WHAT LEVEL OF PERCEIVED VISUAL AIR QUALITY IS ACCEPTABLE?

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December 2013

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1 HUMAN PERCEPTION OF HAZE AND LANDSCAPE FEATURES

Before about 1970, visibility was meant only to denote the human capability to detect, recognize, and identify objects by means of the human visual mechanism. During the 1970s, as energy development in the form of strip mines and coal-fired power plants with associated emissions spread across the United States, the ability to see and appreciate scenic vistas evolved as an environmental value worth preserving. Today it is recognized that emissions from other sources also can have an adverse effect on visibility. Emissions from wild and prescribed fire at times degrade visibility significantly more than conventional industrial sources.

The Clean Air Act Amendments (1977) specifically identified visibility as an air-quality-related value of certain protected geographic areas. The amendments also charged the responsible federal land managers (FLMs) with the duty of protecting the visibility of those areas from adverse impairment. However, adverse impairment was not defined in a quantifiable manner that could be used effectively by the FLMs to carry out this mandate. The Environmental Protection Agency (EPA) attempted to address this situation by defining visibility impairment as "any humanly perceptible change in visibility (visual range, contrast, coloration) from that which would have existed under natural conditions" (Definitions Context, 2012). Consequently, visibility took on a substantially different meaning from how it was interpreted prior to 1977, and the focus of visibility studies became directed toward how haze affects the visual quality of scenic landscape features and on whether haze from a single or multiple sources could be seen or detected.

The overriding goal of human perception studies that link judgments of visual air quality (VAQ) to particles and gases in the atmosphere is to bring about the effective management of emissions for the purpose of protecting the visibility of scenic landscape features. The link between VAQ judgments and aerosol physical/chemical/optical properties is outlined in Figure 1. Emissions of gases and particles into the atmosphere result in an aerosol spatial distribution that can manifest itself either as layered or uniform haze. Layered haze can be thought of as any confined layer of particles or absorbing gas that results in a visible spectral discontinuity between that layer and its background (sky or landscape). The classic example of a layered haze is a tight, vertically constrained, coherent plume (plume blight). Uniform haze exhibits itself as an overall reduction in air clarity.

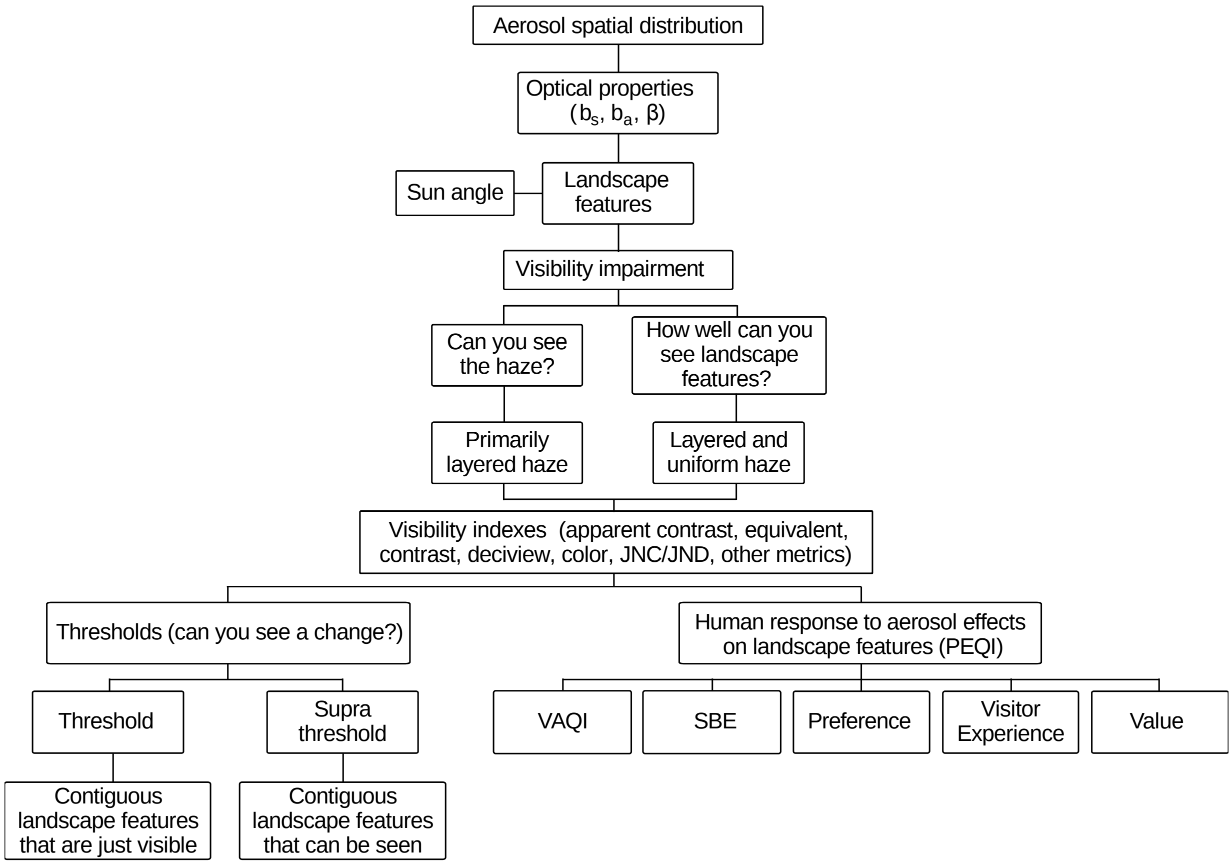


Figure 1.1: Flow diagram of how a spatial distribution of aerosols relates to various judgments of visual air quality.

