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**CUMULATIVE IMPACT OF BENZENE EMISSION AND A POTENTIAL  
APPROACH TO IMPROVE THE ONTARIO AIR QUALITY STANDARD**

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## Abstract

Sources, such as industries, gas stations, and motor vehicles are major contributors of benzene emission into the surrounding air, deteriorating the air quality of the communities. Currently, Ontario does not possess a benzene standard to limit emissions from industrial sources; however, an air quality standard for benzene will be enforced by 2016. AERMOD, an air dispersion model, was used to model the benzene concentration dispersion from industrial, on-road and area sources for comparison purposes and to relate industrial concentration with the standard. Because the standard does not account for the emission contribution from other non-industrial sources, modelling of most, if not all of the other sources was performed in this study.

The City of Hamilton was used as the case study and results were provided after modelling various sources of emission, which included a combination of road, area and industrial sources. The cumulative study has shown a higher concentration and a larger impact in the City of Hamilton compared to simply modelling individual sources. This suggests that even if the industry complies with the standard, the concentration at a point of interest will not be a well-rounded representation of the actual concentration in the air, especially when it was observed that vehicle emission is the highest emission contributor.

Emission contribution from other sources, such as gas stations and vehicle emission play an important role to determine the actual concentration at a specific location for compliance purposes. To improve local air quality, all sources shall be taken in account for modelling and standard compliance purposes. In addition, it is recommended that the Total Maximum Daily Load for the Water Quality-Based Approach utilized by the U.S Environmental Protection Agency be adapted, implementing similar approaches for the air quality standard to allow flexibility in emission trading between sources.

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## 1. Introduction

Pollutant contribution to air emission increased significantly in the 1960s to the 1990s due to the increase of motor vehicles that were present on the roads (Duarte-Davidson et al., 2001). Benzene, is a clear and colorless chemical compound with a sweet odor. The aromatic hydrocarbon has a liquid physical state and appearance, and it is both flammable and volatile (United States Environmental Protection Agency, 1998). Most exposures to benzene are produced by human activities, while it could also be formed through natural occurrences, such as crude oil, forest fires and volcanoes (American Cancer Society, 2010). Benzene could be found as the top 20 most commonly utilized chemicals in the United States, which is most often used as a feedstock to create other chemicals, and as a solvent to extract or dissolve other materials (American Cancer Society, 2010). Despite the chemical popularity, the usage of benzene as a solvent has decreased immensely in the past 30 years; thus, such practice is considered minimal or rare in present years. Furthermore, benzene has also been widely used in the past in industries and manufacturing processes, such as petroleum, gas and coke, chemical, printing, paint, shoe making, tire, adhesives, and cleaning products (Williams et al., 2007).

## 2. Impacts of Benzene Exposure

### 2.1 Health Effects

The most common route of exposure to benzene is through inhalation (Snyder et al., 1997). There are two forms of exposure to benzene, which includes short-term and long-term. Acute exposure through inhalation at low levels may cause illnesses, such as dizziness, drowsiness, headaches, and irritation in the skin, eyes and respiratory tracts; while at high levels, unconsciousness may occur. On the other hand, chronic exposure through inhalation may cause severe effects, including leukemia and aplastic anemia at an occupational setting (United States Environmental Protection Agency, 2012a).

Studies have been conducted to examine the adverse health effects due to the exposure of benzene that were associated with occupational exposures, which involved much higher level of benzene concentrations than the general environment. Numerous reviews have also been performed to evaluate the health effects related to point sources, such as industrial and chemical plants, while others have observed linkage between petrol combustion, vehicle ownership, vehicle exhaust from tailpipe emissions and leukaemia (Duarte-Davidson et al., 2001).

The first report of the effects of chronic exposure to benzene in the workplace dates back for over a century ago, where critical blood clotting defects were found in four women who worked for a tire industry. Needless to say, benzene was used as a solvent. This type of condition is referred today as aplastic anemia (Bird et al., 2010).

Exposure to benzene leads to bone marrow functionality damage. Although studies have shown that chronic exposure to benzene could lead to the deficiency of a single cell type, high level concentration of benzene exposure could lead to the lack of more than one type of circulating blood cells, which results in aplastic anemia (Snyder et al., 1997).

Ever since the realization of the impacts and danger that benzene exposure could cause to the human health, further studies have been conducted in order to learn more about this subject. It was not until later down the road that researchers have discovered leukemia could also be a result of benzene exposure (Bird et al., 2010).

By the 1970s to 1980s people across the world have finally realized the severe impacts and effects that this harmful compound could pose on the human health through both environmental and occupational exposures. Because it has become evident that benzene is a world-wide health issue, a forum was created in order for regulatory officials, scientists, and clinicians to discuss new research objectives and strategies targeted at understanding all the characteristics of benzene, and its impact on the health of the general population (Bird et al., 2010).

## **2.2 Cancer Risk**

According to the United States Environmental Protection Agency (USEPA), benzene, coupled with formaldehyde are the main pollutants contributions to the general cancer risk (United States Environmental Protection Agency, 2011).

A report published by the U.S EPA in 2006, which was based on 1999 emission levels stated that 30% of the overall cancer risk contributed through air pollution was caused by vehicle emission, mainly due to benzene pollutants, while emissions from local industries accounted for roughly 25% (Snowden, 2009).

A further study performed by the U.S EPA estimated that cancer development for a person is one-in-a-million increased chance if the individual is constantly exposed to air with benzene at a concentration that ranges from 0.13 to 0.45  $\mu\text{g}/\text{m}^3$ , as illustrated in Table 1.

Likewise, cancer development for people exposed to benzene concentration in the air that ranges from 1.3 to 4.5  $\mu\text{g}/\text{m}^3$  and from 13 to 45  $\mu\text{g}/\text{m}^3$ , would result in one-in-a-hundred thousand and one-in-ten thousand increased chance, respectively (United States Environmental Protection Agency, 2012a).

**Table 1.** Individual's Chance of Developing Cancer due to Chronic Exposure of Benzene (USEPA, 2012a)

Cancer Risk Exposure Over Lifetime	
Benzene Concentration ( $\mu\text{g}/\text{m}^3$ )	Chance of Developing Cancer
0.13 - 0.45	1/1000000
1.3 - 4.5	1/100000
13 - 45	1/10000

### 3. Major Sources of Benzene Emission

Almost 100 years ago, an inventor and scientist at General Motors (GM) discovered that lead can be a high octane antiknock additive in the gasoline. As a result, this led to an increase in the market for automobiles. After realizing that lead is a highly toxic chemical, it had to be phased out from the gasoline as an additive (Ethanol Across America, 2010). From there on, benzene played a major role in gasoline due to its low threshold limit value, volatility, and the desired performance it provided even though benzene is known to be carcinogenic (Runion, 2010).

One of the major sources of benzene contribution into the ambient air is caused by vehicle exhaust and vapour emission from gasoline (Johnson et al., 2007). High levels of benzene concentrations could be found around homes that are situated close to gas stations (World Health Organization, 2010). Incomplete combustion and vaporization of gasoline accounts for approximately 60% of the benzene emission in the air, which also differs depending



on the amount of benzene content in the gasoline. Therefore, road traffic and refuelling at service stations are essential sources of benzene exposure (Johnson et al., 2007).

Although industrial sources promote significant occupational exposure and emission to the environment, emissions from automobile tailpipe exhaust account for the largest source of benzene in the environment (World Health Organization, 2010).

## **4. Federal and Provincial Standards**

Benzene has been a problem in the past as an occupational health hazard and in the overall environment. Thus, continuous efforts to reduce the usage of benzene and consistent actions have been taken to decrease the benzene exposure limit at the workplace and the general environment. This assured that no issues should be posed to the public health, unless it is due to industrial accidents. Despite the progress to lower benzene emission in the air, present concerns have been focused on the consequences of continuously exposing to low level concentrations of benzene in the long run, both environmentally and occupationally (Duarte-Davidson et al., 2001).

The World Health Organization (WHO) has not established any specific guidelines for benzene concentration in the air. However, it is concluded that benzene causes cancer in humans, and no safe level of exposure can be proposed (World Health Organization, 2010).

