, eight of which were undergraduate classes at either UBC or Langara College. (A small number of graduate students, instructors and staff were also surveyed in the classroom sessions.) The other nine groups were companies, clubs, government offices and a seniors' centre in Metro Vancouver. Table 2 lists the groups along with their locations and number of participants surveyed. For descriptive purposes, the UBC and Langara classes are considered together as "university" groups and the others are referred to as "non-university" groups.

A total of 301 individuals were surveyed and 290 questionnaires were considered complete and valid. Each questionnaire was inspected manually as part of the data entry and quality control process. Surveys were rejected if any of the study slides were not rated or if more than one demographic question was not answered. Surveys from participants who arrived late and missed the introduction and Part 1 instructions were also excluded from the analysis. The basis for excluding each of the 11 rejected surveys is provided in Table 3. The overall survey rejection rate was 3.7%. The rejection rate was higher for the non-university groups (4.9%) than for the university groups (2.8%). Of the 290 complete and valid surveys, 174 (3/5) were from university groups and 116 (2/5) were from the non-university groups.

Table 2: Survey groups in chronological order of survey sessions.

Group #	Location	Primary Participants	City	# Surveyed	# Valid & complete
1	UBC Geography	Undergraduate students	Vancouver	28	27
2	UBC Geography	Undergraduate students	Vancouver	12	12
3	Langara Geography	Undergraduate students	Vancouver	27	24
4	Langara Geography	Undergraduate students	Vancouver	16	16
5	UBC Geography	Undergraduate students	Vancouver	21	21
6	Langara Geography	Undergraduate students	Vancouver	15	15
7	UBC Earth and Ocean Sciences	Undergraduate students	Vancouver	10	10
8	Credential Financial Inc.	Company staff	Vancouver	15	15
9	Alpine Club of Canada	Club members	Vancouver	18	18
10	Brock House Society	Seniors	Vancouver	3	3
11	Green Lake Ski Club	Club members	Vancouver	13	11
12	MacDonald, Dettwiler and Associates Ltd.	Company staff	Richmond	16	15
13	BC Ministry of Environment Regional Office	Agency staff	Surrey	14	13
14	Metro Vancouver	Agency staff	Burnaby	11	10
15	Port Metro Vancouver	Agency staff	Vancouver	20	20
16	Vancouver Aquarium	Aquarium volunteers	Vancouver	12	11
17	UBC Geography	Undergraduate students	Vancouver	50	49
			Totals	**301**	**290**

Table 3: Questionnaires that were excluded from the data analysis.

Group #	Observer #	Reason
1	28	Incomplete questionnaire
3	16	Incomplete questionnaire
3	12	Seems to have lost track of slide # in Part 1
3	26	Multiple answers for same slides
11	8	Incomplete questionnaire
11	13	Missed intro and Part 1 warm-up slides
12	16	Missed intro and Part 1 warm-up slides
13	6	Missed intro and Part 1 warm-up slides
14	11	Missed intro and Part 1 warm-up slides
16	6	Multiple answers for same slides
17	36	VAQ ratings appear random or possibly backwards

Basic demographic information was collected from participants at the end of the questionnaire. 99% of participants reported that they lived in Metro Vancouver at the time of the survey; the others (two respondents) resided in the eastern Lower Fraser Valley. Demographic composition of the overall survey sample is compared to the general Metro Vancouver population with the aid of Figures 2 through 4. Population data for Metro Vancouver are from the 2006 census (Statistics Canada, 2011). The proportion of males (49%) and females (51%) surveyed matched those of the general Metro Vancouver population. Other demographic categories are considered below.

- Age – Figure 2 shows the age comparison. The large number of students surveyed resulted in a large portion of respondents being in the 18-24 year-old range. The 25-34 year-old range was also overrepresented by the survey, while all other ranges, especially 65+, were underrepresented. Children were intentionally excluded from the survey process.
- Income – The inclusion of many students led to an overrepresentation of the lowest income category (see Figure 3). Households with income exceeding $100,000 were

also slightly overrepresented, while the middle income households were underrepresented.

- Education – Although the categories used in the survey do not match those of the census, some obvious conclusions can be made from Figure 4. The survey greatly underrepresented the portion of the population whose highest level of education was a high school or trade school diploma or less (8% for the sample vs. 43% for the population). While the survey sample was dominated by undergraduate students, the proportion of respondents who had completed an undergraduate degree aligned well with the census data. However, the survey overrepresented those with graduate degrees. Overall, the survey sampled a more highly educated demographic than what is found in the general population.
- Geographic origin – Figure 5 summarizes the results of demographic question #7 from the survey questionnaire. Two-thirds of participants had spent their formative years (up to 16 years old) in Canada, while 18% were from Asia and much smaller portions of the sample were from the U.S.A., Europe, Latin America, Oceania (primarily New Zealand and Australia) and Africa. The census data from 2006 indicate that 40% of Metro Vancouver residents were foreign-born, suggesting that the survey slightly underrepresented immigrants. The majority of immigrants to Metro Vancouver were from Asia (65% of foreign-born residents), followed by Europeans (22%) then 3% each for Africa, U.S.A. and Oceania/other (Metro Vancouver, 2008). Thus, it appears that people of European origin were underrepresented by the survey.

Demographic question #8 asked participants about the type of environment in which they had spent their formative years. The responses are summarized in Figure 6, showing that a majority of those surveyed came from highly urban environments and only 14% were from rural locations. Comparable data of this kind are not available from the census.

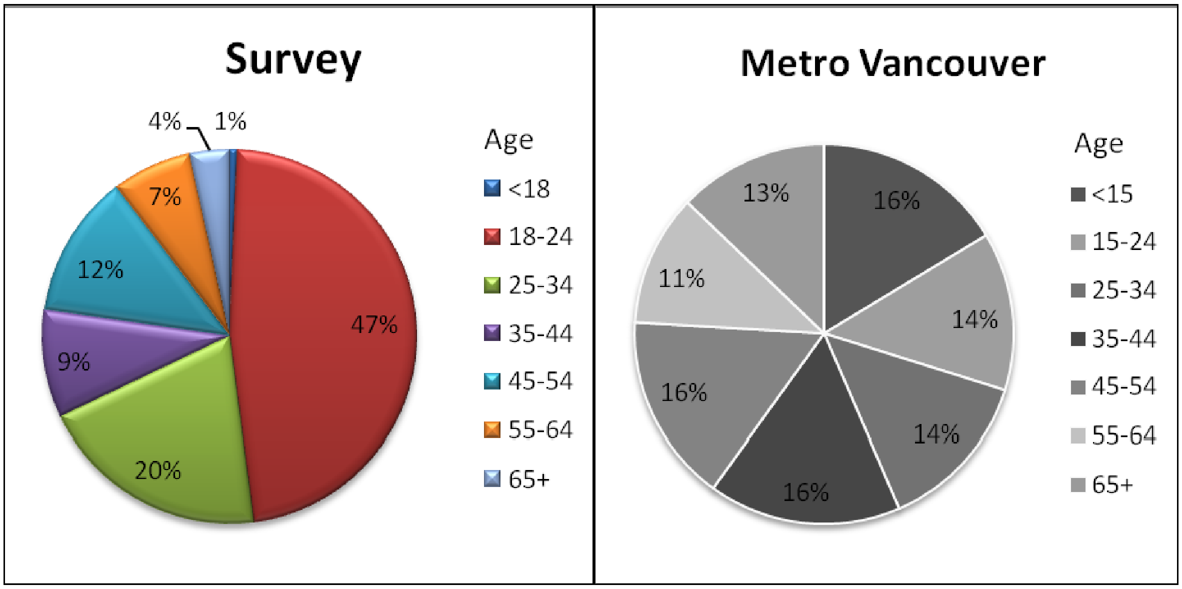

Figure 2: Age comparison of the survey participants and the general population of Metro Vancouver. Note: the lowest two age categories differ between the two charts.

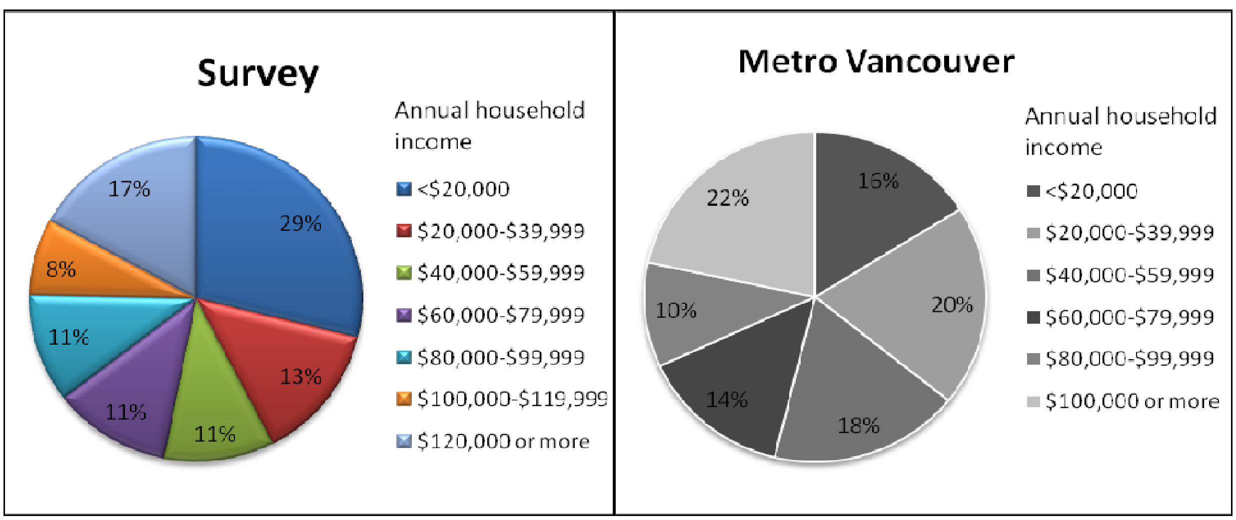

Figure 3: Income comparison of survey participants and the Metro Vancouver population. Note: the highest income categories are represented differently in the two charts.

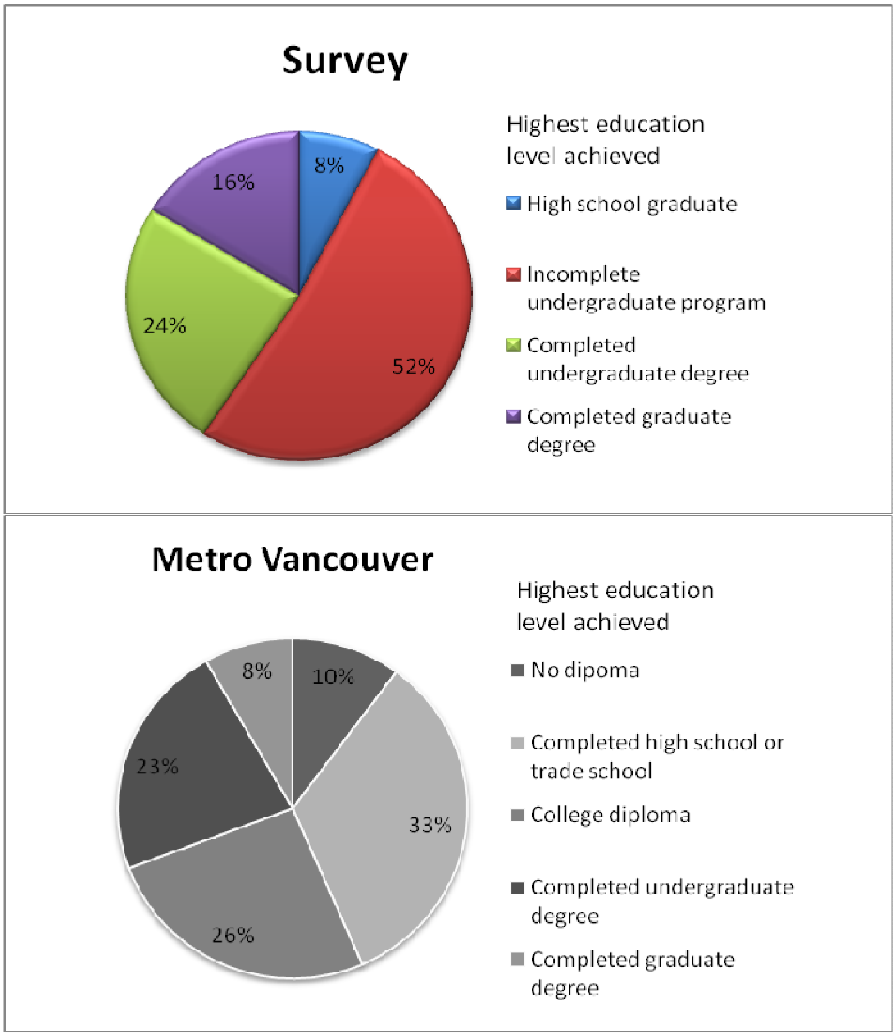

Figure 4: Education level comparison of survey participants and the Metro Vancouver population. Note: categories differ between the two charts.

