Develop With Care 2012:

Environmental Guidelines for Urban and Rural Land Development in British Columbia.

Supporting Information -- Air Quality

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Recommendations

Specific concern is focused on:

- buildings where people spend large amounts of time – seven to eight hours per day; and
- buildings that primarily house susceptible populations (infants, children, pregnant women, the elderly and those who are ill).

Buildings: Locating the Site

To minimize the exposure of building occupants to traffic-related air pollution associated with proximity to major roads, recommendations include:

1. **Setbacks:** 150 metre (500 feet) setbacks from "busy roads[1]" especially for buildings such as day care facilities, schools, hospitals, long-term care facilities and residences.
2. **Truck Routes**: Special consideration should be given to buildings located on major truck routes. Avoiding development of buildings for vulnerable populations on truck routes or using additional setbacks near truck routes or truck distribution centers is recommended (elevated air pollutant concentrations are measurable as far as 750 metres from truck routes). Heavy-duty trucks generally emit larger quantities of air pollutants, including diesel-exhaust particles, a probable[2] human carcinogen, and likely the most harmful vehicle-related pollutant.
3. **Street Canyons:** Avoid developments that create street canyons where susceptible populations may be housed (see Table 3: Street Canyon Definitions). Street canyons can trap air pollution and lead to

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[1] Busy Roads (Definition): A busy road is defined as a road with greater than 15,000 vehicles/day based on annual average daily traffic counts.

[2] Group 2A – International Agency for Research on Cancer. www.iarc.org

high exposures. To avoid creating street canyons, buildings that are perpendicular to the predominant wind direction should be staggered or high-rise buildings should be developed on only one side of the street (when perpendicular to the predominant wind direction).

4. **Major intersection**: Avoid locating buildings that house susceptible populations near major intersections. Traffic related pollution has been shown to be especially elevated surrounding intersections and “stop-and-go” traffic.

Site (Outdoor) Considerations

5. **Trees:** On a local scale, the impact of trees on air quality near roadways has shown mixed results (Baldauf et al., 2011; Hagler et al., 2012), although on a city-wide or regional scale they can provide a source of separation from traffic sources, may increase carbon dioxide conversion to oxygen and promote cooling. For a limited number of pollutants (coarse particles and ozone), there is some evidence to suggest that trees can absorb pollutants by providing increased surface area for deposition. Within urban forests, lower levels of pollutants may be observed, as these spaces do not include combustion sources. However, there is no evidence to support the use of trees as pollution-absorbing barriers along roadways. Further, there is also the potential that trees planted along roadways may affect the dispersion of pollutants in ways that could create street canyon type effects (Buccolieri et al., 2009). Trees and green space are important from the perspective of specific site-quality and general urban livability and should still be considered a valuable feature of land development.
6. **Physical Barriers**: Localized barriers around major roadways, such as sound walls, have showed mixed results in reducing traffic related pollution exposure. Barriers may also result in increased pollution concentration in specific surrounding areas. The primary focus of barriers should remain physical safety and noise reduction.

Building Construction/Design

7. **Building Air Intakes** Air intakes for buildings must not be located near loading docks or where delivery vehicles may be idling. This is particularly important because many medium- and heavy-duty

delivery vehicles have diesel engines. Similarly, building intakes should not be located on a side of a building near a busy traffic corridor. This will help avoid potential intake of traffic-related air pollution.

8. **Filters:** Where proximity to traffic is unavoidable, the use of high-efficiency particulate air (HEPA) filters is recommended to reduce exposure to particulate air pollution. Centralized filtration is preferable (for buildings with mechanical ventilation), but portable (properly sized) single-room air cleaners may also be effective. However, HEPA filters will not reduce exposure to gaseous air pollutants (e.g. CO, NO_X, SO_2), there may be significant capital costs associated with system installation for large buildings, and they require maintenance and increased energy to operate.

Supporting Information

1. Introduction and Rationale

According to a growing body of scientific literature, people living near freeways and major roadways have a higher risk of developing (or exacerbating) a wide range of health impacts. A recent comprehensive critical literature review found causal associations between traffic air pollution and asthma exacerbation, and suggestive casual associations with the onset of childhood asthma, cardiovascular mortality and morbidity, and lung cancer (HEI, 2010). Motor vehicles emit at least 40 different air pollutants, usually concentrated within 100 – 500 metres of freeways and busy roadways, and research points to a need for increased awareness of the public health concerns associated with roadway proximity in creating land-use policy, building design and environmental/air quality management programs.

Existing air quality management programs related to motor vehicles generally focus on reducing the emissions from individual vehicles (e.g. inspection-and-maintenance programs such as the AirCare program in the Lower Fraser Valley) and on “demand-side” programs to reduce the total number of vehicle-km travelled. However, less attention has been placed on reducing population exposures to aggregate traffic sources. The above guidelines are intended to provide general advice regarding building placement (including recommended setbacks) and general land use that will reduce exposures and health risks associated with traffic proximity. These guidelines can be implemented along with existing, more traditional air quality management strategies (for example, those focusing on emissions reduction) to reduce the public health impacts arising from vehicle-related air pollution. In addition, these guidelines can also be used as part of more general land use planning considerations that may focus on increasing opportunities for active transportation and physical activity or greenhouse gas emissions reductions (Perrotta, 2011). "Sensitive land uses" refer to those that are predominantly populated by susceptible populations (infants, children, pregnant women, the elderly and those with pre-existing heart or lung disease) and includes facilities such as daycares, schools, hospitals, long-term care facilities and residences. A recent study reported that approximately 55% of schools in Vancouver were located in zones of high traffic-related air pollution (TRAP) (within 200m of major roadways), with a disproportionate number of these located in low-income areas (Amram et al., 2011). As additional air quality management tools and regulations are implemented, or changes in emissions occur, it is advisable to periodically review these guidelines.