The scattering characteristics of the atmosphere are described by the scattering and absorption coefficients b_s and b_a and the volume scattering function β, which describes the preferential scattering of radiant energy in one direction or the other. Given an aerosol spatial distribution and its scattering and absorption properties, the sun's zenith and azimuth angles, and the landscape reflectance characteristics, one can estimate the radiance field arriving at the eye of an observer or a photometric instrument.

From a human perception perspective, the distribution or variability of the radiance field determines whether an observer can see the haze itself, as well as describes the degradation of the scenic quality of landscape features observed through the haze, whether it is uniform or layered. It is possible that an observer may not even be aware of a haze unless it has a spatial distribution that results in some sort of achromatic or colored contrast edge.

Because of the spatial distribution of radiance values, there have been many and varied visibility metrics proposed to describe the perceptual characteristics of haze as well as the degradation of the visual quality of landscape features. These metrics describe different VAQ characteristics. Indexes such as extinction coefficient, visual range (V_r), unimpaired V_r, and deciview (dv) are all transforms and should be viewed as "local" indicators of visibility impairment. They are independent of landscape characteristics and therefore do not directly describe the appearance of scenic landscape features. They are not expected to be universal predictors of how observers judge the appearance of varying levels of haze on diverse scenic landscapes.

Other metrics, such as apparent universal or equivalent contrast, landscape color, and other landscape specific indexes, that incorporate landscape characteristics, the integrated haziness between the landscape and the observer, and possible characteristics of the human eye–brain system have the possibility of predicting how observers value and judge VAQ. The concept of just noticeable difference or change (JND/JNC) is applicable to estimating the change in haze required to just notice a change in the appearance of landscape features or the appearance of or change in a haze layer (Malm and Pitchford, 1989; Henry, 2002).

Given this wide variety of visibility indexes, an obvious question is when and where they might be applicable to predicting perception-related issues. JND/JNC models are directly applicable to whether an observer can notice a layered haze or not. A simple example of layered haze visibility impairment is plume blight, in which the radiance difference between a plume and a background such as the sky can be noticed. The observer can essentially compare the haze layer edge to its background on a real-time basis. So the calculation of a JNC for haze layers reduces to comparing the radiance field without the haze layer to the field with the haze layer. These types of threshold estimations are discussed in more detail in the last section of this chapter.

The estimation of a JNC associated with how much a radiance field must change after the haze layer is visible or how much a uniform haze must change to cause a noticeable difference in the appearance of a landscape is a more difficult question and is context dependent. Typical laboratory studies are done with side by side comparisons of a baseline scene or stimuli and some altered or degraded stimuli. This type of paradigm is unrealistic for a real-world setting because changes in haze intensity take place over time periods of hours or days and under a variety of illumination conditions, and an evaluation of VAQ change requires a person to "remember" what the scene looked like before a given change in air pollution took place. However, the side by side comparison stimuli set a lower bound of supra-threshold sensitivity. Furthermore, the number of JNCs associated with a change in haze will be scene dependent and therefore is not expected to be universally related to judgments or value assessments of changing VAQ.

Other studies have focused on perceived environmental quality indexes (PEQI). These include VAQ judgments and scenic beauty estimates (SBE) (Craik and Zube, 1976; Daniel and Bolster, 1976; Malm et al., 1981; Stewart et al., 1983; Middleton 1983; Middleton et al., 1984), which use interval scale indexes, acceptability judgments describing the level of haze obscuring landscape features that would be deemed acceptable, ratings of visitor enjoyment as a function of haze levels, and value assessments in terms of willingness to pay for a certain level of visual air quality.

Human judgments of haze effects on landscape features are uniquely different from determinations of whether a landscape feature is just visually degraded or not. VAQ judgments fall into a broader category of using PEQIs as adjuncts to physically based monitoring systems to gauge the state of various aspects of the human environment. VAQ judgments are unique to visibility; however, SBEs have been used extensively to assess the scenic qualities of forest and desert landscapes (Daniel et al., 1973).

Other surveys include visibility preference, visitor experience, and value assessment studies. Visibility preference studies have focused on the levels of haze that were found to be acceptable, primarily in the context of four urban settings. Visitor experience studies have explored the relative importance of visibility to park visitors, visitor awareness of visibility conditions, and the effect of visibility on visitor satisfaction and behavior (Ross et al., 1985, 1987). Value assessment studies, which refer to how much a person is willing to pay to preserve some level of VAQ (Bell, 1985; Loehman et al., 1994; Chestnut and Dennis, 1997; Smith et al., 2005) or how a person might change their behavior as haze levels in their visual environment change (Schulze et al. 1983), have also been carried out.

