Movements of Dangerous Goods Across the Credit Valley Conservation Watershed

Prepared for:

Credit Valley Conservation Authority

September 2011

McMASTER INSTITUTE FOR TRANSPORTATION & LOGISTICS

CVC
CREDIT VALLEY CONSERVATION

PREFACE:

This study was commissioned by Credit Valley Conservation (CVC) with funding support from the Region of Peel for the purpose of developing a higher level understanding of the movement of dangerous goods across the Credit River watershed. It is intended to assist CVC and partner organizations prepare for a potential emergency involving the spill of a hazardous material into the Credit River or its tributaries.

The report provides estimates of hazardous materials movement based on available data and model simulations with a focus on more commonly transported materials and major transportation corridors. In making the report available, CVC and its supporting agencies do not make any warranty, express or implied, with respect to the accuracy or completeness of the information contained herein.

ACKNOWLEDGEMENTS:

CVC Staff: John Kinkead, Christine Zimmer, and Amanjot Singh
Region of Peel: Rodney Bouchard, Sabbir Saiyed, and Elaine Gilliland
Ontario Ministry of Transportation: Rob Tardif
Statistics Canada: Jan Patenaude

CONSULTANTS:

McMaster Institute for Transportation and Logistics: Mark Ferguson, Justin Ryan and Pavlos Kanaroglou
Dymock and Associates Inc.: Ken Dymock

PUBLICATION INFORMATION:

Comments on this report should be directed to:
Amanjot Singh, Ph.D., P.Eng.
Water Quality Engineer
Credit Valley Conservation Authority
1255 Old Derry Road
Mississauga, Ontario, L5N 6R5
Tel: 905 670-1615 Ext. 267
Email: asingh@creditvalleyca.ca

McMaster Institute for Transportation and Logistics
McMaster University
Hamilton, Ontario

September 2011

mitl.mcmaster.ca

Table of Contents

Exhibits

Executive Summary

In Canada, there are in the order of 30 million dangerous goods shipments per year and perhaps 3,500 distinct types of dangerous goods. Over the years, there have been some very significant accidents involving the movements of hazardous materials. The 1917 Halifax Explosion, associated with the movement of munitions over water, resulted in 2000 fatalities. More recently, a 2007 rail derailment about 200km north of North Bay, Ontario resulted in the release of 200 tonnes of sulphuric acid into the Blanche River. While some of the more sensational hazmat releases occur from marine or rail movements, or from industrial plant releases, it is worth noting that trucks carry the vast majority of dangerous goods shipments and a lesser but very substantial share of hazmat tonnage.

Hazmat Geography and Past Incidents

The purpose of this study is to assess the movements of dangerous goods across the Credit Valley Watershed for the modes of truck and rail. To understand the nature of dangerous goods movements in the vicinity, it is necessary to study the general geography of dangerous good movements and to derive movement estimates for the Greater Toronto Hamilton Area (GTHA) as a whole. In a North American context, the GTHA does not stand out with respect to the quantities of dangerous goods that are transported. Far more extreme examples are to be found in metropolitan areas such as Houston, Texas where about 275 million tonnes of hazmat originate annually which is several times the amount for the GTHA. Many of the key dangerous goods facilities in the region have to do with the distribution of gasoline and diesel to gasoline stations and card locks. There is a very large gasoline and diesel complex in the Finch and Keele area of Toronto which distributes to much of the GTHA and other parts of southern Ontario. This is one of the largest such complexes in North America. There is also a significant PetroCanada terminal in Oakville, close to the boundary with Burlington and a Shell terminal near Hamilton Harbour. These facilities are mostly served by pipeline but distribution from the terminals takes place by tanker trucks which can hold up to 68,000 litres.

Other than some chemical distributors in the GTHA and a number of manufacturing firms which use hazmat inputs for their industrial processes, most of the key hazmat facilities are in areas peripheral to the GTHA. The main petro-chemical complex is located in and around Sarnia, Ontario and is associated with firms such as Dow Chemical and Nova. Some associated inputs, such as vinyl chloride, may arrive in Canada at the Sarnia border crossing from origins such as Texas and then get processed in Sarnia. As such, there are examples of dangerous goods that never have the opportunity to cross the Credit Valley Watershed. Ammonia and ammonium nitrate, which are produced by CF Industries, are examples of other prominent substances that are produced in the Sarnia area. Substantial amounts of sulphuric acid, produced largely in Sudbury cross the watershed in transit to the U.S. by rail. Other notable and frequently transported substances that cross the watershed include hydrochloric acid and sodium hydroxide.

Another contribution of this report is an examination of the Dangerous Goods Accident Information System (DGAIS), which was administered by Transport Canada from 1988 to 2002. This database tracked all incidents with dangerous goods nationally across the modes. About 2/3 of all incidents tracked are with goods not in transit (e.g. at rail yards) and the vast majority of incidents are considered minor or moderate. Within the database, Ontario experienced about 1/3 of rail incidents and ¼ of road incidents. These data, combined with more recent incident data from Transport Canada, suggest that the handling of dangerous goods has become safer over the years. Within the time span of the DGAIS there is a decline from 985 incidents per year down to 399 and the more recent data suggests further improvement. Within the Credit valley between 2004 and 2009, there were 18 minor road-related incidents which mostly had to do with goods not in transit.

Data and Methodological Background

The observed dangerous goods flow data that we possess are all at fairly high levels of aggregation such as between or within provinces. To really assess, what is crossing the watershed, it is necessary to break these hazmat flows down to much lower levels of aggregation. In the sense that this approach uses modeling techniques and assumptions it is an imperfect process but it provides a firmer basis for reasonable estimates. To that end, we obtained the Canada Business Patterns data base which catalogues all the significant urban centres in Canada and provides detailed sectoral employment data for each of those sectors. Using an advanced modeling technique (the aggregated spatial logit model) which leveraged hazmat employment data by urban centre, small inter-regional hazmat flows tables were disaggregated to a 144 by 144 matrix of hazmat movements between Canadian urban centres which respected all higher level constraints.

To further assist efforts, a customized zonal system is developed to help track the nature of the longer-distance movements over the watershed. This zonal system is primarily focused on Southern Ontario but captures all inter-regional flows and is adaptable for international flows. The zonal system helps to isolate the specific transportation corridors in the GHTA that would most likely be utilized for hazmat trips between certain origins and destinations. The 144 by 144 flow matrix is easily translated into a 7 by 7 matrix of flows tailored to answering questions about movements across the watershed. Of the seven zones, three relate to Toronto, Hamilton and Oshawa; and two relate to south west Ontario. The bulk of the urban centres are members of the East zone, which includes all urban centres east of Oshawa such as Kingston, Montreal and Halifax and a western zone which includes northern Ontario centres and everything else westward.

Dangerous Goods by Truck

On the trucking side, this process yields an annual estimate of 15.874 million tonnes for dangerous goods movements that are internal to the GTHA (i.e. movements that originate and terminate in the GTHA). Inclusion of movements that involve the GTHA, but are associated with origins or destinations external to the GTHA, increases the total to 24.39 million tonnes of hazmat per year. Freight movements by truck are very complicated as they can involve large numbers of origins and destinations and trips over varying distances. To come up with a reasonable model for this complex set of movements a 2252 by 2252 zonal system for the GTHA is employed to capture the full range of movements at small levels of geography.

For the portion of truck trips relating to intra-GTHA hazmat movements, a simulation framework that previously created an origin-destination matrix for all commercial vehicle movements was employed in conjunction with the detailed zonal system. To adapt this framework for dangerous goods, a 2009 InfoCanada data set was mined for a list of specific firms that could most be associated with hazmat. Trip origination totals associated with the earlier study were appropriately scaled to derive estimated hazmat trip originations for each of the 2252 zones. In terms of vehicle movements from the former model, particular emphasis was given to sub-models dealing with industrial and wholesale firms. In total, 11,419 distinct hazmat trips were associated with intra-GTHA movements for the typical day. As segments associated with "tour-based" behaviour, many of these trips would not be long in terms of distance. For non-GTHA origins and destinations, 910 trips entered the GTHA from outside and 1181 trips left the GTHA for elsewhere. Included as a subset are trips which passed through the GTHA without an internal destination. All of the important geographical information associated with these trips was captured within the 2252 by 2252 origin-destination matrix.

It was considered important for the analysis that the characteristics of this hazmat trucking matrix adhered to targets derived from separate estimation processes. The main targets for the overall GTHA matrix were associated with aggregate tonnage, tonne-km, and vehicle kilometres travelled. The process for tonnage has been described but for the other two quantities, at least two methods were considered for each to estimate appropriate levels for the GTHA.

Tonne-km is a useful quantity because it captures the aggregate "effort" involved in moving goods. From the U.S. commodity flow survey, some useful information was exploited per hazmat commodity class which characterized the proportion of tonne-km associated with shipments of less than 80km in length. This information was used in conjunction with some hazmat origination data for various comparable U.S. metropolitan areas to yield an annual result of 165 million tonne-km of hazmat per million people for movements within metro areas. Application of this quantity to the GTHA resulted in an estimate of 3.6 million tonne-km per typical day. Alternate methods relying more on the Statistics Canada Trucking Commodity Origin Destination survey yielded estimates of between 2.1 and 2.8 million tonne-km per day. The final o-d matrix derived for the GTHA featured 2.426 million tonne-km per typical day which seems within reason. Roughly, the shipping effort was divided in thirds between intra-GTHA trips, trips from outside the GTHA and trips to a location outside the GTHA.

Vehicle kilometers travelled (VKT) is another benchmark of utility, though it can be more ambiguous than tonne-km. From a Cambridge Systematics (2003) report on several metropolitan areas in the U.S., a goods movement VKT to population ratio of 1.18 was estimated. Application of this ratio to the GTHA yields a VKT for goods movement of 7.72 million km per day. Assuming, as from the Canadian Vehicle Survey, that 5.15% of VKT relates to hazmat gives 397,889 per day. An alternate method yielded a total of 645,610. The final matrix derived for the GTHA is associated with 261,632 VKT. Of this amount, a bit less than 120,000 in VKT is associated with movements to and/or from outside the GTHA. It is possible that there is some underestimation of VKT for intra-GTHA movements due to the underlying simulation model which was not specifically geared to hazmat movements.

Having derived a final origin-destination matrix for GTHA dangerous goods movement, the research had progressed to the point where estimates directly applicable to the watershed could be made. The final origin-destination matrix served as the key input into a stochastic user equilibrium traffic assignment algorithm which would assign the daily trip estimates to the network in a reasonable manner given the nature of the trips. Results suggested daily hazmat trips crossing the watershed of 300-400 on the major provincial highways and from 20 to 100 on major arterials associated with the watershed. Hwy 407 was likely overestimated on the basis that tolls were not specifically taken into account. A database of trip volumes on all significant links in the watershed was derived as a final product. A further tabulation exercise was carried out to estimate the actual tonnage crossing the watershed. Of the 24.39 million tonnes of hazmat which interact with the GTHA, it was estimated that 8.857 million tonnes crosses the Credit Valley Watershed or in some way touches the watershed in a year. This total is about 36% of all GTHA hazmat tonnage and works out to just under 30,000 tonnes per day.

Data from the 2006 MTO commercial vehicle survey were obtained for locations on the QEW, Hwy 401 and 403 near the watershed. The hazmat trip totals in these results were quite consistent with the modelled volumes for those highways across the watershed. As well as trip volumes, the MTO data provide some excellent snapshots of hazmat tonnage and types of hazmat. The data suggest that 6,202 tonnes of hazmat would cross the 401 site on a typical day and 5,866 tonnes would cross the QEW. These results do not seem inconsistent with the near 30,000 tonne estimate for the entire watershed but might suggest a slight overestimation. The MTO data tracks the hazmat placards on trucks passing by and reveals a fairly diverse picture for specific substances. One interesting observation is that the QEW appears to be much more "gasoline and diesel" oriented than the 401. In terms of hazmat tonnage, the QEW is about 2/3 flammable liquids whereas the 401, in the vicinity of the watershed, is about 1/3 flammable liquids, 1/3 gases, and 1/3 for other substances. Hwy 403 appears to have more in common with the QEW in this respect.

Dangerous Goods by Rail

Fortunately, a less complex rail network (relative to road) leads to a less involved process to derive estimates of movements across the watershed. The steps have much in common with the high level piece of the road estimation but there is no need to go further and derive flows between large numbers of zones within the GTHA. The aggregated spatial logit model is used along with Canadian Business Patterns data to derive a 144 by 144 national flow matrix of hazmat. Using the customized zonal system, these flows are aggregated to the 7 by 7 matrix. Using some insight gained from hazmat border crossings by rail, imports and export of hazmat to and from the GTHA are worked into the final matrix.

The net result is an estimate of 6.442 million tonnes of hazmat per year that interact with the watershed. This sum can be divided into 2.359 million tonnes that are eastbound across the watershed and 4.083 million tonnes that are westbound. Sulphuric Acid is noted as a particularly important substance in increasing the westbound total as large quantities are destined for the U.S. from mining oriented areas in the north. Expressed in other ways, it is estimated that 695 hazmat rail cars or about 21,473 tonnes would cross the watershed on a typical day. Of this amount, 6671 tonnes would be class 2 gases, 7628 tonnes would be class 3 flammable liquids and 5,049 tonnes would be class 8 corrosives.

The remaining 2,123 tonnes would be divided among the other classes with fairly small amounts in each. Overall, these results assume that there are some fairly substantial movements of dangerous goods by rail which involve the GTHA but do not involve the watershed.

For both road and rail, the report provides some statistics on cross-border movements of hazmat, some of which feed into the watershed. In proportional terms, international flows of hazmat are much more important to rail than to road which makes sense since rail is a longer-distance mode. Interesting observations with respect to hazmat imports show that for rail the Sarnia crossing is by far the most important while for trucking, about 2/3 of Ontario hazmat totals enter at the Niagara crossings.

The report concludes by briefly summarizing the main quantitative findings from the research and making some salient observations. One important observation is that there is potential to take this type of work further by developing a profound understanding of the industrial geography that gives rise to the flows of specific substances and then developing models at the substance level. Another conclusion from the work is that there is a need in Canada for a specialized publication in along the lines of the U.S. Commodity Flow Survey special publication on hazardous materials which would be released every few years for the benefit of stakeholders like municipalities and researchers.

1

Introduction

The purpose of this report is to estimate dangerous goods movements across the Credit Valley Watershed and to rank major transportation corridors that traverse the watershed in terms of such goods. While dangerous goods incidents can take place in-transit or during loading/unloading phases, the focus here is on the road and rail modes while dangerous goods are in-transit.

The Credit River itself is about 90 km long and connects to about 1,500 km of creeks and streams. The area of the entire watershed is about 860 square kilometres and its estimated population is about 750,000 people. Most of these people live in the lower watershed, closer to Lake Ontario, in the cities of Mississauga and Brampton. The watershed is surrounded by a highly populated area which is associated with much of the dangerous goods flow that cross the area. In fact, the Greater Toronto Hamilton Area (GTHA) is one of the most heavily populated metropolitan regions in North America. Exhibit 1 visually outlines the main waterways of the watershed and the main built-up areas.

While the issue of incident risk is very much intertwined with transport of dangerous goods, this report is not focused particularly on estimating risk. The most important objective of this report is to characterize movements across the watershed. Nevertheless, the element of risk is made more transparent in a fairly detailed section of the report. It outlines the range of hazmat incidents that have taken place in Canada and the Credit Valley Watershed in recent decades and shows, among other things, that the risk of incident has been declining over time.

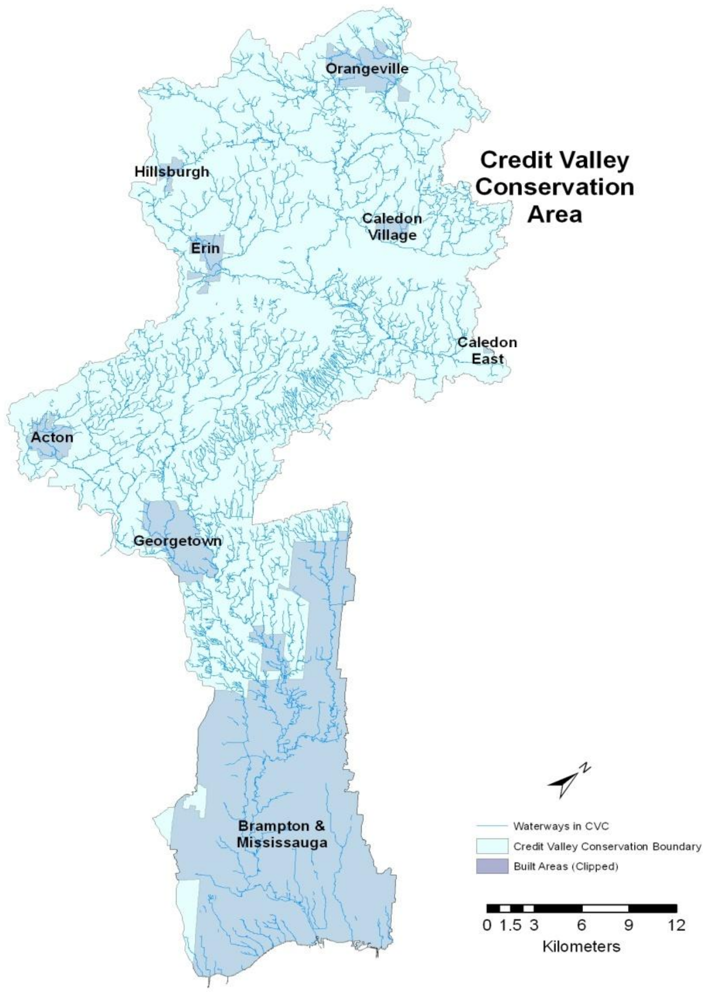
The scope of the research is somewhat limited by a dearth of detailed data on dangerous goods movements in Canada and certainly at smaller levels of geography. There is also a pronounced lack of detail at the level of specific substances which can be an issue since various substances can require quite different responses in the event of an emergency. As a result, more emphasis is given in this report to getting reasonable estimates to total hazmat movements with much less emphasis on providing estimates at the substance level.