This document reviews existing guidelines that have been implemented in other jurisdictions, along with the evidence that higher concentrations of hazardous air pollutants exist near major roadways. It defines a "major roadway," which roadways should also be considered as street canyons, and the specific levels of traffic that lead to concern. Sources for information on characterizing roads in British Columbia are listed. In addition, the information regarding studies of health effects in relation to roadway proximity is summarized.

2. Existing Guidelines: Setbacks

To date the only legislation specifying road setbacks have been those regarding the siting of schools (Rhode Island Legal Services, 2006). With respect to school siting and air pollution sources, the California legislation (described below) is the most strict and explicit regarding school proximity to traffic. However, at least 10 other states have statements (in legislation) to encourage minimizing exposure to air pollution in school siting.

On September 11, 2003, the State of California passed Senate Bill No. 352 (State of California, 2003), which amended previous legislation on planning and siting public schools and essentially required that school sites be selected such that:

a. no pollution-generating facilities (broadly written to specify any hazardous air pollution source) be situated within a ¼-mile radius of any school site; or
b. corrective measures are used to mitigate all hazardous emissions from such pollution-generating facilities; or
c. there are no health risks posed to school occupants from the identified facilities.

Bill 352 amended the previous legislation to include "freeways and other busy traffic corridors, large agricultural operations, and rail yards" in the definition of pollution sources. Furthermore, the legislation attempts to prohibit the location of any school site within 500 feet (150 metres) of a freeway or other busy traffic corridor. In the State of California legislation, the definitions of a "freeway or other busy traffic corridor" are "roadways that, on an average day, have traffic in excess of 50,000 vehicles in a rural area … or 100,000 vehicles in an urban area." Note that this level of vehicle traffic is several-fold higher than the 15,000 Annual Average Daily Traffic (AADT) level that we use throughout these guidelines. The evidence supporting this level of traffic to define a major road is based on evidence collected in British Columbia and is discussed in more detail below.

The justification for California's amendment to their previous legislation pertains to the following (excerpts from the legislation):

a. Higher levels of air pollutants have been detected near freeways and busy traffic corridors; this pollution has been associated with acute health effects (including asthma exacerbation) and negatively impacts the ability of children to learn.
b. Cars and trucks emit at least 40 different air toxics/contaminants; levels are generally concentrated within 500 feet (150 metres) of freeways and busy roadways.
c. A disproportionate number of economically disadvantaged pupils may be attending schools that are close to busy roads; these students are at an increased risk of developing chronic health conditions caused or exacerbated by exposure to traffic-related pollutants.
d. The intent of the legislation is to protect school children from the negative health effects of freeway traffic, as well as other industrial pollution sources.

Similarly, legislation was also passed in New Jersey in 2008 (State of New Jersey, 2008). Called "Terrell James' Law", it concerned the siting of new schools with respect to highway entry/exit ramps, and states that no new ramp can be constructed within 1,000 feet (approximately 300 m) of an existing school, and vice versa (unless no alternative can be found). In San Francisco, land use guidance suggests a potential hazard exists if average daily traffic exceeds 100,000 vehicles/day within a 200 meter radius of a site (roughly equivalent to the State of California definition above), 50,000 vehicles/day within a 50 meter radius or 10,000 vehicles/day on an immediately adjacent street (Bhatia and Rivard, 2008). The latter two thresholds are equivalent with respect to area traffic volume density.

In Canada, the Regional Health Department in Halton, Ontario, published a document in 2009 entitled "Protecting Health: Air Quality and Land Use Compatibility", which offered suggestions for consideration by the Sustainable Halton and Halton Regional Official Plan Review processes (HRHD, 2009). These suggestions mirror the US legislation and recommend that residences, hospitals, schools, child care facilities, and nursing homes should not be located within 150 m of highways with greater than 100,000 AADT, or 30 m from roads with greater than 30,000 AADT.

Outside of North America, the Regional Public Health Service in Auckland, New Zealand, provides analogous guidelines for the siting of early childcare centres. The recommendation is that such centres, which cater to children age 4 and under, are not to be located either within 60 m of district or regional arterial roads, within 150 m of roadways, within enclosed parking facilities, within 300 m of industrial zones, or within 100 m of petrol stations (ARPHS, 2009a). They advise that these recommendations should be incorporated into local authority plans to ensure that developers of early childhood centres avoid hazardous locations. The Health & Safety Guideline for Early Childhood Centres (ARPHS, 2009b) is a published tool for early childhood centre operators whose centre is to undergo a health and safety assessment by the Auckland Regional Public Health Service. This guide summarizes the relevant health standards, including those regarding traffic exposure as outlined in the Position Statement on Air Quality and Early Childhood (currently pending clarification of Ministry of Health policy intentions), that early childcare centres must comply with in order to obtain an operating licence from the Ministry of Education. The surrounding environment in relation to air quality is scrutinized, including current location of major roads adjacent to the facility and future transport and development plans. Under these guidelines, a number of new early childcare centres in Auckland have either been refused licences or are operating on provisional basis pending the results of air monitoring by the Health Ministry, due to air quality concerns (Fisher and Shepheard, 2009).

The California Air Resources Board also produced an informational guide on air quality and land use issues entitled "Air Quality and Land Use Handbook: A Community Health Perspective" (CARB, 2005). This document is an excellent resource to community members seeking to understand the issues around air pollution and health in their communities. In the California recommendations, locating sensitive land uses was also addressed for other community air pollution sources e.g. dry cleaners, refineries, railyards, ports, in addition to vehicle traffic-related air pollution. While this aspect of the British Columbia Environmental

Guidelines for Urban and Rural Land Development is focussed on traffic proximity, it is nevertheless important to avoid locating sensitive land uses near other pollution sources.