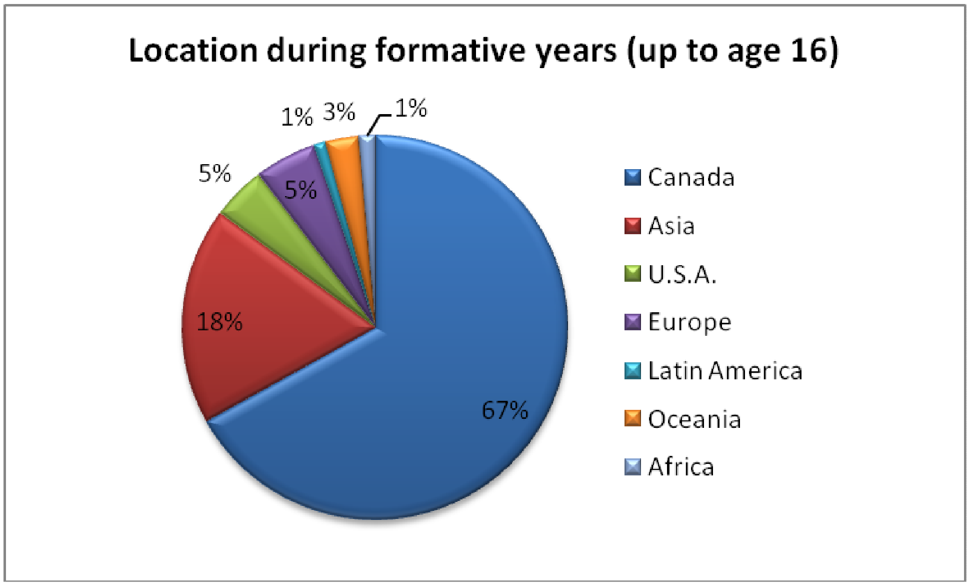

Figure 5: Locations where survey respondents spent their formative years.

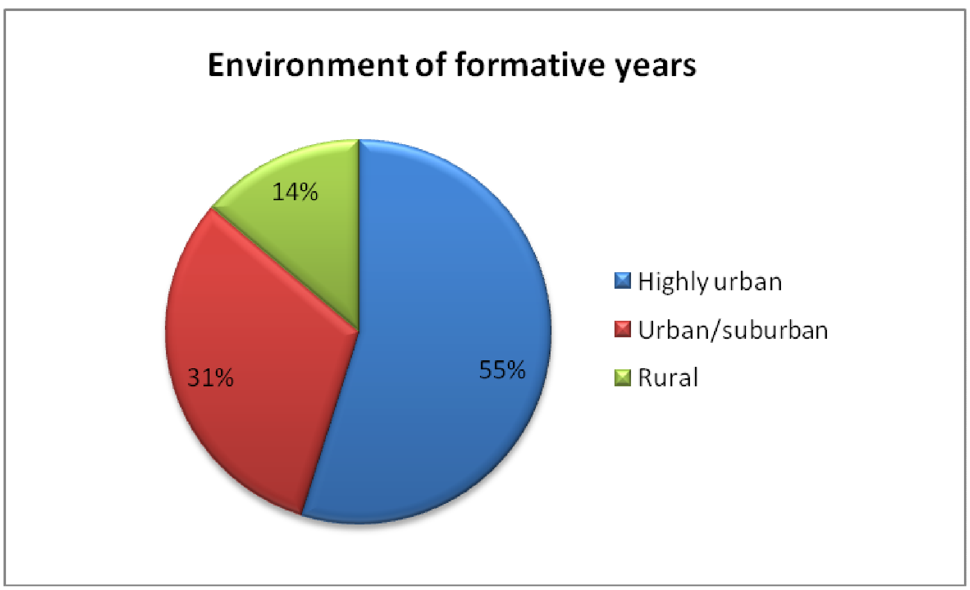

Figure 6: Type of settlement environment in which survey respondents spent their formative years.

In summary, the survey process obtained data from all major categories of the demographic parameters age (except children), income and geographic origin, but the proportional distribution of the categories did not match those of the general population. This was primarily due to the large number of undergraduate students sampled. Regarding education, the survey did not include anyone who had not completed high school, resulting in the overall education level of survey respondents being higher than that of the general population of Metro Vancouver.

5.2 VAQ ratings (Survey Part 1)

In order to develop a visibility standard or index that incorporates the subjective nature of VAQ, averaged respondent ratings of VAQ from the survey need to be correlated to some routine measure of an atmospheric visibility parameter. However, it is important to first assess the amount of variation in the ratings by different survey and demographic groups to see if the practice of averaging ratings from disparate groups is justified.

5.2.1 Ratings by individuals

Descriptive statistics of the individual ratings for each slide are compiled in Table 4. Note that at this point, duplicate images are treated separately. For example, slide 8 and slide 11 were of the same image, but they are listed separately with their corresponding statistics. The ranges and standard deviations in Table 4 indicate a considerable degree of variation amongst individuals. Ratings for three of the slides span across the entire 1-7 VAQ scale and responses for many other slides range from 1 to 6 or 2 to 7. Standard deviations of the VAQ scores by slide are mostly between 0.8 and 1.0. Despite this variability, Figure 7 confirms that a normal distribution of responses can be found in the mean VAQ ratings of individuals. (For each observer, the VAQ scores of the 30 slides were averaged.) Thus, the observers who had a tendency to rank the slides toward the low end of the scale were approximately balanced by the number of observers who tended to give high scores. The overall mean score of the slides by all observers is 3.88.

Table 4: Descriptive statistics of VAQ ratings by slide based on individual responses.

Part 1 Slide #	Image	Min rating	Max rating	Mean	Std. dev.
1	O	2	6	3.9	0.88
2	T	1	6	2.8	0.95
3	C	3	7	5.7	0.87
4	E	2	7	5.8	0.99
5	I	2	7	4.3	0.99
6	Y	1	7	2.1	1.00
7	N	1	6	3.5	1.01
8	X	1	5	2.1	0.94
9	B	4	7	6.5	0.68
10	K	1	6	4.0	0.96
11	X	1	5	2.0	0.95
12	G	3	7	5.7	0.82
13	Q	1	6	3.5	0.97
14	M	1	6	3.6	0.99
15	F	2	7	5.6	0.83
16	A	3	7	6.3	0.78
17	P	1	6	3.5	0.95
18	V	1	5	1.7	0.86
19	D	2	7	5.3	0.92
20	U	1	6	3.1	0.90
21	H	2	7	4.8	0.94
22	Z	1	6	1.6	0.82
23	R	1	6	3.0	0.86
24	S	1	7	2.4	0.94
25	E	2	7	5.9	0.91
26	I	2	6	4.6	0.96
27	L	1	7	4.2	1.06
28	P	1	6	3.2	0.98
29	W	1	5	1.3	0.60
30	J	2	7	4.2	1.02

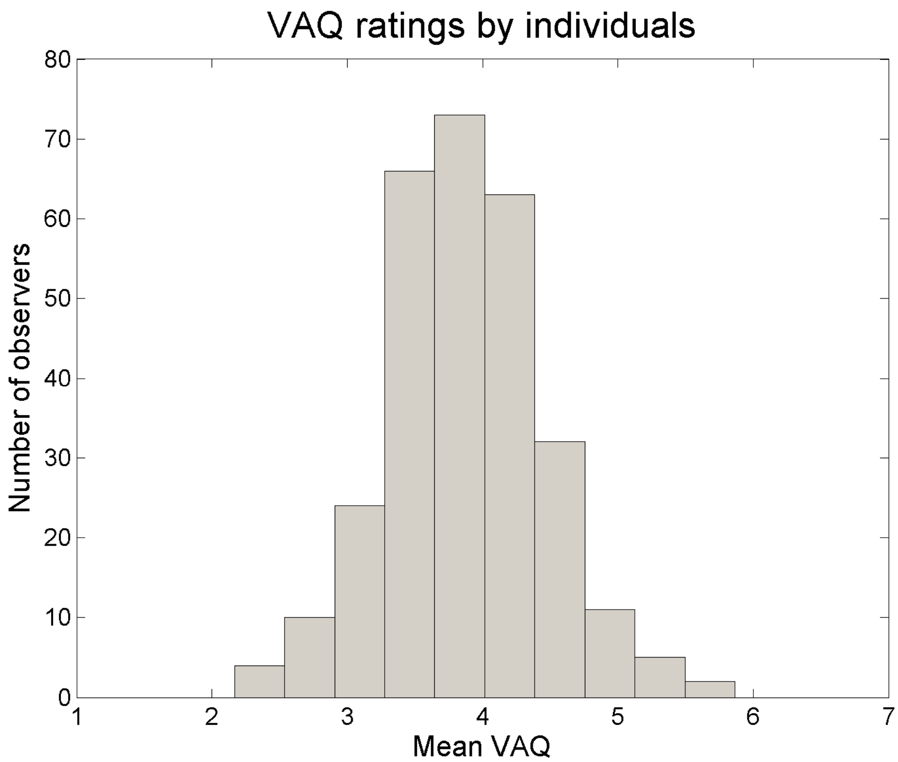

Figure 7: Distribution of individual VAQ ratings. To obtain a mean VAQ score for each person, their VAQ ratings for the 30 slides were averaged.

5.2.2 Comparison of ratings by different survey groups

Results from Part 1 of the survey are given in Table 5 as group-averaged VAQ ratings for each slide. As should be expected, the group-averaged results reflect less variation in the VAQ ratings than the underlying individual responses. Standard deviations of these group means by slide are in the range of 0.14-0.34. The largest difference between any two groups for any of the slides was 1.5 VAQ units. A sensitivity analysis of the mean scores for the slides was done by removing one group at a time from the calculation of the means. In almost every case, the mean slide ratings remained the same to the nearest 0.1. There were just two exceptions to this general finding: removal of group 8 reduced the slide 4 score by 0.1 and removal of group 10 reduced the slide 19 score by 0.1.

Table 5: Group average VAQ ratings for each slide (listed by Part 1 slide number).

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Mean
n	27	12	24	16	21	15	10	15	18	3	11	15	13	10	20	11	49	
Slide																		
1	3.6	4.0	3.8	4.4	4.1	4.1	3.9	3.4	3.9	4.0	4.0	4.3	4.0	3.6	3.8	4.0	4.2	3.9
2	2.4	2.8	2.5	3.3	2.8	2.8	2.7	2.7	2.6	3.3	2.8	3.1	3.5	2.5	2.3	2.9	3.0	2.8
3	5.7	6.0	5.7	5.7	5.8	5.7	5.6	5.1	5.4	5.7	5.6	5.7	6.3	5.7	5.8	5.9	5.9	5.7
4	5.9	5.8	5.3	5.7	5.9	5.7	5.9	4.9	5.7	6.3	5.5	5.9	5.7	5.5	5.8	6.2	6.0	5.8
5	4.3	4.4	4.1	4.6	4.3	4.5	4.3	4.0	3.9	4.7	4.4	4.0	4.5	3.9	4.2	4.7	4.3	4.3
6	1.9	2.3	2.3	3.0	2.0	2.3	2.0	2.2	2.3	2.3	2.4	2.0	2.0	2.4	1.6	1.7	2.1	2.1
7	3.5	3.8	3.4	3.8	3.7	3.1	3.1	3.5	3.6	3.3	3.5	3.5	3.4	3.2	3.1	3.6	4.0	3.5
8	2.1	2.1	1.8	2.6	2.0	1.8	2.0	2.3	2.1	2.3	2.3	2.3	2.2	2.0	1.9	2.0	2.1	2.1
9	6.7	6.3	6.6	6.3	6.7	6.6	6.4	6.1	6.3	6.0	6.5	6.1	6.7	6.0	6.5	6.8	6.5	6.5
10	4.2	4.0	3.7	4.1	4.2	4.0	3.2	3.7	4.1	4.0	3.7	4.0	3.8	3.5	3.9	4.4	4.4	4.0
11	1.9	2.0	2.1	2.8	1.8	1.7	2.1	2.2	1.6	2.3	2.3	2.2	1.9	2.1	1.7	1.9	2.1	2.0
12	5.8	5.8	5.6	5.4	5.6	5.7	5.6	5.5	5.8	5.0	5.5	5.9	5.9	6.0	5.9	5.9	5.8	5.7
13	3.7	3.5	3.1	3.8	3.4	4.1	3.0	3.2	3.4	3.3	3.2	3.7	3.3	3.2	3.6	3.7	3.9	3.5
14	3.7	3.6	3.4	3.6	3.7	4.1	3.1	3.6	3.3	3.3	3.6	3.7	3.5	3.2	3.6	3.7	4.0	3.6
15	5.8	5.6	5.6	5.6	5.6	5.8	5.4	5.4	5.7	5.7	5.4	5.6	5.7	5.4	5.6	6.0	5.7	5.6
16	6.4	6.5	6.3	6.2	6.4	6.3	6.5	5.7	6.2	6.3	6.1	6.4	6.5	6.2	6.4	6.5	6.2	6.3
17	3.5	3.3	3.1	3.9	3.6	3.8	3.4	2.9	3.3	3.7	3.4	3.6	3.0	3.0	3.3	3.7	3.7	3.5
18	1.6	1.7	1.7	2.4	1.6	1.9	1.7	1.7	1.4	2.3	1.7	1.8	1.5	1.5	1.7	1.6	1.5	1.7
19	5.6	5.3	5.3	5.6	5.3	5.5	5.2	5.0	4.9	4.3	5.4	5.1	5.5	5.0	5.5	5.5	5.4	5.3
20	3.3	3.3	3.0	3.4	3.1	3.2	3.0	2.7	3.1	3.3	3.3	2.9	2.8	2.7	3.2	3.3	3.3	3.1
21	5.0	4.8	4.8	4.8	4.7	4.7	4.8	4.4	4.8	4.0	4.8	4.8	4.8	4.9	4.9	5.0	4.8	4.8
22	1.3	1.6	1.8	2.3	1.7	1.7	1.6	1.7	1.4	2.0	1.7	1.5	1.3	1.8	1.5	1.5	1.6	1.6
23	3.1	3.1	2.6	3.1	3.1	2.8	2.8	3.1	2.9	2.7	2.8	3.1	2.4	2.9	2.8	3.3	3.1	3.0
24	2.5	2.7	2.7	2.8	2.4	2.3	2.3	2.4	2.3	1.7	2.4	2.7	2.5	2.1	1.9	2.7	2.5	2.4
25	6.4	5.8	5.5	5.3	5.8	5.9	5.4	5.9	6.1	5.0	5.9	5.9	5.8	5.9	6.0	6.1	6.1	5.9
26	4.9	4.5	4.3	4.4	4.5	5.0	4.3	4.5	4.6	4.3	4.5	4.3	4.5	4.1	4.4	4.8	4.9	4.6
27	4.6	4.1	3.8	4.0	4.2	4.6	4.0	3.9	4.1	4.0	3.9	4.1	4.1	3.8	4.0	4.3	4.7	4.2
28	3.4	3.1	2.9	3.2	3.5	3.5	3.0	3.1	3.2	3.0	3.0	3.1	2.6	2.9	3.1	3.7	3.7	3.2
29	1.3	1.2	1.3	1.8	1.4	1.2	1.3	1.3	1.3	1.3	1.4	1.3	1.1	1.3	1.3	1.3	1.2	1.3
30	4.3	4.3	3.9	4.6	4.5	4.5	4.2	4.1	4.1	3.7	4.0	4.2	4.0	3.7	3.6	4.5	4.4	4.2