To understand dangerous goods movement in the watershed it is necessary to consider a much wider area than the watershed and also it is necessary to assess the industrial character of the region which gives rise to these movements and acts as an origin/destination for many of the movements. In particular, this study will examine hazardous flows that are generated in the GTHA as a whole as well as movements that originate elsewhere but terminate or pass though the GTHA. A substantial proportion of these movements will pass through the Credit Valley Watershed. Four major expressways cut across the watershed along with main lines of the CN and CP railways. While not a focus in this report, large volumes of hazmat cross the watershed via pipeline also.

The outline of this report is as follows. In a background section, an effort is made to review the literature for relevant information and to look at past studies of a similar theme to this one but perhaps carried out for other geographies. This is followed by a sub-section that examines hazmat incidents in Canada. A third sub-section examines substances by hazmat classes and points out some of the locational nuances associated with production and distribution of these substances. A final back ground sub-section attempts to derive some general hazmat benchmarks for the GTHA based largely on transferring learnings from the U.S. commodity flow survey.

A second major section focuses strictly on dangerous goods movement for trucks and traces out the process that has been followed in this report to derive GTHA estimates. The work in this section concludes with reporting on the results of a hazmat trips traffic assignment algorithm and the resulting ranking of road corridors. A third major section of the report details the estimation process that is followed for rail and the final section of the report offers some concluding remarks.

Exhibit 1 Credit Valley Watershed: Main Waterways and Urbanized Areas



Background

The purpose of this section is to provide an overview of supporting background information. In the first section, some studies from North America that have a dangerous goods focus are briefly outlined and some other useful notes from the literature are pointed out. In the second section, an examination of dangerous goods incidents in Canada is carried out with an emphasis on incidents that occurred while goods were in transit. A third section provides an overview of the geography of dangerous goods in Southern Ontario. The focus is on where such goods are produced and how they are distributed within the region. The analysis is considered in light of the most important Transport Canada dangerous goods classes. A final background section provides some estimates of total dangerous goods in circulation without reference to mode. There is an emphasis on developing some reasonable benchmarks for the GTHA.

2.1 Other Studies

To the best of our knowledge, the most definitive recent report on the movements of dangerous goods in Canada was released by Transport Canada (Provencher, 2008) and provides estimates for the year 2004. That report covers the modes of road, rail, marine and air but not pipeline. For rail, the report notes that periodically, CN and CP provide commodity origin and destination statistics to Transport Canada. These statistics are not specifically generated for the purposes of hazmat analysis but can be broken down as such. These are summarized in Provencher (2008) at the inter-provincial level for the various dangerous goods classes. Provencher notes that Canada-wide, CN and CP carry approximately 90% of all rail tonnage, and account for 97% of railway tonne-kilometers. Of all rail-transported goods, dangerous goods represent 14% of tonnage, and 15% of tonne-kilometers.

For the road mode, two main sources are noted as being relevant. Since they are quite useful for this study they are described in some detail here. The two sources are both surveys (not census) and are the Canadian Vehicle Survey and the Trucking Commodity Origin Destination Survey (TCOD). Of the two, the TCOD survey is the more important for the Credit Valley work but has limitations. In particular, the TCOD covers for-hire firms only with annual revenues exceeding $1 million per year (this lower bound has recently been raised). The revenue restriction will likely remove a lot of owner-operators from the results. The survey omits firms whose main business is not trucking but which operate their own private fleets to move goods.

In direct communication with Statistics Canada about the TCOD survey the following description was provided:

"The objective of TCOD is to measure commodity movements and outputs of the Canadian for-hire trucking industry. The estimates produced include total tonnage transported by commodity type, number of shipments, distance traveled and revenue by origin and destination of the shipment. The TCOD survey extracts its frame from Statistics Canada's Business Register (BR). The BR statistical structure of a business contains from top to bottom four levels of statistical entities: enterprise, company, establishment and location. The survey population consists of all companies on the BR with at least one trucking establishment that has at least $1.3 million in annual revenue. The TCOD results are based on a small (less than 15%) sample of shipments from a sample of trucking businesses. Results at detailed geographic and/or commodity levels are less reliable than results at more aggregate levels". This last statement is quite relevant for the current study.

Another source by Transport Canada is the publication: Transportation in Canada (Transport Canada, 2011). This source provides an aggregate view of dangerous goods movements at the national level. The report estimates that there are 30 million shipments of hazmat in Canada annually, with more than half of these moving by road. A consultants report for the Ontario Ministry of Transportation (iTRANS, 2004), notes that in the order of 3500 products are listed as dangerous goods among the nine main categories that are described below. They estimate that approximately perhaps 5% of all intercity trucks are carrying dangerous goods.

An interesting Ontario overview by Gorys (1990) was completed shortly after the "Metropolitan Toronto Goods Movement Study" from the late 1980's. The overview is quite topical for the current research though a bit dated. Gorys reports that “although close to one-quarter of firms surveyed shipped dangerous goods, less than 5 percent of their loads were dangerous goods.” Two decades ago, it was estimated that 39 million tonnes of hazmat was being transported to, from and within Ontario. At that time, nearly 2/3 of this amount was assessed as moving by truck and about 1/4 by rail. Dangerous Goods was representing about 18% of all truck tonnage in Ontario. Since that time, there is evidence that the share for trucking has declined to some degree (Transport Canada, 2011). For the Toronto area in particular, Gorys notes that although the total quantities of dangerous goods being transported could not be measured with certainty, commodity and trip information revealed that at a minimum, there were 18,000 movements per day of chemicals in the Toronto area alone.

One potential source of Hazmat information for road in Ontario is the Ontario Ministry of Transportation Commercial Vehicle Survey (CVS) which is carried out every few years. This is an intercept survey where trucks are stopped while in transit unlike the TCOD which is based on surveying firms. The CVS is not specifically targeted at hazmat but does record the nature of the cargo. Also the survey is oriented to roads which are under the jurisdiction of the province. Essentially, this translates into the 400 series of highways. For this project, MITL has obtained a useful cross-section of dangerous goods data for the 400 series of highways that traverse the watershed. These data are very useful for validation purposes and will be described in a later section.

As a detailed source of dangerous goods data, the U.S. Commodity Flow survey appears to be the most relevant within North America. While the U.S. CFS is not specifically targeted at hazmat, a special report on hazmat is produced soon after each vintage of the CFS is complete(U.S. Departments of Transportation and Commerce, 2010). These reports break down dangerous goods movements to a level of detail which is not yet publicly available in Canada. This report will make periodic reference to the U.S. CFS as a reality check against estimates produced for this project.

We have come across a handful of U.S. studies which attempt to understand hazmat movements within particular jurisdictions. Racca presents a study of hazmat movements in the State of Delaware, USA(Racca, 2002) . At the national level, Racca reports that although trucks move only 43% of hazmat tonnage, they account for 94% of DG shipments, most of which tend to be small. Nonetheless, accidents associated with the truck mode are infrequent, with an estimated 1 per 67,000 shipments. In the case that accidents do occur, they are more likely at highway ramps and intersections. For the rail mode, Racca finds that 11% of total tonnage moved is hazmat, while for Delaware, 34% of dangerous goods tonnage is thru traffic, with origin and destination points located outside of the State.

One other U.S. study (Mitchell et al., 2002) examines hazmat transport in South Carolina. Here, it is suggested that between 4.4 and 7.1% of five-axle truck traffic carries dangerous goods, and that peaks in this traffic occur between 8am and 10am, as well as between 2pm and 4pm. In addition, while the frequency of shipments of corrosive materials is low (approximately 1.8% of shipments), these account for 16.7% of all such movements by volume.

The Texas Transportation Institute developed a report which assessed the movements of hazmat associated with the State of Texas (Warner et al., 2009). The study utilized the U.S. Commodity Flow survey and also benefited from waybill data for rail movements which was acquired. The report contains interesting comparisons among the main cities in Texas. It is estimated that 18M tons of hazmat originate in Dallas and 35M tons terminate there. For Houston, the corresponding figures are 303M and 287M tons. This latter set of figures gives some indication of the extent to which Houston is a massive petrochemicals centre. The report further notes strong flows of hazmat between Texas and

Canada. In particular, Alberta is shown to be a supplier of hazmat ingredients for Texas while Ontario is a large customer. For 2005, a bit less than 700,000 tons of hazmat is sent from Texas to Canada with the largest tonnage substances being propylene oxide and vinyl chloride. This figure includes amounts that passed through Texas on the way to Canada. Ontario received 84% of this amount by tonnage.

A large body of research focuses on the risk associated with dangerous goods transportation, often by analyzing previous accident data. Scott looks at the risks associated with rail transport in particular, finding that between 1982 and 1992, accidents per million miles were cut nearly in half to 4.26, while the overall volume of dangerous goods doubled (Scott, 1996). In 1992, there were 0.019 releases of hazmat for every thousand carloads in transport. Glickman & Rosenfield (1984) address incident fatalities, reporting that the chances of 100 or more fatalities in an incident are 1 in 100,000, while the chances of 100 or more fatalities in a year are the same. Stewart & Van Aerde (1990) show that gas trucks release their goods in 19% of incidents, while liquefied petroleum gas (LPG) trucks do so in 8% of incidents. Quarantelli (1991) reports that between 1980 and 1985, there were 1.25 incidents per 10,000 shipments of hazmat, and in up to 41% of these cases, there were placard violations. Quarantelli notes that although up to 90% of road related incidents involving release occur on highways, there is a threat of dangerous goods exposure almost anywhere, especially given the ability of gases to drift.

Oggero et al. (2006) present a survey of 1,932 hazmat related accidents that occurred on either the road or rail mode. Of the surveyed incidents, 63% occurred on the road. The majority of incidents (78%) were releases of dangerous goods, while 28% were classified as fires, 14% as explosions, and the remaining 6% as gas clouds. These categories add up to greater than 100% since the same incident could give rise to more than one of the outcomes. Verter & Kara (2001) use a GIS framework to examine selected hazmat shipments between Ontario and Quebec during the year 1998. They find that by following a vehicle routing scheme that minimized risk as opposed to one that minimized distance, the number of evacuations due to incidents could be reduced by as much as 41%.

Anand et al (2005) focus on the rail mode, assessing the risk of “the 125 most commonly shipped hazardous materials that were authorized for shipment in non-pressure specification tank cars.” They consider location and chemical type as the key factors affecting cleanup costs resulting from hazmat incidents. They present the Quantitative Risk Assessment Environmental Module (QRAEM), which models the environmental consequence of dangerous goods spills based on chemical type, soil type, and groundwater depth. With regard to risk in rail movements, one common thought is that risk can be reduced by manufacturing rail cars in the most robust way possible. The thinking goes that if rail tankers are “thicker” that they might withstand a derailment without being breached. Barkan et al (2007) found that thicker tanker cars are safer for any given load of DG, but then more rail cars are needed to carry the same amount of goods due to lower capacity. In this way, it is not clear that risk is reduced since more hazardous goods cars could be affected in the event of a derailment.

2.2 An Overview of Past Dangerous Goods Incidents

While Section 2.1 gives some overview of past incidents from the literature, it is useful to focus closely on what has happened in Canada in recent decades. The Dangerous Goods Accident Information System

(DGAIS), which was administered by Transport Canada from 1988 to 2002, contains reports on accidents involving dangerous goods in Canada. The data for each incident are comprehensive, so it is worth providing a brief overview to study some of the primary substances involved in incidents. (Trepanier et al., 2009) conclude that government collection of accident data tends to suffer from under-reporting, and that police records of incidents actually offer better coverage. Nevertheless, the DGAIS offers a fairly rich database for our purposes.

The total number of incidents in the database is 11,360. There are actually 14,446 records (or cases) in the database though since the same incident can result in separate releases. For example, two different ruptured tankers from a derailed train could contain different substances and thus would need to be accounted for separately.

The DGAIS documentation suggests that there are 27 million dangerous goods shipments per year which is somewhat less than the figure that Provencher (2008) reports. The database strongly suggests that handling of dangerous goods was much safer in the second half of the 15 year period. From 1988 to 1994 there was an annual average of 985 incidents per year and from 1995 to 2002 the annual average declined to 558 per year.

Exhibit 2 is from Transport Canada and covers the period 2004 to 2008 after the DGAIS was discontinued. It suggests an average of 399 incidents per year. This outcome indicates even more improvements in safety in recent years.

Exhibit 2 Dangerous Goods Incidents in Canada

Year	Road	Rail	Air	Marine	Not in Transit	Total
2004	106	9	6	0	249	370
2005	129	8	5	0	244	386
2006	102	4	7	0	272	385
2007	125	9	8	0	282	424
2008	114	7	4	0	307	432
Average	115	7	6	0	271	399

Of the 14,446 cases from 1988 to 2002, approximately 36% are related to road transport, while 47% are related to rail transport. Exhibit 3 elaborates on the modal split and context of incidents. Note that for trucks, incidents are more likely on the road than at road terminals. This is not the case for rail, where incidents are approximately 3.5 times more likely at rail terminals than on regular track.

Exhibit 3 Number of Incident Records by Mode and Context

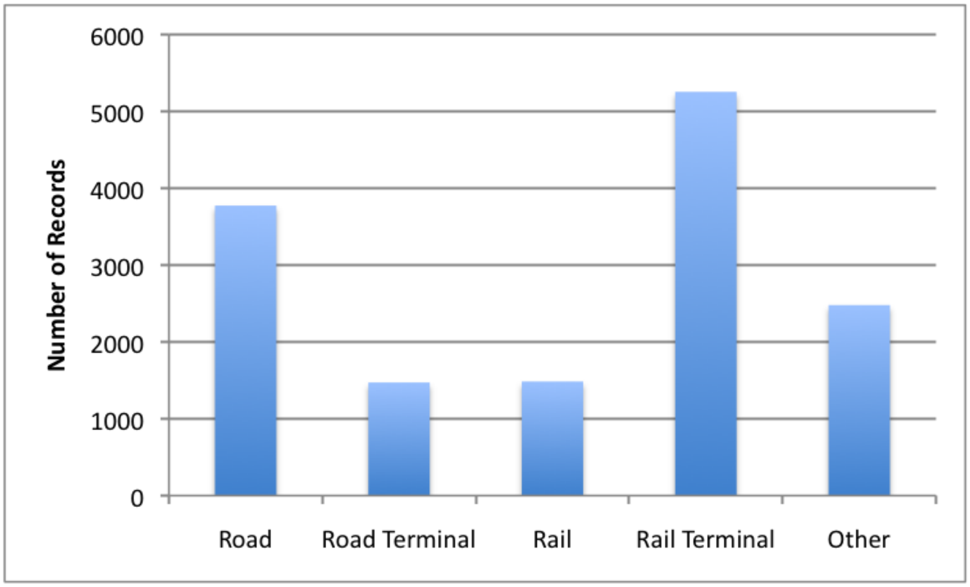


Exhibit 4 below shows the distribution of incidents by phase of transport. Note that "Railyard Operations" and "Loading & Unloading" combine to form a larger percentage of incidents than "In Transit." Note that this chart is across the modes, despite the category specific to rail.