3. Components of Traffic-related Air Pollution and Spatial Patterns in Urban Areas

Vehicles and motor vehicle traffic generate a complex mixture of air pollutants that can vary according to factors such as: the age of the vehicle, type of fuel, engine type, speed of travel, roadway conditions and density of traffic. In general, the concentrations of pollutants decrease away from sources (highways, major roadways) as pollutants are transported and dispersed by wind and turbulence. The amount of transport and dispersion of pollutants is affected by meteorological conditions (e.g. wind speed and direction), topography and vehicle traffic/movement.

Several studies have measured pollutant concentrations and distributions at different locations in urban and rural areas. Pollutant concentrations decrease at increasing distance from a roadway, and this varies according to the specific air pollutant. Components of traffic-related air pollutants are measured using a variety of metrics, including:

- $PM_{2.5}$ (PM or "particulate matter" refers to very small gas and liquid particles in the atmosphere. $PM_{2.5}$ is 2.5 micrometres in aerodynamic diameter or smaller);
- ultrafine particles ($PM_{0.1}$; particles less than 0.1 micrometres in diameter), often measured as particle number concentrations (the number of particles per volume of air);
- carbon monoxide (CO);
- black smoke/black carbon (a measure of elemental carbon);
- nitrogen dioxide (NO_2); and
- nitrogen oxides (NO_x).

In general, $PM_{2.5}$ mass concentrations do not decrease dramatically as a function of distance from major roads because motor vehicles are not the major source of urban $PM_{2.5}$ and because these particles have relatively long atmospheric lifetimes (days) resulting in relatively homogeneous concentrations across short distances in urban areas. For this reason, primary motor vehicle emissions are better represented by NO_2 (or NO_x), or specific components of the particulate mixture such as elemental carbon, particle number concentrations, or ultrafine particles. All these metrics decrease significantly at increased distances from major roads.

4. Specific Measurement of Traffic Pollutants with Distance from Roads

A recent critical review of traffic air pollution and health effects examined the gradients in which pollution is elevated around roadways, and concluded that traffic pollution is generally elevated up to 300-500m from major roadways (HEI, 2010). Previously the World Health Organization summarized over 15 different studies in which pollutant concentrations measured at traffic sites were a factor of 1.2 to 2.3 higher than urban-background sites in the same cities (WHO, 2005). The rate at which pollutant concentration decreases when moving away from the traffic site varies with pollutant; however, there are some overall similarities across different pollutant species.

Primary pollutants, such as NO and black carbon are formed directly in the combustion process and typically have small scales of influence, while secondary pollutants, such as NO_2 or ozone (O_3), are formed in the atmosphere through chemical reactions and physical conversions involving primary pollutants and will have larger scales of influence. Zhou and Levy (2007) conducted a systematic review of measured and modeled pollutant gradients from roadways and found large differences in the spatial extent of gradients by pollutant type (see Figure 1). Inert pollutants, such as CO, benzene and black carbon, with low background concentrations and reactive pollutants that are removed close to the roadways (e.g. NO, ultrafine particles) had the smallest spatial scales, with mean spatial extents below 200 m. Reactive pollutants such as NO_2 that formed close to roadways demonstrated a mean spatial extend of approximately 400 m, but extended to 500 m in some studies. $PM_{2.5}$ mass is an example of a pollutant fitting profile 1 (Figure 1) with a large spatial extent. Recently, Karner et al. (2010) also synthesized findings from 41 monitoring studies of traffic-related pollutant gradients and found gradients ranged from 100–500 m depending on the pollutant (Figure 2). CO had the spatial gradient with the minimum distance while a group of volatile organic compounds, and fine and coarse particles had the spatial gradients with the largest distance.

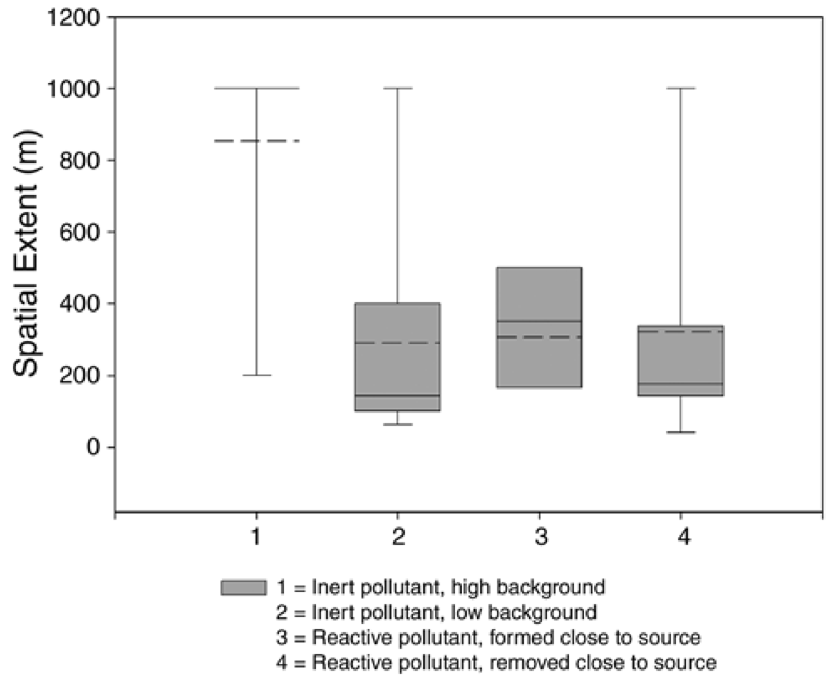

Figure 1. Results of a meta-analysis on the spatial extent of traffic air pollution, stratified by pollutant type (Zhou and Levy, 2007). Boxplots indicate mean (dashed line), median (solid line in box), 25th and 75th percentiles (upper and lower ends of boxes) and 10th and 90th percentiles (upper and lower whiskers). Examples of pollutant types are 1: CO, benzene, black carbon, 2: PM (PM10 or PM2.5) mass concentration 3: NO2, 4: NO, ultrafine particles.