Average slide ratings from each survey group were compared to all other groups by calculating linear correlation coefficients. The results are shown in Table 6. Correlations are all well above 0.9, with a majority being above 0.97, and all are significant to the 1% level. Thus, it appears as though the composition of the different groups surveyed and the different viewing conditions between survey sessions did not create a great deal of variability in the group-averaged Part 1 results.

Table 6: Linear correlation coefficients comparing groups to each other based on group average VAQ ratings for each of the 30 slides.

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1																
2	0.99	1															
3	0.98	0.99	1														
4	0.97	0.99	0.99	1													
5	0.99	0.99	0.98	0.98	1												
6	0.99	0.98	0.98	0.97	0.99	1											
7	0.98	0.99	0.99	0.99	0.99	0.97	1										
8	0.99	0.99	0.98	0.97	0.98	0.98	0.97	1									
9	0.99	0.99	0.98	0.98	0.99	0.98	0.98	0.99	1								
10	0.94	0.95	0.94	0.96	0.96	0.95	0.96	0.93	0.95	1							
11	0.99	0.99	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.95	1						
12	0.98	0.99	0.98	0.98	0.99	0.98	0.98	0.98	0.99	0.95	0.98	1					
13	0.97	0.99	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.95	0.99	0.98	1				
14	0.98	0.99	0.99	0.98	0.98	0.97	0.98	0.98	0.99	0.94	0.99	0.98	0.98	1			
15	0.99	0.99	0.98	0.97	0.99	0.98	0.98	0.98	0.99	0.95	0.99	0.98	0.98	0.99	1		
16	0.99	0.99	0.98	0.98	1.00	0.99	0.98	0.98	0.99	0.95	0.99	0.99	0.98	0.97	0.99	1	
17	0.99	0.99	0.97	0.97	0.99	0.99	0.97	0.98	0.99	0.95	0.98	0.99	0.97	0.97	0.98	0.99	1

5.2.3 Comparison of ratings by different demographic groups

Demographic information was collected from survey participants primarily to assess how well the sample represents the overall Metro Vancouver population. This information is also useful to determine if certain segments of the population regard visual air quality differently than others. In some of the previous public perceptions studies, VAQ and/or acceptability ratings have shown sensitivity to demographic factors such as age, education and political affiliation (Ely et al. 1991; BBC Research & Consulting, 2003), but the differences are not always statistically significant. Malm et al. (1981) cited low standard deviations and high correlations between slide ratings by different demographic groups to conclude that the demographic background of respondents had little effect on VAQ ratings. In the first LFV VAQ study, Pryor and Steyn (1994) found significant differences between graduate students and undergraduates in the ranking of the more "extreme" slides (those toward either end of the VAQ scale). In their subsequent study, Pryor et al. (1985) found some statistically significant differences based on income level and education, but only for a few of the slides; most of the comparisons found no significant differences based on demographic factors.

Demographic comparisons for Part 1 results of the current study were done by running t-tests based on the individuals' mean VAQ scores. For example, to compare results by gender, average VAQ scores by each of the 143 males were tested against average VAQ scores by each of the 147 females. The t-test was run to determine whether or not the mean of the male scores differed significantly from the mean of the female scores. For demographic questions with only two possible answers to choose from (questions 1 and 9), a 5% significance level ($\alpha = .05$) was used. For demographic questions with multiple categories, α was reduced to .01 to account for multiple comparisons (t-tests for each possible combination of demographic categories). This adjustment was made rather than applying the Bonferroni correction for multiple comparisons, which is considered by some statisticians to be too conservative (e.g. Nakagawa, 2004). Results are summarized below. Tabular comparisons by slide are given for only the first two items (gender and age) to provide a sense of the magnitude of differences between demographic categories.

Gender – Mean ratings by gender for each slide are shown in Table 7. On average, females gave lower VAQ ratings than males to 21 of the 30 slides. However, the differences were small and the overall difference between male and female VAQ results was not statistically significant.

Age – In demographic question #2, age was divided into seven categories. Category 1 (< 18 years old) was excluded from these comparisons because it only included two observers. Results for the other six categories are shown in Table 8. Respondents in age category 2 (18-24 years old) on average gave (statistically significant) higher VAQ ratings than those in categories 5 (45-54 years old) and 7 (65+). In each case, the mean VAQ difference was approximately 0.4. Respondents in the 35-44 year-old range actually gave a slightly higher mean VAQ score than the 18-24 year-old group, but the smaller number of persons in the former group resulted in the differences with other groups not being statistically significant at $\alpha = .01$.

Income – Annual household gross income was also divided into seven categories. No significant differences in VAQ ratings were found for any of the 21 possible combinations of category comparisons.

Education – There were five categories for highest level of education attained, but none of the respondents marked category 1 (some high school or less). Category 4 (completed undergraduate degree) had the lowest mean VAQ score: average ratings on 26 of the 30 slides were lower for category 4 than for category 3 (incomplete undergraduate program). However, these differences based on education level were not found to be statistically significant.

Length of Residence – Demographic question #6 asked respondents how long they had lived in the LFV. As a group, respondents who had lived in the LFV for more than ten years provided the lowest average VAQ score, but no clear trend in ratings based on residence time was evident nor were any of the differences in means found to be significant.

Geographic origin – Question #7 asked participants to name the country in which they spent their formative years. Responses were compiled by continent, except that Canada and the U.S.A. were considered separate categories. No significant differences in VAQ ratings were found based on these divisions.

Table 7: Comparison of mean VAQ ratings for each slide by male and female participants.

Part 1 Slide #	**Mean VAQ Male**	**Mean VAQ Female**
	n = 143	n = 147
1	4.0	3.9
2	3.0	2.6
3	5.8	5.7
4	5.8	5.8
5	4.3	4.3
6	2.2	2.0
7	3.5	3.6
8	2.2	2.0
9	6.4	6.6
10	4.0	4.0
11	2.2	1.9
12	5.8	5.7
13	3.6	3.5
14	3.7	3.6
15	5.7	5.6
16	6.3	6.2
17	3.5	3.4
18	1.8	1.6
19	5.3	5.3
20	3.2	3.0
21	4.8	4.8
22	1.8	1.5
23	3.0	2.9
24	2.6	2.3
25	5.9	5.9
26	4.6	4.5
27	4.2	4.2
28	3.3	3.2
29	1.4	1.2
30	4.3	4.1
Mean	**3.9**	**3.8**

Table 8: Comparison of mean VAQ ratings for each slide by age category.

Part 1 Slide #	**Mean VAQ 18 - 24**	**Mean VAQ 25 - 34**	**Mean VAQ 35 - 44**	**Mean VAQ 45 - 54**	**Mean VAQ 55 - 64**	**Mean VAQ 65+**
	n = 137	n = 58	n = 27	n = 36	n = 20	n = 10
1	4.1	3.9	4.1	3.5	4.0	3.6
2	2.9	2.7	3.0	2.4	3.1	2.5
3	5.8	5.7	5.8	5.4	6.0	5.2
4	5.9	5.7	5.9	5.5	5.8	5.3
5	4.4	4.2	4.4	4.0	4.2	4.2
6	2.2	2.0	2.5	1.9	2.0	2.0
7	3.7	3.3	4.0	3.2	3.5	2.9
8	2.1	1.8	2.6	2.0	2.1	2.1
9	6.6	6.5	6.4	6.1	6.5	6.1
10	4.2	3.9	3.9	3.7	4.2	3.6
11	2.1	1.9	2.3	1.8	1.9	1.9
12	5.7	5.8	6.0	5.7	5.7	5.2
13	3.6	3.5	3.9	3.4	3.2	2.8
14	3.8	3.6	3.9	3.5	3.4	2.7
15	5.7	5.6	5.8	5.6	5.6	5.0
16	6.4	6.3	6.5	6.1	6.2	5.9
17	3.6	3.3	3.6	3.2	3.3	3.2
18	1.7	1.6	2.1	1.5	1.6	1.7
19	5.4	5.4	5.5	5.1	5.0	5.3
20	3.2	3.0	3.4	2.9	2.9	3.1
21	4.8	4.7	5.1	4.6	4.9	4.7
22	1.6	1.5	2.0	1.4	1.6	1.5
23	3.0	3.0	3.3	2.7	2.7	2.6
24	2.5	2.4	2.6	2.1	2.4	2.2
25	5.9	5.8	6.2	5.8	5.9	6.0
26	4.7	4.5	4.8	4.3	4.2	4.8
27	4.4	4.0	4.2	4.0	3.8	4.1
28	3.4	3.2	3.1	2.9	3.0	2.9
29	1.3	1.3	1.5	1.2	1.3	1.3
30	4.4	4.1	4.2	3.7	4.0	4.2
Mean	**4.0**	**3.8**	**4.1**	**3.6**	**3.8**	**3.6**

Environment of formative years – Question #8 inquired whether the place in which respondents had spent their formative years was highly urban, urban/suburban or rural. Mean VAQ ratings were highest for respondents from highly urban areas and lowest for observers from rural areas, but again, the differences were small and statistically insignificant.

Previous participation in a visibility study – Out of 290 observers, eight responded that they had participated in some kind of prior visibility study. This sub-group on average rated the slides a bit higher than the overall sample, but the difference was not significant.

In summary, while some interesting trends can be found in the Part 1 results as broken down into demographic groupings, age was the only parameter that manifested statistically significant differences based on the methods outlined above. Participants in the 18-24 year-old demographic, which was composed mostly of college and university students, tended to provide higher VAQ ratings than two of the older age groups. In fact, a division of the data into university and non-university categories also yields a significant difference in overall mean VAQ ratings (at $\alpha = .05$). The mean score for the university groups (n = 174) was 3.93 and the mean score for the non-university groups (n = 116) was 3.80. On average, the students rated 22 out of 30 slides higher than the non-students. This result could suggest that university students are not an entirely representative sample of the population at large, or it may simply reflect age-based differences in the population.

5.2.4 Duplicate slides

In both parts of the survey, four of the images were shown twice. Thus, the set of 30 slides contained 26 unique images. Table 9 repeats the statistics found in Table 4 for the four slide pairs that represent the duplicates. The difference in mean VAQ ratings for duplicate slide pairs ranges from 0.1 to 0.3, which is much less than the standard deviations of individuals' slide ratings. Although the slides were shown in the same order to each survey group and it can be expected that a conditioning effect influenced respondents' ratings as the slide show progressed, no clear pattern is evident in the duplicate slide ratings. For two of the pairs, the average rating was higher for the second viewing, and for the other two pairs the rating was lower for the second viewing. Table 9 also shows the percentage of respondents who rated the same image within +/- 1 VAQ increment and the percentage who rated the image differently by two or more VAQ units. For all of the duplicates, over 80% of respondents were within +/- 1 unit, which indicates a general tendency for individuals to rank the images in a reasonably consistent manner. The most consistent results are from slides 8 & 11, which 98% of observers rated within +/- 1 VAQ unit and a majority (59%) rated with the same score both times. The image used for slides 8 & 11 showed a high level of haziness, resulting in low VAQ scores. It may be that participants were more decisive about the relatively extreme images than they were for slides showing moderate amounts of haze.