Exhibit 4 Number of Incident Records by Phase

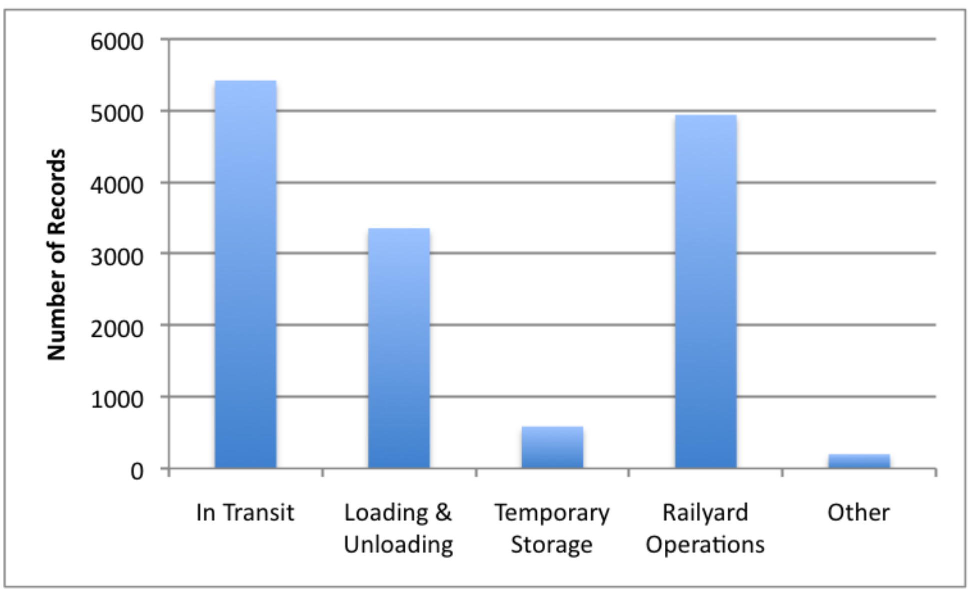


Exhibit 5 Major and Severe Incidents by Mode

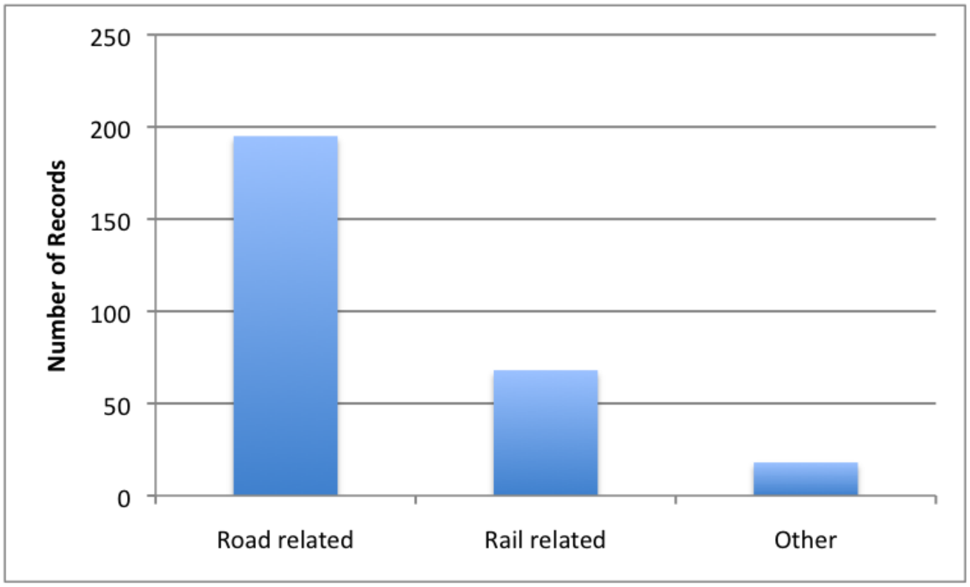
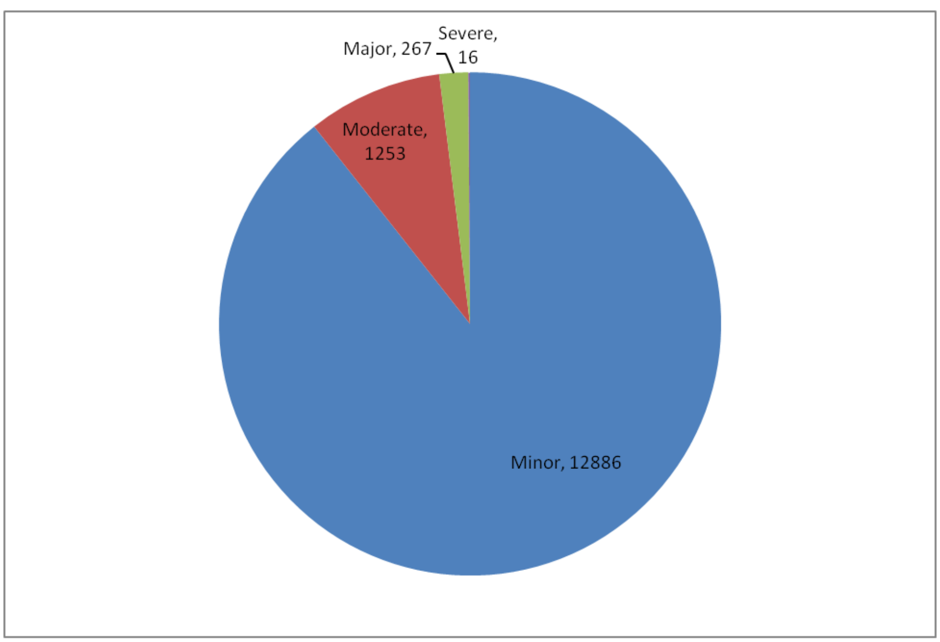


Exhibit 5 above shows the distribution of "Major and Severe" incidents by Mode. The big difference between road and rail is largely accounted for by in-transit road incidents in rural locations.

Exhibit 6 illustrates the severity of incidents recorded in the DGAIS. "Major" refers to a dangerous incident which could be catastrophic under certain conditions of traffic, weather or inadequate response and could escalate to a catastrophic situation. "Severe" refers to an incident with high catastrophic potential, high probability of loss of life, serious injury or long term damage to environment.

Exhibit 6 Number of Incident Cases by Severity



Having outlined some of the basic characteristics of all dangerous goods incidents, the focus for the remainder of this review moves to "in-transit" incidents as is consistent with the focus of this report. Of the 14,446 cases in the database, 5,175 occurred In-Transit by either the road or rail mode. Exhibit 7 shows the number of incident records that occurred In-Transit for Road and Rail, for both Ontario and all of Canada. While Ontario had more than 1/3 of the rail incidents, the proportion for road incidents is little more than 1/4. A review of the DGAIS suggests a large number of hydrocarbon related road incidents in Alberta which explain much of this differential.

Exhibit 7 Number of In-Transit Cases by Mode for Canada and Ontario

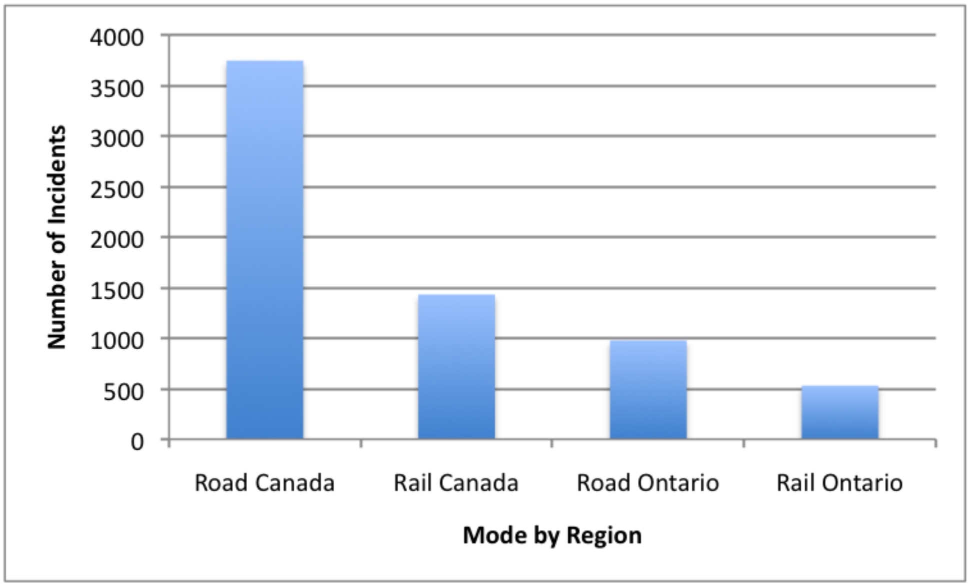
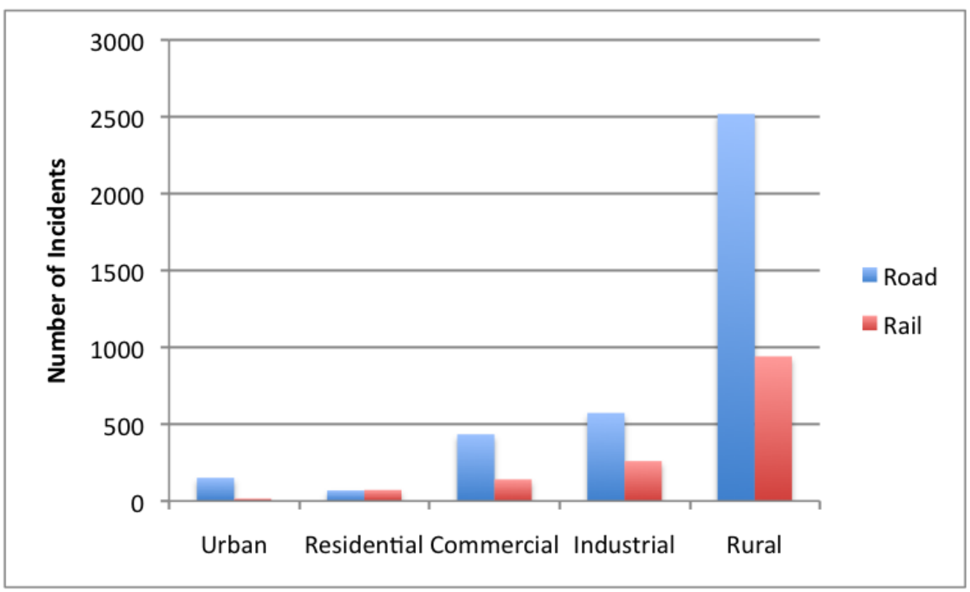


Exhibit 8 Number of In-Transit Incident Records by Land Use



One interesting lens through which to view in-transit incidents is where the incidents took place. Accordingly, the breakdown of cases by land use type is displayed in Exhibit 8. While the category definitions provided by Transport Canada are cryptic, note that Urban and Commercial both refer to business premises. Industrial refers to areas hosting manufacturing and production services. Residential refers to areas where people live and Rural relates to agricultural land or uninhabited terrain. The main take away from the table is the prominence of rural incidents for both road and rail. One could speculate that this result derives from higher rural speeds for both modes.

Moving on to specific substances, Exhibits 9 and 10 show the ten substances with the highest case counts, for road and rail modes, respectively. Recall that a single incident can result in several cases, for example, in a train with multiple cars derailed.

Petroleum products dominate road incidents, while rail incidents are more associated with other chemicals. Many of the listed rail chemicals are less commonly moved by truck over long distances but may be moved relatively more in urban settings. The absence of non-petroleum incidents for road may also have to do the quantities involved. While gasoline and fuel oil are moved by truck in big shipments, the shipment sizes for other substances will tend to be smaller. In the event of an accident there may be a lesser chance of a release with other substances.

Exhibit 9 In-Transit Road Incident Cases in Canada - Prominent Substances

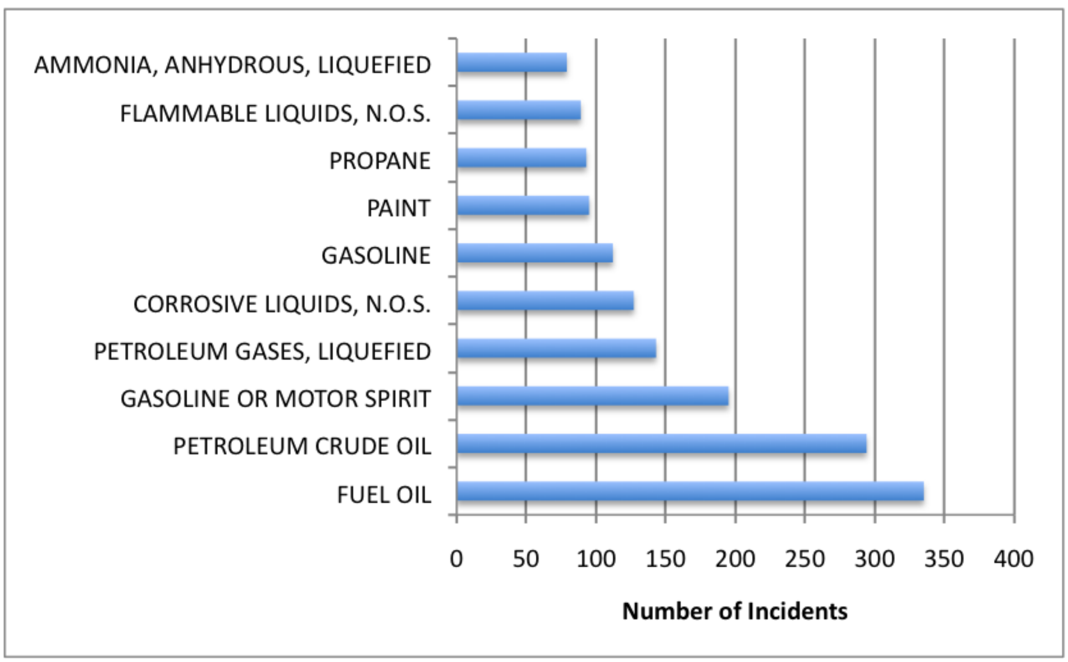
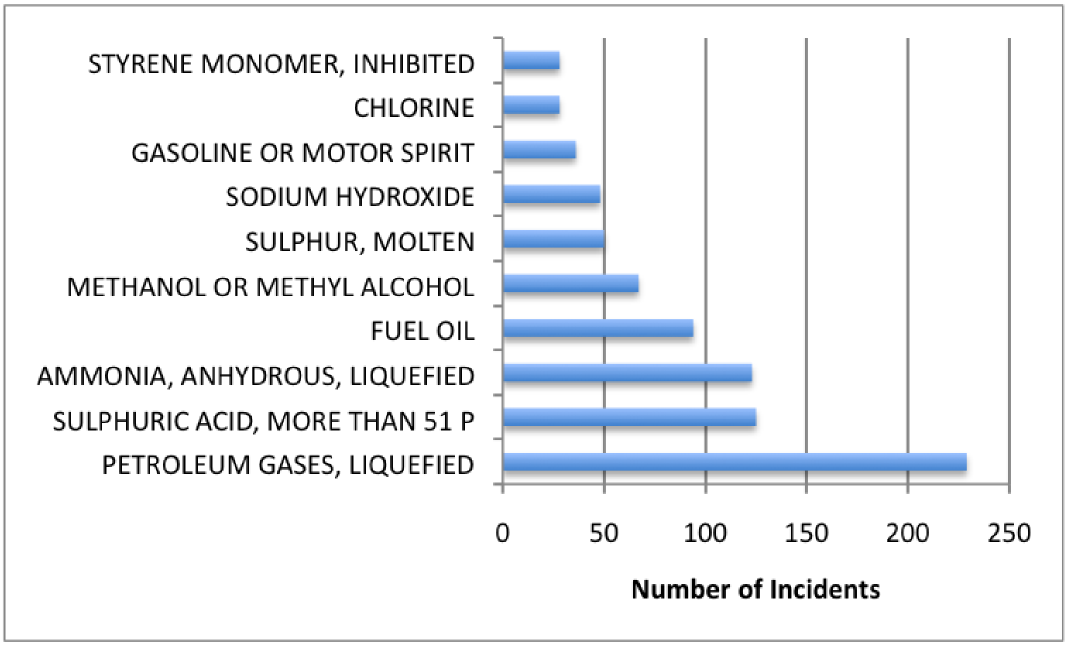
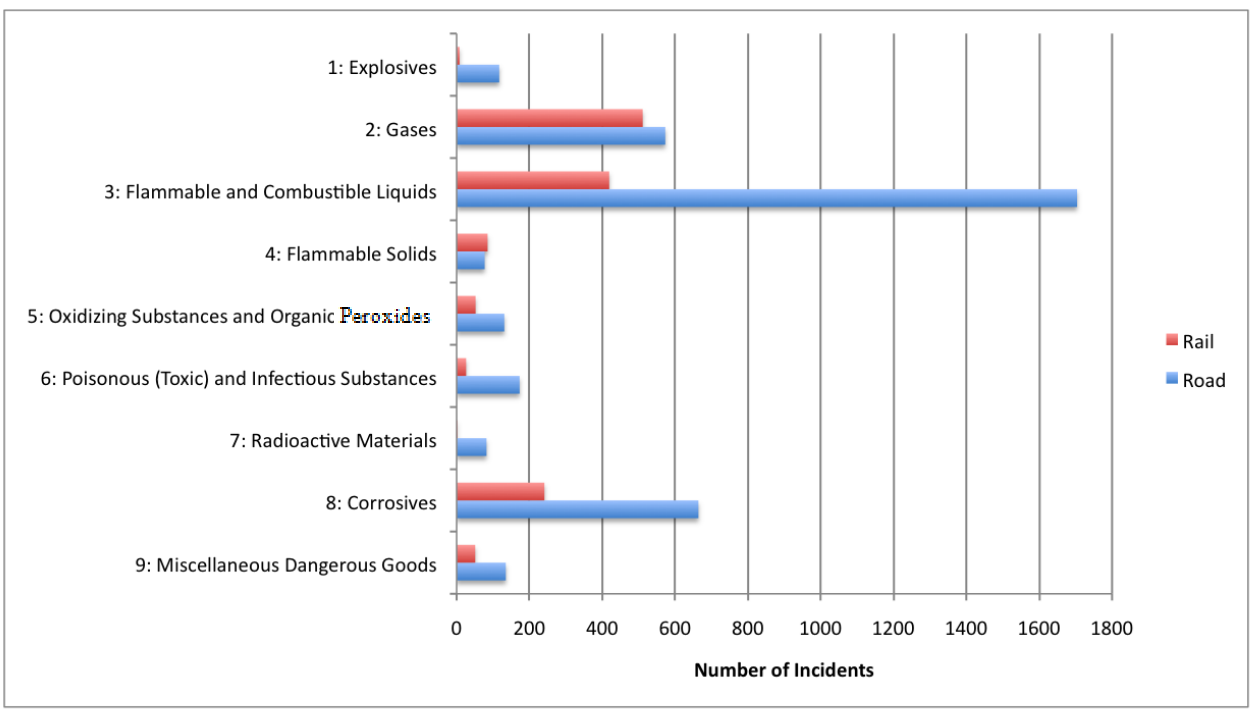


Exhibit 10 In-Transit Rail Incident Cases in Canada - Prominent Substances



Overall, there is a reasonable correspondence between the number of cases and the amounts released. One exception is molten sulphur where there have been a fair number of incidents but small amounts released.