This review will focus on visibility preference studies or studies which link the level of haze or visibility degradation that is judged to be acceptable. These types of studies have only be carried out in an urban setting, although in three of the studies the scene used included distant landscape features.

2 URBAN VISIBILITY PREFERENCE STUDIES

The urban visibility preference studies used a focus-group method to estimate the level of visibility impairment that respondents described as "acceptable." In addition to determining the amount of haze deemed to be acceptable, respondents were also asked to make VAQ judgments of the various scenes. The specific definition of acceptable was largely left to each individual respondent, allowing each to identify their own preferences. There are three completed studies that used this method and a pilot study (designed as a survey instrument development project) that provides additional information.

The completed studies were conducted in Phoenix, Arizona (AZ DEQ, 2003), two cities in British Columbia, Canada (Pryor, 1996), and Denver, Colorado (Ely et al., 1991). The pilot study was conducted in Washington, D.C. (Abt Associates, 2001). The studies are summarized in Table 2.1.

Table 2.1: Summary of urban visibility preference studies.

	Denver	**Phoenix**	**British Columbia**	**Washington, D.C.**
Report Date	1991	2003	1996	2001
Session duration		45 min	50 minutes	2 hrs
Compensation	None	$50	None	$50
# focus-group sessions	17	27 total at 6 locations,	4	1
# participants	214	385	180	9
Age range	adults	18–65+	University students	27–58
Annual or seasonal	Wintertime	Annual	Summertime	Annual
Total scenes presented	Single scene of downtown with mountains in background at about 150 km	Single scene of downtown and mountains, 42 km maximum distance	Single scene from each city with distant mountains at about 30 km	Single scene of DC Mall with 8-km maximum sight path
# of total visibility conditions	20 levels (+ 5 duplicates)	21 levels (+ 4 duplicates)	20 levels (10 each from each city)	20 levels (+ 5 duplicates)
Source of slides	Actual photos taken between 9 am and 3 pm	WinHaze	Actual photos taken at 1 pm or 4 pm	WinHaze

	Denver	Phoenix	British Columbia	Washington, D.C.
Medium of presentation	Slide projection	Slide projection	Slide projection	Slide projection
Ranking scale used	1–7 scale	1–7 scale	1–7 scale	1–7 scale
Extinction level presented	0.03–0.55 km^{-1}	0.045–0.331 km^{-1}	0.037–0.122 km^{-1} (Chilliwack) 0.039–0.233 km^{-1} (Abbotsford)	0.025–0.447 km^{-1}
Health issue directions	Ignore potential health impacts; visibility only	Judge solely on visibility, do not consider health	Judge solely on visibility, do not consider health	Health never mentioned, "Focus only on visibility"
Key questions asked	a) Rank VAQ (1–7 scale) b) Is each slide "acceptable" c) "How much haze is too much?"	a) Rank VAQ (1–7 scale) b) Is each slide "acceptable" c) How many days a year would this picture be "acceptable"	a) Rank VAQ (1–7 scale) b) Is each slide "acceptable"	a) Rank VAQ (1–7 scale) b) Is each slide "acceptable" c) if this hazy, how many hours would it be acceptable (3 slides only) d) valuation question
Mean b_{ext} found "acceptable"	0.067 km^{-1} (19 dv)	0.12 km^{-1} (24.5 dv)	0.10 km^{-1} (~23 dv) (Chilliwack), 0.09 km^{-1} (~22 dv) (Abbotsford)	0.16 km^{-1} (~28 dv)

In each study, information was collected in a focus-group setting in which slides depicting various visibility conditions were presented. In each study, photographs of a single scene from the study's city were used; each photo included images of the broad downtown area and out to the hills or mountains composing the scene's backdrop. The maximum sight distance under good conditions varied by city, ranging from 8 km in Washington, D.C., to mountains hundreds of kilometers away in Denver. Multiple photos of the same scene were used to present approximately 20 different levels of visibility impairment.

Actual photographs taken in the same location were used in the Denver and British Columbia studies to depict various visibility conditions. Photographs prepared using WinHaze software (Air Resource Specialists, Inc., http://www.air-resource.com/resources/softwaredownloads) were used in the Phoenix and Washington, D.C., studies. WinHaze is a computer-imaging software program that simulates VAQ differences of various scenes, allowing the user to "degrade" an original, near-pristine-condition visibility photograph to create a photograph of each desired VAQ level.

2.1 Denver, Colorado, Urban Visibility Preference Study

The Denver urban visibility preference study was conducted on behalf of the Colorado Department of Public Health and Environment (CDPHE). A series of focus-group sessions were conducted with 17 civic and community groups, in which a total of 214 individuals were asked to rate slides. The slides depicted varying levels of VAQ, of which three are shown in Figure 2.1a–c. The extinction coefficient corresponding to each of these images is approximately 0.03 km^{-1} (11 dv), 0.07 km^{-1}(19 dv), and 0.25 km^{-1}(32 dv). This well-known Denver vista includes a broad view of downtown Denver, with the mountains to the west composing the scene's background. The participants were instructed to base their judgments on three factors:

- The standard was for an urban area, not a pristine national park area where the standards might be stricter.
- The level of an urban visibility standard violation should be set at a VAQ level considered to be unreasonable, objectionable, and unacceptable visually.
- Judgments of standard violations should be based on visibility only, not on health effects.


a


b

c

Figure 2.1a–c: View of Denver, Colorado. The mountain in the background is about 150 km distant. Haze levels for a, b, and c correspond to b_{ext} = 0.03 km^{-1} (11 dv), 0.07 km^{-1} (19 dv), and 0.25 km^{-1} (32 dv), respectively.