Table 9: VAQ ratings for duplicate slide pairs based on individual responses.

Part 1 Slide #	Image	Min rating	Max rating	Mean	Std. dev.	+/- 1	+/- 2+
4 25	E	2 2	7 7	5.8 5.9	0.99 0.91	88%	12%
5 26	I	2 2	7 6	4.3 4.6	0.99 0.96	84%	16%
8 11	X	1 1	5 5	2.1 2.0	0.94 0.95	98%	2%
17 28	P	1 1	6 6	3.5 3.2	0.95 0.98	93%	7%

The similar average ratings for the duplicate pairs reflect the observers' skill in evaluating the degree of haziness and justify combining duplicate slide results so that each image has a single mean VAQ score. This has been done for Table 10 and subsequent results.

Table 10: Part 1 results for each of the 26 study slide images.

Part 1 Slide #	Image	Date	Time (LST)	RH (%)	b_{sp} (Mm^{-1})	Deciview (dv)	Mean VAQ
1	O	8/16/2010	1530	32	68.8	21.8	3.9
2	T	8/11/2010	1530	56	94.7	24.3	2.8
3	C	9/25/2010	1530	42	12.6	10.5	5.7
4, 25	E	8/24/2010	1230	39	16.7	11.9	5.8
5, 26	I	7/27/2010	1530	42	45.4	18.6	4.4
6	Y	8/4/2010	1530	51	177.4	30.1	2.1
7	N	8/11/2010	1330	59	68.3	21.6	3.5
8, 11	X	8/5/2010	1330	50	147.3	28.3	2.1
9	B	9/22/2010	1330	48	10.6	9.8	6.5
10	K	8/25/2010	1230	45	50.6	20.1	4.0
12	G	8/24/2010	1530	35	23.2	14.6	5.7
13	Q	7/28/2010	1230	53	83.9	23.4	3.5
14	M	8/2/2010	1200	60	65.4	21.1	3.6
15	F	9/3/2010	1530	35	17.8	12.7	5.6
16	A	9/21/2010	1600	42	4.7	6.0	6.3
17, 28	P	8/16/2010	1230	40	79.8	23.3	3.3
18	V	8/6/2010	1130	65	104.4	25.2	1.7
19	D	8/23/2010	1530	36	14.5	11.1	5.3
20	U	8/17/2010	1430	34	91.8	24.5	3.1
21	H	8/25/2010	1530	33	32.2	16.3	4.8
22	Z	8/5/2010	1530	47	195.6	30.9	1.6
23	R	8/17/2010	1130	42	82.9	23.8	3.0
24	S	8/18/2010	1530	57	89.8	23.9	2.4
27	L	7/30/2010	1530	51	59.4	20.6	4.2
29	W	8/3/2010	1530	72	108.5	26.0	1.3
30	J	8/2/2010	1530	51	54.1	19.6	4.2

5.2.5 Relating VAQ to physical measurements

In Table 10, the date and time of each image is given along with the corresponding RH, particle scattering coefficient (b_{sp}), deciview and mean VAQ score. RH and b_{sp} are from instruments that are co-located with the camera at the Chilliwack airport; all meteorological and air quality variables are hourly averages valid for the hour beginning at the recorded observation time.

The deciview scale is a haziness index developed by Pitchford and Malm (1994) to be linear with respect to perceived changes in visibility. Deciview is calculated from the extinction coefficient:

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

A change of 1.0 dv relates to about a 10% change in b_{ext}, which usually results in a small but perceptible change in visibility. For this study, b_{ext} was not measured directly, but was calculated based on measurements of b_{sp}, NO_2 and black carbon.

To determine how well the public perception data relate to measureable visibility parameters, the mean VAQ scores are compared to deciview values from the corresponding image times. This is shown as a scatter plot in Figure 8. The linear trendline shows that the VAQ scores decrease as the degree of haziness increases. The r^2 value in excess of 0.9 means that more than 90% of the variation in VAQ ratings can be explained by changes in deciview. This strong correlation also confirms that deciview has a linear relation to perceived changes in VAQ, making it useful as haziness index.

The remaining variation in VAQ scores not accounted for by deciview (≈ 9%) can be attributed to other factors which have not been fully controlled in this study (e.g., sun angle, varying snow cover on the mountains, etc.) and to errors of measurement and survey procedures. Regarding measurement, the deciview value for each image was derived from instrument readings that have been averaged over an hour's time. In fast-changing conditions, the hourly average may not be representative of the situation at the image time. Additionally, the instruments only measure atmospheric conditions at the observation site; these conditions will not always be uniform throughout the length and depth of the viewscape.

Regarding survey procedures, it is likely that a conditioning effect influenced some of the individual image ratings. The definition of what sort of picture constitutes a “1” rating vs. a “7” rating was left to the participants. Therefore, a person’s application of the scale could have been fluid, influenced by the warm-up slides as well as the conditions most recently depicted. Conditioning effects could have been randomized by re-ordering the slides for each survey group. For this study, the slide order was kept consistent, adhering to the goal of minimizing variability in the viewing conditions of each survey session.

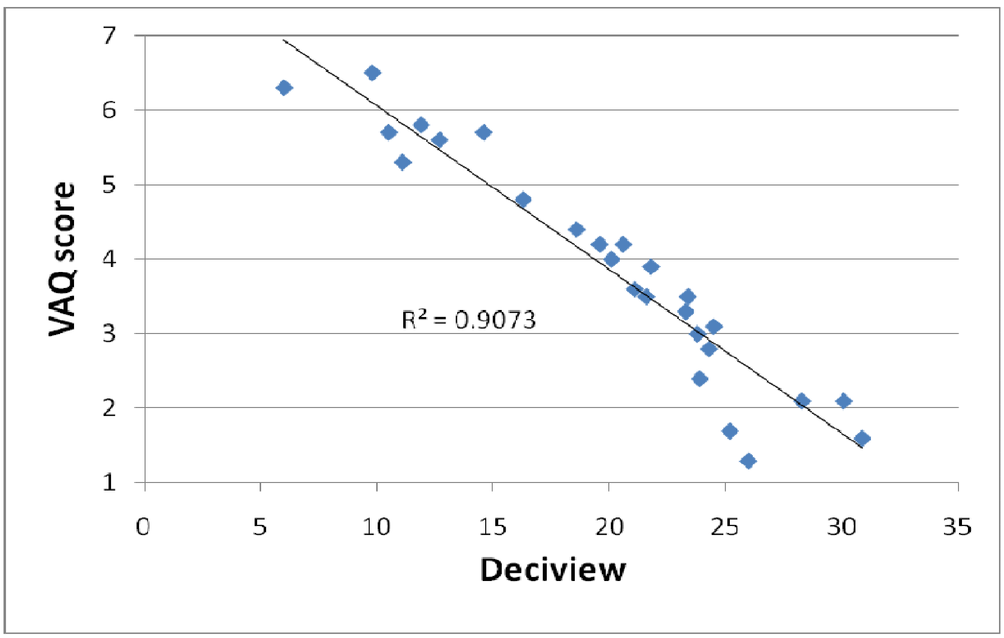

Figure 8: Scatter plot of mean VAQ ratings and deciview with a best-fit linear trendline. Each data point represents one of the 26 images used in the survey.

5.3 Acceptability ratings (Survey Part 2)

For Part 2 of the survey, participants were asked to view the slides a second time and rate each one as either acceptable or unacceptable based on their own visibility standards. The participants were informed that the same 30 slides as in Part 1 would be shown, but in a different order. Acceptability ratings have been used previously to determine a consensus visibility standard for a particular area, e.g., Ely et al. (1991) for Denver.

5.3.1 Ratings by individuals

A summary of the individual responses is shown as a histogram in Figure 9, which depicts an approximately normal distribution, but with greater variance than the mean VAQ ratings (Figure 7).

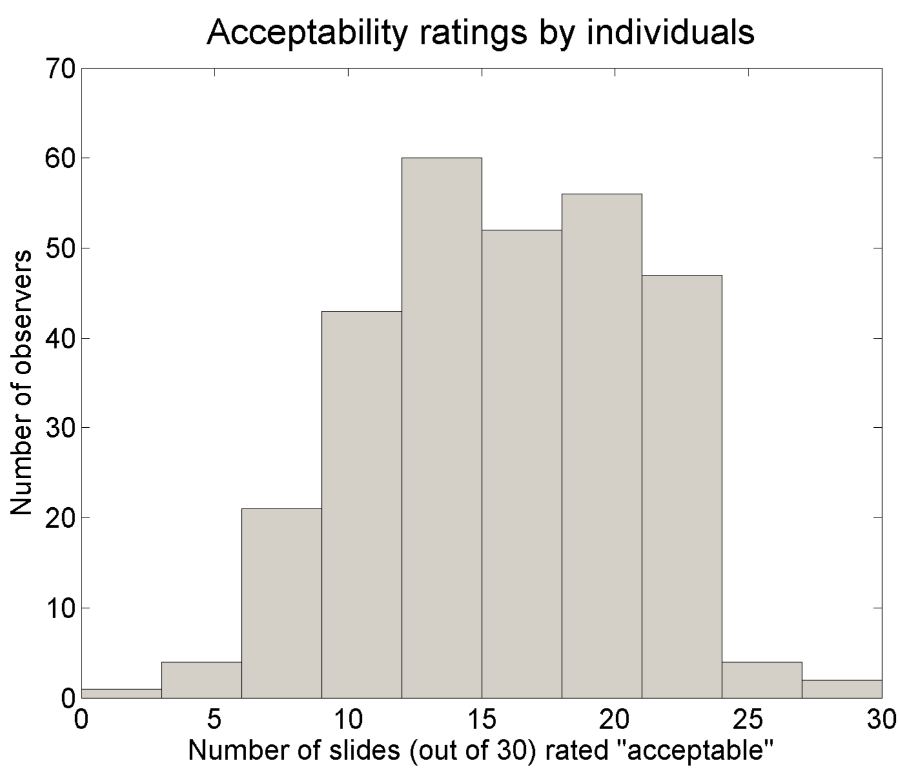

Figure 9: Distribution of acceptability ratings by individuals.

On average, respondents rated 16 of 30 slides as having acceptable visual air quality and the standard deviation was 5 slides. This apparently large spread in individual results can be explained by the abundance of slides that depicted moderate amounts of haze. A small shift in visibility standard from one individual to another can presumably account for different acceptability ratings being given to numerous slides. The binary nature of the ratings contributes to this variability.

5.3.2 Duplicate slides

As in Part 1 of the survey, four duplicate pairs of images were included in Part 2 to assess the observers' consistency in rating the photos. Analysis of these duplicates is summarized in Table 11. For each of the four images, a large majority of observers consistently judged the scene as acceptable or unacceptable in both appearances of the photo. However, there was considerable variation amongst the images in how many observers provided consistent ratings, ranging from 77% for slides 6 & 20 (image P) to 99% for slides 10 & 28 (image E). The slide pairs with the highest consistency rates (images E & X) depicted scenes that were toward the extreme ends of the available deciview range. Thus, for these "very clear" and "very hazy" photos, the observers most likely found it easy to choose between "acceptable" and "unacceptable" and did so consistently. In contrast, image P depicted a moderate amount of haze (dv = 23.3, overall acceptance rate 40.2%), which likely made the decision more difficult for many observers. Consequently, 23% of the respondents rated the image inconsistently.

Unlike the Part 1 results for the duplicate slides, responses from Part 2 show an interesting trend in how the slides were inconsistently rated. The right-most column of Table 11 compares the two possible tendencies for cases of inconsistent ratings: to rate the first but not the second occurrence of the image as acceptable, or vice versa. For image E, just two respondents rated the slides inconsistently: one respondent rated only slide 10 as acceptable and the other rated only slide 28 as acceptable. For the other three duplicate pairs, more than three-quarters of inconsistent ratings favoured the first occurrence of the image (i.e., only the first slide of the pair was rated as acceptable). In other words, there was a tendency for observers to judge the image more strictly the second time it was shown. The cause of this trend is unknown, but the fact that the slides were shown in the same order for all participants suggests that perception conditioning may have affected these results. However, the overall rate of consistency found in the duplicate slide results is the primary finding here, and the data from duplicate slides have been combined for further analysis of the Part 2 results.

Table 11: Consistency of acceptability ratings for duplicate slide pairs, based on individual responses in Part 2 of the survey.

Part 2 Slide #	**Image**	**Deciview**	**% Consistent**	**Trend when inconsistent**
6 20	P	23.3	77	Y→N 84% N→Y 16%
7 15	I	18.6	88	Y→N 79% N→Y 21%
8 24	X	28.3	98	Y→N 86% N→Y 14%
10 28	E	11.9	99	Y→N 50% N→Y 50%

5.3.3 Relation between VAQ and acceptability ratings

Part 2 results for each image are summarized in Table 12, which shows the acceptability ratings as a percentage of all respondents who rated each image as acceptable, along with the corresponding RH, b_{sp} and deciview values. Table 13 summarizes results of survey Parts 1 & 2 together. Figure 10 compares the data graphically, showing that a strong correlation exists between the VAQ ratings and the acceptability judgments. The nature of the acceptability data makes the correlation non-linear toward the extremes of 0% and 100%. A Spearman's rank correlation coefficient of $\rho = 0.994$ reflects the strong positive correlation in this dataset. This result means that VAQ scores from Part 1 are a good predictor of the percentage of respondents rating the images as acceptable in Part 2, confirming that participants assessed the images in a similar manner for the two parts of the survey. Thus, rather than performing a separate demographic analysis of Part 2 responses, the acceptability ratings are considered to be an extension of the first part of the survey exercise, where the inclusion of all valid responses is justified by the similarity found between groups.