### **4.1 Canada-Wide Standard**

Realizing the impacts and harm that benzene could cause to human beings in the long term, the government of Canada have been taking initiatives to mitigate and reduce the amount of benzene emissions in the air through planning and policy implementations. The Canadian

Council of Ministers of the Environment (CCME) had put forward a Canada-Wide Standard (CWS) which consisted of two phases. Phase 1 was aimed at achieving a 30% national reduction of total benzene emission from 1995 to 2000 (Canadian Council of Ministers of the Environment, 2000a). The initial set of actions was targeted towards major sources, such as oil and gas, transportation, petroleum, chemical manufacturing and steel manufacturing (Canadian Council of Ministers of the Environment, 2000b). Phase 2 of the CWS, which was executed from 2001 to 2010, required an additional 6-kilotonne (12%) reduction of benzene emissions from the initial set of actions in Phase 1. In addition, it also required the reduction of benzene emission utilizing best management practices, pollution prevention strategies, control techniques, and jurisdictional regulations for new and expanding facilities (Canadian Council of Ministers of the Environment, 2001). By the end of the year of 2010, a total of 42% in the reduction of benzene emission would be achieved relative to the base year of 1995.

All of the Canadian jurisdictions participated in the CWS except for Quebec. However, the emission limits from Quebec were similar to those in the CWS and had been striving to meet environmental standards to protect the health of the general population and the environment (Canadian Council of Ministers of the Environment, 2012).

Through the cooperation and efforts from the various Canadian jurisdictions, both phase 1 and 2 objectives from the CWS were achieved by the end of 2003. Not only the target of 42% was achieved, but an additional 21.3% of benzene had been reduced, totalling 63.3% in benzene reduction (from 50.86 kt to 18.65 kt) from 1995 to 2003 (Canadian Council of Ministers of the Environment, 2012). As shown in Table 2, after the year of 2003, the national total for benzene emissions continued to decrease, which declined to 14.56 kt in 2008, resulting in a cumulative of 71.4% in benzene reduction from the base year of 1995.

**Table 2.** Canadian National Benzene Emission from 1995 to 2008 (CCME, 2012)

	1995	1999	2003	2008	% Reductions between:	
	(kt)				1995 & 2003	1995 & 2008
<b>Transportation - On Road Vehicles</b>	30	15.6	10.38	6.66	65.4	77.8
<b>Natural Gas Dehydrators - Upstream Oil and Gas</b>	8.74	4.01	1.99	1.8	77.2	79.4
<b>Steel Manufacturing - Steel Mills</b>	1.2	0.72	0.37	0.14	69.2	88.3
<b>Petroleum Distribution</b>	0.5	0.5	0.4	0.4	20	20
<b>Petroleum Refining (including oil sands)</b>	0.44	0.26	0.25	0.25	43.2	43.2
<b>Chemical Manufacturing Plants</b>	0.44	0.18	0.08	0.1	81.8	77.3
<b>Residential Wood Combustion</b>	4.34	4.56	4.5	4.43	-3.7	-2.1
<b>Miscellaneous Combustion</b>	4.7	4.8	0.48	0.48	89.8	89.8
<b>Prescribed Burning</b>	0.5	0.4	0.1	0.2	80	60
<b>Other Sources Reporting to NPRI</b>	-	0.25	0.1	0.1	-	60
<b>National Total</b>	<b>50.86</b>	<b>31.28</b>	<b>18.65</b>	<b>14.56</b>	<b>63.3</b>	<b>71.4</b>

Among all the sources, the largest reduction of benzene emission occurred in the transportation sector, specifically on-road vehicles, which decreased from 30 kt in 1995 to 6.66 kt in 2008, a reduction of 23.34 kt. This large reduction was made possible due to the federal implementation of the ‘Benzene in Gasoline Regulations’ in 1999. The regulation enforced by the federal government required that benzene in gasoline be reduced to 1% by volume in order to promote cleaner vehicles and fuels (Department of Justice Canada, 2013). Even though large reduction of the pollutant could be achieved in the transportation sector, on-road vehicles remain one of the major sources of benzene emission in Canada, which is followed by the combustion of residential wood category, as observed in the table above.

On the basis of percentages, excluding miscellaneous combustion, the sector with the largest decline of benzene emission took place in the steel manufacturing, specifically steel mill with an 88.3% in reduction. Miscellaneous combustion is excluded due to uncertainties that might be involved in the assumptions of the total benzene emissions emitted through the various

sources, such as landfill, wood products, pulp and paper and other general types of combustions (Canadian Council of Ministers of the Environment, 2012).

## **4.2 Ontario Benzene Standard**

Ontario have been monitoring and controlling air toxic pollutants for over the last 30 years by regulating emissions from various industrial sources. Ontario Regulation 419/05 (Regulation 419) was first established in November 30, 2005 by the Ontario Ministry of the Environment (MOE). The regulation acted as a key tool to protect the local air quality through various standards, which introduced requirements for compliance assessments and the usage of air dispersion models (Ontario Ministry of the Environment, 2011a).

New or updated standards have been phased-in overtime with more stringent air standards and the requirement for more advanced air dispersion models to better observe and assess the impacts of the air emissions on the communities. Ontario currently has two other standards where industries could apply for (under certain criteria) if the air standard cannot be met by the phase-in periods. The Site-Specific Standard and the Technical Standard are essentially alternatives to comply with the Ontario regulation to make continuous improvements by reducing industrial emissions as much as possible (Ontario Ministry of the Environment, 2011a).

There is currently no existing air standard or guideline for the emission of benzene. However, a proposal was reviewed in 2009 and a decision to have an air standard for benzene emission was made in 2011. Since the standard is new, a general five year period is required for the phase-in of a standard (Ontario Ministry of the Environment, 2011b). Therefore, the regulation will not be enforced until the year of 2016, where industries will be encountered with

an annual average standard of  $0.45 \mu\text{g}/\text{m}^3$  for benzene (Ontario Ministry of the Environment, 2012).

Despite the fact that there is no air standard to limit the emission of benzene, emitters are required to, at a minimum, limit their emission in order not to exceed the Upper Risk Thresholds (URT) limit for benzene (Ontario Ministry of the Environment, 2012). The URT is not a standard, but simply a concentration value where industries must take immediate actions if exceedences occur. The URT is used to manage risks and to evaluate requests for alternative standards (Ontario Ministry of the Environment, 2009). Currently, the 24 hour URT for benzene is  $100 \mu\text{g}/\text{m}^3$  under Schedule 6 of the Ontario regulation 419 (Ontario Ministry of the Environment, 2012). If an industry's emission exceeds the URT set by the MOE, the industry is required to notify the Ministry immediately about the exceedences and submit an Emission Summary and Dispersion Modelling (ESDM) report for review (Ontario Ministry of the Environment, 2009). Industries are encouraged to start working towards the 2016 benzene standard in order to be in compliance by the time the standard phases-in (Ontario Ministry of the Environment, 2012).

## **5. Jurisdictional Review of Benzene Standards and Guidelines**

The Ontario Air Quality standard for benzene that will be enforced in 2016 has an annual averaging period of  $0.45 \mu\text{g}/\text{m}^3$ , as demonstrated in Table 3. This limit is relatively low compared to most of the jurisdictions chosen for this study, including the European Union, India, Ireland and South Korea, which consist of a benzene concentration limit of  $5 \mu\text{g}/\text{m}^3$  that are already enforced. This means, that Ontario standard will be approximately 10 times as low, suggesting that the soon-to-be standard will be at a more than reasonable level. Waikato in New

Zealand has a benzene limit of  $3.6 \mu\text{g}/\text{m}^3$  which is a guideline instead of an enforceable standard. Japan has a surprisingly low limit of  $0.003 \mu\text{g}/\text{m}^3$ ; that is, a limit 150 times lower than the Ontario soon-to-be enforceable benzene limit of  $0.45 \mu\text{g}/\text{m}^3$ . Although standards may vary based on sciences, geographical area, industrial sector and other parameters from individual jurisdictions, Ontario should adapt to the lowest possible limit from other jurisdictions having similar aspects in order to protect the public health. After all, the World Health Organization has stated that no exposure level to benzene is safe for the public health (World Health Organization, 2010).