Exhibit 11 In-Transit Incidents by Mode and Dangerous Goods Class (1988-2002)



In- transit incidents can also be classified based on the nine Transport Canada Dangerous Goods Classes (Exhibit 11). For both modes, gases, flammable liquids and corrosives predominate. Flammable liquids are by far the biggest category for the road mode and for the rail mode, gases are slightly more prevalent.

Exhibit 12 Credit Valley Watershed Incidents: 2004-2009

Date	Location	Mode of Transport	Material	Quantity	Unit of Measurement
20040530	Mississauga	Road (in transit)	Diesel Fuel	200	litres
20040457	Mississauga	Road (in transit)	Resin Solution, Flammable	204	litres
20040457	Mississauga	Road (in transit)	Flammable Solids, Organic	500	kilograms
20040127	Mississauga	Road (in transit)	Chlorine	1	litres
20060566	Brampton	Road (in transit)	Corrosive liquids, n.o.s.	15	litres
20040467	Brampton	Road terminal (not in transit)	Batteries Wet, Filled with Acid	5	litres
20040518	Mississauga	Road terminal (not in transit)	Corrosive liquids, n.o.s	10	litres
20050039	Brampton	Road terminal (not in transit)	Toluene Diisocyanate	300	litres
20050472	Mississauga	Road terminal (not in transit)	Corrosive liquids, n.o.s.	20	litres
20060499	Mississauga	Road terminal (not in transit)	Organotin compounds, liquid, n.o.s.	500	litres
20070141	Mississauga	Road terminal (not in transit)	Fluorosilicic Acid	15	litres
20070294	Brampton	Road terminal (not in transit)	Self-heating solid, toxic, inorganic, n.o.s.	8	litres
20070596	Mississauga	Road terminal (not in transit)	Ferric Chloride, solution	300	litres
20080128	Brampton	Road terminal (not in transit)	Corrosive liquid, basic, inorganic, n.o.s.	205	litres
20080408	Mississauga	Road terminal (not in transit)	Corrosive liquids, toxic, n.o.s.	272	kilograms
20090349	Massey	Road terminal (not in transit)	Gasoline	2313	litres
20080512	Mississauga	Road terminal (not in transit)	Propane	4.5	kilograms
20090491	Mississauga	Road terminal (not in transit)	Sodium Fluorosilicate	9	kilograms

Finally, we conclude the analysis by focusing on specific, recent incidents that have occurred within the Credit Valley Watershed between 2004 and 2009. The source database for this table is national but does not contain in-transit rail incidents. While there have been rail terminal incidents shown within the national database, Exhibit 12 shows that there have not been any within the watershed. The 18 incidents are all road-related and only 5 of them are in-transit. Compared to some of the worst incidents in the DGAIS, the quantities released within the watershed have been modest. Many of quantities are less than the quantity of gasoline that might be released in the event of a car accident. The source national database for 2004 to 2009 covers 2131 incidents. It is worth noting that 1333 of these recent incidents have occurred in Alberta while only 158 have occurred in Ontario.

2.3 The Geography of Dangerous Goods in Southern Ontario

To gain necessary perspective, it is useful to consider the main types of dangerous goods which move around Southern Ontario and, in many cases, across the Credit Valley Watershed. For the most part, the Credit Valley is a passive participant to the passage of these goods and, with some exceptions, has not been involved with the origination of the shipments. To a large extent, this task is carried out in Exhibit 13 which provides a brief summary for each of the substances of interest as were initially identified by Credit Valley Conservation and which characterizes the production and distribution of these substances. This Exhibit and much of the material in Section 2.3 is based on the insight of Ken Dymock of Dymock Associates. Also, in the Appendix, the interested reader will find a detailed summary by many hazmat substances which outlines industrial uses and associated North American Industrial Classification (NAICS) codes.

The GTHA itself is not a major centre for the production of petrochemicals or other types of chemicals. The major centre for these activities in Southern Ontario is Sarnia and small towns nearby. Some further specifics by substance are discussed below as they relate to the Sarnia Region. With regard to specific industrial chemicals there are some significant movements. Chemical Distributors in the GTHA are generally the largest recipients of large truckloads of these specific chemicals. Wholesale distributors such as Canada Colors and Chemicals Ltd. transport the chemicals to end users within the region. In the case of Canada Colors, the main distribution facility is in Brampton just to the east of the watershed.

The dominant class of dangerous goods that impact the study area are hydrocarbon products, especially fuels. It is useful to classify hydrocarbons by volatility. These classes are: 1) Gases 2) Low flash materials (Flash Point < $40^{o}C$) and 3) high flash materials (Flash Point > $40^{o}C$). The flash point is the lowest temperature at which a liquid can vaporize to form an ignitable mixture in air. In other words, low flash hydrocarbons are more hazardous because ignition can conceivably take place at fairly low temperatures. All hydrocarbons are insoluble in water and with a lower density they will float. The greatest risk in handling them and cleaning up spills is fire, whether from a gas or a low flash material. Hydrocarbons are predominately in liquid form.

The discussion below is organized in terms of the main Transport Canada hazardous materials classes. The sub-sections are ordered based on the relative importance of the associated class. By far, the most important class is Flammable Liquids.

Exhibit 13 Ontario Production and Distribution of Selected Dangerous Goods

Substance	Ontario Production	Uses	Distribution
Acetic Acid	N/A	dilute solutions are vinegar and widely used in foods	Small volume consumers by truck: tote, drum and pail
Acetic Anhydride	N/A	Used as a chemical intermediate and for photographic film	Small volume consumers by truck: tote, drum and pail
Ammonia	CF Industries, Courtright	Million tons per annum, world scale ammonia plant, makes derivatives	Supplies Customers in Eastern Canada/ NE USA
Ammonium Nitrate	CF Industries, Courtright	derived from nitric acid and ammonia made on site	Supplies Customers in Eastern Canada/ NE USA
Benzene	In 2002 4 Producing Sites	Basic petrochemical feedstock and produced as a byproduct of coking	Delivered from Sarnia, Hamilton & Montreal
Butyraldehydes	N/A	Used in manufacture of rubber accelerators, resins, solvents & plasticizers	Used in relatively small quantities
Chlorine	N/A	Used as a bleach, disinfectant and in chemical manufacture	Truck and rail, two Ontario plants in Sarnia & Cornwall shut down
Cyclohexane	N/A	used as a feedstock in the manufacture of nylon	produced in Montreal and shipped to Kingston
Ethylenebenzene	NOVA , Sarnia	an intermediate used in the manufacturer of styrene	an intermediate consumed on site
Ethylene	2 Plants, Sarnia	generated by cracking and used to make polymers & other monomers	in Ontario most consumed at site as a process intermediate
Ferric Choride	N/A	Used in treatment of drinking water and sewage	supplied by aqueous solution
Hydrochloric Acid	N/A	shipped as a compressed liquid, sold typically as an aqueous solution	many small quantities used in diverse industries
Mercury	N/A	used in electronics and precious metal extraction	only used in very small quantities due to toxicity
Methanol	N/A	widely used as a solvent	shipped in from Western Canada by rail,distributed by truck
Nitric Acid	CF Industries, Courtright	derived from ammonia production	Supplies Customers in Eastern Canada/ NE USA
Phenol	N/A	precursor to bisphenol-A & polycarbonates, drugs and antiseptics	small quantities by truck and perhaps rail, no Canadian plants
Phosphoric Acid	N/A	shipped as pyrophosphates or aqueous solutions	used to make fertilizers and for metal treatment
Phosphorous	N/A	Used to make matches and other incendiaries, reacts with water	unknown but very small
Propylene Oxide	Dow Sarnia	used to make polyether polyols, propylene glycol, propylene glycol ethers & carbonates	usually consumed where it is prepared
Sodium Hydroxide	N/A	largely used in paper making, cleaning and food prepartion	chloralkalii plants in Sarnia & Cornwall closed
Sodium Hypochlorite	N/A	used as a household bleach and disinfectant, diluted and sold in small containers	produced in conjunction with chloralkali plants
Styrene	NOVA , Sarnia	produced as a petrochemical monomer for resin production	shipped widely to polystyrene and other resin plants
Sulphuric Acid	large plants at smelters	largest tonnage industrial chemical used in world	unit trains supply large storage terminal in Mid West
Urea	CF Industries, Courtright	derived from ammonia and carbon dioxide on site	Supplies Customers in Eastern Canada/ NE USA
Vinyl Chloride	Imperial Oil	Basic petrochemical feedstock and monomer	likely all used to make PVC in Sarnia
Xylenes	2 Sarnia Producers	Basic petrochemical feedstock and solvent	widely distributed by truck and some rail
Diesel Fuel	4 Ontario Refineries	transportation fuel	moved to large bulk terminals by Pipeline and to customers by truck
Ethanol	6 Plants mainly SW ON	largest use is for gasoline in Southern Ontario	from Ontario: Chatham, Alymer, Sarnia, Tiverton & Johnstown
Gasoline	4 Ontario Refineries	transportation fuel	moved to large bulk terminals by Pipeline and to customers by truck
Fuel Oil	4 Ontario Refineries	transportation fuel	moved to large bulk terminals by Pipeline and to customers by truck
Kerosene	4 Ontario Refineries	transportation fuel	moved to large bulk terminals by Pipeline and to customers by truck
Toluene	2 Sarnia Producers	Basic petrochemical feedstock and solvent	widely distributed by truck and some rail
Acetone	N/A	Solvent and a starting material for organic synthesis	Supplied to small volume consumers by truck, tote, drum and pail

Source: Dymock Associates

2.3.1 Class 3 - Flammable Liquids

Gasoline

Gasoline is the largest low flash fuel which is trucked throughout the area and its distribution depends very much on service station locations. Generally, gasoline will enter the GTHA area by pipeline and after having ethanol added at one of the four main terminals in the region will be distributed to service stations by truck. From the 2009 InfoCanada data, a total of 906 gas stations were identified which serve the GTHA area.

On the supply side, the key facilities are five large terminals located within the GTHA. Three terminals are located in close proximity to one another in North Toronto and each are associated with serving specific gas retailers. The north Toronto terminals are Shell Keele Street, Esso Finch Avenue and Sunoco Finch Avenue. Meanwhile, there is a Petro Canada Oakville terminal and also a Shell Terminal located in the Hamilton industrial complex. These main terminals are served largely by pipeline – so most of the “liquid” flow into the region is neither road nor rail (see Exhibit 32 in the rail section). The north Toronto complex is one of the largest distribution complexes in North America. If gas stations are assumed served from the closest terminal, the implication would be that 72% are served from North Toronto, 16% from Oakville and 12% from Hamilton. Reality may depart from these proportions to some extent.

In 2007, in Ontario, 12.3 billion litres of gasoline (Statistics Canada, 2008) was sold which works out to 8.98 million tonnes. Assume that 7 billion litres of that is consumed within the GTHA. The TCOD survey shows that average gasoline shipment size is 41,000 litres. This translates to 170,732 shipments for the year which is 570 shipments per business day within the GTHA. Gasoline shipments are noted as being more "point-to-point" in nature as opposed to tour-based in that a truck carrying a full load can likely service no more than 2 service stations before it needs replenishment.

If it is assumed that 75% of the demand for gasoline in Ontario is served by GTHA terminals, then the implication is that 9.22 billion litres must be served from the GTHA terminals and 2.22 billion litres of that must travel outside the GTHA. That volume translated to 210 shipments per business day for destinations outside that GTHA which are served by GTHA terminals. There are terminals in Sarnia and Ottawa, for example, which also shoulder some of the burden in Ontario.

It is worth considering also that large quantities of ethanol are trucked into the main GTHA terminals to act as a gasoline additive. About 9% of gasoline is ethanol. For the GTHA this amount would be produced at plants in Montreal, Johnstown, Collingwood, Aylmer, Chatham, Tiverton and Sarnia

Note that this discussion on gasoline is focused on movements between the main terminals and gas stations. As we see from the U.S. data in Exhibit 14, a considerable proportion of movements is linked to wholesalers and also there are networks of storage facilities known as "bulk plants" which make the distribution process a bit more involved. Because of more complex distribution, there may be instances where the same fuel is "moved twice" as it goes from terminal to bulk plant to end user. As a result, the shipment estimates above are likely to represent a lower bound.

Diesel

Diesel is the second most prominent hazardous material that is transported widely throughout the region and its main role is to power the enormous fleet of commercial trucks which move cargo within and outside the region. As the gas station is to gasoline, the cardlock is to diesel. Cardlocks are facilities maintained by companies such as Esso or PetroCanada which largely serve the refueling needs of diesel trucks. In 2007, it was estimated that 3.86 billion litres of diesel were consumed in Ontario (Statistics Canada, 2008). If it is assumed that GTHA terminals supply 2/3 of this amount then this implies 2.573 billion litres per year which originate in the same GTHA terminals which are relevant for gasoline.

The TCOD survey suggests an average shipment size of about 25,000 tonnes which is approximately 30,000 litres for diesel. Dividing average shipment size into total volume results in an estimated 85,766 shipments per year which are served from the GTHA or 286 shipments per day.

Other Flammable Liquids

The predominant high flash hydrocarbons distributed throughout the area are diesel (discussed above) and home heating fuel. While use of the former is increasing as goods movement by truck flourishes, home heating fuel volumes have been in decline. Households have been switching to natural gas and other alternatives in recent decades.

Many industrial solvents and chemicals are hydrocarbons and can be both low and high flash materials. Low flash solvents include mineral spirits, toluene, xylenes, styrene, toluene and rubber solvent. They are typically used for industrial processes or in resin manufacturing. Most large volume hydrocarbon streams are shipped by tank truck and include solvents of various boiling ranges and chemical structures. Depending on flash point, they should be treated as gasoline or diesel fuel in case of a spill.

Here is a list of other significant hydrocarbon movements that may impact the Credit Valley Watershed:

- Jet Fuel is trucked from the Vopak terminal in Hamilton Harbour to Pearson Airport and does cross the watershed. Larger volumes of this material are moved from a rail transload facility in Concord to Pearson and would not cross the watershed.
- Large quantities of naphtha and platformate are shipped daily from Montreal to the Clarkson Lubricants Plant by truck. Shipments can be up to twelve large tank trucks per day. These materials are essentially gasoline components and are handled as such.
- Up to 24 rail tank cars of vacuum gas oil, a waxy liquid, are shipped from Montreal daily to Oakville and cross the Credit Valley. These materials are low flash.
- The Suncor lubricant facility, located in Mississauga near the border with Oakville, manufactures significant volumes of low flash lubricant base stocks, mineral seal oils and commercial blended lubricants which are distributed worldwide by marine, rail and truck.

- Fibre Reinforced Polymer (FRP) resins which consist of a polymer dissolved in styrene are shipped by large tank truck in the GTHA to manufacturers of fiberglass reinforced plastic products such as boats, truck cabs etc. In the event of an incident, these would be treated as a hydrocarbon spill.
- Alkyds used for oil based paints and coatings are dissolved in hydrocarbon solvents and also shipped by tank truck.

2.3.2 Class 2 - Gases

Of course, the most prominent incident in recent memory of direct relevance for the watershed was the famous Mississauga train derailment of 1979 which involved compressed liquefied chlorine (CLC) gas but resulted in no fatalities. CLC is used for water treatment and as a bleaching agent for pulp. The latter use has declined with the use of newsprint. CLC production in the vicinity has declined as nearby plants in Sarnia and Cornwall have closed.

The major petroleum gas transported through the area is propane, with smaller amounts of butanes also moved by truck and rail from Quebec to Sarnia/Marysville, Michigan for fractionation and seasonal storage. When spilled these materials evaporate and only present a risk for fire and/or explosion. Petroleum gases are the most important of all gases which traverse the region.

Other gases, such as Compressed Liquefied Vinyl Chloride, are mentioned in Exhibit 13 and also details of gas loads intercepted by the MTO commercial vehicle survey are shown in Exhibit 31.

2.3.3 Class 8 - Corrosives

Corrosives cover a wide range of substances used for varied industrial processes and which will in many cases cross the watershed. Typically these substances are not produced in the GTHA but there will be varied manufacturing firms that consume the substances as inputs.

Inorganic acids including sulphuric, nitric, hydrochloric and phosphoric acids are all used in commercial operations. Sulphuric acid is the largest tonnage industrial chemical in the world. One of the biggest uses of sulphuric acid was alkylation and now that process is not carried out in the GTHA. Huge quantities of acid are shipped by unit train (a multiple car train loaded with one substance) to the US from Northern Ontario and Northwestern Quebec base metal smelters which convert SO_2 to sulphuric acid to reduce sulphur emissions. Those trains are bound for large storage facilities in the Midwest and pass through the Credit Valley. Chemtrade Logistics is a prominent firm responsible for these unit train movements. Sulphuric acid precursors, including SO_2 and oleum, are also shipped by rail for other industrial uses.