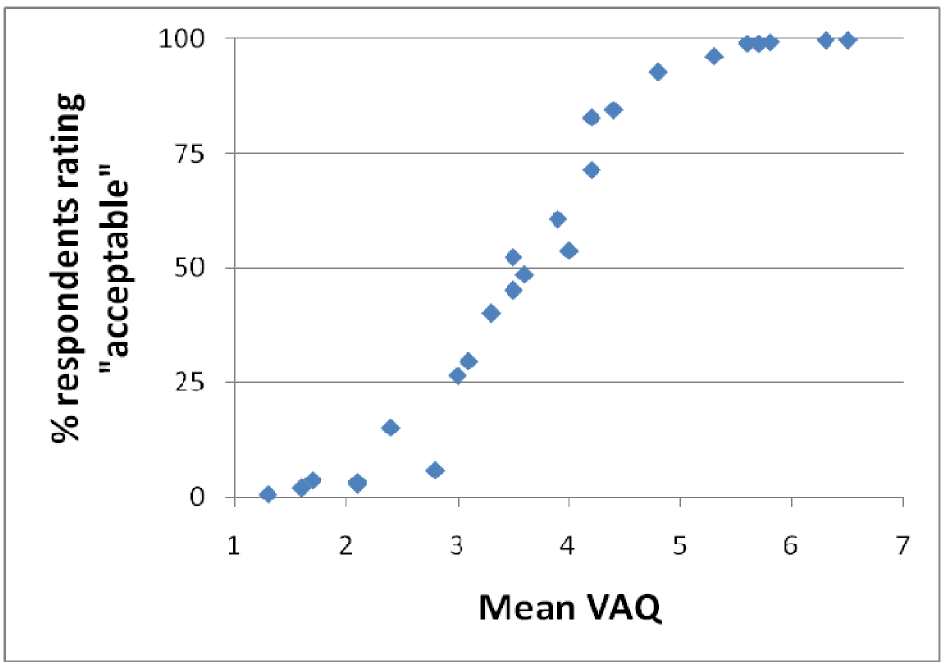

Figure 10: Scatter plot of mean VAQ scores and acceptability ratings. Each data point represents one of the 26 images used in the survey.

Table 12: Part 2 results for each of the 26 study slide images, listed by slide number.

Part 2 Slide #	Image	Date	Time (LST)	RH (%)	b_{sp} (Mm^{-1})	Deciview (dv)	% Acceptable
1	C	9/25/2010	1530	42	12.6	10.5	99.0
2	Y	8/4/2010	1530	51	177.4	30.1	3.4
3	Q	7/28/2010	1230	53	83.9	23.4	52.4
4	S	8/18/2010	1530	57	89.8	23.9	15.2
5	F	9/3/2010	1530	35	17.8	12.7	99.0
6, 20	P	8/16/2010	1230	40	79.8	23.3	40.2
7, 15	I	7/27/2010	1530	42	45.4	18.6	84.5
8, 24	X	8/5/2010	1330	50	147.3	28.3	2.9
9	U	8/17/2010	1430	34	91.8	24.5	29.7
10, 28	E	8/24/2010	1230	39	16.7	11.9	99.3
11	A	9/21/2010	1600	42	4.7	6.0	99.7
12	M	8/2/2010	1200	60	65.4	21.1	48.6
13	W	8/3/2010	1530	72	108.5	26.0	0.7
14	G	8/24/2010	1530	35	23.2	14.6	99.0
16	V	8/6/2010	1130	65	104.4	25.2	3.8
17	H	8/25/2010	1530	33	32.2	16.3	92.8
18	O	8/16/2010	1530	32	68.8	21.8	60.7
19	D	8/23/2010	1530	36	14.5	11.1	96.2
21	K	8/25/2010	1230	45	50.6	20.1	53.8
22	Z	8/5/2010	1530	47	195.6	30.9	2.1
23	R	8/17/2010	1130	42	82.9	23.8	26.6
25	N	8/11/2010	1330	59	68.3	21.6	45.2
26	J	8/2/2010	1530	51	54.1	19.6	71.4
27	L	7/30/2010	1530	51	59.4	20.6	82.8
29	T	8/11/2010	1530	56	94.7	24.3	5.9
30	B	9/22/2010	1330	48	10.6	9.8	99.7

Table 13: Combined Parts 1 & 2 results for each of the 26 study slide images, in order of deciview value.

Image	Part 1 Slide #	Part 2 Slide #	Date	Time (LST)	b_{sp} Mm^{-1}	dv	Mean VAQ	% Acceptable
A	16	11	9/21/2010	1600	4.7	6.0	6.3	99.7
B	9	30	9/22/2010	1330	10.6	9.8	6.5	99.7
C	3	1	9/25/2010	1530	12.6	10.5	5.7	99.0
D	19	19	8/23/2010	1530	14.5	11.1	5.3	96.2
E	4, 25	10, 28	8/24/2010	1230	16.7	11.9	5.8	99.3
F	15	5	9/3/2010	1530	17.8	12.7	5.6	99.0
G	12	14	8/24/2010	1530	23.2	14.6	5.7	99.0
H	21	17	8/25/2010	1530	32.2	16.3	4.8	92.8
I	5, 26	7, 15	7/27/2010	1530	45.4	18.6	4.4	84.5
J	30	26	8/2/2010	1530	54.1	19.6	4.2	71.4
K	10	21	8/25/2010	1230	50.6	20.1	4.0	53.8
L	27	27	7/30/2010	1530	59.4	20.6	4.2	82.8
M	14	12	8/2/2010	1200	65.4	21.1	3.6	48.6
N	7	25	8/11/2010	1330	68.3	21.6	3.5	45.2
O	1	18	8/16/2010	1530	68.8	21.8	3.9	60.7
P	17, 28	6, 20	8/16/2010	1230	79.8	23.3	3.3	40.2
Q	13	3	7/28/2010	1230	83.9	23.4	3.5	52.4
R	23	23	8/17/2010	1130	82.9	23.8	3.0	26.6
S	24	4	8/18/2010	1530	89.8	23.9	2.4	15.2
T	2	29	8/11/2010	1530	94.7	24.3	2.8	5.9
U	20	9	8/17/2010	1430	91.8	24.5	3.1	29.7
V	18	16	8/6/2010	1130	104.4	25.2	1.7	3.8
W	29	13	8/3/2010	1530	108.5	26.0	1.3	0.7
X	8, 11	8, 24	8/5/2010	1330	147.3	28.3	2.1	2.9
Y	6	2	8/4/2010	1530	177.4	30.1	2.1	3.4
Z	22	22	8/5/2010	1530	195.6	30.9	1.6	2.1

5.3.4 Relating acceptability ratings to physical measurements

Acceptability ratings vs. deciview are plotted in Figure 11. A best-fit curve for this dataset would approximate the "backward-S" shape observed in previous visibility studies (U.S. EPA, 2010). Below a certain deciview level, nearly 100% of respondents rated the scene as acceptable, and above a certain deciview level close to zero respondents judged the scene as acceptable. In between, the percent of observers rating the images as acceptable declined sharply, and roughly linearly, as deciview increased. For this dataset, images of deciview ≤ 16 had very high acceptability rates (> 90% of respondents) and images depicting deciview > 25 had near-zero acceptability rates. The Spearman's rank correlation coefficient for these variables is -0.971, indicating a strong negative correlation between deciview and acceptability ratings.

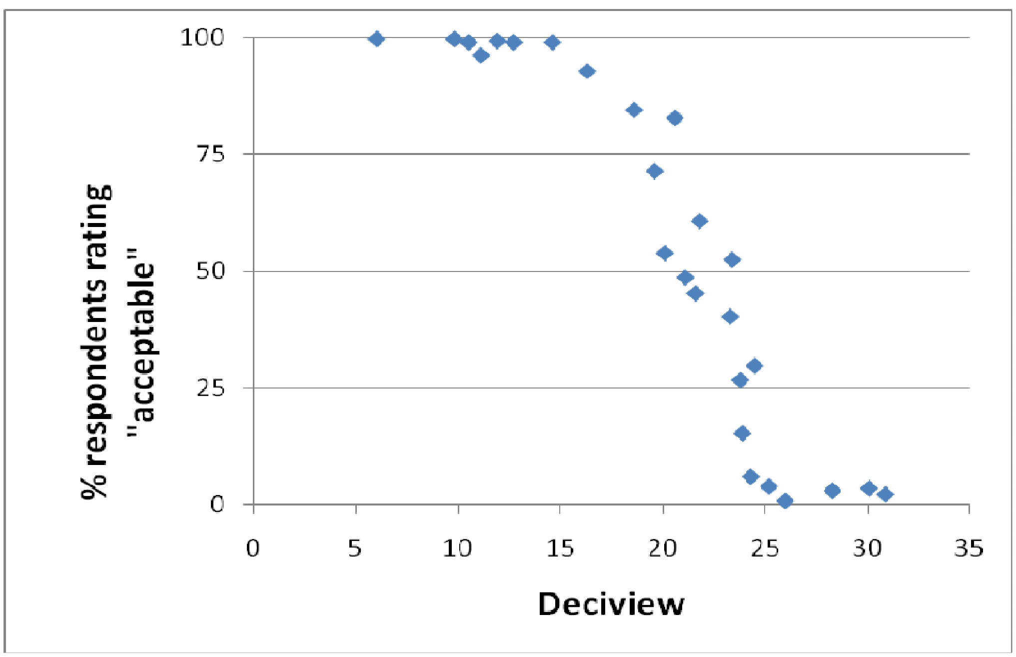

Figure 11: Scatter plot of of acceptability ratings and deciview.

For comparison to other studies, a 50% acceptability criterion can be approximated from the data in Figure 11 and Table 13. The image having nearest to 50% acceptability was image M (presented as slide #12 in Part 2 of the survey; included in Appendix C), which 48.6% of observers rated as acceptable. The deciview value corresponding to this image is 21.1. If dv = 21 is chosen as the 50% acceptability criterion, then just two of the images will be "misclassified": images O & Q both had greater than 50% acceptability with dv > 21. Any criterion other than dv = 21 (e.g. dv = 20 or dv =22) would result in a greater number of images being misclassified. The corresponding scattering and extinction coefficients for a 50% acceptability criterion of dv =21 are $b_{sp} \approx 65\ Mm^{-1}$ and $b_{ext} = 81.7\ Mm^{-1}$. This criterion is slightly stricter than the value of dv = 22.45 estimated by the U.S. EPA (2010) from the first LVF VAQ study, but it retains the same position in comparison to results from other urban areas (i.e., Denver's 50% acceptability criterion was at a lower deciview value while those of Phoenix and Washington, D.C. were at higher deciview values).

Atmospheric particulate matter (PM) concentration is another physical variable that affects visibility. For this study, measurements of fine particulate matter ($PM_{2.5}$) were available from the Chilliwack airport site. Figure 12 compares $PM_{2.5}$ observations with acceptability ratings. Although the same general trend can be detected in this dataset as that of Figure 11, the $PM_{2.5}$ data show a weaker relation to acceptability rating (more scatter) than deciview. $PM_{2.5}$ is simply a concentration of fine particles, whereas b_{ext} and deciview account for the fact that certain types of particles attenuate light more efficiently than others. Therefore, deciview is a better predictor of visibility and VAQ assessments than PM concentration.

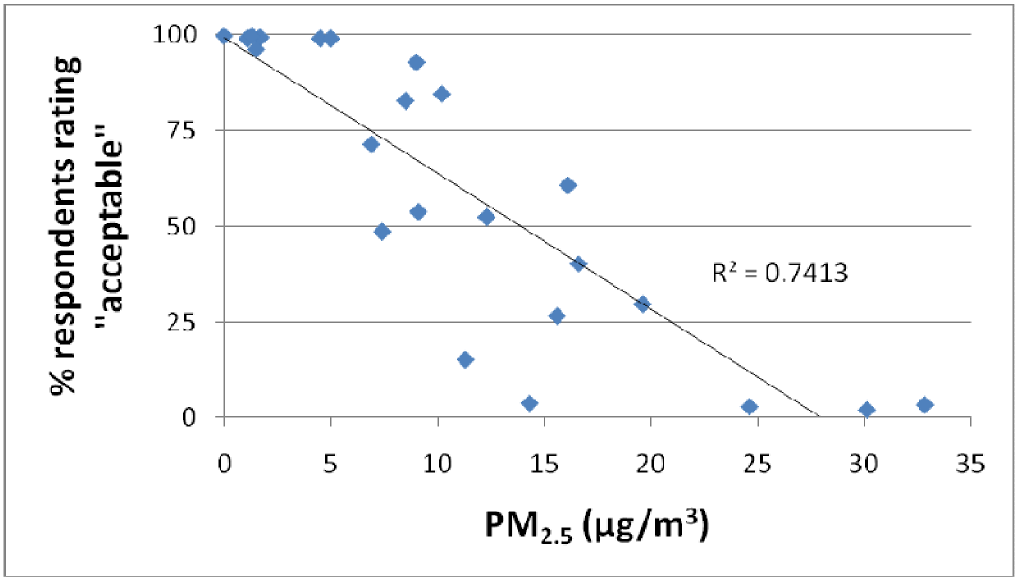

Figure 12: Scatter plot of of acceptability ratings and one-hour mean concentration of fine particulate matter ($PM_{2.5}$) with a best-fit linear trendline.