**Table 3.** Jurisdictional Review of Benzene Limit at an Annual Averaging Period

Jurisdiction	Regulator	Standard	Year Enforced	Annual Averaging Concentration ( $\mu\text{g}/\text{m}^3$ )	Reference / Source
Canada - Ontario	Government of Ontario - Ministry of the Environment	Air Quality Standard	2016	0.45	Ontario Ministry of the Environment, 2012
European Union	European Commission - Environment	Air Quality Standard	2010	5	European Commission, 2013
India	Government of India - Ministry of the Environment and Forests	National Ambient Air Quality Standard	2009	5	Government of India, 2009
Ireland - EPA	Environmental Protection Agency	Air Quality Standard	2010	5	Ireland Environmental Protection Agency, 2013
Japan	Government of Japan - Ministry of the Environment	Environmental Quality Standard	1997	0.003	Government of Japan
New Zealand	Waikato Regional Council	National and Regional Air Quality Standard	2010	3.6	Waikato Regional Council, 2010

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Zealand - Waikato	Council - Environment	Regional Ambient Air Guidelines			Regional Council
South Korea	Government of Korea - Ministry of Environment	National Ambient Air Quality Standard	2010	5	Republic of Korea Ministry of the Environment, 2011
United States - EPA	U.S Environmental Protection Agency	Reference Concentration	2003	0.03	United States Environmental Protection Agency, 2012a
World Health Organization	-	-	-	No safe level	World Health Organization, 2010

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## 6. Water Quality-Based Approach

The United States Clean Water Act provides two methods to protect and restore the waterbodies of the nation. The first approach is the EPA's technology-based approach, which offers guidelines that are based on available technologies to eliminate waste stream pollutants. Through these guidance principals, individual technology-based permit limit could be developed (United States Environmental Protection Agency, 2012c). The second approach is the water quality-based approach, and is structured to emphasize the water quality of a waterbodies, and to provide a process to control pollutants of the waterbodies that are not meeting water quality standard. This approach generally begins when the waters are not in compliance or not expected to comply with the water quality standard even after technology-based controls have been put in place (United States Environmental Protection Agency, 2012b).

The Total Maximum Daily Load (TMDL) is a component within the water quality-based approach, and is the maximum allowable amount of certain pollutants that a body of water can attain while still meeting water quality standards. Bodies of water that are not in compliance with

the water quality standard are known as ‘impaired’ for the pollutants of concern. Therefore, under the Clean Water Act, TMDL must be adapted and implemented in order to reduce the pollutant and to restore water quality (Florida Department of Environmental Protection, 2013).

The TMDL is characterized into two types of allocations, the wasteload allocation (WLA) and the load allocation (LA), which is associated with point sources and non-point sources, respectively. Point sources are facilities and operations that are subject to the National Pollutant Discharge Elimination System (NPDES) program, which includes stormwater discharges, industrial and municipal wastewater treatment facilities, and concentrated animal feeding operations. On the other hand, non-point sources include natural background sources and all the remaining sources that discharge the pollutant of concern (United States Environmental Protection Agency, 2013). Apart from all the sources, the TMDL also takes into consideration seasonal variations (SV) and a margin of safety (MOS) to account for future growth and scientific uncertainties (Illinois Environmental Protection Agency).

The following is the formula to calculate the TMDL:

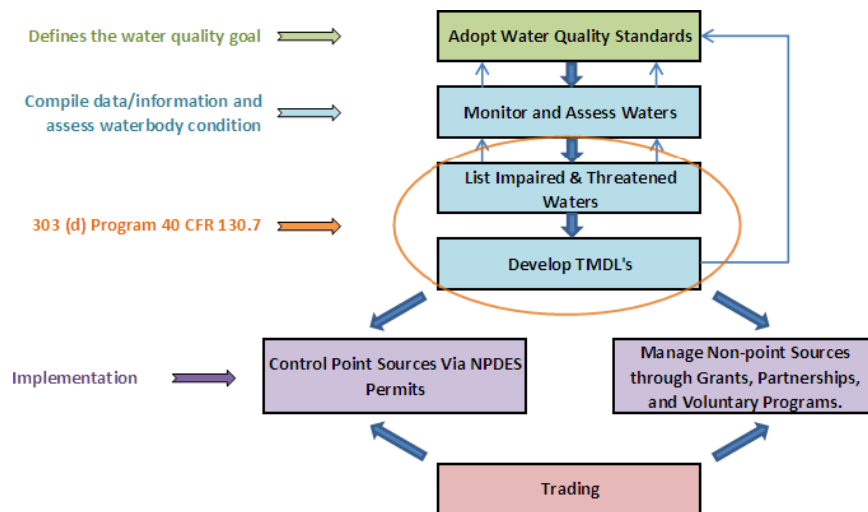
$$\text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS} + \text{SV}$$

The ultimate objective of calculating the TMDL is to determine the maximum loading capacity for a waterbody. Portions of this load are then assigned to the various identified sources, which often involves a cutback in their pollution discharge in order to resolve the issue. By doing so, appropriate measures could be taken and water quality standard could be achieved (United States Environmental Protection Agency, 2013).

The entire process of the water quality-based approach is outlined in Figure 1 as shown below. Once the TMDL’s have been derived, trading could potentially occur depending on whether or not the individual industries meet standards. Controlling a given pollutant at the



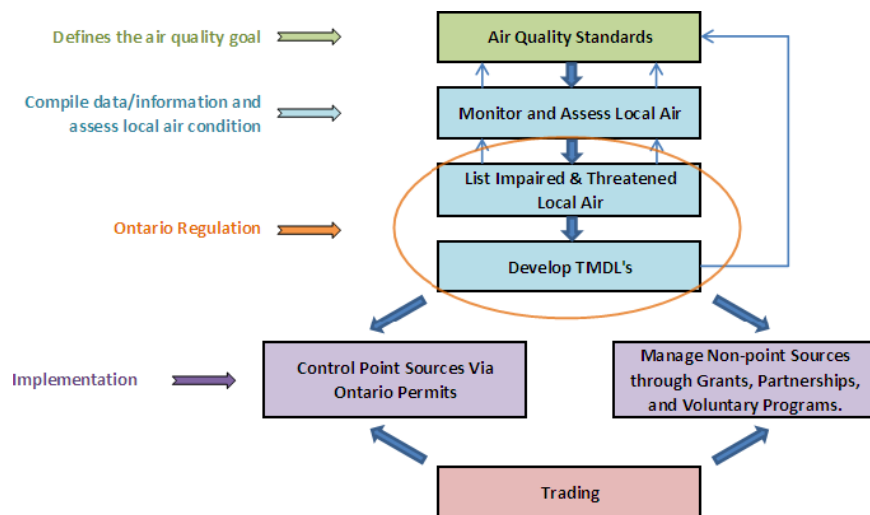
discharge in comparison with the runoff in a watershed could vary significantly in terms of cost. Therefore, the Water Quality Trading program, which is a market-based approach, could achieve efficiency and lower controlling cost in the watershed to meet regulatory obligations (United States Environmental Protection Agency, 2007). A facility that encounters a higher control cost to meet standard could utilize the trading program to purchase environmentally equivalent or greater pollution cutback from other sources at a lower cost. Therefore, lower overall cost could be achieved while attaining the same water quality (United States Environmental Protection Agency, 2012d).



**Figure 1.** U.S EPA Water Quality-Based Approach (USEPA, 2012c)

The U.S Water Quality-Based Approach could potentially be adapted by the Air Quality Standard, which could serve as an alternative method to reduce the pollutant of concern and to improve and restore the air quality of the communities and airsheds, as illustrated in Figure 2. In general, the approach and process to develop the TMDLs for the Air Quality-Based Approach would be the same as the Water Quality-Based Approach. The Ontario Air Pollution – Local Air

Quality (O. Reg. 419/05) would first be adapted and implemented in participating airsheds or communities. The various local air qualities would be monitored and assessed subject to the air standard to determine whether or not present or potential pollutant of concerns would be encountered. TMDLs would be calculated and developed for the pollutants of concern for each of the individual impaired airsheds, where the loading would then be assigned among all the sources that emits or discharges the pollutant. Ideally, the process would stop at this stage (excluding the trading program) if the pollutant of concern is toxic and complex to deal with. The Trading program would only work if the pollutants are non-toxic, since toxic pollutants would promote higher risk to the communities that buys the environmental credits through industries. Otherwise, the entire process would be accounted for; up until the Air Quality Trading Program if the airsheds are dealing with non-toxic pollutants.



**Figure 2.** Adapting U.S Water Quality-Based Approach for Ontario’s Air Quality Standard

## 7. Cumulative Impact of Benzene Emission

Air emissions can travel thousands of miles from one urban neighbourhood to the other. It can also travel across the borders and the oceans, which are most commonly referred to as “long range atmospheric transport” (Environment Hamilton).

Current Ontario standards and guidelines that are utilized to assess and evaluate the contribution of a pollutant to the air quality are focused on emissions from a single commercial or industrial facility. The Ontario Air Pollution – Local Air Quality (O. Reg. 419/05) under the Environmental Protection Act, require ESDM reports from industries that emit a pollutant with a concentration level that is not in compliance with the air quality standard. An estimated maximum point of impingement (POI) concentration of a pollutant that is located within an area of a facility is presented within the ESDM report, and is often developed in order to obtain an Environmental Compliance Approval (ECA) or subjected to other requirements from the Local Air Quality Regulation (Ontario Ministry of the Environment, 2012).