Nitric and hydrochloric acid are used in much smaller quantities and as a result are more typically delivered by tank truck, totes or even drums and pails as aqueous solutions. Hydrogen chloride can also be shipped as a condensed gas but movements are relatively small. Phosphoric acids are typically shipped in a manner to reduce acid weight and are primarily used in the manufacture of fertilizers.

Sodium hydroxide, an inorganic base, is another large volume chemical that is widely used. The material is a solid and easily handled. Caustic solutions are also shipped but only short distances since the solid form is more economical to transport. This substance is quite relevant in a watershed context because it reacts violently when exposed to water and is shipped within the region in fairly large quantities.

Eastern Canada currently has only one ammonia plant which is run by CF Industries at Courtright, Ontario near Sarnia. Ammonia is soluble in water and will increase the pH of any aqueous environments that it comes into contact with. The Courtright facility is an integrated system of plants based on a world-scale ammonia unit. In downstream plants, much of the ammonia is upgraded to produce nitric acid, ammonium nitrate and urea. In addition to agricultural purposes, the plant's products are also used in the mining industry, and to make pulp, paper, explosives, resins, textiles and other products. The plant serves customers in Ontario and the North East United States.

2.3.4 Other Transport Classes

A number of reactive organic compunds such as TDI (toluene diisocyanate), MDI (methylene diisocyanate), formaldehyde, acetic anhydride etc are both toxic and highly reactive. Typically these materials are shipped in chemical tank trucks with a maximum capacity of 10,000 U.S. gallons and in smaller packaging such as totes or drums. Because chemical manufacturing is being consolidated world-wide, the total quantities shipped are declining. A prominent Class 6 Toxic is Phenol but to the best of our knowledge, this substance is not manufactured in Canada. A near miss involving a Phenol load occurred on April 20, 2011 on Hwy 427 near the watershed. The truck ended up in the median but did not spill its toxic cargo. Substances such as phosphorous, mercury and butyraldehydes are certainly hazardous but are transported around the area in extremely small quantities.

2.4 Benchmarking of Dangerous Goods Movements

Data representing dangerous goods movements in Canada are less plentiful than in the United States. Therefore, it is a good idea to supplement our analysis with hazardous goods insight from the U.S. via the 2007 Commodity Flow Survey. This is a very large survey of firms aimed at understanding the nature of goods movement across the country. Hazardous materials are a specific sub-theme of targeted interest in the survey methodology. Luckily, the industrial geography of Canada has many similarities to that of the United States so insights gained from the U.S. will assist in Canada.

Exhibit 14, derived from the U.S. CFS is effective in showing that very few industries account for most of the hazardous materials that are transported. The table divides industries according to the North American Industrial Classification Code and is sorted based on tonnages shipped. The table does not take mode into account. Nearly 90% of the tonnages in circulation are related to petroleum, coal and chemical manufacturing and also wholesaling of petroleum and its products. The corresponding "shipping effort" percentages are also very high as captured by the tonne-km quantities. Another point worth noting is that much of the hazardous materials volume is originated by wholesalers, both on the petroleum products side and also the chemicals side.

Exhibit 14 US Hazmat Origin Characteristics Ranked by NAICS Code

NAICS Code	NAICS Code Description	tonnes 2007 (thousands)	tonnes Percent	tonne-km 2007 (millions)	tonne-km Percent	Average km per shipment
	Total	**2,024,050**	**100**	**472,238**	**100**	**154.5**
324	Petroleum and coal products manufacturing	844,315	41.7	187,008	39.6	185.1
4247	Petroleum and petroleum products merchant wholesalers	729,280	36.0	57,643	12.2	66.0
325	Chemical manufacturing	225,835	11.2	147,530	31.2	851.3
551114	Corporate, subsidiary, and regional managing offices	66,127	3.3	25,935	5.5	254.3
4246	Chemical and allied products merchant wholesalers	58,543	2.9	18,707	4.0	130.4
45431	Fuel dealers	43,379	2.1	2,571	0.5	35.4
4249	Miscellaneous nondurable goods merchant wholesalers	19,057	0.9	17,036	3.6	548.8
4931	Warehousing and storage	11,356	0.6	2,384	0.5	572.9
4238	Machinery, equipment, and supplies merchant wholesalers	5,469	0.3	879	-	95.0
311	Food manufacturing	2,000	0.1	2,872	0.6	1123.3
4245	Farm product raw material merchant wholesalers	1,930	0.1	199	-	29.0
4231	Motor vehicle and parts merchant wholesalers	1,602	0.1	289	-	S
327	Nonmetallic mineral product manufacturing	1,371	0.1	502	-	S
335	Electrical equipment, appliance, and component manufacturing	1,217	0.1	1,752	-	1324.5
4242	Drugs and druggists' sundries merchant wholesalers	1,197	0.1	466	-	S
4239	Miscellaneous durable goods merchant wholesalers	797	-	274	-	490.8
331	Primary metal manufacturing	754	-	493	-	782.1
4234	Commercial equip. merchant wholesalers	582	-	128	-	342.8
332	Fabricated metal product manufacturing	513	-	553	-	1313.2
4244	Grocery and related product merchant wholesalers	446	-	S	-	S
4236	Electrical and electronic goods merchant wholesalers	366	-	S	-	729.0
4237	Hardware and plumbing merchant wholesalers	256	-	S	-	78.9
4248	Beer, wine, distilled alcoholic beverage merchant wholesalers	253	-	S	-	S
326	Plastics and rubber products manufacturing	82	-	118	-	1577.2
339	Miscellaneous manufacturing	82	-	S	-	2362.5
4241	Paper and paper product merchant wholesalers	76	-	6	-	593.8
313	Textile mills	10	-	S	-	S
4541	Electronic shopping and mail-order houses	8	0.0	10	-	1622.2
4232	Furniture and home furnishing merchant wholesalers	3	-	S	-	135.2

Note: *S=Suppressed

While the U.S. Commodity Flow Survey does not provide hazmat shipment totals for metropolitan areas, it does provide this information for individual states. Data are provided for shipments originating from each state and shipments destined for each state. The data are across all modes and pipeline is included. Examination of this data suggested that hazmat shipments, with some exceptions, are strongly related to population. A basic set of regression models was estimated which expressed hazmat tonnage by state as a function of population.

Exhibit 15 State-Level Regression Models for Hazmat Tonnage Originated

	origin model (a)	origin model (b)	dest model (a)	dest model(b)
constant	2,761,262	-	3,305,856	-
population	5.08	5.30	5.09	5.36
r-squared	0.77	0.77	0.85	0.85

The resultant models are shown in Exhibit 15 above, where it can be seen that there are two models for the states as hazmat origins and two for the states as hazmat destinations. In both cases, one model is specified with a constant and one without. The key insight is that the model based solely on population explains 77% of the variation in hazmat shipments in the origin case and 85% of the variation in the destination case. Another rule of thumb derived from the parameter on population is that approximately 5 tons of hazmat per year is generated per person.

Clearly, population is only a proxy variable since hazmat shipments are directly related to industrial activity but the result is useful. One important note is that the states of Texas, Louisiana and Florida were not used to build these models because they are clear outliers. The first two states generate far more in hazmat movements than their populations would indicate and the latter state generates far less. Texas and Louisiana are the centres of the petrochemical industries in the United States while Florida is a major tourist and retirement destination. Other state-specific patterns are evident for other states but did not result in the exclusion of other states from the models. The inclusion of the data for Texas, Florida and Louisiana as observations in the model had the effect of reducing the r-squared to below 0.5.

While the models of Exhibit 15 are state models, it is possible to insert populations of metropolitan entities in the equations to derive hazmat estimates. The models are based on a fairly large number of state observations and a majority of the state populations are actually less then metropolitan areas the size of the GTHA. Also, we know that hazmat shipments are largely a metropolitan phenomenon in terms of where they originate and terminate. On this basis, using a population of 6.54 million for the GTHA, we would expect our region to originate approximately 35.8 million tons or 32.6 million tonnes of hazmat. On a similar basis, the GTHA would be estimated to receive 36.6 million tons or 33.1 million tonnes of hazmat. In both cases, bear in mind that the majority of shipments would begin and terminate within the GTHA. The two models with constants were used to generate these estimates. Since these estimates would include pipeline, which we know is a significant factor for the GTHA, these estimates could probably be taken as upper bounds on annual hazmat tonnage.

The CFS does provide information on the origination of commodities by metropolitan area and by SCTG code but the shipments are not specifically identified as hazmat. In Exhibit 16, which is expressed in thousands of tonnes per million people, the set of SCTG codes that are most strongly identified with producing hazmat are listed along with estimates of the amount of each originated by metropolitan area. These metro areas are chosen so as to be somewhat comparable with the GTHA. The "S" values that show up in some cells indicate that the result was suppressed in the CFS.

Exhibit 16 Hazmat Tonnages by Selected US Metropolitan Areas and SCTG Code

SCTG Class	Denver	Miami	Phoenix	Chicago	Boston	Detroit	Philadelphia	Pittsburgh	Dallas	Cleveland
Gasoline and aviation	1,789	3,293	1,137	2,240	2,479	1,539	3,627	1,307	2,475	3,880
Fuel oils	2,346	S	735	789	1,400	S	S	429	1,445	980
Coal and petroleum products	375	383	305	1,478	S	692	S	779	1,040	S
Basic chemicals	137	53	266	726	S	273	976	714	239	S
Fertilizers	S	68	S	1,761	2	S	S	176	32	S
Chemical prods and preparations	229	91	146	630	243	150	281	646	446	894
Total	**4,876**	**3,888**	**2,590**	**7,625**	**4,124**	**2,654**	**4,885**	**4,050**	**5,677**	**5,755**

Note: *S=Suppressed

Certainly for gasoline and fuel oils, for example, we can be quite confident in the shipment being pure hazmat but for the likes of basic chemicals, this will not be the case. Bearing this caveat in mind, we see that somewhere in the range of 4-6 million tonnes of hazmat are generated per million people per year in the typical metropolitan area. For the GTHA, this range would correspond to totals of between 26.16 and 39.24 million tonnes. The midpoint of this range is quite consistent with our prior state-based origination estimate. Note also that for all estimates SCTG code 16, which is crude petroleum, is excluded from the CFS. For gasoline and aviation fuel, the most plausible range is between 1.5 to 3.5 million tonnes per million people, which corresponds to a tonnage range of 9.81 to 22.89 million tonnes for the GTHA. On the inbound side, this material would move largely by pipeline.

3

Trucking

For the movement of hazmat, trucking is certainly the dominant mode over shorter distances. On a number of shipments basis, the numbers for trucking will be far larger than for rail but this is less the case on a tonne-km basis where rail moves large amounts over large distances. The spatial patterns of truck hazmat movements will certainly be more complex than for rail in the sense that hazmat will move to and from more places and will be more associated with tour-based behavior. In this section, dangerous goods origin-destination matrices for trucking for the GTHA will ultimately be derived. The first step outlined is the derivation of a seven region zoning system that allows us to classify whether dangerous goods originating from, or destined for a range of locations would impact the Credit Valley Watershed or not. Subsequently, efforts are made to develop macro-level constraints for a few variables such as tonnage, tonne-km and vehicle kilometres travelled (VKT). Finally, the process to develop disaggregate estimates for the GTHA is traced out.

3.1 Developing a Zoning System to Determine Crossing of the Watershed

In Section 3 as a whole, a considerable amount of work is carried out to break down dangerous goods flows by origin and destination. Ultimately, this work is done so that we can trace out whether flows between certain origins and destinations would involve crossing the watershed. A set of disaggregate origins/destinations is available to us through the Census Metropolitan Area/ Census agglomeration version of the Canadian Business Patterns data set. These data are valuable in that they provide detailed sectoral business count/employment data for each urban node and for the current purpose because they capture all the major nodes across the country for shipments to originate or terminate. In particular, 144 cma/ca urban nodes are identified across the country.

A zonal system was derived so that for each origin/destination pair in the country, we would be able to make a determination as to whether the associated trip would be likely to involve crossing the watershed. Ideally, the zonal system would assist in this process for both trucking and rail shipments and in fact this has turned out to be the case. In Exhibit 17, the 144 urban agglomerations have been arranged into such a zonal system and the count of the urban centres in each zone is detailed to given an idea of composition.

Exhibit 17 Urban Agglomeration per Zone in Custom Zoning System

Region	CMA/CA Count
Toronto	1
Hamilton	1
Oshawa	1
Ontario SW	15
Ontario North	5
East	56
West	65

Toronto, Hamilton and Oshawa are isolated from the other 141 centres because they are so relevant and nearby for the watershed. Through a separate process, these three regions are put through a later, more exacting process to analyze patterns for specific origins/destinations within these three urban centres. For the other centres, which are further from the watershed, this finer level of detail is not necessary.

The largest set of centres is found in the west region. It is important to note that this region also includes most of the centres in Ontario which are north of the Muskokas. North Bay, Sudbury, Thunder Bay and some small mining agglomerations in the western reaches of Northern Quebec are considered to be part of the west zone because flows from there would need to access the GTA via the Hwy 400 corridor. Clearly, the west region includes centres such as Calgary, Winnipeg and Vancouver. Note that the assumption is made that dangerous goods movements which originate in Alberta, for example, and terminate in southern Ontario would make the trip through Canada as opposed to travelling through the United States. In essence, for such an example, we assume entrance to the GTA via Hwy 400 as opposed to Hwy 401 from Michigan.

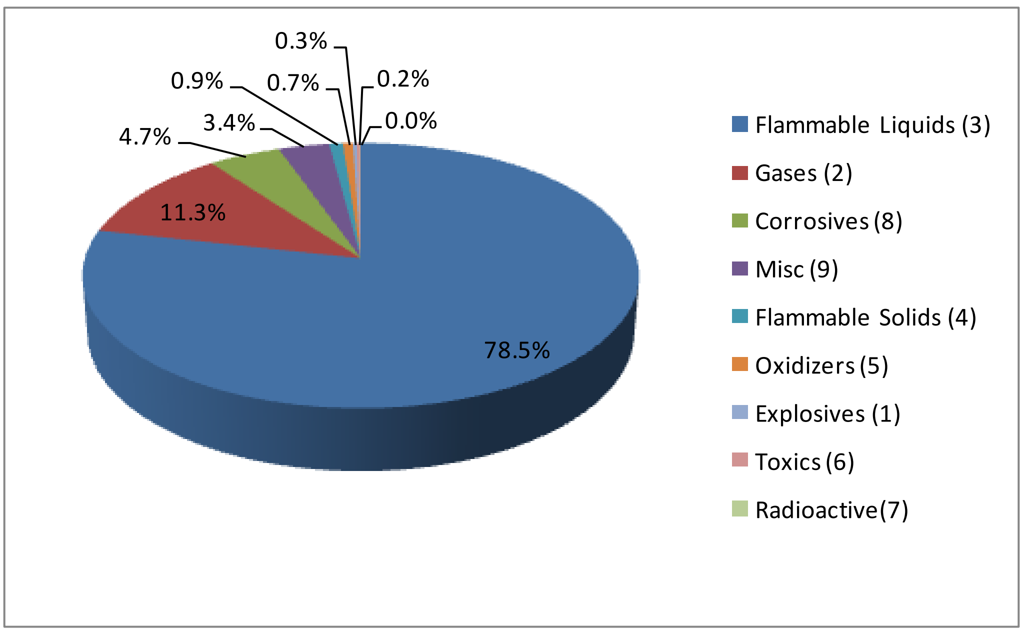
The second zone in terms of number of centres is the East Zone. The purpose of this zone is to isolate all the flows that would approach the GTHA for the Hwy 401 East corridor from Montreal. There are many Ontario centres in the east zone such as Ottawa, Kingston, Belleville and several others. In addition, the east zone is intended to capture flows from all the urban centres in Quebec and the east coast provinces.

The main purpose of the Ontario South West zone is to isolate flows that would tend to cross the watershed from the south and west via Hwy 401, Hwy 403 and the QEW. There are 15 centres in this zone including places like Windsor, London, Kitchener-Waterloo and centres in the Niagara region. The Ontario North zone is a minor zone with not a lot of industrial activity. It includes Barrie, Owen Sound, Collingwood, Orillia and Midland and was included mainly to separate more distant flows from the west region from these centres which are much closer to the watershed. Effectively though, these centres probably could have been assigned to the west zone as the main corridor of entry in the GTA is Hwy 400 as is the case for the western centres.

3.2 Tonnage

Section 2.4 worked towards answering the question of total hazmat tonnages for the GTHA irrespective of transport mode. The current objective is to derive this total for trucking.

Exhibit 18 US Hazmat Tonnages by Dangerous Goods Classes



One useful graphic is Exhibit 18 which is derived from the U.S. CFS and shows the trucking tonnages by hazard class for the U.S. (CFS, 2007). Note that the classes are numerically labeled in the legend. The only real significant trucking tonnages in relative terms are Class 3 flammable liquids and Class 2 Gases. All other classes are associated with shares that are minor in comparison. Of course, tonnage in and of itself does not provide the entire picture but the fact that 78.5% of hazmat truck tonnage across the U.S. is Flammable Liquids is a useful quantity to keep in mind for the GTHA in estimating total hazmat tonnage.