5.4 Additional analysis topics

5.4.1 Time of day comparisons

Results from two same-day image pairs are compared in Table 14. In each case, the level of haziness as quantified by deciview did not change much between image times. On 24 August, the haziness increased slightly from dv = 11.9 at 1230 LST to dv = 14.6 at 1530 LST. Acceptability ratings for these two images were essentially the same at 99% and the mean VAQ score was just 0.1 lower for the 1530 image than for the 1230 image. On 17 August, the haziness also showed a slight diurnal increase from dv = 23.8 at 1130 LST to dv = 24.5 at 1430 LST. In this case, the mean VAQ increased slightly from 3.0 to 3.1 and the acceptability rate increased from 26.6% to 29.7%.

Table 14: Data comparison for two same-day image pairs.

Image	Date	Time (LST)	dv	Mean VAQ	% Acceptable
E	8/24/2010	1230	11.9	5.8	99.3
G	8/24/2010	1530	14.6	5.7	99.0
R	8/17/2010	1130	23.8	3.0	26.6
U	8/17/2010	1430	24.5	3.1	29.7

For the 17 August case, the afternoon image was rated slightly more favourably than the late morning image despite the fact that the afternoon image was associated with a higher deciview value. One factor which may have influenced these results is the change in illumination conditions from late morning to mid-afternoon as the sun's position in the sky changed. As a result of the view being toward the southeast, the afternoon images are partially backlit, which may produce a more pleasing scene to some observers. However, other factors could have affected these results. For instance, the deciview value as calculated from instrument readings at one or both of the image times may not have been properly representative of the view to the southeast due to spatial variations. Additional cases of appropriate time-of-day comparisons would need to be analyzed before attributing the trends in perception data to any one factor.

5.4.2 Cloud cover and humidity

Although an aim of this study was to include a greater variety of meteorological conditions than previous studies, image selection criteria in the end limited the variability in cloud cover and humidity conditions associated with the slides. However, the cloud conditions do cover a range of what could be described as "partly cloudy" situations (approximately 1/8 to 7/8 coverage) as well as at least six cloud-free images. (For very hazy scenes, the cloud cover is difficult to assess.) No trends could be found in which VAQ or acceptability ratings seem to show dependency on amount or type of cloud cover.

Regarding humidity, 24 of the 26 images are from times when the RH was in the range of 30-60%. It is noteworthy that the image with the lowest VAQ and acceptability ratings, which was image W (despite three images having higher deciview values), also had the highest RH (72%). In this image from 3 August, the scene appears to be quite dark, suggesting the presence of forest fire smoke. While this image was indeed from a period of elevated black carbon levels at Chilliwack, its associated black carbon concentration was lower than that of two of the three images which had higher deciview values (but also higher VAQ scores). Thus, it is possible that high humidity conditions during the time of image W contributed to the opacity of the scene in a manner not properly represented by the measurements that go into the calculation of deciview, despite the fact that b_{sp} values derived from the ambient nephelometer do account for the effect of humidity on the particles. It may be that the higher elevations of the viewscape had even higher RH and thus enhanced scattering as compared to conditions at instrument level. Due to the exponential increase of scattering by hygroscopic particles with increasing RH, such effects due to spatial inhomogeneities would be accentuated in high RH conditions.

The image with the second-highest associated RH also had a low mean VAQ score for its deciview. Image V from 6 August had a mean VAQ rating of 1.7, which is considerably lower than ratings for two of the images with higher deciview values. Images X & Y both had VAQ scores of 2.1; the RH readings associated with those images were 50% and 51%, respectively, while the RH for image V was 65%. These cases provide some evidence that high RH conditions may influence the perceived VAQ more than predicted by a linear relation to deciview, although more examples of RH > 60% would be needed to support such an assertion.

5.4.3 Residents' perceptions of the VAQ trend

Demographic question #6a asked participants for their opinions on how visual air quality in the LFV has changed over the past five years. This question was to be answered only by respondents who had lived in the LFV for more than five years. As can be seen from Figure 13, approximately two-thirds of the respondents were qualified to answer question #6a.

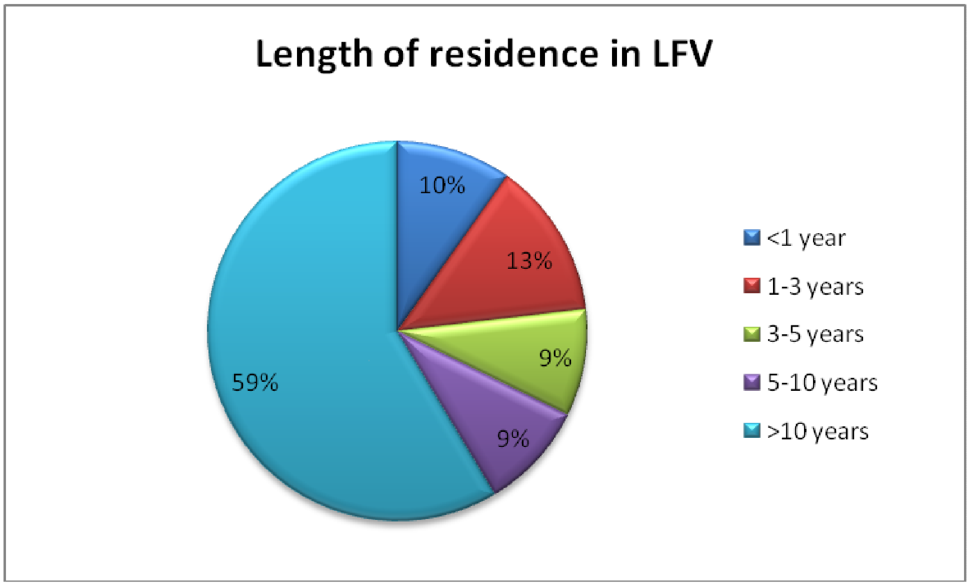

Figure 13: Length of residence in the Lower Fraser Valley of survey respondents.

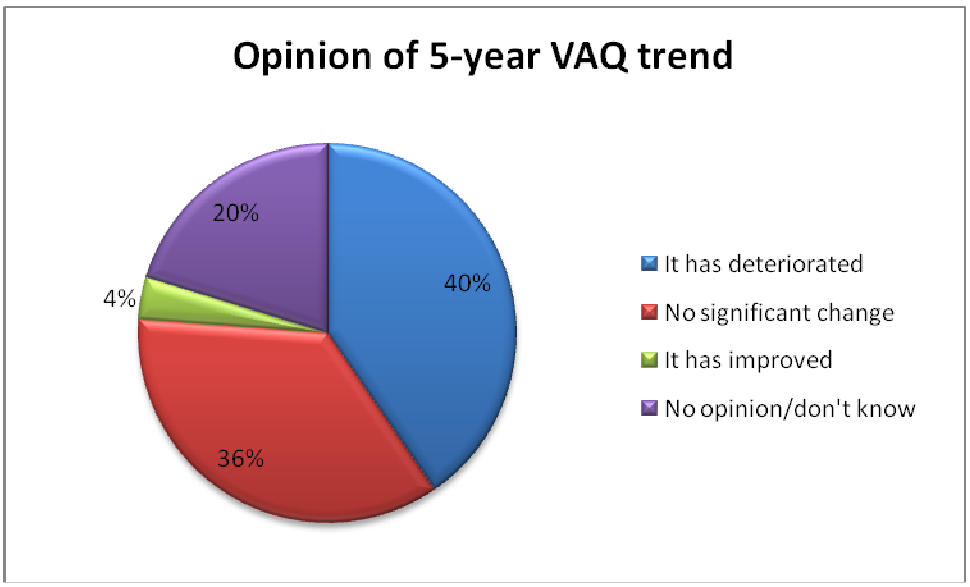

Figure 14: Perception of the VAQ trend over the previous five years by respondents who had lived in the LFV for more than five years.

The distribution of responses to question #6a is shown in Figure 14. The most common opinion was that the VAQ had deteriorated (40% of respondents), followed by those who felt there had been no significant change (36%). Only 4% of respondents felt that the VAQ had improved, and the remaining 20% answered that they didn't know or had no opinion on the matter.

The mean VAQ rating by respondents who perceived an improving VAQ trend was higher than the mean rating by those who felt the VAQ had deteriorated (4.01 vs. 3.79), but due to the small number of responses in the "improved" category, the difference was not statistically significant. Respondents having no opinion of the VAQ trend actually provided a mean VAQ score slightly below that of observers who perceived worsening conditions (3.77 vs. 3.79). Thus, the results provide only weak evidence that survey participants who were more optimistic about the trend of the region's VAQ also tended to rate the scenes with higher VAQ scores than other respondents.

5.4.4 Comparison to previous LFV studies

The current study is similar in design to those of Pryor and Steyn (1994) and Pryor et al. (1995) for the LFV. Therefore, comparison of results can be used to determine if there are any obvious trends in how residents of the region regard visibility conditions.

The pilot study (Pryor and Steyn, 1994) was a survey that included 206 students in Geography undergraduate classes at UBC. Images from Chilliwack and Abbotsford were used, with ten study slides included from each location. Similar to the current study, a linear relation between averaged VAQ ratings and the natural logarithm of b_{ext} was found in the results. Following the practice of the Denver study by Ely et al. (1991), Pryor and Steyn (1994) determined the 50% acceptability criteria for both sites. They stated each criterion as a range of optical variables, which represented the slides immediately above and below the 50% acceptability position in results from Part 2 of the survey. For Chilliwack this range was b_{ext} = 96-105 Mm^{-1} or b_{sp} = 61-73 Mm^{-1}. For Abbotsford, the range was b_{sp} = 35-49 Mm^{-1}. Values were given in b_{ext} and b_{sp} for Chilliwack because that location had both a nephelometer and a transmissometer. Abbotsford had just a nephelometer, and presumably insufficient additional instrumentation to calculate b_{ext}, thus the results were given in b_{sp} only.

The second LFV study (Pryor et al., 1995) surveyed primarily residents of the eastern part of the valley (Abbotsford, Chilliwack and Agassiz). Ten study slides each were included from Chilliwack, Abbotsford and Matsqui. The following 50% acceptability criteria were derived from the results: b_{sp} = 26-39 Mm^{-1} for Chilliwack, b_{sp} = 31-34 Mm^{-1} for Abbotsford, and b_{sp} = 32-40 Mm^{-1} for Matsqui.

The above data from the previous studies appear to give mixed results. In the first study, the 50% acceptability criterion was at a considerably lower b_{sp} range (implying a stricter standard) for Abbotsford than for Chilliwack. In the second study, the stated range for Chilliwack is much lower than in the first study and is in better agreement with the other sites. However, Part 2 results examined by slide for Chilliwack and Matsqui in the second study appear to be inconsistent, lacking a strong correlation between b_{sp} and acceptability ratings. For Chilliwack, Pryor et al. (1995) mentioned the concept of a "dual threshold" owing to some of the slides depicting non-uniform haze. The range of 26-39 Mm^{-1} was the first instance of the results passing through the 50% acceptability threshold. Use of this range would misclassify four slides with higher b_{sp} that were rated as acceptable by more than 50% of respondents. If the 50% acceptability criterion for Chilliwack is selected to minimize the number of misclassified slides, then the b_{sp} range becomes 63-67 Mm^{-1}. The Matsqui results are similarly ambiguous, with the acceptability ratings passing through 50% several times as b_{sp} increases. For Abbotsford, the stated criterion only misclassifies one slide.

If the above adjusted range is taken as an appropriate 50% acceptability criterion for Chilliwack in the 1995 study, then results from that location are remarkably consistent for the three studies: b_{sp} = 61-73 Mm^{-1} for the 1994 study, b_{sp} = 63-67 Mm^{-1} for the 1995 study, and $b_{sp} \approx 65$ Mm^{-1} for the current study. It should be noted that in the two earlier studies the Chilliwack photos were taken from the hospital rather than the airport and the view was toward a different direction.

Abbotsford results from the earlier studies suggest a stricter visibility standard for that location. Pryor and Steyn (1994) speculated that differences in physical characteristics between the two viewscapes could have affected the ratings. However, the small number of images used for each site and the fact that the cameras and nephelometers were not co-located both contribute to the inconclusive quality of results from the earlier studies. All instruments for the current study were located with 5 m of each other at the Chilliwack airport. The effect of different viewscapes on the results was not tested for the current study. However, it is of interest that the Chilliwack results are in good agreement between the three studies despite the very different viewscapes used from the hospital and airport sites.