Participants were shown 25 randomly ordered slides of actual photographs. The visibility conditions presented in the slides ranged from 11 to 40 dv, approximating the 10th to 90th percentiles of wintertime visibility conditions in Denver. The participants rated the 25 slides based on a scale of 1 (poor) to 7 (excellent), with 5 duplicates included. They were then asked to judge whether the slide would violate what they would consider to be an appropriate urban visibility standard (i.e., whether the level of impairment was "acceptable" or "unacceptable"). A level of 18.9 dv was judged by 50% of the participants to be unacceptable, which corresponds to slide 12b.

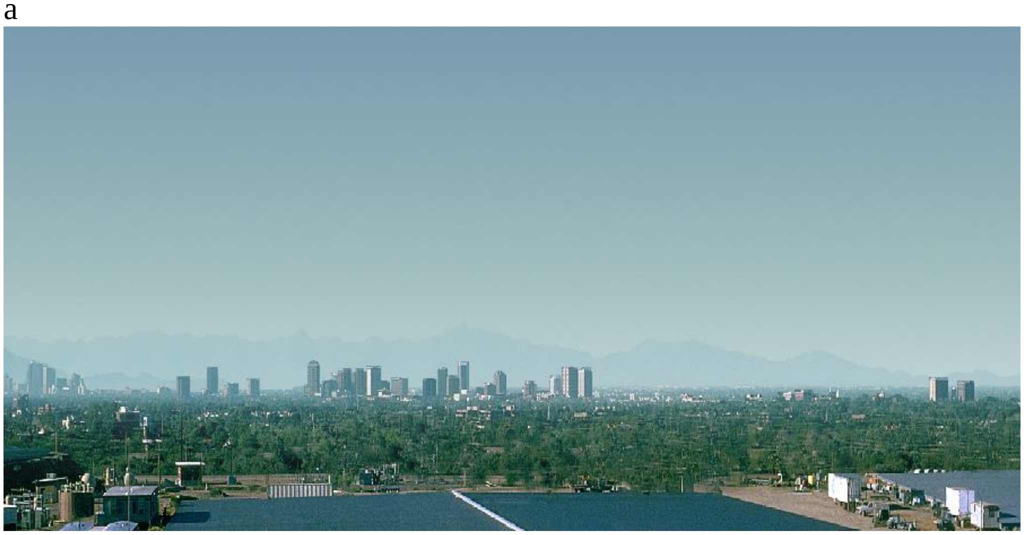
2.2 Phoenix, Arizona, Urban Visibility Preference Study

The Phoenix urban visibility preference study was conducted on behalf of the Arizona Department of Environmental Quality. Its focus-group survey process was patterned after the Denver study. The study included 385 participants in 27 separate focus-group sessions. Participants were recruited using random-digit dialing to obtain a sample group designed to be demographically representative of the larger Phoenix population. Focus-group sessions were held at six neighborhood locations throughout the metropolitan area to improve the participation rate. Three sessions were held in Spanish in one region of the city with a large Hispanic population (25%), although the final overall participation of native Spanish speakers (18%) in the study was moderately below the targeted level. Participants received $50 as an inducement to participate.

Participants were shown a series of 25 images, examples of which are shown in Figure 2.2a–c, of the same vista of downtown Phoenix, with South Mountain in the background at a distance of about 40 km. Photographic slides of the images were developed using WinHaze. The visibility impairment levels ranged from 15 to 35 dv (the extinction coefficient, b_{ext}, range was approximately 45 Mm^{-1} to 330 Mm^{-1}, or a V_r of 87 to 12 km). Images a, b, and c correspond to extinction coefficients of 0.045 km^{-1} (15 dv), 0.11 km^{-1} (2 4 dv), and 0.33 km^{-1} (35 dv), respectively. First, participants individually rated the randomly shown slides on a VAQ scale of

1 (unacceptable) to 7 (excellent). Participants were instructed to rate the photographs solely on visibility and to not base their decisions on either health concerns or what it would cost to have better visibility. Next, the participants individually rated the randomly ordered slides as "acceptable" or "unacceptable," defined as whether the visibility in the slide is acceptable or objectionable. The middle slide in Figure 2.2 was judged to be acceptable by 50% of the participants (24 dv).

a



b

c

Figure 2.2a–c: Examples of photos used in the Phoenix preference study. The most distant mountainous feature is 40 km distant. The extinction levels of the three photos are 0.045 km^{-1} (15 dv), 0.11 km^{-1} (24 dv), and 0.33 km^{-1} (35 dv), respectively.

2.3 British Columbia, Canada, Urban Visibility Preference Study

The British Columbia (B.C.) urban visibility preference study was conducted on behalf of the B.C. Ministry of Environment. Focus-group sessions were conducted that were also developed following the methods used in the Denver study. Participants were students at the University of British Columbia who participated in one of four focus-group sessions with between 7 and 95 participants. A total of 180 respondents completed surveys (29 did not complete the survey).