Approach based on TCOD Toronto CMA data

Given that the TCOD survey does not cover the universe of truck movements, one issue is the relative importance of private fleets and owner operators. In Exhibit 19 below, which has been derived from raw CFS data, we see that in the U.S., private fleets play a substantial role in moving dangerous goods. For example, in the movement of gases by truck, private operators dominate and they predominate in the movement of the large flammable liquids category. Bear in mind that this table covers all movements whereas we are focused at present on intra-metropolitan movements. In general, private fleets are more prevalent at the intra-metropolitan scale than at the inter-regional scale which is more the domain of for-hire trucking. While the results in Exhibit 19 indicate, if anything, that private fleets are more important than for-hire for the movement of hazmat, we will assume equality for the purposes of this analysis.

Exhibit 19 US For-Hire versus Private Movements of Dangerous Goods by Class

Hazard Class	Tonnes 2007 (thousands)	Tonnes Percent	Tonne-km 2007 (millions)	Tonne-km Percent	Average km per shipment
Class 1, Explosives					
Total	2,732	98.9	1,253	94.2	726
For-hire truck	732	26.5	914	68.8	1,387
Private truck	2,000	72.4	337	25.4	174
Class 2, Gases	-		-		
Total	123,318	54.3	30,243	37.5	66
For-hire truck	22,399	9.9	16,172	20.0	391
Private truck	100,920	44.4	14,070	17.4	50
Class 3, Flammable Liquids	-		-		
Total	856,629	53.9	81,662	30.8	97
For-hire truck	362,762	22.8	44,417	16.8	269
Private truck	493,866	31.1	37,247	14.0	48
Class 4, Flammable Solids	-		-		
Total	9,749	52.7	1,899	23.5	295
For-hire truck	6,418	34.7	1,222	15.1	435
Private truck	3,329	18.0	S	S	148
Class 5, Oxidizers and organic peroxides	-		-		
Total	7,115	52.4	3,212	31.3	409
For-hire truck	4,100	30.2	2,529	24.7	821
Private truck	3,015	22.2	683	6.7	127
Class 6, Toxic (poison)	-		-		
Total	2,677	26.2	1,240	15.0	396
For-hire truck	2,190	21.4	1,130	13.7	702
Private truck	487	4.8	111	1.3	95
Class 7, Radioactive materials	-		-		
Total	454	97.1	39	73.0	48
For-hire truck	15	3.0	22	41.5	715
Private truck	440	94.1	18	31.5	48
Class 8, Corrosive materials	-		-		
Total	51,769	49.9	21,584	33.3	217
For-hire truck	28,858	27.8	18,070	27.9	694
Private truck	22,912	22.1	3,513	5.4	92
Class 9, Miscellaneous dangerous goods	-		-		
Total	36,741	64.1	10,700	31.9	336
For-hire truck	21,653	37.8	7,923	23.6	488
Private truck	15,088	26.3	2,777	8.3	161
All Classes					
Total	1,091,185	100.0	151,833	100.0	
For-hire truck	449,126	41.2	92,399	60.9	
Private truck	642,058	58.8	58,755	38.7	

Statistics Canada, via the most recent TCOD survey, has provided MITL with tonnages and number of shipments for specific hazmat substances within the Toronto Census Metropolitan Area (CMA). In Exhibit 20 the "to" column includes shipments that have the CMA as destination but originate from outside the CMA. It also includes shipments with origin and destination within the CMA. The "from" column captures only those shipments that originate in the CMA for destinations outside the CMA. The "all" column captures the tonnages for all shipments related to the CMA although it would seem to omit pass-thru shipments with neither origin nor destination in the CMA. These figures are based on averaging out six years of data which show significant variation across years at the substance level.

Exhibit 20 Toronto Annual TCOD Estimates of CMA Dangerous Goods Tonnage by Substance

Substance	TO	FROM	ALL
Gasoline and Aviation	1,650,896	1,177,805	2,828,701
Fuel Oils	445,207	281,977	727,184
Sodium Hydroxide	33,613	19,865	53,478
Phenols	35,279	1,353	36,632
Organic acids	22,015	12,177	34,192
Acyclic Alcohols	24,942	5,422	30,364
Crude Petroleum	11,900	16,902	28,802
Chlorine	9,048	2,677	11,725
Cyclic Hydrocarbons	3,909	1,608	5,517
Acyclic Hydrocarbons	2,851	2,453	5,304
Sulphuric acid	2,839	1,520	4,359
Hydrochloric Acid	1,479	934	2,413
Kerosene	182	1,080	1,262
Calcium Carbide	0	0	0

Using Gasoline and aviation, fuel oils and cyclic hydrocarbons (i.e. benzene, toluene, xylenes, styrene) as a surrogate for flammable liquids the total is 3.590 million tonnes. Scaling up based on population, to allow for the fact that the CMA is smaller than the GTHA, results in 4.279 million tonnes. Doubling the amount to account for private trucking and omission of small for-hire firms yields an estimate of 8.559 million tonnes of flammable liquids. Using the U.S. proportion that 78.5% of hazmat tonnage is flammable liquids leads to a hazmat estimate of 10.9 million tonnes for the GTHA related to trucking. Gasoline consumption numbers from section 2.3.1 are quite consistent with the estimate for flammable liquids. Overall though, the tonnage estimate would seem to define a lower bound relative to other information.

It is worth commenting on Exhibit 20 further in terms of what it tells us about the relative transport importance of each substance. The most striking thing is that the tonnages of all substances are quite trivial relative to gasoline and aviation and fuel oils. For many substances other than the main two, the daily number of truckloads within the GTHA would possibly translate to single digits. And then, only a portion of those would be likely to cross the watershed. Calcium Carbide is included in the table simply to remind us that the results are based on a survey and are not fact. This substance is used in steelmaking, an industry that is certainly relevant to the GTHA, so it is unlikely that this substance is not moved in the area.

Approach Based on Aggregated Spatial Logit Model

For another approach, a TCOD-based table provided in Provencher (2008, Appendix D, p. 7) is useful for the work on tonnage. This table captures inter-provincial tonnages relating to for-hire trucking within Canada and also truck-based trade of hazmat with the United States and Mexico. A unique process was followed to derive tonnage estimates at the sub-Ontario level.

This process to take tonnages down to the level of the GTHA has been carried out via the aggregated spatial logit model Kanaroglou & Ferguson, 1996). While a description of the entire process is beyond the scope of this report, the technique is based on discrete choice modelling where the tonnages that flow between provinces are seen as the outcome of a choice process undertaken by shippers. What is unique about the aggregated spatial logit model is that the actual choice information is always at a higher level of aggregation than the explanatory variables that drive the model. In the current example, the choice information (tonnage flows) are inter-provincial while the explanatory variables (drive distances and employment variables) are at the level of the Canadian urban agglomeration. The key urban dataset for this task was detailed North American Industrial Classification (NAICS) data that outlined employment data by detailed sector of employment for 144 distinct urban agglomerations in Canada. From these employment data, a variable was defined which captured total employment in each of the 144 areas for the key hazmat sectors. To define the distance variable, a matrix of drive distances was developed which captured the distances in kilometres over the road network between all combinations of the 144 urban areas.

While it might seem unusual to calibrate a national model on truck movements when our interest is primarily within the GTHA, the use of hazmat flows between all the provinces results in a stronger overall model. We can have more confidence in our intra-Ontario predictions because the overall model makes use of all available flow information. In fact, the overall model could not be calculated solely on Ontario as there is inadequate tonnage information.

Exhibit 21 Ontario-Focused Estimates of For-Hire Trucking Hazmat Tonnages

Region	toronto	hamilton	oshawa	ont sw	ont north	east	west
toronto	10,336,282	1,237,013	228,850	1,182,086	124,812	542,819	140,756
hamilton	857,459	329,991	6,396	191,891	15,566	61,839	19,875
oshawa	143,986	3,621	84,904	29,053	13,149	76,044	9,348
ont sw	641,664	177,079	26,848	1,693,443	52,582	265,569	91,641
ont north	51,013	11,718	13,649	63,537	153,085	82,432	21,070
east	334,745	56,806	82,292	317,663	113,491	19,957,453	198,774
west	83,137	18,917	11,635	109,486	27,724	185,463	56,535,469

The key tabular result of the exercise is shown in Exhibit 21 above where hazmat tonnages for a regional and national system focused on the GTHA has been calculated. Note that the results are presented in the zonal classification system that was described in some detail in Section 3.1. The known totals in the inter-provincial matrix from TCOD have been preserved as constraints but sub-provincial flows, such as those between Toronto and the rest of Ontario have been estimated. The three major urban centres recognized in the NAICS data which make up the GTHA are Toronto, Hamilton and Ottawa. While tonnage flows between these centres are estimated, a primary number of interest is the summation of the nine cells between the three cities. The total of 13,228,502 tonnes is the estimated annual intra-GTHA flow of hazmat relating to for-hire trucking. This is in comparison to the total of 56.5 million tonnes which flows within the western region of Canada and 97 million tonnes relating to the entire matrix.

For annual inflows into the GTHA from the rest of Canada, the total estimated tonnage is 1,509,503 with the majority of that arriving from other parts of Ontario. For outflows, the estimate is 2,407,238 tonnes of which 1,556,557 of that is destined for other parts of Ontario. While not shown in Exhibit 21, from the U.S. there are inflows of 1,646,581 tonnes into Ontario and to the U.S. there are outflows of 3,037,549 tonnes. These flows are split to estimate the actual interactions with the GTHA as opposed to Ontario.

Of the seven regions captured in the table, five relate to Ontario. Apart from the GTHA regions, two Ontario regions outside the GTHA have been formed and are composed of that subset of the 144 urban agglomerations which are within Ontario but outside the GTHA. A 144 by 7 lookup table was defined which maps each of the 144 centres in Canada to the 7 regions defined above including the grouped regions within Ontario. After running the process associated with the aggregated spatial logit model, a large matrix of tonnage flows of dimension 144 by 144 was defined. Using the newly defined lookup table and the large matrix, a simple application of matrix multiplication yielded the result in Exhibit 21.

One issue with tonnage in the TCOD is that total shipment weight is reflected. For pure hazmat cargoes, this does not pose a problem but for categories such as machinery, where the vast majority of a given load is not hazmat, the convention is problematic. A review of the "pure" hazmat SCTG codes suggests that approximately 80% of the tonnage covered nationally in TCOD resides in those codes. However, this percentage is heavily influenced by large trucking-based hydrocarbon flows in Western Canada. For Ontario, which is much more manufacturing based, we will assume 60%. This latter scaling factor is applied to the tonnages in Exhibit 19 in an effort to focus on those SCTG codes that are virtually 100% hazmat.

If we apply the .6 multiple in conjunction with a doubling associated with private fleets then the final total for intra-GTHA shipments is 15,874,202 tonnes or approximately 53K tonnes per typical day. Shipments that originate or terminate from elsewhere will raise this estimate. This 15.8M tonne estimate is considerably larger than the 10.9M tonne estimate that was derived from Exhibit 20. Both seem low relative to U.S. CFS benchmarks which admittedly were not focused purely on trucking. For total outflows from the GTHA to other places, we settled on a total of 4,807,806 tonnes and for inflows the total was 3,709,981. These of course are distinct quantities quite separate from the intra-GTHA flows.

One way to put this estimate into perspective is to express it in terms of full tanker trucks. The largest double trailer tanker trucks are capable of carrying up to 68,000 litres while the typical single tanker can carry up to around 35,000 litres. In the latter case this works out to about 25.55 tonnes. Thus, the total trucking hazmat tonnage for the typical day works out to about 2100 completely full single tankers were it to be carried entirely in tankers. We know of course that this is not the case and that hazmat shipments can often come smaller loads.

3.3 Tonne-kilometres

The Tonne-km quantity is one of the more useful ways of considering the total magnitude of shipping because the quantity captures the aggregate effort involved in moving goods. From the U.S. CFS, there are statistics on the percentage of tonne-km that are incurred by shipments less than 80km. While not perfect, this tool gives some lens through which to view hazmat shipments at the metropolitan level. There are probably some distortions to consider. For one thing, some metropolitan regions will be larger than 80km across. Also, these proportions do not strictly assume trucking but we will make the assumption that trucking constitutes the vast majority of shipments less than 80km. One other issue is that there may be trucking shipments of 200-400 km or more whose tonne-km are partly relevant to a metro area but which are omitted below.

Exhibit 22 Proportion of Originating Hazmat Annual Tonne-km that are Short Distance

SCTG Class	U.S. Total (Billions)	U.S. Total < 80 km (Billions)	Proportion
Gasoline and aviation turbine fuel	24.33	13.60	0.559
Fuel oils	20.31	9.71	0.478
Coal and petroleum products, nec	33.93	6.93	0.204
Basic chemicals	50.12	3.67	0.073
Fertilizers	19.52	1.62	0.083
Chemical products and preparations, nec	44.82	1.00	0.022

Nevertheless, it can be seen in Exhibit 22, based on the proportion field, that gasoline/aviation fuels and fuel oils are much more metropolitan-oriented than fertilizers and chemical products. The first class moves around in a given metro area largely to serve that area whereas fertilizers and chemical products may be serving as inputs in a city or region hundreds of miles away or more. It is interesting that there is much more variation in the total U.S. tonne-km figure (first numeric column) than there is in the U.S. total for short distance shipments (2nd numeric column).

To leverage the results from this table, some specific metro areas in the U.S. are examined for the hazmat tonne-km that they generate. Exhibit 23 is quite similar to Exhibit 16 earlier which was focused on tonnage for those main SCTG codes associated with hazmat. In particular, the tonne-km numbers are expressed in millions of tonne-km per million people and note that many of the entries are set to “S” which indicates data suppression. The figures are per million people to enable “apples to apples” comparisons between metropolitan regions. It is important to note that the proportions from the prior Exhibit 22 have been applied to scale down the tonne-km for localized shipments.

Exhibit 23 Hazmat Tonne-km Originations by Metro Area and SCTG Code

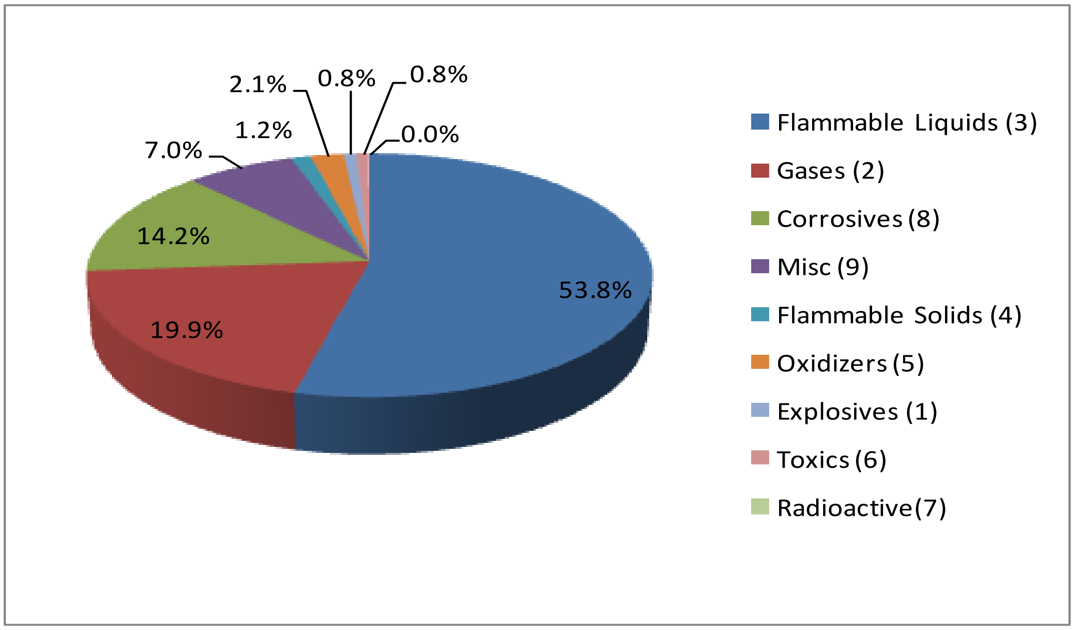
SCTG Class	Denver	Miami	Phoenix	Chicago	Boston	Detroit	Philadelphia	Pittsburgh	Dallas	Cleveland
Gasoline and aviation	68	103	134	71	84	S	S	33	185	117
Fuel oils	S	S	128	30	S	51	S	13	88	27
Coal and petroleum products	S	3	S	S	S	36	22	S	35	16
Basic chemicals	3	2	14	24	4	S	43	30	S	S
Fertilizers	S	S	S	172	S	S	S	5	S	0
Chemical prods and preparations	3	S	1	13	6	3	4	10	8	16
TOTAL	**73**	**107**	**276**	**310**	**93**	**89**	**68**	**92**	**315**	**176**

An unweighted average among these urban centres produces a total hazmat quantity of 165 million annual tonne-km per million people. For gasoline and aviation fuel, the average is 113 million tonne-km. For a metropolitan area the size of the GTHA, these figures would translate into annual totals of 1.079 Billion tonne-km for all hazmat and 0.739 Billion tonne-km for gasoline and aviation fuels. For a typical day, these figures are 3.60 million tonne-km and 2.46 million tonne-km for the GTHA.