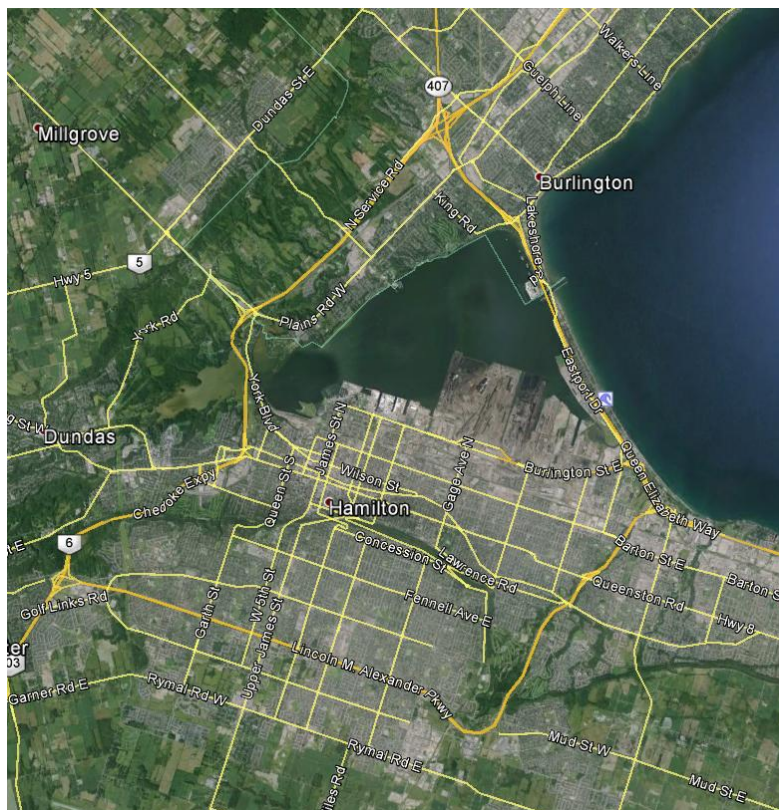
In summary, the Ontario air quality standard evaluates the emission contribution from a single industrial source without accounting for other neighbouring facilities or other non-industrial sources for standard compliances. For this reason, a cumulative impact of benzene emission would be performed within this section for the purpose of comparison, between evaluating emissions from a single source type to emissions from most, if not all of the sources that discharges the pollutant of concern.

### 7.1 General Information for Modelling

Benzene is known to be problematic in Hamilton due to its cancer-causing effects. The pollutant is also often emitted into the air at higher levels than many of the neighbouring cities.

In 2008, ArcelorMittal Dofasco accounted for nearly 50% of the total benzene emission within the city (Environment Hamilton).

The City of Hamilton in Ontario is chosen as a case study for this research not only because Hamilton consists of industrial facilities that emit the contaminant of concern, benzene, but is also uniquely enclosed by provincial and municipal highways, and surrounded by the Niagara Escarpment, as shown in Figure 3. For the purpose of this study, various sources have been taken into account for modelling, which includes industrial, on-road (vehicles) and area (gas stations and dry cleaning facilities) sources. This will essentially cover several of the major emission contributors of benzene that is presented in the City of Hamilton.



**Figure 3.** Map of the City of Hamilton (Google Earth)

## 7.2 Data Collection

The data collected for modelling was gathered from various instruments that were publicly available. Industrial data was gathered from the National Pollutant Release Inventory (NPRI) website, where four industries were found to have emitted benzene into the air in 2012, as displayed in Appendix – A1.

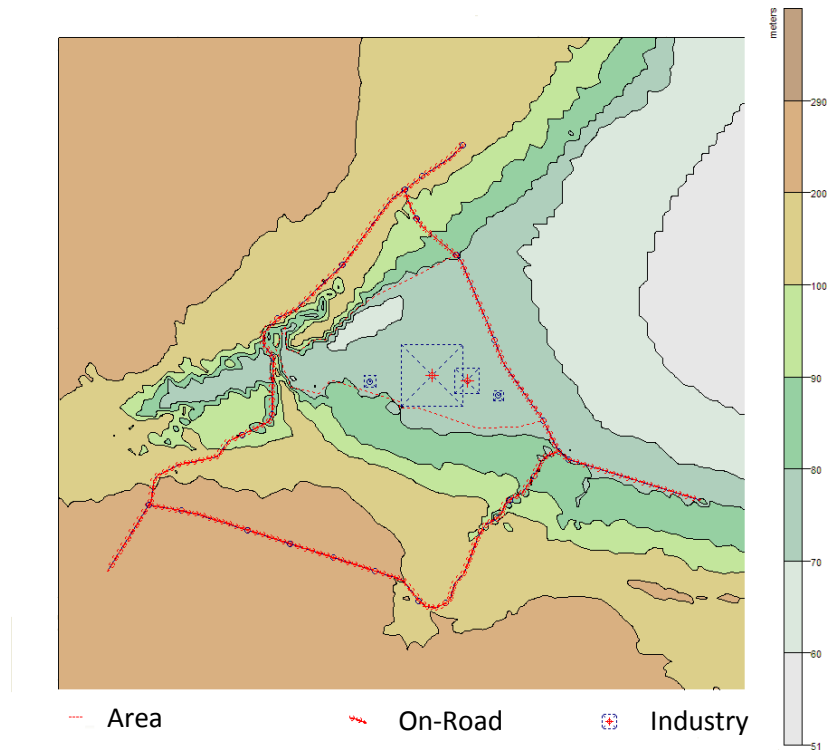
The traffic data was collected from several sources and documents, which included the Ontario Ministry of Transportation (MOT) website that contained information for highways Queen Elizabeth Way (QEW) and 403; the City of Hamilton Public Works Department which provided information for the Lincoln M. Alexander Parkway and the Red Hill Valley Parkway; and the emission factor/rate for vehicle tail pipe emission was extracted from the U.S EPA publication, named “Locating and Estimating Air Emissions from Sources of Benzene” (United States Environmental Protection Agency, 1998). Traffic data are tabulated in Appendix – A2.

As for the area source data, which included information for gas stations and dry cleaning facilities were obtained from the Regional Air Pollutant Inventory Development System (RAPIDS) database. The overall data that were collected externally for this study were generally available to the public, and assumptions and estimations were made for data that were not presently available to the public, in order to properly model the community effects and impacts from the various types of emission sources.

## 7.3 Air Dispersion Model

The air dispersion model utilized for this study is AERMOD View (Version 12345), which is an approved dispersion model by the Ministry of the Environment for the releases of a pollutant of concern (Ontario Ministry of the Environment, 2013).

The interface of AERMOD View is as displayed in Figure 4, where the input file has been created for industrial, on-road and area sources. The numerous contour colours represent the various land elevation from the Hamilton Terrain, which plays an important role in determining the dispersion impact, especially when the City of Hamilton is surrounded by the Niagara Escarpment.

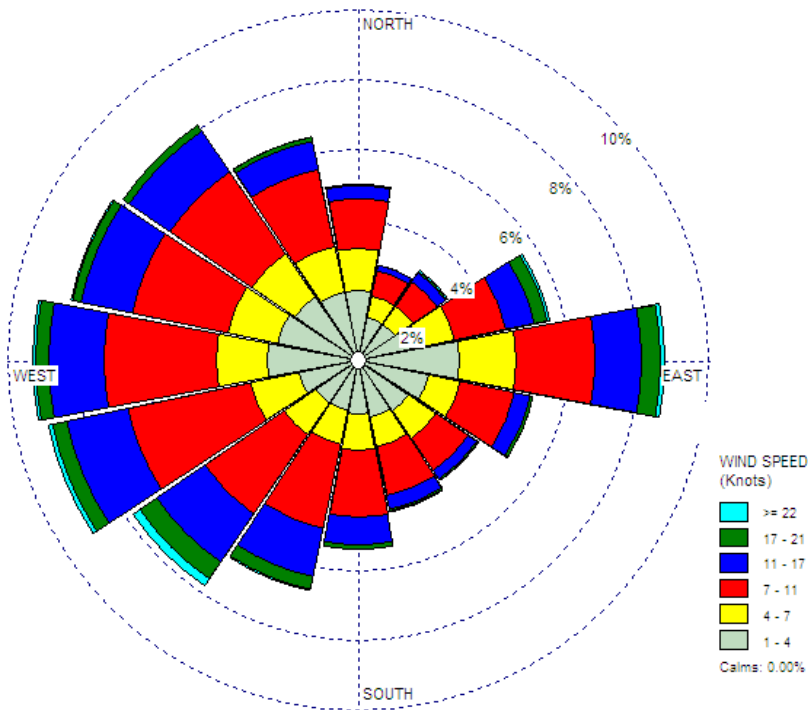


**Figure 4.** Set-up of Sources and Hamilton Terrain in AERMOD View

## 7.4 Wind Rose

The Wind Rose, as shown in Figure 5, could be extracted from AERMOD View once the meteorological input data (AERMET) have been attached to the model. For the purpose of this study, the wind rose is shown in order to compare and interpret the effects of air dispersion from the various sources that emits the contaminant. The wind rose is a crucial component in determining the direction in which the wind is travelling. In this case, the wind is travelling from

the outermost orbit to the center of origin where all the “slices” meet. Clearly, the wind blowing from the west-end dominates the wind blowing from the east-end, and this effect could be seen further in this discussion.