Participants in the study were shown slides of two suburban locations in B.C.: Chilliwack and Abbotsford. The Chilliwack landscape shown in Figure 2.3a–c corresponds to extinction coefficients of 0.05 km^{-1} (13 dv), 0.96 km^{-1} (23 dv) and 0.17 km^{-1} (28 dv), respectively, while the Abbotsford scene photos, Figure 2.4a–c, corresponds to 0.045 km^{-1} (15 dv), 0.1 km^{-1} (23 dv), and 0.164 km^{-1} (28 dv), respectively. Using the same general protocol as the Denver study, Pryor (1996) found that responses from this study showed the acceptable level of visibility was 23 dv in Chilliwack and 19 dv in Abbotsford. Pryor discusses some possible reasons for the variation in standard visibility judgments between the two locations, including the relative complexity of the scenes, potential bias of the sample population (only university students participated), and the different levels of development at each location. Abbotsford (population 130,000) is an ethnically diverse suburb adjacent to the Vancouver metro area, while Chilliwack (population 70,000) is an agricultural community 100 km east of Vancouver in the Frazier Valley.

a


b

c

Figure 2.3a–c: Examples of photos used in the Chilliwack preference study. The most distant mountainous feature is about 30 km distant. The extinction levels of the three photos are 0.05 km^{-1} (13 dv), 0.96 km^{-1} (23 dv), and 0.17 km^{-1} (28 dv), respectively.

a

b

c

Figure 2.4a–c: Examples of photos used in the Abbotsford preference study. The most distant mountainous feature is about 30 km distant. The extinction levels of the three photos are 0.045 km^{-1} (15 dv), 0.1 km^{-1} (23 dv), and 0.164 km^{-1} (28 dv), respectively.

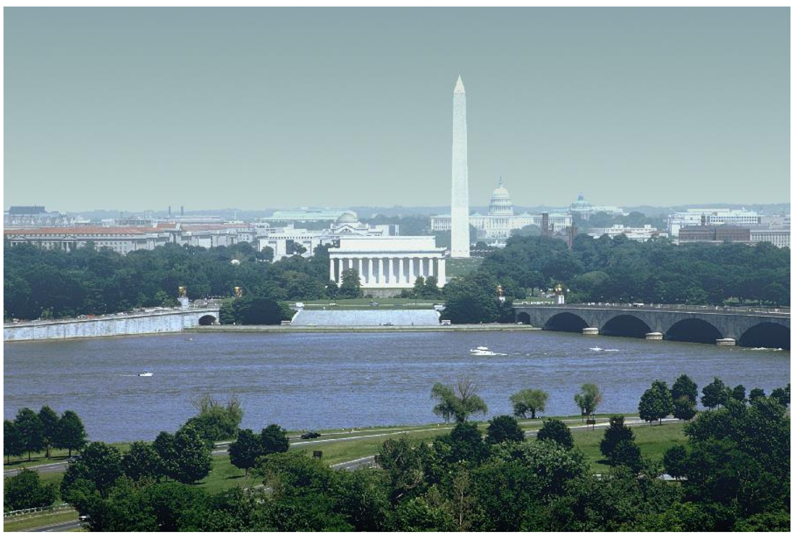
The photos labeled as b in both Figures 2.3 and 2.4 correspond to the level of haze found to be acceptable by 50% of the participants. The B.C. urban visibility preference study is being considered by the B.C. Ministry of the Environment as a part of establishing urban and wilderness visibility goals in B.C.

2.4 Washington, D.C., Urban Visibility Preference Pilot Study

The Washington, D.C., urban visibility pilot study was conducted on behalf of the U.S. Environmental Protection Agency (EPA) and was designed to be a pilot focus-group study, an initial developmental trial run of a larger study. The intent of the pilot study was to study both focus-group method design and potential survey questions. Due to funding limitations, only a single focus-group session was held, consisting of one extended session with nine participants.

The study also adopted the general Denver study method, modifying it as appropriate to be applicable in an eastern urban setting that has substantially different visibility conditions than any of the three western locations of the other preference studies. Washington's (and the entire East) visibility is typically substantially worse than western cities and has different characteristics. Washington's visibility impairment is primarily a uniform, whitish haze dominated by sulfates, relative humidity levels are higher, the low-lying terrain provides substantially shorter maximum sight distances, and many residents are not well informed that anthropogenic emissions impair visibility on hazy days. A single scene, shown in Figure 2.5a–c, was used. It is a panoramic shot of the Potomac River, Washington mall, and downtown Washington, D.C. The extinction levels shown in the three photos are 0.045 km^{-1} (15 dv), 0.16 km^{-1} (28 dv), and 0.37 km^{-1} (36 dv), respectively. Again, it is image b that 50% of the participants found to be at the acceptability level.

a



b

c

Figure 2.5a–c: Examples of photos used in the Washington, D.C., preference study. The most distant mountainous feature is about 30 km distant. The extinction levels of the three photos are 0.045 km^{-1} (15 dv), 0.16 km^{-1} (28 dv), and 0.37 km^{-1} (36 dv), respectively.