An alternate approach is to utilize the SCTG level tonne-km figures that are available nationally from TCOD in Provencher (2008) and to apply the proportions in Exhibit 22 along with representing the GTHA as a percentage of national population. In Provencher, the five key SCTG categories 17 through 23 sum up to 15.23 Billion tonne-km nationally. If the proportions in Exhibit 22 are applied to each category, to represent shipments less than 80km, the tonne-km figure is reduced to 3.80 Billion. Given that the GTHA represents about 19.3% of Canada's population, the annual tonne-km figure that would apply for this region would be 734 million or approximately 2.45 million per day. Bear in mind that this total has not been adjusted upward for private fleet contributions.

One final approach builds on the work done in Section 3.1 for the disaggregation of the inter-provincial hazmat movements. From the 144 by 144 derived table of o-d flows between significant urban agglomerations in Canada, it is possible to make some inferences about aggregate hazmat tonne-km. In particular, the estimated disaggregate o-d matrix provides the tonnages and we are able to calculate a good approximation of the distances between the 144 locations referenced in the o-d matrix. For example, it is quite easy to estimate the drive distance between Vancouver and Toronto.

Exhibit 24 US Hazmat Share of Tonne-km by Dangerous Goods Class



One area of uncertainty though relates to the 144 intra-urban cells where the distances for a typical intra-zonal movement are not known. How far would the typical tonne within an urban agglomeration travel? By making different assumptions about this distance, it is possible to derive an estimate of aggregate VKT for the GTHA. Having defined the tonne-km for all cells, it is then required only to select those cells relevant to the GTHA. Assuming a typical shipment distance of 30km within urban agglomerations, the information available suggests that 5.7% of the hazmat tonne-km in Canada would be associated with movements within the GTHA which translates to 2.10 million tonne-km per day. Again, this would not include private fleets or internal/external flows. Assuming a 50km typical shipment distance, intra-GTHA tonne-km rise to 2.82 million per day.

In Exhibit 24 some further clarification about tonne-km is given from the U.S. CFS where it can be seen that flammable liquids defines the majority. One interesting aspect is that flammable liquids is much less dominant in tonne-km than it is with tonnage (53.8% versus 78.5%) and the shares for the other classes expand somewhat. The implication is that the movements of flammable liquids by truck are much more intra-urban oriented. In the case of the GTHA, a significant proportion is pipelined in and then distributed by truck around the metropolitan area. These U.S. distributions would appear to represent the same sort of dynamic.

3.4 Vehicle Kilometres Travelled

Any final o-d result and its associated trips can be characterized by the number of aggregate kilometres travelled (VKT) in completing those trips. VKT does have its problems in the sense that it is completely separate from shipment size. Moving 1 tonne a km is the same as moving 1kg a km. Nevertheless, we can use it as a guide.

Exhibit 25 Estimated Daily Goods Movement VKT by Selected US Metropolitan Areas

Metro Area	VMT	VKT	POP (2010)	VKT/POP
Los Angeles	6,880,364	11,072,873	12,828,837	0.863
San Francisco	2,741,858	4,412,593	4,335,391	1.018
Detroit	3,007,662	4,840,363	4,296,250	1.127
Atlanta	5,629,046	9,059,071	5,268,860	1.719

Initially, we derive a VKT estimate for all goods movement within the GTHA. Cambridge Systematics (2003) has provided a detailed breakdown of daily commercial VKT for selected metropolitan areas within the United States. Their presentation is one of the most detailed available regarding movements of commercial vehicles such as rental cars, school buses, taxis and public service vehicles among others. They have developed a categorization that relates to the movement of goods and which accounts for package, product and mail delivery, urban freight distribution and construction transport. In Exhibit 25, the goods movement totals for selected U.S. metro areas are provided. The original distances travelled are expressed in vehicle miles travelled (VMT) and we have translated to VKT. A ratio is developed relating metropolitan populations to metropolitan VKT. Taking the four metro areas as an average, the result is 1.18. Thus for the GTHA, the implied commercial VKT relating to the movement of all goods would work out to 7.72 million VKT per day.

Meanwhile, via Provencher (2008), the TCOD survey indicates that 5.15% of total for-hire trucking VKT is related to hazmat. Of course, this is a national percentage that is not adjusted in any way for metropolitan areas or for private fleets for that matter. Under the assumption that it is valid in the metropolitan context, and applying it to the 7.772 million goods movement estimate for the GTHA, the estimated hazmat VKT would be 397,889 within the metropolitan area.

An alternative estimate of GTHA hazmat VKT can be derived by starting with provincial estimates of VKT for all medium and heavy vehicle movements across the province. The Canadian Vehicle Survey (Statistics Canada, 2008) provides some benchmarks. It differentiates medium vehicles, those weighing from 4.5 to 15 tonnes, from heavy vehicles, those weighing over 15 tonnes. For the province of Ontario, for all movements, medium size vehicles are estimated to travel 1.788 billion VKT and heavy vehicles 9.265 billion VKT, which would work out to a combined amount of approximately 34 million VKT per day. The latter amount allocates some medium vehicle VKT to the provision of services as opposed to just moving goods. Given that we have already obtained a daily estimate of 7.772 million goods movement VKT for the GTHA and 34 million for the province, it could be concluded that 23% of Ontario's commercial goods VKT is travelled within the GTHA.

Again from the CVS, it is estimated that 4.65% of all VKT covered by medium vehicles is associated with hazmat shipments while the corresponding figure for heavy vehicles is 8.2%. If it is assumed that these national hazmat percentages can be applied to Ontario, then it can be estimated that medium vehicles are associated with 83.1 million VKT of hazmat while heavy vehicles are linked to 761 million VKT, both on an annual basis. Using a denominator of 300 business days to allow for weekend shipments the result for the typical day across Ontario would be 277,000 VKT for medium vehicles and 2.53 million VKT for heavy vehicles. Assuming that the 23% share can apply to hazmat and by vehicle type implies a GTHA medium vehicle hazmat VKT of 63,710 and a heavy vehicle hazmat VKT of 581,900 for a total VKT of 645,610. This estimate of GTHA VKT could be taken as an upper bound.

3.5 Cross-Border Movements

In section 3.2, which described estimates for hazmat tonnages, some discussion was provided about movements to and from the NAFTA partners based largely on the TCOD data sourced from Provencher (2008). Data for 2010 were also obtained from Statistics Canada originally collected by the Canadian Border Services Agency and relating to hazmat imports for particular substances of interest. Some of the results for rail are described in Section 4.1 but for now, a few observations are made about imports by truck.

Exhibit 26 illustrates the pattern of hazmat truck inflows by border crossing into Ontario and is based on tonnages. One of the surprising things is that the role of the Ambassador Bridge in Windsor appears to be trivial when it comes to moving hazmat. The reason is that all hazmat crossing at that point are required to use a truck ferry instead. The fact that this quantity is not zero suggests that some material is getting through, perhaps as less than truckload shipments. The bridge at Sarnia, which feeds more directly into the petrochemical industry and has no such restrictions, is very prominent. Both play a minority role compared to the crossings in Niagara and Fort Erie which lead to the QEW expressway. The pattern is very much different for rail where the flows from Michigan appear to be much more significant.

Exhibit 26 Prominent Ontario Ports of Entry for Dangerous Goods Imports by Truck

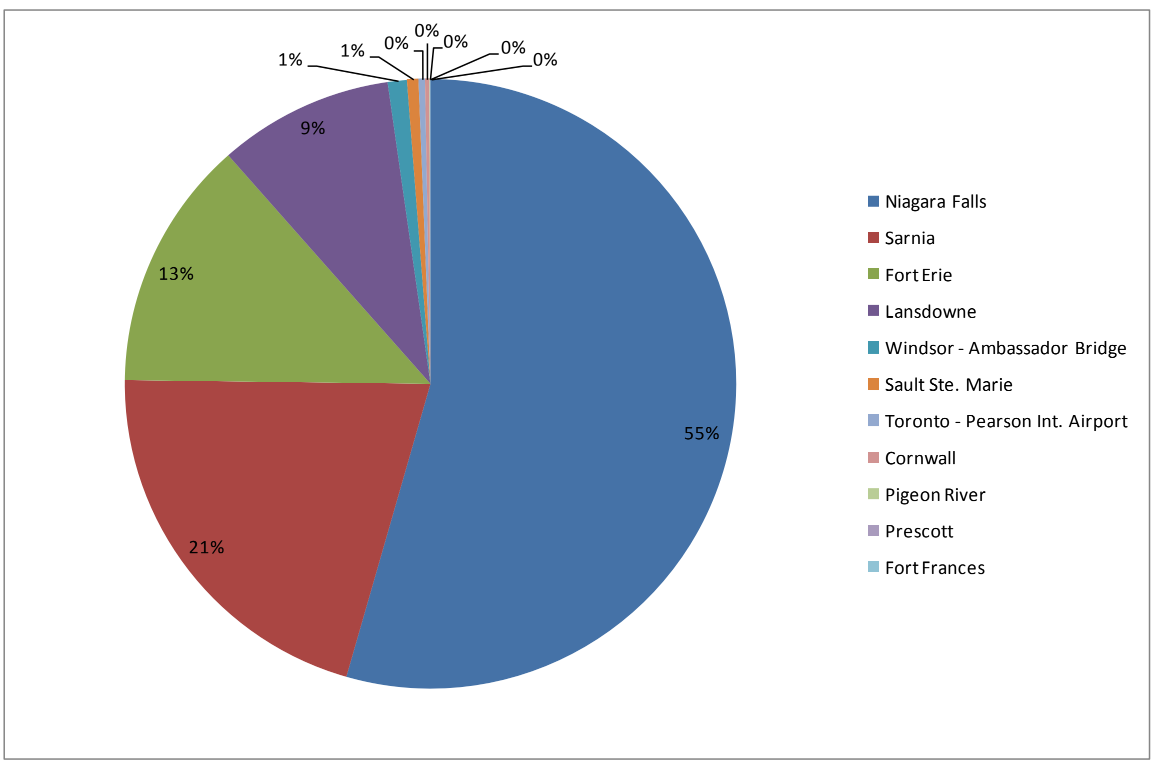


Exhibit 27 Prominent Substances Imported by Truck into Ontario (by tonnage)

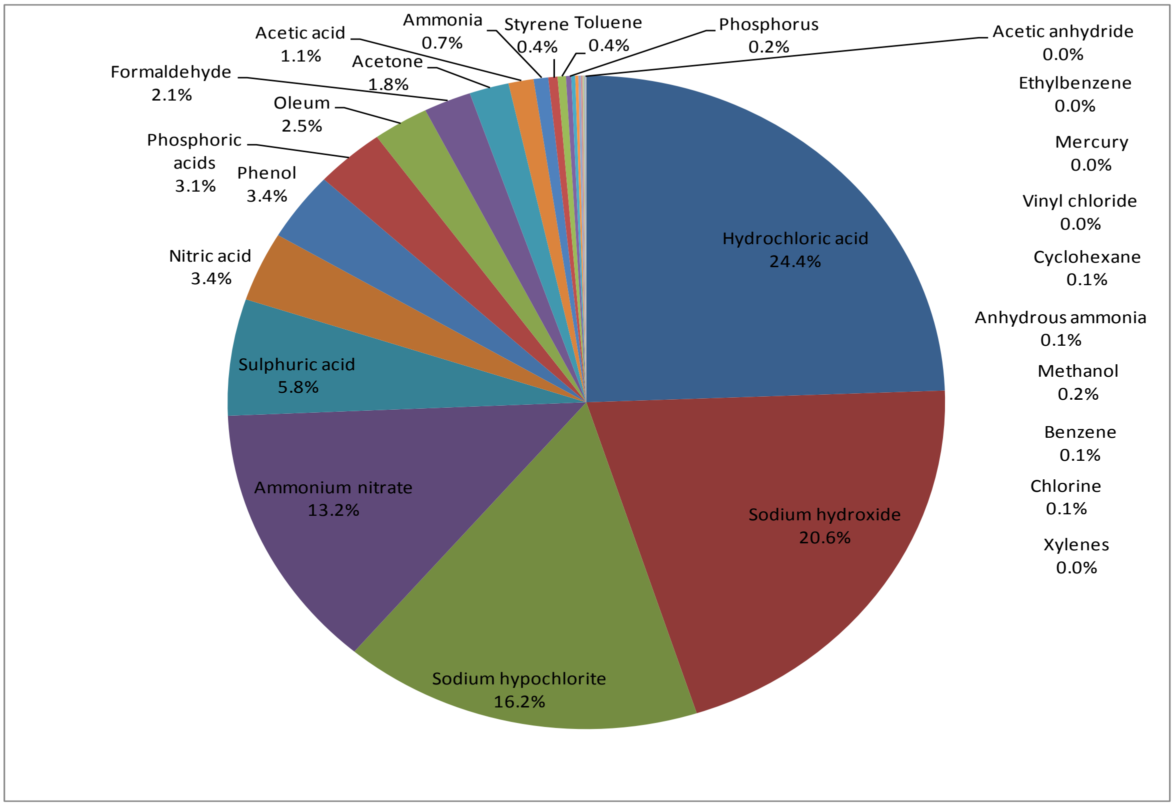


Exhibit 27 is not comprehensive for all hazardous substances crossing the border by truck but is fairly comprehensive for the most important ones. The selections are are based heavily on the list provided by CVC at the outset of the project. A total of 183,445 tonnes for 2010 are represented in the chart which is a fairly miniscule amount compared to the forecast hazmat movements within the GTHA. The dominant trucked substances crossing the border into Ontario are Hydrochloric Acid, Sodium hydroxide and Sodium hypochlorite.

3.6 Deriving a GTHA origin-destination table

In the earlier sections, the legwork for determining the high-level constraints for an origin-destination matrix has been completed. The purpose of this section is to outline the process for developing a 2252 zone by 2252 zone hazmat tonnage origin-destination matrix for the GTHA. The process used to infer dangerous goods movements at small levels of geography is speculative and is an estimate only. An initial basis for the process was the 2009 InfoCanada data which has been purchased for the GTHA and which contains information on about 185,000 establishments within the area. An effort was made to screen out those firms within the list which would be most associated with the movement of hazmat. This was facilitated by the fact that the data are coded by the Standard Industrial Classification although not the more recent NAICS system mentioned earlier. At the end of this process, a list of 2588 firms had been derived which were associated with 78,617 jobs.

This list of firms was treated as an essential input into a microsimulation framework that MITL had developed to estimate the movements of all commercial vehicles within the GTHA (Ferguson et al., 2010). Concepts from this GTHA framework in turn had been heavily based on the initial efforts of Hunt and Stefan in Alberta (Hunt & Stefan, 2007; Stefan et al., 2005).

The overall framework is based on the premise that intra-metropolitan commercial vehicle movements are tour-based. In other words, in conducting its intra-metropolitan duties, the typical truck will carry out a co-ordinated series of stops in the process of delivering or picking up goods or providing services. The simulation framework was also focused on trips generated in providing services but in the cases of hazmat, the interest is in a particular type of goods movements.

In the original framework, Peel Survey data was used to estimate tour originations per employee for the major types of firm establishments. InfoCanada employment data for each firm were applied against these Peel findings to generate an estimated figure for tours per firm. These data were aggregated across firms and the 2252 zones to develop a list of tour originations per zone. To develop the corresponding table for this analysis, the employment totals for the select list of hazmat firms was also aggregated to the zonal level and then a proportional analysis between the full employment set and the hazmat employment set was used to derive a set of tour origination totals for the hazmat firms. Tour totals for retail and service firms were set to zero as these would be the firms least associated with the movement of hazmat. With tour originations in place, the overall simulation framework was run as normal to generate a set of tours over the course of the day for each of the firms.

Thirteen distinct segments are utilized in the overall framework (e.g. service tours by service firms using light vehicles). For the current study, the decision was made to focus on goods tours by industrial and wholesale firms as these would be the segments most related to the movements of hazmat. The strategy was to derive a good relative pattern of tour movements and then use macro-level constraints such as VKT, tonnage and tonne-km to appropriately scale the trip matrix.

Upon scaling of the simulated o-d matrix, a total of 11,419 daily intra-gtha hazmat trips or movements was derived. By way of comparison, Gorys (1990) estimated about 18,000 distinct movements for Toronto. A number approaching the Gorys result is only possible, given our tonnage constraints, if relatively small shipments are included in the totals. Due to some uncertainty about small tonnage movements of hazmat, and the fact that we are not particularly focusing on them, the 11,419 total movements seems reasonable.

A total of 910 trips were estimated for inflows into the GTHA and 1181 trips were estimated for trips destined for outside the region. A specific allocation of those trips to appropriate GTHA gateways like the 401 and QEW, for example, was undertaken. In the case of flows to/from each of the 144 Canadian urban agglomerations, the appropriate gateway in each case was fairly obvious. For flows to/from the U.S. into Ontario, assumptions were made based on the hazmat border crossing data from Statistics Canada. Certain crossings into Ontario were associated with specific GTHA gateways.