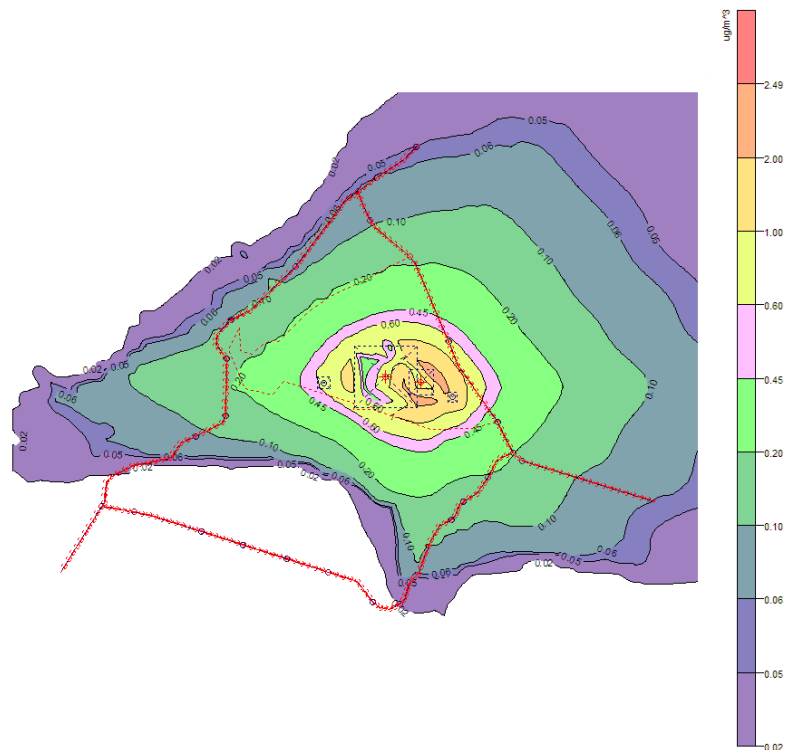


**Figure 5.** Wind Rose: Speed and Direction of the Wind

## 7.5 Final Cumulative Impact Results

Instead of simply jumping into the cumulative impact of benzene emission from all the sources identified in this study, emission dispersion for individual sources has been modelled for comparison purposes. For industrial permitting, emission dispersion from a single industrial source should be looked at for compliances purposes; however, for the intention of this study, industries that emit benzene have been grouped and modelled together in order to compare the impact and magnitude of the benzene concentrations with the other source types.

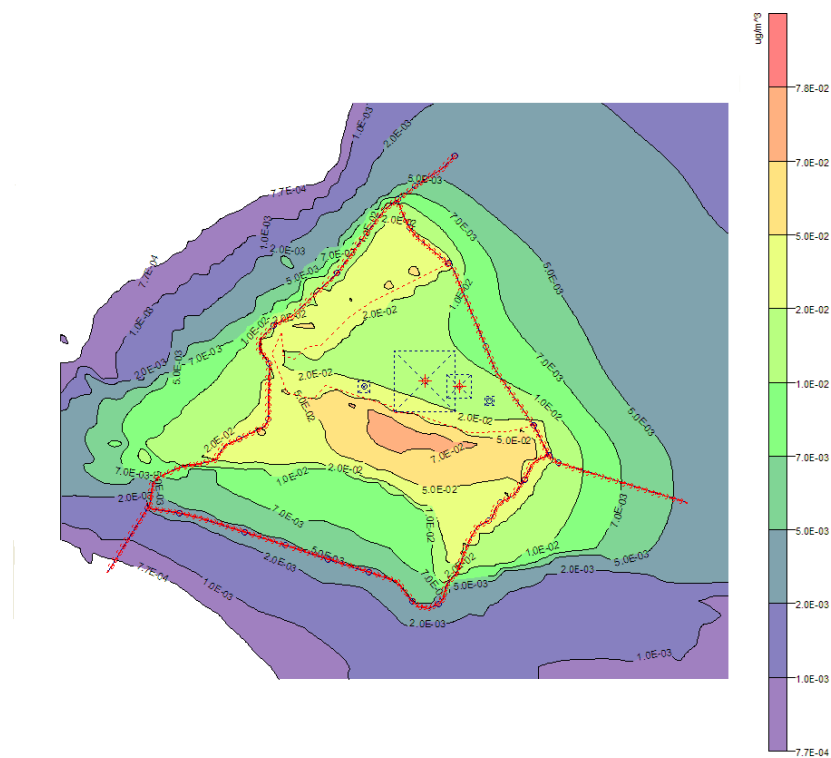
The impact of benzene emission from industrial sources is demonstrated in Figure 6. These emissions are produced by industries including ArcelorMittal Dofasco Inc., U.S Steel Canada Inc., Ruetgers Canada Inc., and Vopak Terminals of Canada Inc., with ArcelorMittal Dofasco Inc. and U.S Steel Canada Inc. being the major emitters of benzene. The wind rose effect discussed previously is observed in this air dispersion figure, where emissions can clearly be seen dispersed outward towards the east-end. An interesting point to note in this figure is that the west-end emission has the shape of the Niagara Escarpment, which means that industrial emissions are enclosed and captured by the escarpments, preventing emissions from travelling further outwards to the west-end of Hamilton. Therefore, the only path for air emission to travel to is towards the harbour and Lake Ontario.



**Figure 6.** Impact of Benzene Emission from Industrial Sources



The colour contours represent the benzene concentration level in  $\mu\text{g}/\text{m}^3$ , where the areas highlighted in pink colour is considered as not in compliance in an industrial permitting perspective, since Ontario standard for benzene is  $0.45 \mu\text{g}/\text{m}^3$  at an annual averaging period. Any colour above the pink region on the colour legend is also considered not in compliance with standard. From the figure, we could also clearly observe that industrial emission would overlap with other sources of emission, such as on-road if the cumulative impact has been modelled.

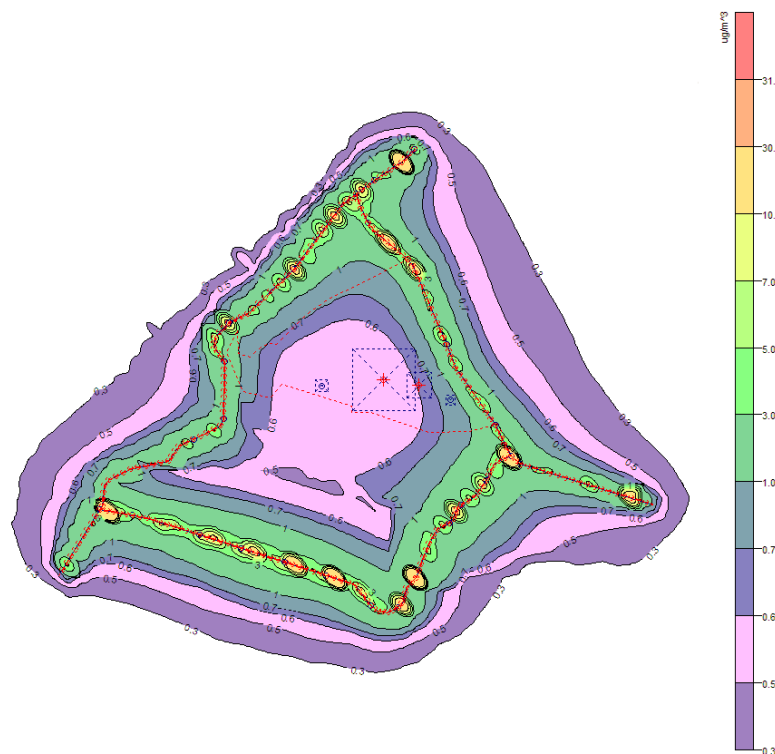


**Figure 7.** Impact of Benzene Emission from Area Sources

Area sources, which includes gas stations and dry cleaning facilities has a similar effect as the industrial impact, where the air emissions travel towards the east-end more than the west end due to the wind direction and the high elevations of the Niagara Escarpment, which prevents emissions from travelling further out to the west-end of Hamilton, as illustrated in Figure 7. A

wider coverage of emission could be observed with area sources, since gas stations and dry cleaning facilities are more spread out in Hamilton compared to the industries, which are centered on the industrial sector at the harbour. In addition, the emission concentration level is not as high as that of the industrial sources, but is crucial when performing a cumulative impact, since emissions from different sources add-up to a higher concentration.