As shown in Table 1, various studies have confirmed that black carbon (also referred to as black smoke) decreased by 80-55% in the first 150 metres away from the road. Black carbon reaches urban background levels at 150-200 metres. In contrast, $PM_{2.5}$ concentrations decreased by only 20-10% in the first 200 metres from the road, with no further decrease at greater distances (Table 2).

Measured NO_2 concentrations decreased by 30-70% in the first 150 metres from the roadside and then reached urban background levels by 150-300 metres from the roadside. Particle number concentrations generally had a 50% reduction at 150 metres from roads in several different wind conditions. In addition, the particle number distributions (the numbers of differently sized particles in the air) at 150 metres were comparable to urban background, indicating that little contribution remains (at 150 metres) from vehicle traffic (Hitchins et al., 2000).

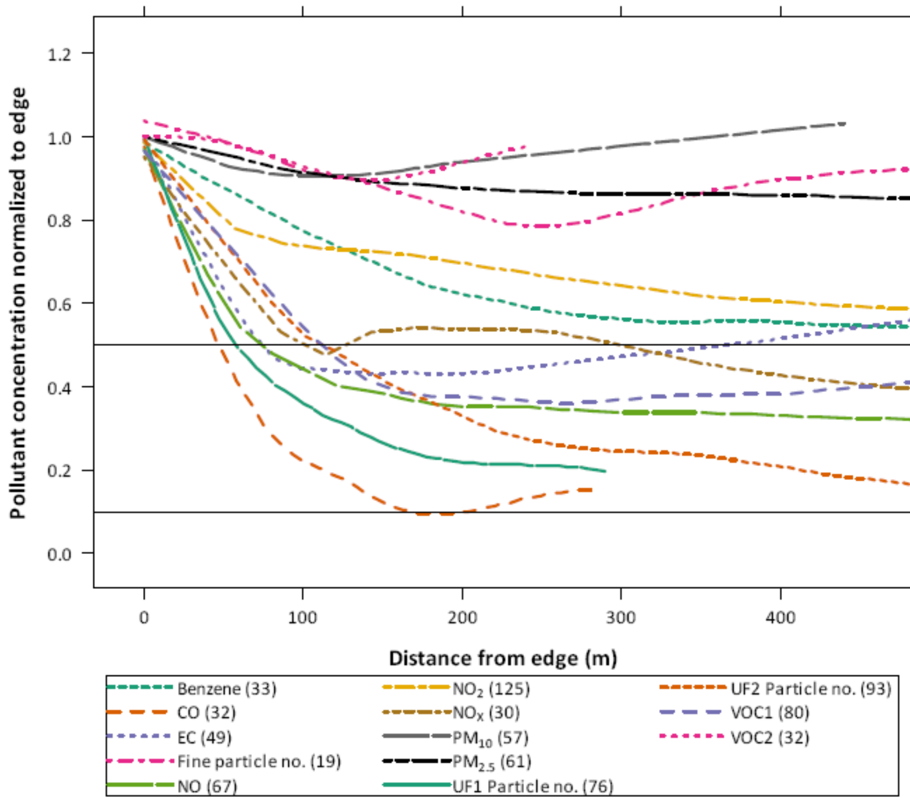

Figure 2. Estimated traffic pollutant gradients (Karner et al., 2010). The horizontal black lines show a reduction from the edge of road concentration of 50% (at 0.5) and 90% (at 0.1). The number of published measurements (n) used to estimate the curve is given in parentheses after each pollutant. UF1 particle number indicates particles > 3 nm, while UF2 particle number is for particles > 15 nm in diameter. Fine particle number is counts of particles > 300 nm. VOC1 refers to a group of eight volatile organic compounds (e.g. 1,3 butadiene and methyl tert-butyl ether) whose concentrations generally varied with distance from roads. VOC2 includes four volatile organic compounds (e.g. propane, n-butane) whose concentrations generally did not vary as a function of distance from roads.

Several studies have found higher concentrations and gradients near highways with a greater percentage (than normal) of diesel truck traffic – specifically black carbon and ultrafine particles (Zhu et al., 2002). Particle concentrations ($PM_{2.5}$) decrease only slightly with increased distance from busy roads. However, particle number concentrations (reflecting ultrafine particles) decrease much more significantly and provide a better measure of decreasing traffic-source particles with distance from a road.

Table 1. Fractions of Pollutant Concentrations (NO_2, Black Smoke, PM1.0) at 150 m from Major Roads

Study and Location		% Fraction of Maximum (close to road)	% Above Background (steady-state)	Traffic Data at Nearby Road (vehicles/day)
Singer et al., 2004 (LA)	NO_2	0.55	0.5	200,000
Kodama et al., 2002 (Tokyo)	NO_2	0.78	0.15	60,000
Gilbert et al., 2003 (Montreal)	NO_2	0.75	0.3	100,000
Roorda-Knape et al., 1998 (Netherlands)	NO_2	0.6	0.1	100,000
Roorda-Knape et al., 1998 (Netherlands)	Black Smoke	0.55	0.1	120,000
Zhu et al., 2002 (LA; high diesel)	Black Smoke	0.3	0.3	200,000
Zhu et al., 2002 (LA; low diesel)	Black Smoke	0.3	0.5	200,000
Zhu et al., 2002 (LA; both)	$PM_{1.0}$	.15	n/a	200,000

Table 2. $PM_{2.5}$ Pollutant Fractions (of Roadside Maximum) at Varying Distances from Traffic Sites

Study and Location	Distance from Busy Road (m)	Fraction of Max. $PM_{2.5}$ at this Distance	Traffic Data at Nearby Road (vehicles/day)
Nitta et al.,1993 (Tokyo)	150	0.8	>50,000
Roorda-Knape et al., 1998 (Netherlands)	300	0.90	>120,000
Janssen et al., 1997 (Netherlands)	1000	0.82	15,000
Hoek et al., 2002a (Munich)	>1000	0.84	"traffic site" compared to urban background
Hoek et al., 2002a (Netherlands)	>1000	0.79	"traffic site" compared to urban background