2.5 Comparing the Four Preference Studies

Figure 2.6 shows a scatter plot of the percent of observers judging an urban scene to have acceptable VAQ as a function of judged VAQ for each of the studies described above. Wash, Phx, Chil, Abbt, and Den refer to the Washington, Phoenix, Chilliwack, B.C., Abbotsford, B.C., and Denver studies, respectively. Notice that the shape of the curves representing each of the studies is the same. When asked to judge VAQ, the participants distributed their ratings approximately uniformly across the images they were shown, but when asked to judge acceptability, there tends to be a level of VAQ that is acceptable and one that is not acceptable. Above ratings of about 5, the VAQ is judged to acceptable and below 2, unacceptable.

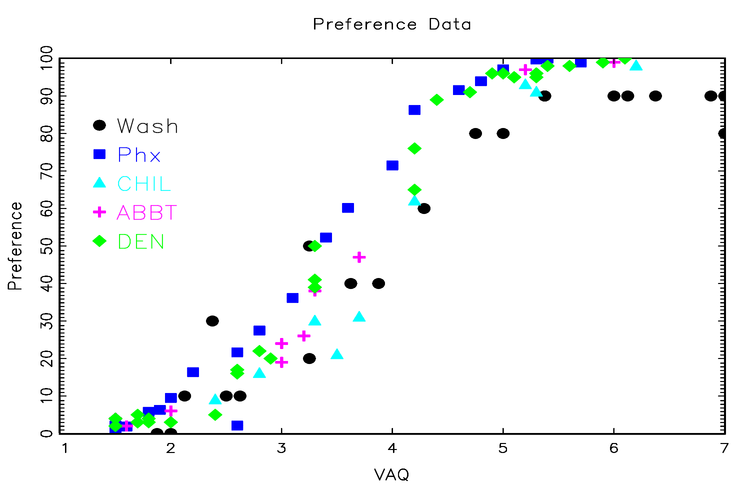


Figure 2.6: Scatter plot of the percent of observers judging an urban scene to have acceptable visual air quality (VAQ) as a function of judged VAQ for each of the studies described in the text.

It is also interesting to note that the median VAQ of 4 corresponds to about 40% of respondents finding the VAC acceptable for the Washington, D.C., image and about 70% of the respondents for the Phoenix scene. Clearly, judging overall VAC and making a judgment as to what level of haze is acceptable/unacceptable evoked a different response in participants. An underlying goal of eliciting an observer-based response to varying haze levels on scenic resources is to develop a physical indicator of response functions, in this case, visibility preference levels.

Figure 2.7 shows the same acceptability data in Figure 2.6, plotted against the dv levels associated with the various haze levels. A logistical regression model, applied to each dataset, was used to estimate the acceptability levels summarized in Table 2.2. Table 2.3 is the data as in Table 2.2 but represented in terms approximate atmospheric mass concentration.

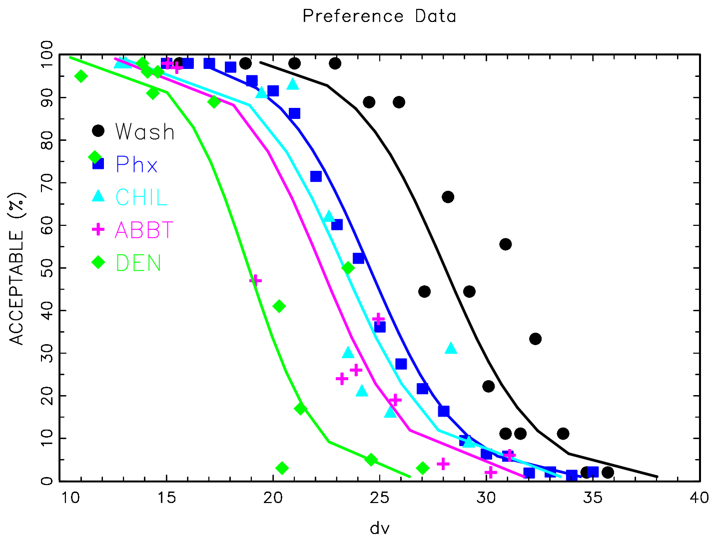


Figure 2.7: Percent acceptability levels plotted against deciviews for each of the images used in the various studies.

Table 2.2: Percentile acceptability levels and associated uncertainties, expressed in deciviews, for each of the scenes studied.

Acceptability	**10%**	**25%**	**50%**	**75%**	**90%**
Washington	32.81±0.60	30.44±0.56	28.06±0.51	25.69±0.47	23.31±0.43
Phoenix	29.25±0.22	26.89±0.20	24.53±0.19	22.17±0.17	19.81±0.16
Chilliwack	28.18±0.97	25.76±0.90	23.33±0.83	20.91±0.76	18.48±0.69
Abbotsford	26.82±0.75	24.55±0.70	22.29±0.65	20.02±0.59	17.76±0.54
Denver	22.46±1.36	20.66±1.26	18.86±1.16	17.06±1.06	15.26±0.96

Table 2.3: Percentile acceptability levels, expressed in $\mu g/m^3$, for each of the scenes studied.