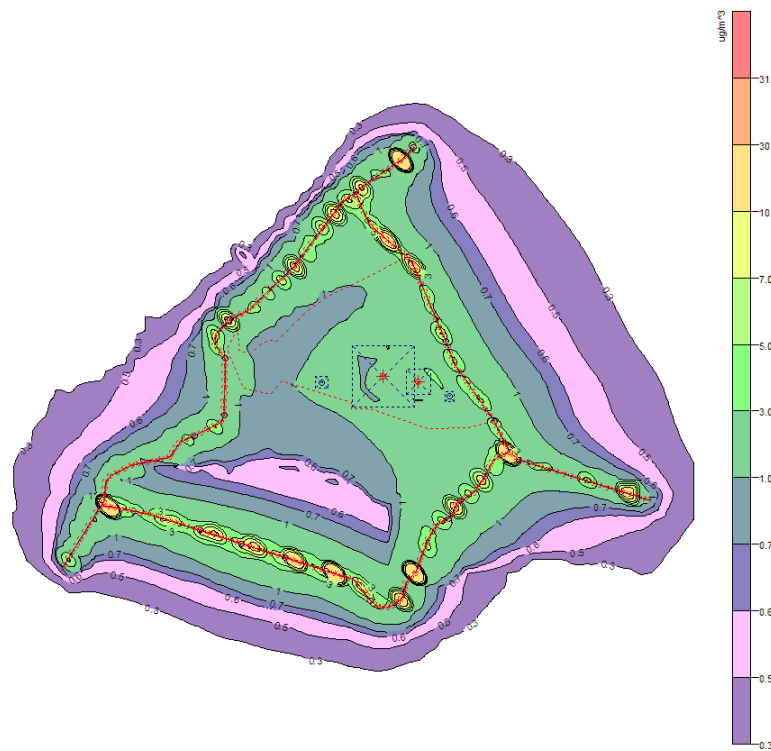
On-road sources, such as vehicles are the highest emitter of benzene emission, which could reach emission at a concentration of over  $31.4 \mu\text{g}/\text{m}^3$ , as demonstrated in the legend in Figure 8.



**Figure 8.** Impact of Benzene Emission from On-Road Sources

The maximum concentration is located along the highway as that is where the vehicles travel. However, an interesting point to note by observing at the figure is that the concentration

drops significantly as the distance increases away from the highways. Approximately 1 to 1.5 kilometers away from the highway, the concentration drops from over  $31.4 \mu\text{g}/\text{m}^3$  to roughly  $1 \mu\text{g}/\text{m}^3$ , that is, a difference of around  $30 \mu\text{g}/\text{m}^3$ . Although vehicles are considered the greatest emitters among the industrial and area sources, vehicle has an immense impact on people only if individuals live or reside close to the highways, and as people live further away from the highway the concentration decreases, having a lesser chance of developing cancer.



**Figure 9.** Cumulative Impact of Benzene Emission from all of the Accounted Sources

Finally, the cumulative impact of benzene emission is the benzene contribution from all the sources, as illustrated in Figure 9. The figure is similar to the On-Road sources impact from benzene emission, where the maximum concentration is still along the highway, but the area within and enclosed by the highways has altered due to the summation of the impact from all the

sources. It is interesting to observe that there are still small tiny regions within the city, around the downtown Hamilton area with concentrations lower than  $0.45 \mu\text{g}/\text{m}^3$ , even after taking into account emissions for all sources. However, these could be potential areas where emissions were not being reached by those emitted by industrial sources. As a result, the addition could have only accounted for area and on-road sources for locations that are away from the industrial sector.

Furthermore, the south-west location, roughly 0.5 kilometers away from the industrial facilities consisted of a concentration of around  $0.45 \mu\text{g}/\text{m}^3$  when modelling only the industrial sources (Figure 6). When examining the same area and accounting for all the source types, the concentration level increased to approximately  $1 \mu\text{g}/\text{m}^3$ , which is more than doubling the concentration compared to simply modeling industrial sources. This suggest that cumulative impact plays a crucial role when determining the actual concentration that the public is exposing to, and should also be adapted and implemented by the Ontario Air Quality Standard for permitting purposes to cut-back on the discharge of the pollutant of concern.

## **7.6 Other Parameters to be Considered for Future Modelling**

Due to data limitations, unavailability and sensitivity, other parameters could be taken into account for future modelling in order to demonstrate a better representation of the actual concentration in the community. Because AERMOD View does not perform well with the surrounding water bodies, other air dispersion programs, such as CALPUFF could be utilized in order to account for emissions from water vessels and cargo ships at the Hamilton ports. Since vehicles are considered high emitters of benzene emission, small roads within the City of Hamilton should also be modelled along with the major highways.

## 8. Conclusion and Recommendations

Benzene has long been known as a carcinogenic chemical substance and according to the World Health Organization no level of benzene exposure is safe for the human health. Individual jurisdictions have established its own air quality standard or guideline for benzene. Ontario air quality standard for benzene is  $0.45 \mu\text{g}/\text{m}^3$ , while there are jurisdictions with both higher and lower concentrations than Ontario. Nevertheless, Ontario air quality standard is more stringent than many of the jurisdictions identified in this research study.

Because benzene is toxic and a complex chemical to deal with, the government of Ontario should adapt and implement the Air Quality-Based Approach in the Air Quality Standard in order to cap industrial emission and emission from other sources. The current air quality standard allows industries to go over the benzene limit, but also provide industries with alternative solutions with the intention to assist industries to lower their emission. On the contrary, the TMDL within the Air Quality-Based Approach would attempt to develop a maximum allowable amount of benzene that an airshed or an even smaller domain could attain while still meeting air quality standard.

The only potential method the trading program would take place when dealing with a complex or toxic chemical is that industries be located at a relatively close distance or adjacent to one another. For instance, ArcelorMittal Dofasco Inc. and U.S Steel Canada Inc., which are the major emitters of benzene in the City of Hamilton, along with other smaller emitters, including Ruetgers Canada Inc. and Vopak Terminals of Canada Inc. All these four industries are located relatively close to each other at the industrial sector in the Hamilton harbour. This way, the impact of the industries' emission would be within the same region or domain should an industry decides to buy credits from the others. This method would reduce the pollutant of concern by

cutting back on the emissions discharged by the industrial sources, and air quality could potentially be achieved.

In addition to the air quality-based approach, cumulative impact of benzene emission should be considered for permitting in order to protect the health of the public. Since emissions from certain sources could travel long distances, emissions from two or more sources could potentially overlap at a point of interest or receptor, which would increase the chance of individuals developing cancer or other severe effects. Therefore, only by modelling all sources and with industrial permit accounting for all the emitters, the true concentration would be found for a specific receptor or place of interest, which could be used for environmental assessment purposes or public awareness in regards to the environmental or air quality.

In an ideal world, industrial data should be transparent and available to the government, if not the public, upon request in order for true concentrations to be modelled. Industries have the option on whether or not to provide industrial specific data to the government. Often when an industry does, an agreement between the government and the industry is established in order to maintain the data confidential and not sharable with third parties. The reason why businesses are reluctant on providing operational data to the public is to protect the company from going out of business due to complaints of potential high emissions, which would promote a higher chance of developing harmful effects to the human health. Providing operational data to the government however, not only will the data transparency protect the public health, but will also allow the government to assist industries in improving industrial operations through utilization of up-to-date processes and best management practice to protect and restore environmental quality.