6. Conclusions

This visual air quality study was undertaken to build upon the methodology and findings of previous public perception studies that have been conducted in the LFV and elsewhere. A larger and more representative sample of the region's population than what was obtained in earlier studies was sought for this study. This goal was achieved by surveying 301 people in 17 different groups at the University of British Columbia and various other locations within Metro Vancouver. While the distributions of income, age and education categories did not match those of the latest census for Metro Vancouver, it was found that different demographic groups for the most part did not produce statistically significant differences in their ratings of VAQ. Age was the one demographic factor that produced significant differences, whereby the 18-24 year-old group, which was dominated by undergraduate students, had a tendency to give higher VAQ scores than some of the older age groups.

The second objective of this study was to investigate whether visibility perception has changed over time in the LFV since the last study of this kind. Broadly, the results of this and earlier studies show similar relations between public perception data from surveys and measured optical variables such as particle scattering coefficient. Using deciview as a measure of haziness, it was found that mean VAQ scores from surveys decrease as deciview increases. Likewise, the percentage of respondents rating a scene as acceptable (according to their own individual visibility standards) decreases as deciview increases. For comparison to past studies, an approximate 50% acceptability threshold was derived from the results of Part 2 of the survey. This threshold was found to lie at a deciview level of approximately 21, which corresponds to $b_{sp} \approx 65\ Mm^{-1}$. This value of b_{sp} is in good agreement with 50% acceptability criteria derived for Chilliwack from the two earlier LFV visibility studies. However, there were differences between the studies – such as a changed viewscape and different number of images used – that make such comparisons tenuous. From the similar results, it can be asserted that there is no evidence of a significant change in public perception of VAQ in the LFV between the early 1990s and 2011.

A third objective of the study was to investigate whether the methods of previous studies are applicable to a broader range of atmospheric conditions, specifically humidity and partial cloud cover. In practice, these factors were difficult to isolate from the dominant effect of changing deciview, and it can be said that cloud cover had no discernable effect on VAQ ratings. Regarding humidity, some evidence was found that conditions of high RH (> 60%) may reduce the perceived VAQ more than predicted by a linear relation between VAQ and deciview values. The image selection criteria used for this study were similar to those of Pryor et al. (1995), but were less restrictive concerning cloud and humidity conditions. Similar overall results between the studies suggest that changes in image selection procedures and other methodological adjustments did not adversely impact the outcomes.

Limitations of this study include the geographic scope of the survey and the inclusion of only one viewscape. All of the survey sessions were conducted within Metro Vancouver, with an emphasis on the city of Vancouver. Although this still allowed for inclusion of eastern LFV residents who commute to Metro Vancouver, in practice almost all of the participants lived in the western half of the LFV. Residents of the eastern LFV would likely be more familiar with the view from Chilliwack that was presented in the survey; it is not known if such familiarity would have any effect on the results. Also, the inclusion of only one view in the survey meant that no additional information was obtained on the possible effects of varying scenic composition on VAQ perception.

The relatively large sample size of this study adds confidence to preliminary findings from earlier LFV studies, which demonstrated strong correlations between public perception data and visibility variables as measured from instruments. Results averaged over all valid responses provide a consensus assessment of VAQ for widely varying degrees of visibility impairment. Therefore, the perception data collected from the community for this study can be used to properly account for the subjective nature of VAQ during future work, which may include development of a visibility index and/or standard for the region. Establishment of a visibility index or standard is an important step toward long-term monitoring and management of visibility in this region of esteemed scenic assets.

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References

BBC Research & Consulting, 2003: Phoenix area visibility study. Final report for the Arizona Department of Environmental Quality.

Boubel, R. W., D. L. Fox, D. B. Turner, and A. C. Stern, 1994: *Fundamentals of Air Pollution, 3rd edition*. Academic Press, 574 pp.

Ely, D. W., J. T. Leary, T. R. Stewart, and D. M. Ross, 1991: The establishment of the Denver visibility standard. Presented at the 84th Annual Meeting and Exhibition of the Air & Waste Management Association, Vancouver, BC, June 16-21.

Hyslop, N. P., 2009: Impaired visibility: the air pollution people see. *Atmospheric Environment*, 43 (1), 182-195.

Latimer, D. A., H. Hogo, and T. C. Daniel, 1981: The effects of atmospheric optical conditions on perceived scenic beauty. *Atmospheric Environment*, 15 (10-11), 1865-1874.

Malm, W., K. Kelley, J. Molenar, and T. Daniel, 1981: Human perception of visual air quality (uniform haze). *Atmospheric Environment*, 15 (10-11), 1875-1890.

McNeill, R. and A. Roberge, 2000: The impact of visual air quality on tourism revenues in Greater Vancouver and the Lower Fraser Valley. Tech. rep., Georgia Basin Ecosystem Initiative, Environment Canada, Vancouver, BC.

Metro Vancouver, 2008: 2006 Census Bulletin #6, Immigration and Cultural Diversity. Accessed online at http://www.metrovancouver.org/about/publications/Publications/Census2006_Immigration_Bulletin_6.pdf.

Middleton, P., T. R. Stewart, D. Ely, and C. W. Lewis, 1984: Physical and chemical indicators of urban visual air quality judgments. *Atmospheric Environment*, 18 (4), 861-870.

Nakagawa, S., 2004: A farewell to Bonferroni: the problems of low statistical power and publication bias. *Behavioral Ecology*, 15 (6), 1044-1045.

Pitchford, M. L. and W. C. Malm, 1994: Development and applications of a standard visual index. *Atmospheric Environment*, 28 (5), 1049-1054.

Pryor, S., K. Stephens, and D. Steyn, 1995: Visibility perception in the Lower Fraser Valley. Final report submitted to the Air Resources Branch, British Columbia Ministry of Environment, Lands and Parks.

Pryor, S. and D. Steyn, 1994: Development and validation of a methodology for assessing visibility perception in the Lower Fraser Valley. Final report submitted to the British Columbia Ministry of Environment, Lands and Parks.

Statistics Canada, 2011: Data from 2006 Census of Canada. Accessed online via Canadian Census Analyser, Computing in the Humanities and Social Sciences (CHASS), University of Toronto. http://datacentre.chass.utoronto.ca/census/.

U.S. EPA, 2010: Particulate matter urban-focused visibility assessment. Final document. Tech. rep., Health and Environmental Impacts Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Appendices

Appendix A. Survey questionnaire

Visibility Perception Study for the Lower Fraser Valley, BC

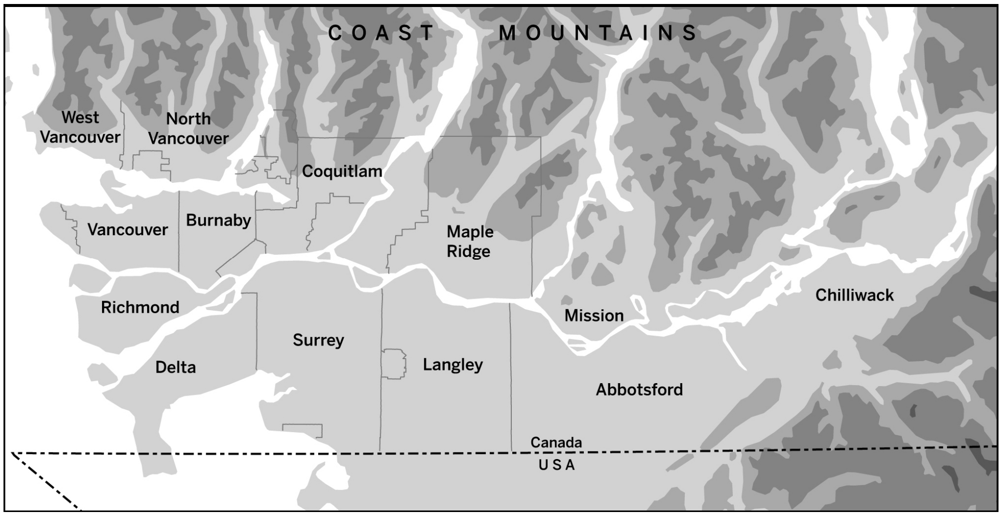
Purpose of this study: To assess perception of visibility conditions in the Lower Fraser Valley. Residents of the region are being surveyed to obtain data on perceived visual air quality for a range of conditions and to gauge what constitutes acceptable visibility.

Method: You will be asked to view 34 slides (digital photos) of views from a single vantage point in the Lower Fraser Valley and to assess:

1) The quality of the visibility conditions portrayed (on a scale of 1 to 7), and
2) Whether or not the conditions shown on each slide are considered acceptable or unacceptable based on your own visual air quality standard for the Lower Fraser Valley.

You will also be asked to provide some personal demographic information. This information is requested for the purpose of assessing how representative the sample group is of the general population. ALL INFORMATION IS STRICTLY CONFIDENTIAL. THE COMPLETED QUESTIONNAIRES WILL NOT BE REVIEWED BY ANYONE OTHER THAN THE INVESTIGATORS. Your participation in this survey is entirely voluntary. Please do not identify yourself to the investigators. You may withdraw at any time, but a completed questionnaire will be regarded as evidence of your consent to full survey participation. THANK YOU!

Time commitment: approximately 40 minutes.



Map of the Lower Fraser Valley

If you have any questions about this study, feel free to ask at the end of the survey or contact us later:

Principal Investigator: **Dr. Ian McKendry** ***ian.mckendry@geog.ubc.ca***
Survey Director: **John Gallagher** ***gallagjo@interchange.ubc.ca***
UBC Office of Research Services: **http://www.ors.ubc.ca** **604-822-8581**

Part 1

Group # ________ Observer # _______

Instructions for Part 1

Please rate the visual air quality (VAQ) of the scene depicted on each slide using the 1–7 VAQ scale. Check one box for each slide. Your rating should be based solely on how the air looks, without trying to consider what health effects may be associated with the pictured conditions. There are no right or wrong answers.

Warm-up slides

Visual Air Quality

	Very Poor						*Excellent*
	1	2	3	4	5	6	7
A.	☐	☐	☐	☐	☐	☐	☐
B.	☐	☐	☐	☐	☐	☐	☐
C.	☐	☐	☐	☐	☐	☐	☐
D.	☐	☐	☐	☐	☐	☐	☐

Part 1

Group # ________ Observer # _______

Study slides

Visual Air Quality

	Very Poor						***Excellent***
	1	2	3	4	5	6	7
1.	☐	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐	☐	☐
5.	☐	☐	☐	☐	☐	☐	☐
6.	☐	☐	☐	☐	☐	☐	☐
7.	☐	☐	☐	☐	☐	☐	☐
8.	☐	☐	☐	☐	☐	☐	☐
9.	☐	☐	☐	☐	☐	☐	☐
10.	☐	☐	☐	☐	☐	☐	☐
11.	☐	☐	☐	☐	☐	☐	☐
12.	☐	☐	☐	☐	☐	☐	☐
13.	☐	☐	☐	☐	☐	☐	☐
14.	☐	☐	☐	☐	☐	☐	☐
15.	☐	☐	☐	☐	☐	☐	☐

Part 1

Group # ________ Observer # _______

Visual Air Quality

Very Poor ***Excellent***

	1	2	3	4	5	6	7
16.	☐	☐	☐	☐	☐	☐	☐
17.	☐	☐	☐	☐	☐	☐	☐
18.	☐	☐	☐	☐	☐	☐	☐
19.	☐	☐	☐	☐	☐	☐	☐
20.	☐	☐	☐	☐	☐	☐	☐
21.	☐	☐	☐	☐	☐	☐	☐
22.	☐	☐	☐	☐	☐	☐	☐
23.	☐	☐	☐	☐	☐	☐	☐
24.	☐	☐	☐	☐	☐	☐	☐
25.	☐	☐	☐	☐	☐	☐	☐
26.	☐	☐	☐	☐	☐	☐	☐
27.	☐	☐	☐	☐	☐	☐	☐
28.	☐	☐	☐	☐	☐	☐	☐
29.	☐	☐	☐	☐	☐	☐	☐
30.	☐	☐	☐	☐	☐	☐	☐

Part 2

Group # ________ Observer # _______

Instructions for Part 2

In order to help us determine what is considered acceptable vs. unacceptable visual air quality, we now ask you to view the slides again and to decide whether or not each one portrays acceptable visibility based on your own standard.

When making your decisions, please consider the following:

1.) As in Part 1, please base your assessments solely on the quality of the visibility, i.e. how the air looks, without trying to consider what health effects may be associated with the pictured conditions.
2.) Unacceptable visual air quality should represent a visibility that you consider unreasonable or objectionable for the area. Do not rate the slide as unacceptable every time there is any amount of scenery degradation detectable unless you believe that any amount of visibility impairment is too much to live with.

For each slide, indicate whether you consider the visibility condition to be acceptable or unacceptable based on your own visibility standard. Circle "Y" for acceptable or "N" for unacceptable. There are no right or wrong answers.