Road dust (primarily coarse particles larger than $PM_{2.5}$) concentrations measured at roadside are higher than background. While few studies have examined the specific impact of road dust on health, there are some indications of impacts (Meister et al., 2011; Bell et al., 2010). The California EPA land use handbook (California Environmental Protection Agency and Air Resources Board) suggests green space and regular watering of road surfaces to reduce suspended dust near schools but no specific evidence of effectiveness of such practices is available. Measurements of road dust upwind of major roads decrease only slightly, or not at all, with distance away from roads. Increased wind speeds cause pollutants to disperse more rapidly, and background concentrations are reached even closer to the roadway

Higher gradients have also been observed around high volume traffic intersections. Stop and go traffic can lead to increased pollution gradients (Ryan et al., 2005; Klems et al., 2010) and idling vehicles have been found to emit higher pollution concentrations than moving vehicles (Zhu et al., 2002). Epidemiological evidence also supports the importance of stop and go traffic to health effects. For example, Ryan et al. (2005) found that infants living very near (<100 m) stop-and-go bus and truck traffic in Cincinnati had a significantly increased prevalence of wheezing (adjusted odds ratio, 2.50; 95% CI, 1.15-5.42) when compared with unexposed infants.

5. Traffic Volumes and Pollution Gradients

Vehicle traffic (annual average daily traffic counts) on the major roads in the studies cited above varied from over 15,000 vehicles per day to 200,000 vehicles per day. Reported gradients of traffic-based pollutants are similar for most roads with more than 15,000 vehicles per day when sampled downwind of the roadway.

Higher traffic volumes generally increase pollutant concentrations at roadside, but the concentration gradient is comparable for both higher and lower traffic volumes. **For most traffic volumes and pollutants, the major decrease in traffic-based pollutants occurs in the first 150-200 metres from the roadside**. Pollutants decline at much slower rates from 150-1000 metres from the roadside. Statistical (regression) models for pollutant concentrations generally found logarithm of the distance from the roadway, wind speed and wind direction to be the greatest predictor of pollutant decline with distance from a major road. A recent study of the road proximity of Canadian primary schools used measurement data for NO and ultrafine particles to empirically define the zone of TRAP influence and identified a zone of 75 m as a conservative estimate (Amram et al., 2011), although gradients in Vancouver clearly extended as far as 200 meters.

6. Traffic Speed and Emissions

Similar concentration gradients are measured for both highways (Zhu et al., 2002) and urban "high-traffic" roads (Gilbert et al., 2003) with relatively lower traffic speeds. In general, idling vehicles emit higher pollution concentrations than moving vehicles (Zhu et al., 2002) with emissions also generally increasing at speeds above 60 – 80 km/hr. Few studies, however, have measured the differential health effects of idling-traffic pollution as compared to highway pollution. As mentioned previously, one available study reported that infants living very near (<100 m) stop-and-go bus and truck traffic in Cincinnati had a significantly increased prevalence of wheezing when compared with infants who did not live very close to stop-and-go traffic (Ryan et al., 2005). In terms of costs, the only estimate for congestion-related $PM_{2.5}$ mortality concluded that the monetized value of $PM_{2.5}$-related mortality attributable to congestion in 83 major cities was approximately $31 billion (2007 dollars), as compared with a value of time and fuel wasted of $60 billion (Levy et al., 2010). was estimated as $31 billion (2007 dollars) for 83 major U.S. cities (Levy et al., 2010).

7. Topography and Street Canyons

In addition to windspeed and direction, urban topography can significantly alter the dispersion of traffic-based pollution from a major road. A specific type of urban topography is a street canyon: a canyon formed in a street between two rows of tall buildings.

A street canyon is defined by calculating the ratio of the height (H) of the buildings and the width (D) of the street. The following table is used to define a street canyon (ADEME, 2002):

Table 3. Street Canyon Definitions

H/D Ratio	Type of Roadway
<0.3	Wide street
0.3 to 0.7	Canyon street **without** risk of pollution accumulation
>0.7	Canyon street **with** risk of pollution accumulation

Street canyons can trap and limit dispersion of pollutants, due to the lack of wind flow out of the canyon. As a result, the concentration of pollutants in street canyons can be significantly elevated over urban background levels (Wehner et al., 2002). In many locations, including the British Columbia Lower Mainland, under typical meteorological conditions, air pollution concentrations are higher in areas of lower altitude, such as river valleys. Specific local and regional meteorological conditions that can lead to high air pollution episodes should be addressed with overall air quality management strategies and are not the focus of this document. In addition to topography, height of buildings and where people live in those buildings will affect TRAP exposures. The influence of vertical distance from a road on TRAP exposures is only beginning to be explored, although studies do suggest that exposures decrease vertically in a similar fashion to the horizontal gradients that have been well-described and explained in this document (Wu and Lung, 2012).

8. Road Type and Traffic Levels (British Columbia)

Road classification data for British Columbia are available from the Digital Road Atlas (DRA) (http://archive.ilmb.gov.bc.ca/crgb/products/mapdata/digital_road_atlas_products.htm), as well as from commercial databases such as DMTI Spatial (http://www.dmtispatial.com/).

DMTI uses five classifications:

1. Expressway;
2. Highway Principal;
3. Highway Secondary;
4. Major; and
5. Local.

DRA uses:

1. Freeway;
2. Highway;
3. Arterial;
4. Collector; and
5. Local.

DRA further classifies roads with eight subclasses as shown in Table 4, below.

A measurement program in the Greater Vancouver Regional District linked elevated air pollution levels to locations up to 200 metres from DMTI classification types 1-4 (expressways, principal and secondary highways, and major roads). It also linked elevated pollution concentrations to locations up to 750 metres from a designated truck route (Henderson and Brauer, 2005). Although at present trucks represent a specific vehicular source of air pollution, expected reductions in (diesel) truck emissions (for example resulting from application of particle traps and the use of low-sulphur fuel) combined with turnover in truck fleets are expected to decrease total truck emissions in the long term. However, truck routes are expected to continue to be classified as "busy roads" even as (diesel) truck emissions are reduced and approach those of (spark-ignition engine) car emissions.