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## Appendices

### Appendix A1 – Industrial Data

**Table 4.** On-site Benzene Releases to Air in 2012 (NPRI)

2012 On-Site Benzene Releases to Air					
NPRI ID	Company Name	Stack or Point		Fugitive	
		Tonnes	g/s	Tonnes	g/s
3713	ArcelorMittal Dofasco Inc. / Dofasco Hamilton	16.3999	0.5200	22.4645	0.7123
2984	US Steel Canada Inc. / Hamilton Works	0.0032	0.0001	31.7785	1.0077
2070	Ruetgers Canada Inc.	2.8000	0.0888	1.3000	0.0412
5714	Vopak Terminals of Canada Inc. / Vopak Terminal - Hamilton	0.0000	0.0000	0.2000	0.0063

**Table 5.** ArcelorMittal Dofasco Inc. Process Information (NPRI)

REP_PERIOD	NPRI_ID	STAC_CODE	NAME	HEIGHT	DIAMETER	EXIT_VELO	EXIT_TEMP
2011	0000003713	16507	No. 1 Coke Plant: No. 3 Battery Flue Stack	76	5.4	0.5	225
2011	0000003713	16502	No. 2 Boilerhouse: No. 9 Boiler	51.6	3.1	20.9	157
2011	0000003713	16479	No. 2 Reheat Furnace Stack	84	3.5	0.7	800
2011	0000003713	16509	No. 4 Blast Furnace: Stoves Stack	65	1.8	4	343
2011	0000003713	16510	KOBM (Basic Oxygen Furnace):Ladle Additive Collection System	68.8	1.3	2.1	21
2011	0000003713	16486	No. 4 Blast Furnace: Lock Hopper Equalizing Vent	58	0.3	10	50
2011	0000003713	16505	No. 2 Coke Plant: No. 4 Battery Flue Stack	67.7	2.9	3.1	225
2011	0000003713	16501	No. 2 Acid Regeneration Plant and No.4 Pickle Line Scrubber	50.6	1	19.1	39
2011	0000003713	16503	No.1 Ladle Metallurgical Furnace Barometric Sump Exhaust	53.1	0.5	14.4	61
2011	0000003713	16504	No. 1 Coke Plant: No. 1 Battery Flue Stack	76	2.5	3.8	225
2011	0000003713	16508	No. 4 Blast Furnace: Blast Furnace Gas Bleeder	67.1	1.7	7.9	120
2011	0000003713	16506	No. 2 Blast Furnace: Backdraft Stack	61.5	0.8	11.4	100
2011	0000003713	16490	PCI Silo Depressurizing Filters	50.9	0.305	20.35	21
2011	0000003713	16477	No. 2 Blast Furnace: Blast Furnace Gas Flare Stack	54.8	0.9	9.1	727
2011	0000003713	16478	No. 1 Caster: Steam Exhaust - North Stack	56.5	1.4	29.1	59
2011	0000003713	16479	No. 2 Reheat Furnace Stack	84	3.5	0.7	800
2011	0000003713	16480	No. 2 Blast Furnace: Lock Hopper Equalizing Vent	58.2	0.3	1.4	21
2011	0000003713	16481	No. 3 Blast Furnace: Stoves Stack	61.2	3	3.1	343
2011	0000003713	16482	No. 1 Reheat Furnace Stack	84	3.5	0.7	800
2011	0000003713	16483	No. 4 Blast Furnace: Backdraft Stack	65.8	0.8	11.4	100
2011	0000003713	16484	PCI Dryer Stack	60.62	1.4	10.4	100
2011	0000003713	16485	No. 1 Continuous Caster: Tundish Dump and Lancing Baghouse	50.4	1.2	20.19	21
2011	0000003713	16488	DSG After Pot Galvanneal Soak Section and Strip Dryers	68	5.8	7.5	60
2011	0000003713	16489	KOBM (Basic Oxygen Furnace): Baumco Scrubber Stack	102	2.7	8.7	51

2011	0000003713	16500	No. 3 Coke Plant: No. 6 Battery Flue Stack	136.2	2.4	12	225
2011	0000003713	16491	No. 2 Blast Furnace: Stoves Stack	61.2	2.1	17.9	315
2011	0000003713	16492	No. 2 Coke Plant: No. 5 Battery Flue Stack	76	2.9	5	225
2011	0000003713	16493	DoSol Galva Preheat, Radiant Tube and Soak Section Exhaust	60	1.6	18.2	360
2011	0000003713	16494	No. 2 Blast Furnace Slag Pelletizer	50	3	9	66
2011	0000003713	16495	No. 4 Blast Furnace: Blast Furnace Flare Stack	65.1	2	8.4	727
2011	0000003713	16496	No. 2 Boilerhouse: No. 8 Boiler	53.6	3.1	35.7	239
2011	0000003713	16497	No. 2 Blast Furnace: Blast Furnace Gas Bleeder	70.7	1.6	6	120
2011	0000003713	16498	No. 1 Coke Plant: No. 2 Battery Flue Stack	76	2.3	3.8	225
2011	0000003713	16499	No. 1 Caster: Steam Exhaust - South Stack	52.7	1.4	29.1	59
2011	0000003713	16487	No. 1 LMF: Cooling Tower	53.3	5.8	8.7	37
2011	0000003713	16500	No. 3 Coke Plant: No. 6 Battery Flue Stack	136.2	2.4	12	225
2011	0000003713	16509	No. 4 Blast Furnace: Stoves Stack	65	1.8	4	343
2011	0000003713	16508	No. 4 Blast Furnace: Blast Furnace Gas Bleeder	67.1	1.7	7.9	120
2011	0000003713	16507	No. 1 Coke Plant: No. 3 Battery Flue Stack	76	5.4	0.5	225
2011	0000003713	16506	No. 2 Blast Furnace: Backdraft Stack	61.5	0.8	11.4	100
2011	0000003713	16505	No. 2 Coke Plant: No. 4 Battery Flue Stack	67.7	2.9	3.1	225
2011	0000003713	16477	No. 2 Blast Furnace: Blast Furnace Gas Flare Stack	54.8	0.9	9.1	727
2011	0000003713	16504	No. 1 Coke Plant: No. 1 Battery Flue Stack	76	2.5	3.8	225
2011	0000003713	16503	No.1 Ladle Metallurgical Furnace Barometric Sump Exhaust	53.1	0.5	14.4	61
2011	0000003713	16510	KOBM (Basic Oxygen Furnace):Ladle Additive Collection System	68.8	1.3	2.1	21
2011	0000003713	16501	No. 2 Acid Regeneration Plant and No.4 Pickle Line Scrubber	50.6	1	19.1	39
2011	0000003713	16497	No. 2 Blast Furnace: Blast Furnace Gas Bleeder	70.7	1.6	6	120
2011	0000003713	16499	No. 1 Caster: Steam Exhaust - South Stack	52.7	1.4	29.1	59
2011	0000003713	16498	No. 1 Coke Plant: No. 2 Battery Flue Stack	76	2.3	3.8	225
2011	0000003713	16496	No. 2 Boilerhouse: No. 8 Boiler	53.6	3.1	35.7	239
2011	0000003713	16495	No. 4 Blast Furnace: Blast Furnace Flare Stack	65.1	2	8.4	727
2011	0000003713	19942	No. 3 Blast Furnace: Blast Furnace Flare Stack	69.02	3.5204	104.83	1000
2011	0000003713	19941	No. 3 Blast Furnace: Lock Hopper Equalizing Vent	54.5	0.3993	10	100
2011	0000003713	19940	No. 3 Blast Furnace: Backdraft Stack	51.2	0.759	11.399	100
2011	0000003713	19939	No. 3 Blast Furnace: Blast Furnace Gas Bleeder	66.8	1.271	5.502	120
2011	0000003713	19938	No. 3 Blast Furnace: Slag Pelletizer	51	3	9	66
2011	0000003713	16502	No. 2 Boilerhouse: No. 9 Boiler	51.6	3.1	20.9	157
2011	0000003713	16478	No. 1 Caster: Steam Exhaust - North Stack	56.5	1.4	29.1	59
2011	0000003713	16490	PCI Silo Depressurizing Filters	50.9	0.305	20.35	21
2011	0000003713	16489	KOBM (Basic Oxygen Furnace): Baumco Scrubber Stack	102	2.7	8.7	51
2011	0000003713	16488	DSG After Pot Galvanneal Soak Section and Strip Dryers	68	5.8	7.5	60
2011	0000003713	19940	No. 3 Blast Furnace: Backdraft Stack	51.2	0.759	11.399	100
2011	0000003713	16487	No. 1 LMF: Cooling Tower	53.3	5.8	8.7	37
2011	0000003713	19942	No. 3 Blast Furnace: Blast Furnace Flare Stack	69.02	3.5204	104.83	1000
2011	0000003713	16486	No. 4 Blast Furnace: Lock Hopper Equalizing Vent	58	0.3	10	50
2011	0000003713	16483	No. 4 Blast Furnace: Backdraft Stack	65.8	0.8	11.4	100
2011	0000003713	16482	No. 1 Reheat Furnace Stack	84	3.5	0.7	800
2011	0000003713	16491	No. 2 Blast Furnace: Stoves Stack	61.2	2.1	17.9	315
2011	0000003713	16480	No. 2 Blast Furnace: Lock Hopper Equalizing Vent	58.2	0.3	1.4	21
2011	0000003713	16492	No. 2 Coke Plant: No. 5 Battery Flue Stack	76	2.9	5	225
2011	0000003713	19939	No. 3 Blast Furnace: Blast Furnace Gas	66.8	1.271	5.502	120