Warm-up slides

A. Acceptable? Y N

B. Acceptable? Y N

C. Acceptable? Y N

D. Acceptable? Y N

Part 2

Group # ________ Observer # _______

Study slides

1. Acceptable?	Y	N	11. Acceptable?	Y	N	21. Acceptable?	Y	N
2. Acceptable?	Y	N	12. Acceptable?	Y	N	22. Acceptable?	Y	N
3. Acceptable?	Y	N	13. Acceptable?	Y	N	23. Acceptable?	Y	N
4. Acceptable?	Y	N	14. Acceptable?	Y	N	24. Acceptable?	Y	N
5. Acceptable?	Y	N	15. Acceptable?	Y	N	25. Acceptable?	Y	N
6. Acceptable?	Y	N	16. Acceptable?	Y	N	26. Acceptable?	Y	N
7. Acceptable?	Y	N	17. Acceptable?	Y	N	27. Acceptable?	Y	N
8. Acceptable?	Y	N	18. Acceptable?	Y	N	28. Acceptable?	Y	N
9. Acceptable?	Y	N	19. Acceptable?	Y	N	29. Acceptable?	Y	N
10. Acceptable?	Y	N	20. Acceptable?	Y	N	30. Acceptable?	Y	N

Group # ________ Observer # _______

Demographic Information

(Reminder: this information is strictly confidential. Do not write your name.)

Please check one box for each question.

1.) Gender

☐ **Male** ☐ **Female**

2.) Age

☐ **<18**
☐ **18-24**
☐ **25-34**
☐ **35-44**
☐ **45-54**
☐ **55-64**
☐ **65+**

3.) Annual household gross income

☐ **<$20,000**
☐ **$20,000 – $39,999**
☐ **$40,000 – $59,999**
☐ **$60,000 – $79,999**
☐ **$80,000 – $99,999**
☐ **$100,000 – $119,999**
☐ **$120,000 or more**

4.) What is the highest level of education that you have attained?

☐ **Some high school or less**
☐ **High school graduate**
☐ **Incomplete undergraduate program**
☐ **Completed undergraduate degree**
☐ **Completed graduate degree**

5.) What city do you currently live in? (If you reside on the UBC campus or Endowment Lands, please answer "UBC.")

____

Group # ________ Observer # _______

6.) How long have you lived in the Lower Fraser Valley (LFV)?

- ☐ **I don't live in the LFV**
- ☐ **Less than 1 year**
- ☐ **1 to 3 years**
- ☐ **3 to 5 years**
- ☐ **5 to 10 years**
- ☐ **More than 10 years**

If you have lived in the Lower Fraser Valley for more than 5 years, please answer question 6a:

6a.) In your opinion, how has the visual air quality in the Lower Fraser Valley changed over the last 5 years?

- ☐ **It has deteriorated (gotten worse)**
- ☐ **No significant change**
- ☐ **It has improved**
- ☐ **No opinion / I don't know**

7.) In which country did you spend your formative years (up to 16 years old)?

- ☐ **Canada**
- ☐ **Other (please specify) ________________________**

8.) Did you spend your formative years in a highly urbanized environment (a city of more than 250,000 people), an urban/suburban environment (a city or town or more than 20,000 people but less than 250,000 people), or a rural environment (rural location or town of less than 20,000)?

- ☐ **Highly urban**
- ☐ **Urban/suburban**
- ☐ **Rural**

9.) Have you ever participated in a visibility study of any kind before?

- ☐ **Yes**
- ☐ **No**

Appendix B. Survey script

(Hand out questionnaires and pencils as people enter the room. When they are all seated and settled, ask if anyone does not have a questionnaire or pencil.)

Good morning (*or afternoon, evening)*. My name is John Gallagher and I am a research technician at the UBC Department of Geography. I am here today to request that you participate in a survey regarding perception of visibility in the Lower Fraser Valley. Your participation is entirely voluntary. You may withdraw at any time, but a completed questionnaire will be regarded as evidence of your consent to full survey participation. All your responses will be considered confidential, although summarized survey results will be released into the public domain. The purpose of this survey is to get your input on what you consider to be an appropriate visibility standard for the Lower Fraser Valley. Please note that there are no right or wrong answers to the questions; it is your opinion on visual air quality that we are collecting. Visual Air Quality, or VAQ, is defined as the visibility effect caused solely by air quality conditions, not those associated with weather conditions such as fog and rain.

There are two parts to the survey. First you will rate the visual air quality depicted on a number of slides. You will then view the slides again and decide whether each one depicts acceptable or unacceptable visibility conditions based on your own visibility standard.

(Turn on the projector and show the first warm-up slide.)

The slides I will show you were all taken from the same location in Chilliwack, which is about 100 km east of Vancouver. They will be presented fairly quickly; you will be given 10 seconds to view each slide and record your response on the questionnaire sheet. *(Note that "slide" = digital photo.)*

There are 4 warm-up slides and 30 study slides. The warm-up slides will give you a sense of the range of visibility conditions that you will see in the study slides. Days affected by rain or ground-based fog have been excluded from our slide selection.

For Part 1 of the survey, you will rate the visibility conditions using the 7-point visual air quality scale that you can see on page 2 of your questionnaire. The "1" is labeled as "very poor" visual air quality and thus corresponds to severely impaired visibility. At the other end of the scale, "7" is labeled as "excellent" visual air quality, corresponding to excellent visibility. So, the lower numbers go with lower visibility and relatively poor visual air quality, while the higher numbers go with higher, or better, visual air quality. As you look at each slide, decide how it should be rated on this 7-point scale.

Please provide one response for each slide and do not leave any blank.

At this time, please turn to page 2 of your questionnaire, where you will see Instructions for Part 1. I'll read those instructions now.

(Read instructions for Part 1.)

Now let's move through the warm-up slides. I'll give you 10 seconds to view each slide and mark your rating on the sheet. The order of the slides is random, so you should not expect a steady progression of air quality conditions. Therefore, you should try to evaluate each slide on its own. The warm-up slides are just for practice and will not be used in the study.

(Go though the warm-up slides, calling out the letter of each slide as it is shown.)

Are there any questions about the instructions? Just to remind you of the visual air quality scale, the higher the number the better the visual air quality, and the lower the number the lower the visual air quality. We will now go through the 30 study slides. Again, you'll have 10 seconds to evaluate each slide and record your rating. Record your answers on pages 3 & 4 of the questionnaire.

(Go through the study slides using a 10 second exposure. Call out the number of each slide as it is shown. Remind them to turn to page 4 after slide 15.)

Next we will do Part 2 of the survey. I'll read those instructions to you now. This is on page 5.

(Read instructions for Part 2 and show the first warm-up slide.)

Are there any questions about the instructions? We will go through the 4 warm-up slides and 30 study slides again with 10-second exposure. This time you just need to make a yes or no judgment on whether or not the visibility condition is acceptable.

(Go though the warm-up slides, calling out the letter of each slide as it is shown.)

Now we'll go through the 30 study slides. These are the same slides as in Part 1, but you will see them in a different order. Your answer sheet for this part is on page 6.

(Go through the study slides using a 10 second exposure, calling out the number of each slide as it is shown.)

Finally, please fill out the demographic information at the end of the questionnaire. This information is confidential and is requested only to help us assess how representative the sample group is of the population at large. We do need all the questions answered for your survey to be counted, so please answer all questions 1 through 9. Note that the last few questions are on the back page of your questionnaire.

Thank you very much for your participation.

Appendix C. Viewscape used in survey

The below image from the Chilliwack airport was recorded at 1530 PST on 24 August 2010 and is one of the photos used in the survey (image G). Annotations show distances from the camera location to various landmarks.

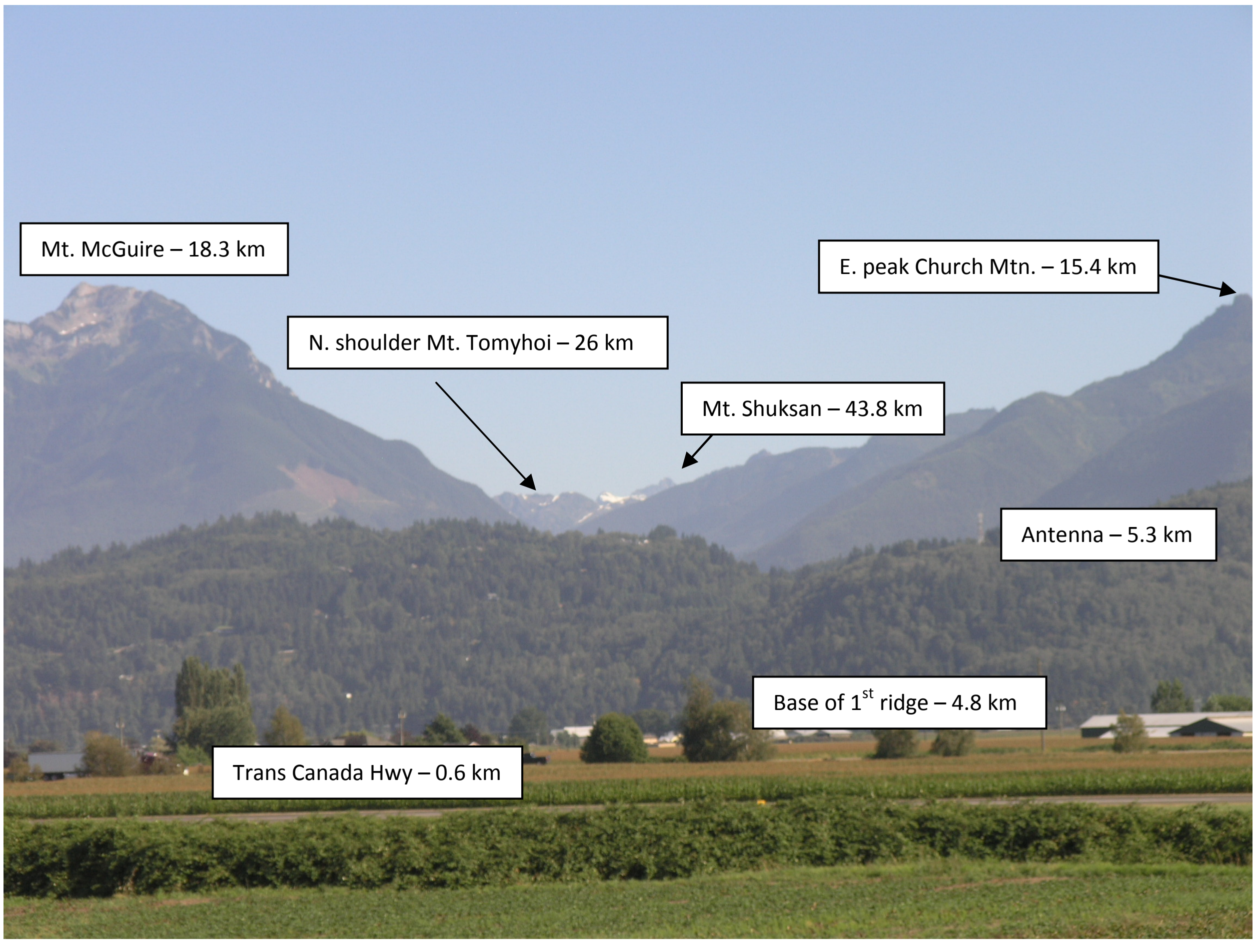


Image from 1200 PST on 2 August 2010. This photo (image M) is the closest representation of the 50% acceptability threshold as determined from Part 2 survey results.

b_{sp} = 65.4 Mm^{-1} dv = 21.1   Acceptability = 48.6%   Mean VAQ score = 3.6

Appendix D. Projection Conditions

Group #	Location or course code	Room	Projector model	Resolution*	Brightness (Lumens)
1	GEOB 402	UBC GEOG 201	Sanyo XT20	XGA	3800
2	GEOB 102	UBC GEOG 100	Sanyo PLC-XP56	XGA	5000
3	GEOG 1180a	Langara classroom	Sanyo PLC-XM100	XGA	5000
4	GEOG 1180b	Langara classroom	Sanyo PLC-XM100	XGA	5000
5	GEOB 304	UBC GEOG 214	Sanyo PLC-WM4500L	WXGA	4500
6	GEOG 2230	Langara A229	Sanyo PLC-XM100	XGA	5000
7	ATSC 303	UBC EOS Main 121	NEC NP2250	XGA	4200
8	Credential Financial	Boardroom	Sanyo PLC-XU300	XGA	3000
9	Alpine Club of Canada	Floral Hall, Van Dusen Gardens	Sanyo PLC-XU300	XGA	3000
10	Brock House	Activities room	Sanyo PLC-XU300	XGA	3000
11	Green Lake Ski Club	Apartment living room	Sanyo PLC-XU300	XGA	3000
12	MDA	Meeting room	Sanyo PLC-XU300	XGA	3000
13	Surrey MoE	Boardroom	Sanyo PLC-XU300	XGA	3000
14	Metro Vancouver	Boardroom	Sanyo PLC-XU300	XGA	3000
15	Port Metro Vancouver	Boardroom	Sanyo PLC-XT25^	XGA	4500
16	Vancouver Aquarium	Boardroom	Sanyo PLC-XU300	XGA	3000
17	GEOG 310	UBC GEOG 200	Sanyo XT20	XGA	3800

*Resolution codes: XGA = 1024 x 768 pixels; WXGA = 1280 x 720 pixels

^This unit was used with a Draper RPX rear projection system.