Levels of traffic for different classifications have been compared (Setton, Hystad, and Keller, 2005) and show the general relationships described in Table 4, below. **The shaded rows are classifications/traffic levels that are considered significant sources in terms of air pollution.**

Table 4. Road Classifications Available for B.C. Roads and Mean Traffic Count Data from (Setton, Hystad, and Keller, 2005)

DMTI Class	*Count data (mean)*	**DRA Class**	*Count data (mean)*	**DRA Subclass**	*Count data (mean)*
Local	6,511	Local	3,976	Local	4,126
Major	15,207	Collector	8,953	Collector minor	8,580
				Collector major	9,964
Highway Secondary	18,254	Arterial	18,457	Arterial minor	15,321
				Arterial major	17,407
Highway Principal	21,025	Highway	27,961	Highway minor	22,242
				Highway major	36,684
Expressway	113,789	Freeway	113,789	Freeway	113,789

Levels of traffic for highways and selected major roads are available for B.C. from the Ministry of Transportation (http://www.th.gov.bc.ca/publications/planning/Trafficvolumes/index-trafficvolumes.htm); additional data for Greater Vancouver is available from http://www.city.vancouver.bc.ca/engsvcs/transport/traffic/counts.htm. For other roads, traffic data are available from municipal sources, although typically measurements are made for much shorter averaging periods such as for peak morning (two hours) or evening traffic periods. There is, however, only a moderate relationship between these shorter-term measurements and the longer-term averages that are most relevant for health assessment. For a select number of locations in the Lower Mainland, total daily traffic counts were found to be roughly 11 times higher than peak morning (7:30-8:30 am) hourly traffic counts (Henderson and Brauer, 2005). Truck routes are usually identified at the municipal level. In a community without existing truck routes, it may be appropriate to designate routes. Clearly, new truck routes should be sited to avoid the sensitive land uses identified in this document.

9. Health Impacts of Traffic-Related Air Pollution

Motor vehicle exhaust has long been known as a significant contributor to urban air pollution and its associated health effects. However, only recently have studies demonstrated that people living in areas near major roadways experience increased health effects due to air pollution. The Health Effects Institute[3] (HEI) published a comprehensive critical review of the literature on emissions, exposure, and health effects of traffic-related air pollution (HEI, 2009, updated in January 2010 [HEI, 2010]). The HEI (2010) review builds on established efforts to assess and communicate the health effects of exposure to outdoor air pollution (e.g. WHO, 2005). The HEI Review identified the evidence regarding TRAP exposure and asthma exacerbation as sufficient to infer causality and that the evidence for TRAP causing new cases of childhood asthma was on the borderline between "sufficient and suggestive" and "suggestive but insufficient". Evidence for adult onset asthma, lung function decrements, cardiovascular mortality, myocardial infarction onset and progression of atherosclerosis was deemed to be suggestive but insufficient to infer causality. Research published since the end of this review contributes to the strength of evidence linking asthma onset in children and adults and lung cancer to TRAP. Table 5 summarizes the strength of evidence between exposure to TRAP and specific health outcomes, along with evidence from Canadian Studies.

As shown in Table 5, important information linking TRAP and several health effects have been documented in Canadian studies. This is important as Canadian cities have relatively good ambient air quality; however, health effects associated specifically with TRAP are similar to those seen in other international urban settings.

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[3] HEI (www.healtheffects.org) is a nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the health effects of air pollution. Typically, HEI receives half of its core funds from the US Environmental Protection Agency and half from the worldwide motor vehicle industry.

Table 5. Summary of the strength of evidence between exposure to TRAP and health outcomes. Revised conclusions are presented based on the HEI (2010) conclusions as well as new evidence since 2009. A summary of whether Canadian-specific studies support each conclusion is also presented.

Health Outcome	HEI Conclusion on Strength of Causality	Updated Conclusion on Strength of Causality	Canadian Literature Supports Conclusion on Causality
Respiratory			
Asthma exacerbation	Sufficient	(No change)	Dales et al. (2008); Deger et al. (2010); Sahsuvaroglu et al., 2009; Wang et al. (2010)
Respiratory symptoms (non-asthmatic children)	Inadequate and insufficient	(No change)	Dales et al. (2009); Karr et al., (2009); Smargiassi et al. (2006)
Asthma onset			
Adults	Suggestive, but insufficient	Sufficient / Suggestive, but insufficient	No Studies
Children	Sufficient / Suggestive	Sufficient	Clark et al. (2010); Carlsten et al. (2011)
Lung function	Suggestive, but insufficient	(No change)	Dales et al. (2008); Cakmak et al. (2012)
COPD	Inadequate and insufficient	(No change)	No Studies
Allergy	Inadequate and insufficient	(No change)	No Studies
Cardiovascular			
CVD mortality	Suggestive, but insufficient	(No change)	Gan et al. (2011); Jerrett et al. (2009); Crouse et al. (2012)
MI onset	Suggestive, but insufficient	(No change)	No Studies
Atherosclerosis	Suggestive, but insufficient	(No change)	No Studies
Cancer			
Lung cancer	Inadequate and insufficient	Suggestive, but insufficient	Band et al. (2011)
Other (non-lung) cancer	Inadequate and insufficient	(No change)	Crouse et al. (2010)
Childhood cancer	Inadequate and insufficient	(No change)	No Studies
Pregnancy/Birth Outcomes	Inadequate and insufficient	(No change)	Brauer et al., (2008); Genereux et al., (2008)
All Cause Mortality	Inadequate and insufficient	(No change)	Finkelstein et al. (2004); Jerrett et al. (2009); Crouse et al. (2012)