			Bleeder				
2011	0000003713	19941	No. 3 Blast Furnace: Lock Hopper Equalizing Vent	54.5	0.3993	10	100
2011	0000003713	16484	PCI Dryer Stack	60.62	1.4	10.4	100
2011	0000003713	16493	DoSol Galva Preheat, Radiant Tube and Soak Section Exhaust	60	1.6	18.2	360
2011	0000003713	16494	No. 2 Blast Furnace Slag Pelletizer	50	3	9	66
2011	0000003713	19938	No. 3 Blast Furnace: Slag Pelletizer	51	3	9	66
2011	0000003713	16481	No. 3 Blast Furnace: Stoves Stack	61.2	3	3.1	343
2011	0000003713	16485	No. 1 Continuous Caster: Tundish Dump and Lancing Baghouse	50.4	1.2	20.19	21
<b>Average</b>				<b>65.106</b>	<b>2.1347359</b>	<b>13.189</b>	<b>221.871795</b>

**Table 6.** U.S Steel Canada Inc. Process Information (NPRI)

REP_PERIOD	NPRI_ID	STAC_CODE	NAME	HEIGHT	DIAMETER	EXIT_VELO	EXIT_TEMP
2011	0000002984	20783	BOF ESPs	64	3.2	17	249
2011	0000002984	20784	Coke Oven Underfiring Stack	89	3.6	9.1	350
2011	0000002984	20784	Coke Oven Underfiring Stack	89	3.6	9.1	350
2011	0000002984	20783	BOF ESPs	64	3.2	17	249
<b>Average</b>				<b>76.5</b>	<b>3.4</b>	<b>13.05</b>	<b>299.5</b>

## Appendix A2 – Traffic Data

**Table 7.** Designated ID Codes for Highway Segments (MOT/ Hamilton Public Works)

<b>ROUTE - HWY 403</b>			<b>ID</b>
<b>Start Point</b>	<b>End Point</b>		
QEW IC-BURLINGTON	WATERDOWN RD IC-HALTON RD 26		403.00
WATERDOWN RD IC-HALTON RD 26	E JCT HWY 6 IC-BURLINGTON/DUNDAS LT		403.01
E JCT HWY 6 IC-BURLINGTON/DUNDAS LT	YORK BLVD IC-HAMILTON		403.02
YORK BLVD IC-HAMILTON	MAIN ST IC-HAMILTON		403.03
MAIN ST IC-HAMILTON	ABERDEEN AVE IC-HAMILTON		403.04
ABERDEEN AVE IC-HAMILTON	HAM/WENT RD 215-MOHAWK RD IC		403.05
HAM/WENT RD 215-MOHAWK RD IC	W JCT HWY 6/GARNER RD-IC		403.06
<b>ROUTE - QEW</b>			<b>ID</b>
<b>Start Point</b>	<b>End Point</b>		
APPLEBY LINE-IC	WALKERS LINE-IC		100.00
WALKERS LINE-IC	GUELPH LINE RD-IC-BURLINGTON		100.01
GUELPH LINE RD-IC-BURLINGTON	BRANT ST IC		100.02
BRANT ST IC	HWY 403/407-IC-BURLINGTON		100.03
HWY 403/407-IC-BURLINGTON	FAIRVIEW ST IC		100.04
FAIRVIEW ST IC	HWY 2(TO N SHORE BLVD)IC		100.05
HWY 2(TO N SHORE BLVD)IC	HWY 7189-EASTPORT RD IC		100.06
HWY 7189-EASTPORT RD IC	BURLINGTON ST-IC-HAMILTON		100.07
BURLINGTON ST-IC-HAMILTON	HWY 20-IC-CENTENNIAL PKWY-HAMILTON		100.08
HWY 20-IC-CENTENNIAL PKWY-HAMILTON	FRUITLAND RD-IC-STONEY CREEK		100.09
<b>ROUTE - LINC. ALEX PKWY/RED HILL VALLEY PKWY</b>			<b>ID</b>
<b>Start Point</b>	<b>End Point</b>		
HWY 20-IC-CENTENNIAL PKWY-HAMILTON	POINT-A		200.00
POINT-B	POINT-C		200.01
POINT-C	POINT-D		200.02
POINT-D	POINT-E		200.03
POINT-E	POINT-F		200.04
POINT-F	POINT-G		200.05
POINT-G	POINT-H		200.06
POINT-H	POINT-I		200.07
POINT-I	POINT-J		200.08
POINT-J	POINT-K		200.09
POINT-L	HAM/WENT RD 215-MOHAWK RD IC		200.10

**Table 8.** Traffic Counts and Emission Rates with its Designated ID Codes

ID	Dist. (km)	Vehicle	LDV	LDT	HDV	MC	Emission Rate (g/s)	Emission Rate (g/s-m <sup>2</sup> )
403.00	3.682	214200	148052	46296	19724	128	0.770	6.97E-06
403.01	3.156	116900	80800	25266	10764	70	0.360	3.81E-06
403.02	1.789	115300	79694	24920	10617	69	0.201	3.75E-06
403.03	2.131	97000	67045	20965	8932	58	0.202	3.16E-06
403.04	1.411	104200	72022	22521	9595	62	0.144	3.39E-06
403.05	4.836	87700	60617	18955	8075	53	0.414	2.85E-06
403.06	2.894	81900	56608	17701	7541	49	0.231	2.67E-06
100.00	2.064	184800	127731	39942	17016	111	0.372	4.51E-06
100.01	2.053	191100	132086	41303	17597	114	0.383	4.67E-06
100.02	1.906	208300	143974	45021	19180	125	0.388	5.09E-06
100.03	0.842	155700	107618	33652	14337	93	0.128	3.80E-06
100.04	1.156	153400	106028	33155	14125	92	0.173	3.74E-06
100.05	2.023	149800	103540	32377	13794	90	0.296	3.66E-06
100.06	3.496	149400	103263	32290	13757	89	0.510	3.65E-06
100.07	3.538	120800	83495	26109	11123	72	0.417	2.95E-06
100.08	1.752	152200	105199	32896	14015	91	0.260	3.72E-06
100.09	5.167	100600	69533	21743	9263	60	0.508	2.46E-06
200.00	1.383	62612	43277	13533	5765	38	0.085	6.11E-06
200.01	1.312	62612	43277	13533	5765	38	0.080	6.11E-06
200.02	0.853	62612	43277	13533	5765	38	0.052	6.11E-06
200.03	3.832	62612	43277	13533	5765	38	0.234	6.11E-06
200.04	1.134	61947	42817	13389	5704	37	0.069	6.05E-06
200.05	2.067	61947	42817	13389	5704	37	0.125	6.05E-06
200.06	1.633	91678	63367	19815	8442	55	0.146	8.95E-06
200.07	1.715	91678	63367	19815	8442	55	0.154	8.95E-06
200.08	1.645	91678	63367	19815	8442	55	0.147	8.95E-06
200.09	2.590	61567	42555	13307	5669	37	0.156	6.01E-06
200.10	1.236	61567	42555	13307	5669	37	0.074	6.01E-06

**Table 9.** Vehicle Emission Factor by Type (USEPA, 1998)

Vehicle Type	Emission Factor (g/mi)	Emission Factor (g/km)	Relative %
LDV	0.088	0.054681	0.691187
LDT	0.191	0.118682	0.216134
HDV	0.365	0.226801	0.09208
MC	0.111	0.068972	0.000599