Acceptability	**10%**	**25%**	**50%**	**75%**	**90%**
Washington	88.67	69.96	55.15	43.51	34.29
Phoenix	62.11	49.06	38.74	30.60	24.17
Chilliwack	55.81	43.81	34.36	26.98	21.16

Acceptability	10%	25%	50%	75%	90%
Abbotsford	48.71	38.82	30.97	24.68	19.69
Denver	31.50	26.31	21.98	18.36	15.33

First it should be noted that it takes considerably more haze, whether that haze is represented by dv, atmospheric extinction, V_r, or particulate concentration, to cause the Washington, D.C., scene to be judged unacceptable than the Denver scene. The difference in the amount of haze required to create an unacceptable judgment for the Washington and Denver scenes was almost 10 dv or about 33 µg m^{-3} of particulate matter, assuming the particles are not hygroscopic. The amount of haze required in other scenes to be judged as unacceptable is intermediate to Washington and Denver. The dv or extinction level required to reach the 50% level of acceptability is directly related to the distance of the more distant features in the scene. Closer scenes require higher extinction levels to cause equal amounts of visibility reduction. Extinction or any transforms of extinction are not universal indicators of visibility preference levels.

The same data shown in Figure 2.7 were plotted against a host of scene- or image-specific variables. They included JNCs (just noticeable change) and the variants in JNC calculations discussed above: contrast, including average contrast of the overall scene, and mean-square fluctuation and its variants. Variables like JNC, average contrast, and mean-square fluctuation are highly dependent on detail and the number of contrast edges in the image and therefore are not good universal indicators of judgments of VAQ. For instance, the number of JNCs relative to a baseline least-haze reference for the 50% acceptance level for the Washington study is 100 JNCs, while for Phoenix it is approximately 50 JNCs.

The best predictor of acceptability level is apparent contrast of a distant, prevalent, but not necessarily dominant, feature (Malm et al., 2011). Figure 2.8 show the acceptability levels for each of the studies, plotted against the apparent contrast of the distant feature that is most sensitive to haze. Also shown in Figure 2.8 is a logistic model curve fit of each of the datasets. Using the logistic equation, the apparent contrast associated with different acceptability percentiles can be estimated. Table 2.4 shows the apparent contrast associated with the 10%, 25%, 50%, 75%, and 90% acceptability levels along with their estimated uncertainties.

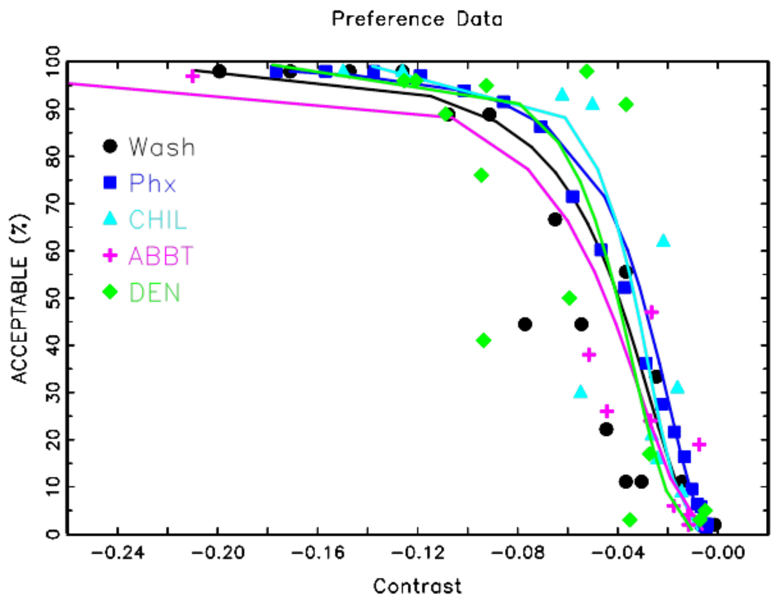


Figure 2.8: Percent acceptability levels plotted against apparent contrast of distant landscape features.

Table 2.4: Percentile acceptability levels, expressed as apparent contrast, for each of the scenes studied. Also shown are the uncertainties of each of the reported contrast values.

Acceptability	**10%**	**25%**	**50%**	**75%**	**90%**
Washington	-0.016±0.0007	-0.025±0.0011	-0.040±0.0017	-0.063±0.0028	-0.099±0.0044
Phoenix	-0.011±0.0004	-0.018±0.0006	-0.030±0.0010	-0.049±0.0016	-0.080±0.0025
Chilliwack	-0.017±0.0015	-0.024±0.0024	-0.033±0.0039	-0.046±0.0061	-0.065±0.0096
Abbotsford	-0.017±0.0007	-0.028±0.0011	-0.045±0.0018	-0.072±0.0028	-0.115±0.0044
Denver	-0.021±0.0022	-0.029±0.0035	-0.040±0.0055	-0.029±0.0087	-0.076±0.0138

When the feature approximately reaches the V_r or a contrast between about -0.03 to -0.05, about 50% of the observers rated the scene or image as not being acceptable. Referring to Table 2.2, and converting dv to V_r, one sees that these features are at 150 km, 42 km, 30 km, and 8 km for the Denver, Phoenix, British Columbia, and Washington, D.C., images, respectively. Because it takes a considerably greater amount of haze/particulate matter to cause an 8-km landscape feature to reach a threshold contrast of -0.03 to -0.05 than a 150-km vista, any visibility metric that is proportional to aerosol concentration, without consideration of the distance to and characteristics of landscape features, will not be a general predictor of judgments of VAQ.