A number of TRAP epidemiological studies summarized in Table 5 have been conducted in Metro Vancouver and use indicators of traffic-related pollution exposure that support the guidelines presented in this document (e.g. proximity to highways and major roads or land use regression (LUR) estimates of traffic-related pollutants). A significant amount of research has examined childhood health effects in Metro Vancouver, such as asthma development and exacerbations, bronchiolitis, and otitis media. Clark et al. (2010) examined the effect of early-life TRAP exposures on the development of childhood asthma in a large birth cohort in Metro Vancouver during 1999/2000 (n=37,401). Asthma diagnoses up to 3-4 years of age were assessed using administrative health databases and high-resolution models of traffic-related NO, NO_2, $PM_{2.5}$ and BC; the study estimated exposure at mothers' residential histories during pregnancy and the children's addresses during follow-up. Results found that these traffic-related pollutants were associated with the highest risks of asthma diagnosis, for instance, an adjusted OR[4] of 1.12 (95% CI[5]: 1.07–1.17) for a 10$\mu g/m^3$ increase in NO_2. Carlsten et al. (2011) also examined TRAP and incident asthma in a high-risk birth cohort (272 high-risk infants during born during 1995) in Vancouver. High risk was defined as having at least one first-degree relative with asthma or two first-degree relatives with other IgE-mediated allergic disease (according to parental report). NO, NO_2 and $PM_{2.5}$ LUR models were applied to birth-year residential addresses and asthma was assessed by pediatric allergists at age 7, and adjusted for a number of known risk-factors. Exposure estimates were available for 184 children (23 diagnosed with asthma and 68 with bronchial hyper-reactivity). For each IQR increase (4.1$\mu g/m^3$) of $PM_{2.5}$ at birth residence there was a significant increase in the risk of asthma (OR: 3.1; 95% CI 1.3–7.4). Elevated (non-significant) associations were also seen for NO and NO_2, while little association was seen for BC. In addition, Chen et al. (2008) examined interactions between exposure to TRAP and stress on biological and clinical outcomes of asthma for asthmatic children (n=73, 9–18 years of age) located in Vancouver. NO_2 LUR models were used to estimate TRAP, information about life stress was collected in interviews, and asthma-relevant inflammatory markers were measured. In children reporting low levels of chronic psychological stress, higher levels of TRAP exposure were associated with increases in measures of inflammation, whereas the detrimental effects of stress were most evident among children living in lower-pollution areas. These results suggest that chronic

[4] OR: Odds Ratio: a measure that quantifies the association between an exposure and a health outcome. An Odds Ratio larger than 1.0 indicates a positive association between the exposure and the health outcome.

[5] 95% CI: The 95 percent confidence interval. A range of values (typically for an Odds Ratio) for which the probability of including the true value is 95%. A 95 percent confidence interval for an Odds Ratio in which the upper and lower limits are both larger than 1.0 indicates a statistically significant positive association between the exposure and the health outcome.

stress may have the ability to accentuate the effects of TRAP only when TRAP exposure levels are lower, perhaps due to some saturation mechanism. A case-control study in Vancouver (Karr et al., 2009) also reported associations between physician visits and hospitalizations for bronchiolitis among infants with TRAP. MacIntyre et al. (2011) examined TRAP exposure during the first two years of life and risk of otitis media in a large population-based birth cohort in southwestern British Columbia. Children born during 1999-2000 were followed using administrative health databases until the age of 2 years. TRAP was estimated using high spatial resolution land use regression NO, NO_2, $PM_{2.5}$, BC and woodsmoke models that were applied to all children's residential locations. Exposure was estimated from NO LUR models. After adjusting for a number of known risk factors, exposure was found to be significantly associated with risk of otitis media (RR[6] 1.10; 95% CI: 1.07–1.12). Other LUR estimates showed weak associations, as did proximity measures to highways and majors roads.

In terms of TRAP exposure during pregnancy, Brauer et al. (2008) identified small but consistent higher associations between exposure to NO, NO_2, and $PM_{2.5}$ during the entire period of gestation, as well as residence within 50 m of a highway, and small-for-gestation-age birth weight in 70,249 births from 1999 to 2002 in Vancouver. There were no associations observed with living within 150 m of a highway. As well, associations were noted between exposure to specific traffic-related pollutants and preterm births.

A series of analyses in Vancouver have provided evidence to suggest a causal association between cardiovascular mortality and exposure to TRAP. In a population-based cohort of 452,735 individuals (45-85 years of age) created from administrative health record linkages in 1999, living close to a major road was associated with increased coronary heart disease (CHD) mortality, while changes in distance of residences in relation to major roads were associated with altered CHD mortality risk in an exposure-response fashion (Gan et al., 2010; Gan et al., 2011). The most recent analysis of this cohort suggests that the increased CHD risk appears to be independently related to both exposures to black carbon and to traffic noise (Gan et al., 2011).

The health effects studies contributing to Table 5 differ in their approach to determining the impact of traffic-related air pollution, but they have relied mainly on simple measures of proximity, or specific traffic related pollutant measurements or models. In terms of proximity, most studies use distances of 50-300

[6] A general term for measures of association calculated from data in a two-by-two table (exposed/unexposed; yes/no health outcome) including the odds ratio.

metres to indicate exposure to traffic-related air pollution. For example, in studies in Holland (Brunekreef et al., 2009; van Vliet et al., 1997), an association between decreased lung function in children and exposure to truck traffic was strongest for children living within 300 metres of motorways. Andersson et al. (2011) also examined a proximity model of average daily traffic and average daily heavy-duty vehicle traffic within 200 meters from families of all children attending first or second grade in Luleå (72,000 inhabitants) in Northern Sweden. The authors reported a dose-response relation with an increased though not significant odds ratio of 1.5 (confidence interval 0.8-2.9) for those children living closer than 200 meters to a road with ≧500 heavy-duty vehicles per day. This study demonstrated health effects in population living in proximity to a relatively low levels of traffic and may therefore have important parallels to smaller communities in British Columbia. A number of international and Canadian studies have also used land use regression models of primary traffic pollutants (NO, BC) to estimate exposure to TRAP, as we described in the study by Clark et al. (2010), which support the use of a 150 m setback from major roads to limit TRAP health effects.

Toxicological evidence also supports the conclusions from epidemiological studies in Table 5 and provides information on biological mechanisms linking TRAP and specific health outcomes. The HEI (2010) review concluded that the toxicological evidence supports the hypothesis that oxidative stress in an important determinant of the health effects associated with ambient air pollution, but evidence linking specifically TRAP exposure to oxidative stress remains less clear. The review did note a growing body of evidence that demonstrates oxidative stress in response to exposure to components of TRAP, of which the majority of studies focused on PM from diesel engine exhaust and the presence of surface-absorbed transition metals and polycyclic aromatic hydrocarbons.

No direct quantification has been conducted of the expected impact that application of these guidelines would have on population health within British Columbia. Evidence from southern California suggests 6-9% of childhood asthma is attributable to traffic proximity and could therefore be mitigated by full application of these guidelines (Perez et al. 2009). Based on European data, the roadway proximity effect is responsible for as much as a doubling of cardiovascular mortality risks (Hoek et al., 2002b), and traffic emissions modeling estimated that approximately half of the adult mortality from air pollution was attributed to traffic-related air pollution (Kunzli et al., 2000. WHO, 2005). Therefore, completely removing sensitive individuals from the impact of traffic-related air pollution could reduce air pollution related mortality by up to 50%. This is supported by the analysis of Gan et al. (2010), who showed that individuals living in Vancouver who moved away from TRAP proximity zones reduced their risk of coronary heart disease mortality by as much as 40%.

Glossary

Black Smoke

A measure of the blackness of airborne particulate matter. This is determined by passing the air through standard filter material and measuring the blackness or light absorbance of the stain that is produced. Blackness is related to the amount of elemental carbon and is an indicator of combustion-related particulate matter.

Confidence Interval (CI)

A range of values (typically for an odds ratio) for which the probability of including the true value is a specified percentage. A confidence interval for an odds ratio in which the upper and lower limits are both larger than 1.0 indicates a statistically significant positive association between the exposure and the health outcome.

Downwind

The direction toward which the wind is blowing. With the wind.

Elemental Carbon

Inorganic carbon, as opposed to carbon in organic compounds, sometimes used as a surrogate measure for diesel particulate matter, especially in occupational health environments.

Freeway (or other busy traffic corridor)

Roadways that, on an average day, have traffic in excess of 50,000 vehicles in a rural area or 100,000 vehicles in an urban area.

Gradient

The rate at which a physical quantity, such as temperature or pressure, increases or decreases relative to change in a given variable, especially distance (in a specified direction).

High-Efficiency Particulate Air (HEPA) Filter

Efficient mechanical filters that remove 99.97% of particles of an aerodynamic diameter of 0.3 micrometres

– the most penetrating particle size. Generally, efficiencies are higher for larger and smaller particles . These filters can be portable room filters, or centralized building units.

Highway

A major road within a city, or linking several cities together.

Idling

Running a vehicle while it is sitting still for more than about 10 seconds. Idling can release a substantial amount of pollutants.

Inflammatory Markers

Chemicals present in the circulation that are an indicator of the amount of inflammation occurring in the body.

IgE-mediated Allergic Disease

Disease in which the allergic reaction involves the antibody immunoglobulin E (Ig-E).

Interquartile Range (IQR)

The distance between the 75^{th} and 25^{th} percentile, in which the x^{th} percentile is the value below which x% of the observations may be found.

Land Use Regression Model

A statistical model that predicts pollutant concentrations at a given site based on traffic and land use characteristics within various distances around the site.

Log (Logarithm)

An exponent used in mathematical equations to express the level of a variable quantity.

Meta-analysis

Any systematic method that uses statistics to integrate results from several independent studies.

Metrics

Specific indicators that are measured in order to assess a pollutant's impact on the physical or social environment.

Odds Ratio (OR)

A measure that quantifies the association between an exposure and a health outcome. An odds ratio larger than 1.0 indicates a positive association between the exposure and the health outcome.

Otitis Media

Infection of the middle ear.

Particle Number Concentration

The number of particles per volume of air.

Particle Number Distributions

The numbers of differently sized particles in the air.

Particulate Matter (PM)

Small gas and liquid particles in the atmosphere:

- PM10: particles that are 10 micrometres and less in (aerodynamic) diameter
- PM2.5: particles that are 2.5 micrometres and less in (aerodynamic) diameter
- PM1.0: very small particles that are 1.0 micrometres and less in (aerodynamic) diameter.

Road, Busy

Busy road is defined as a road with greater than 15,000 vehicles/day, based on annual daily average traffic counts.

Roadway

Road over which vehicles travel (same as "road").

RR

A general term for measures of association (including the odds ration) calculated from data in a two-by-two table (exposed/unexposed; yes/no health outcome).

Setback

Distance separating one parcel of land from another that acts to soften or mitigate the effects of one land use on the other.

Sensitive Land Uses

Those land uses that are predominantly populated by susceptible populations such as infants, children, pregnant women, the elderly, and those with pre-existing heart or lung disease.

Street Canyon

A canyon formed in a street between two rows of tall buildings. Vehicle exhaust fumes (in particular) are trapped there because the buildings on each side protect the street from the wind. If wind directions do not flow parallel to the street, pollutants can build up to high concentrations.

Traffic-related air pollution (TRAP)

Gases and particles associated with on-road transportation sources.

Turbulence

An instability in the atmosphere that disrupts the wind flow, causing gusty, unpredictable air currents.

Ultrafine Particles

Very small atmospheric particles, 0.1 micrometres and less in diameter.

Upwind

The direction from which the wind is blowing. Against the wind.

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