2.6 Comparing the Urban Visibility Preference Studies to the Health-related Air Quality Index

It is of interest to examine these results in the context of EPA, California Department of Public Health, California Office of Environmental Health Hazard Assessment, California Air Resources Board, and Missoula County Health Department co-authored document titled "Wildfire Smoke, A Guide for Public Health Officials" (2008, http://oehha.ca.gov/air/risk_assess/wildfirev8.pdf), which links V_r estimates to particulate matter (PM) concentrations, which in turn are linked to air quality health index (AQI) categories (Wildfire Smoke, 2008). An abbreviated table from this document is reproduced in Table 2.5. The V_r estimates in Table 2.5 (last column) only correspond to 1–3 hr concentrations.

Table 2.5: AQI categories linked to ambient mass concentrations and visual range as reported in "Wildfire Smoke, A Guide for Public Health Officials" (2008).

Air Quality Index Category	$PM_{2.5}$ or PM_{10} Levels (μg/m^3, 1-3 hr avg)	Visibility-Arid Conditions (miles)	Visibility-Arid Conditions (km)
Good	0-38	≥11	17.71
Moderate	39-88	6-10	9.66
Sensitive Groups	89-138	3-5	4.83
Unhealthy	139-351	1.5-2.75	2.42
Very Unhealthy	352-526	1-1.25	1.61
Hazardous	>526	<1	<1.61

The best predictor of acceptability level is apparent contrast of a distant, prevalent, but not necessarily dominant, feature (see Table 2.4). The average apparent contrast of the 10%, 50% and 90% acceptability levels are -0.017, -0.04, and -0.09, respectively. That is, 10% of the observers found the scene to be unacceptable at an apparent contrast of -0.017, 50% at a contrast of -0.04, and 90% at a contrast of -0.09. The distance at which a landscape or urban feature would reach that contrast is plotted for the 10%, 50%, and 90% acceptance levels as a function of atmospheric mass concentration in Figure 2.9. Also plotted in Figure 2.9 are the atmospheric mass concentrations corresponding to the first five health breakpoints listed in Table 2.5.

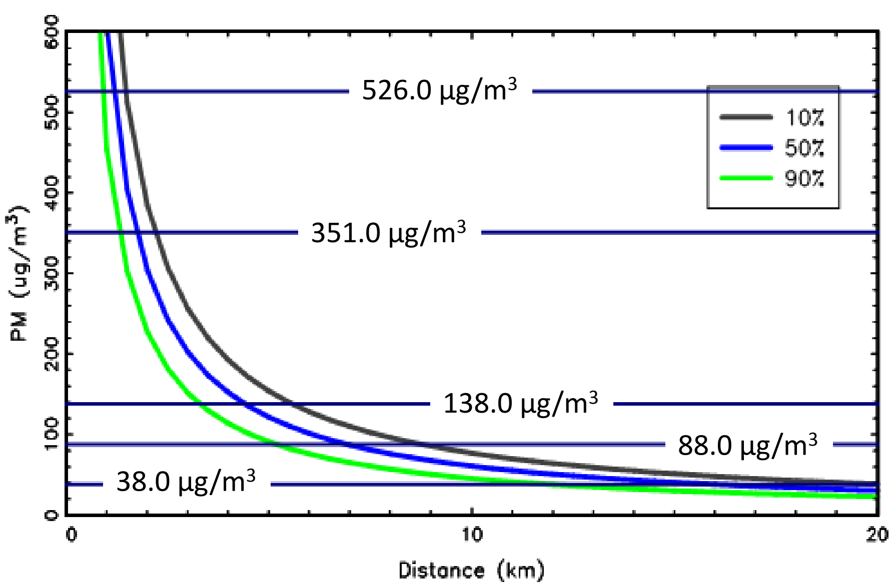


Figure 2.9: Distance at which a landscape or urban feature would reach an apparent contrast corresponding to 10%, 50%, and 90% acceptance levels as a function of atmospheric mass concentrations. Also shown are the mass concentrations corresponding to the first five health breakpoints.

For the first health breakpoint of 38 $\mu g/m^3$, the 50% acceptability level corresponds to a distance of about 16 km. If the most-distant prevalent landscape feature in a scene were 16 km or more, the visibility impairment associated with that scene would be judged to be unacceptable by 50% of the observers. If that feature were at 11.5 km, only 10% would find the scene to be unacceptable, and at 20 km, over 90% would find the scene unacceptable. The same data are available in Figure 9 for each of the health breakpoints. The distances for the 10%, 50%, and 90% acceptability levels for the 138 $\mu g/m^3$ health breakpoint are 3.5 km, 4.5 km and 6 km respectively. Any scene with a landscape feature greater than 3–6 km would be found to be unacceptable at 138 $\mu g/m^3$.

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