Tonnages were distributed in proportion to trips so that each trip would receive the same tonnage. Clearly, this is not an ideal assumption. Some trips are small hazmat totes within a trailer and accompanied by non-hazmat cargo while other trips are large tankers full of gasoline. Another dynamic at play is that the first trip in a tour will have the full cargo, while the second trip on the tour might have only half the cargo. Since more tonnage is likely attributable to early legs on a tour, tonne-km would accumulate faster on those same early legs. Unfortunately, the data are not available to build this level of sophistication into the framework.

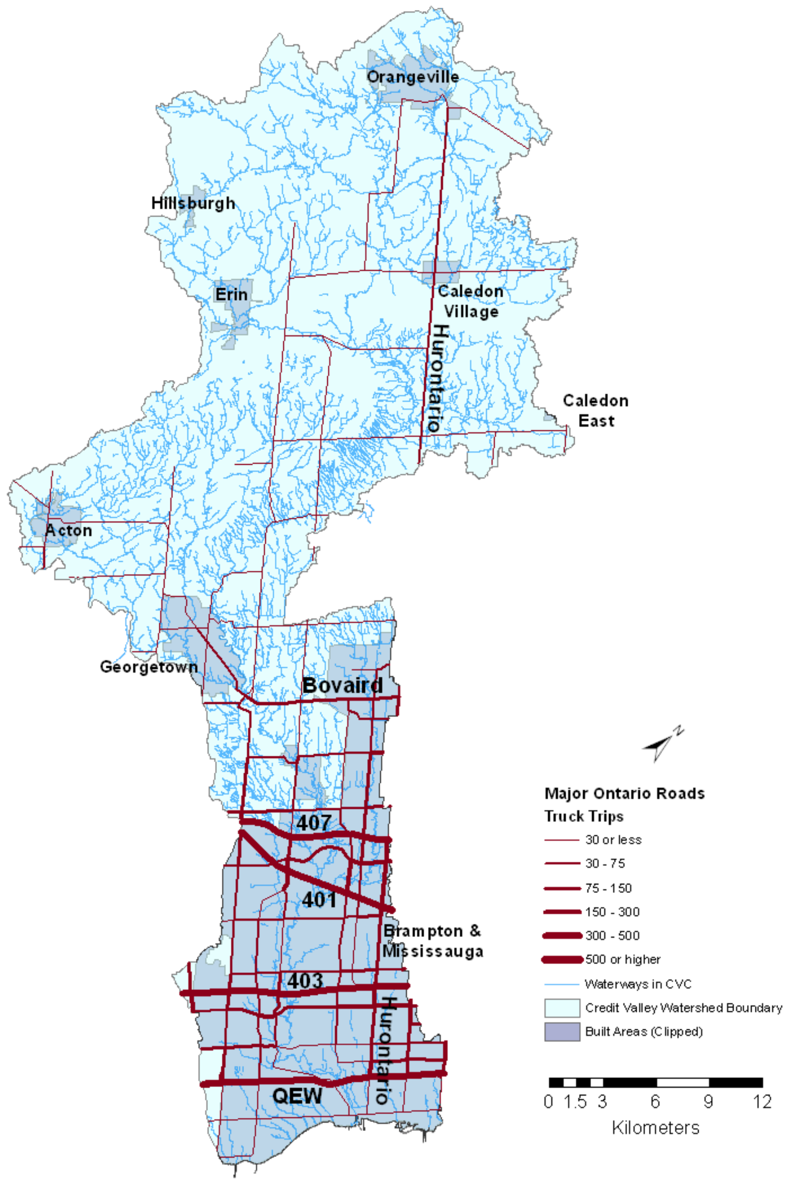
As mentioned in Section 3.1, the final intra-GTHA tonnage of trucking hazmat estimated is 15,874,202 per annum which works out to approximately 52,914 tonnes per day. Since drive distances between all the zones have been pre-calculated, it is possible to multiply the associated distance matrix element by element against the trip matrix to derive a total VKT of 261,632 which is very much on the low end of the top down estimates derived in section 3.3. Of this total, an estimated 66,397 is associated with trips exiting the GTHA and an estimated 52,957 is associated with trips entering the GTHA.

With tonnages distributed evenly across trips as described, for all categories of hazmat trips, the total tonne-km associated with the o-d matrix is 2,425,573 per typical day. This total is associated with an intra-GTHA total of 807,083; 715,545 tonne-km associated with trips entering the GTHA and 903,945 tonne-km associated with trips exiting the GTHA. These estimates for the GTHA are within the bounds derived in Section 3.3. The three tonne-km categories mentioned above are more or less in thirds compared to the overall total. Intuitively, it seems that the intra-GTHA component may seem a bit low.

Having derived tonnage estimates for the entire GTHA, one reasonable question is: what is the tonnage that actually crosses the Credit Valley Watershed? To do this we analyze the characteristics of the final o-d matrix and we remove the tonnage flows that stay east of the watershed and also those tonnage flows that stay west of the watershed. The remainder are flows that stay entirely within the watershed or else originate or terminate within the watershed. Recall that flows arriving in or leaving the GTHA have been taken into account in this large 2252 by 2252 o-d matrix.

Considering all tonnages that are associated with the GTHA in some way, we arrive at a total of 24.39 million tonnes per year or 81,306 tonner per day. Some of this will cross the watershed but some will not. In the end, we estimate that 29,522 tonnes per day will cross the watershed. The net result of this process is 16,588 tonnes per day or about 8.857 million tonnes per year that are estimated to "cross" the watershed by truck. This result suggests that a bit more than 1/3 of all hazmat tonnage to do with the GTHA involve the watershed in some manner by truck

Exhibit 28 Estimated Daily Dangerous Goods Trips within the Credit Valley Watershed



3.7 Traffic Assignment and Ranking of Travel Corridors

The fundamental ingredient for a traffic assignment algorithm is an origin-destination matrix. The painstaking process which we have used to derive such a matrix for total hazmat movements within the GTHA has been outlined in much of Section 3. In this section, we use the stochastic user equilibrium algorithm to assign the estimated trips to the road network fully taking into account where each trip starts and ends. Upon assigning trips to the road network, it is possible to actually rank the relative importance of the road travel corridors within the region for the movement of hazmat. It is important to bear in mind that the traffic assignment process is a model or a representation of reality and that the o-d matrix which it uses as an input is based on a large list of assumptions and educated guesses. With the relative scarcity of data for this project, there will no doubt be error in these predictions.

Exhibit 28 above gives a visual representation of the 24 hour assigned hazmat trips. The map clearly illustrates that the vast majority of hazmat movement is in the southern built up region of the watershed which is not surprising and that the 400 series of highways in the region are forecast to serve most of the demand.

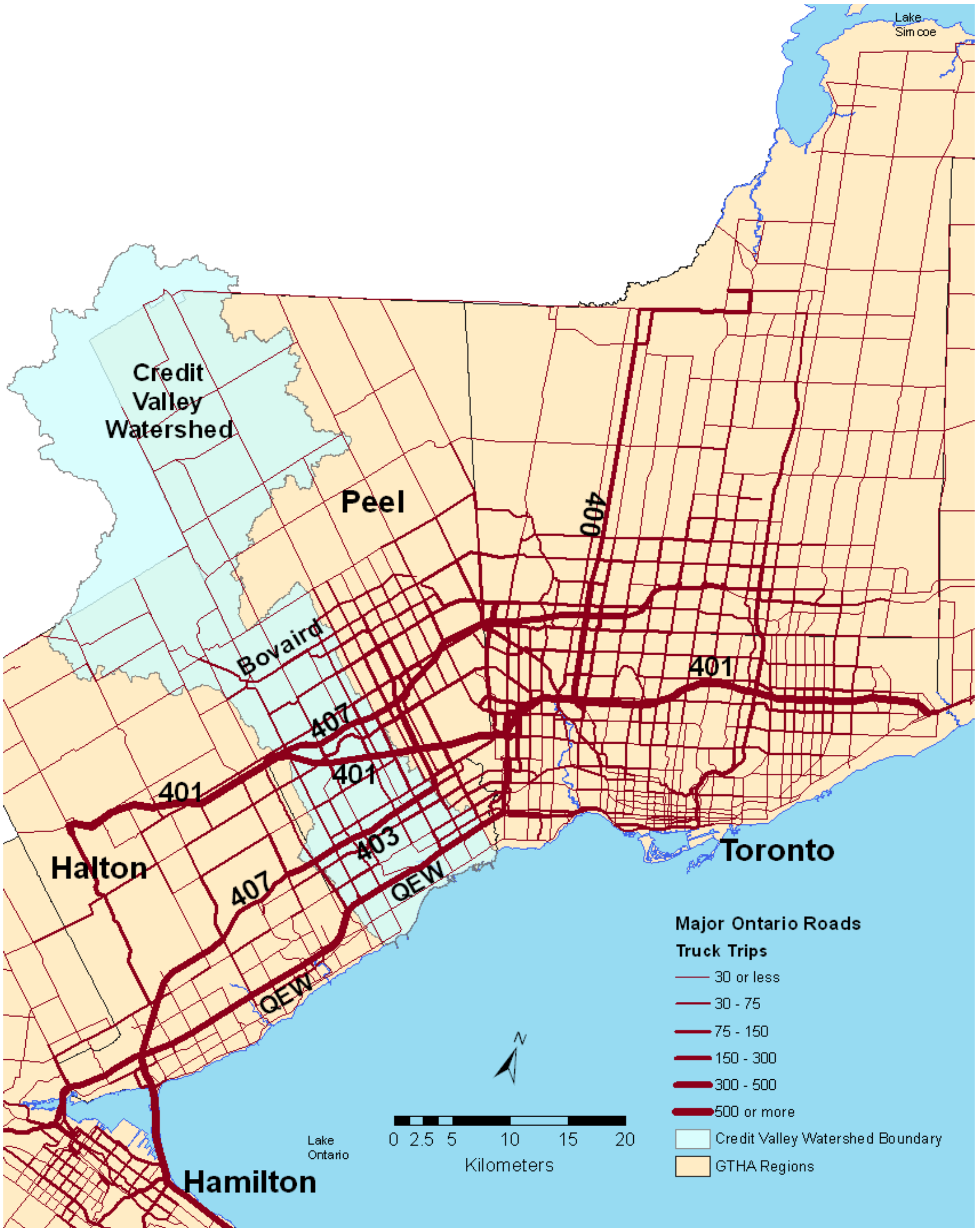
Exhibit 29 Estimated 24-Hour Hazmat Truck Volumes by Selected Traffic Links

Location	24 Hour Volume
Hwy 401	437
QEW	398
Hwy 407	328
Hwy 403	325
Hurontario St.	102
Bovaird Dr. W	89
McLaughlin Rd. S	78
Burnhamthorpe Rd W	75
Winston Churchill Blvd	63
Eglinton Ave W	55
Derry Road W	54
Queen St. W (Brampton)	51
Steeles Ave. W	46
Mavis Road	35
Mississauga Rd(near 401)	29
Mississauga Rd(near QEW)	27
Erin Mills Parkway	23
Mayfield Road	21
Dundas Street W	20
Sandalwood Parkway	16
Lakeshore Road	12

Exhibit 29 provides some specific results that provide a more precise frame of reference for the mapped information. The focus is on the road links as they cross the watershed. East-West links are sampled at a point about half way between Winston Churchill Blvd. and Hurontario Street which loosely define the east-west extents of the watershed. North-South links are sampled either between Hwy 407 and Hwy 401 or to the south of the 401.

As was seen in Exhibit 28, the largest flows are associated with the 400 series highways as they provide the easiest means of getting around. The estimate for the 407 is probably too high as tolls are not specifically taken into account in the traffic assignment and it is known that these have a large impact on route choice in commercial movements. All of the forecasts obtained for the northern watershed are very low. Partly this is because the hazmat flows likely really are low, but also the active road network for our traffic assignment does not cover the northern watershed very well. As a result, specific link results for that area are not reflected in Exhibit 29.

Exhibit 30 Watershed Dangerous Goods Road Traffic Relative to the GTHA



A complementary map to Exhibit 28 is shown in Exhibit 30. This map reports on the same volumes as in the watershed version but puts into the wider context of the wider area for which the o-d matrix derivation and traffic assignment process was carried out. While the hazmat volumes within the watershed are relatively high, the peak volumes are to be found to the east of the watershed in the area where Hwy 401 joins the Hwy 400 to Hwy 427. The peak hazmat flows in the region are estimated to occur on the 401 between Hwy 400 and Hwy 427 and reach nearly 1100 trips per day which is nearly three times the peak levels within the watershed. It is also worth noting that Hwy 410 is not far east of the watershed and is estimated to reach 24 hour volumes of 329 hazmat trips.

3.8 Validation

For the purposes of validating these results, MITL was able to obtain some snapshots from the Ministry of Transportation (MTO) 2006 Commercial Vehicle Survey (CVS). Three sites are considered in the received data: the 401 at Trafalgar Road, the QEW near Dorval Drive in Oakville and the 403 at Winston Churchill. The latter location is not at a true CVS intercept point implying that some work was done by MTO to infer the results. The 401 and QEW locations, of course, are not actually in the watershed but are close enough by to give a reasonable sense of hazmat volumes.

Exhibit 31 MTO CVS Hazmat Trip Breakdown by UN Number and Site

Substance	UN	Hwy 401	QEW	Total
gasoline	1203	42	92	134
petroleum gases	1075	78	24	102
diesel or heating oil	1202	19	29	48
flammable liquids	1993	19	15	34
sodium hydroxide	1824	25	9	34
corrosive liquids	1760	17	8	25
hydrochloric acid	1789	15	14	29
toxic flammable liquid	1992	11	13	24
paint related	1263	7	12	19
sulphur dioxide	1079	11	8	19
carbon dioxide	2187	18	3	21
petroleum distillates	1268	5	10	15
resin solution	1866	5	7	12
oxygen	1073	0	12	12
hazardous solid	3077	9	6	15
liquid argon	1951	4	7	11
liquid nitrogen	1977	0	8	8
wet batteries	2794	8	3	11
alcohols	1987	7	3	10
isopropanol	1219	6	1	7
corrosive liquid	3264	4	3	7
acetone	1090	5	1	6
corrosive liquids	3265	0	5	5
air bag inflators	3268	5	0	5
Total		**320**	**293**	**613**

Note: Some of the UN groups cover more than one compound

At the 401 site, 6,202 tonnes of dangerous goods are estimated to pass which is 3.6% of all commodity tonnage. At the QEW, 5,866 tonnes are estimated to pass which is 5.1% of all commodity tonnage. In terms of dangerous goods trips, the 401 site is estimated to accommodate 404 trips per day and the QEW 412 trips per day. BY way of comparison, the MITL results suggest 437 for the 401 and 398 for the QEW. Admittedly, the locations are not identical for the comparison of MTO and MITL results, but nevertheless, the findings suggest that the MITL results are very much of the right order of magnitude. For the 403, MTO suggests that the results are lower than for the other highways but requested that the absolute values not be shared.

In Exhibit 31, considerable detail is provided for various hazmat UN numbers which are obtained from truck placards at the time of survey. The results are provided for the 401 and QEW sites and provide the most detailed glimpse of the nature of the substances that are likely to cross the watershed. This table does not cover all the UN numbers that were captured, simply those that are most prominent in terms of trips. One thing that stands out is that the QEW is much more gasoline (class 3) oriented than Hwy 401 while the 401 is relatively more gas (class 2) oriented. For Hwy 401, roughly 1/3 of the tonnage is flammable liquids and another third is gases. At the QEW site, about 2/3 of the tonnage is flammable liquids. Based on the MTO breakdown Hwy 403 is much more similar to the QEW than the 401 in terms of substance classes.

Results can be further reconciled against some brief survey work that was carried out by MITL. A 30 minute count of tanker truck traffic was obtained at a pedestrian overpass of the QEW near Dixie Mall and from a good vantage point near the 401 at Mavis Road. Mostly the purpose was to get an idea whether our analytically obtained estimates appeared to be of the right magnitude. The brief survey was done prior to receipt of the valuable MTO CVS data.

The QEW vantage point was just to the east of the watershed but was thought to offer a reasonable approximation with the advantage of a good site to view the traffic. The 401 site was a bit further away from the traffic but adequate to count tankers. Of course, counting tankers has its problems. Some share of hazmat movements will be in relatively small amounts carried along with non-hazmat goods in non-tanker vehicles. The other problem is that a large share of tankers does not carry hazmat. They may be carrying food products or non-hazardous chemicals.

At the QEW site, a strong effort was made to differentiate placarded tankers from those with no placards. The placards identify the nature of the hazardous substance that a vehicle is carrying. If we rely on actual placard views then the tanker counts would be reduced substantially since few placards were observed relative to the number of tankers. Nevertheless, at the QEW site, from 1:40 to 2:10 in the afternoon a total of 34 tankers were observed travelling in both directions. At the 401 site, a surprisingly low total of only 16 tankers were observed between 3:10pm and 3:40pm. These figures omit tankers that were clearly carrying non-hazardous substances such as dairy products.

Previous work on commercial vehicle movements in the area suggests that about 6% of 24 hour trips might be expected to take place around that one hour time period during the day. If the empirical results are scaled up to 24 hours, taking into account the half hour counting period, the results are 1133 for the QEW site and 533 for the 401 site. Perhaps a more representative number is the average of the two which is 833. Our survey work illustrated clearly that tanker volumes will overestimate hazmat volumes by a substantial margin and that trucks really need to be intercepted, as is done in the CVS, to provide the most reasonable results.

Rail

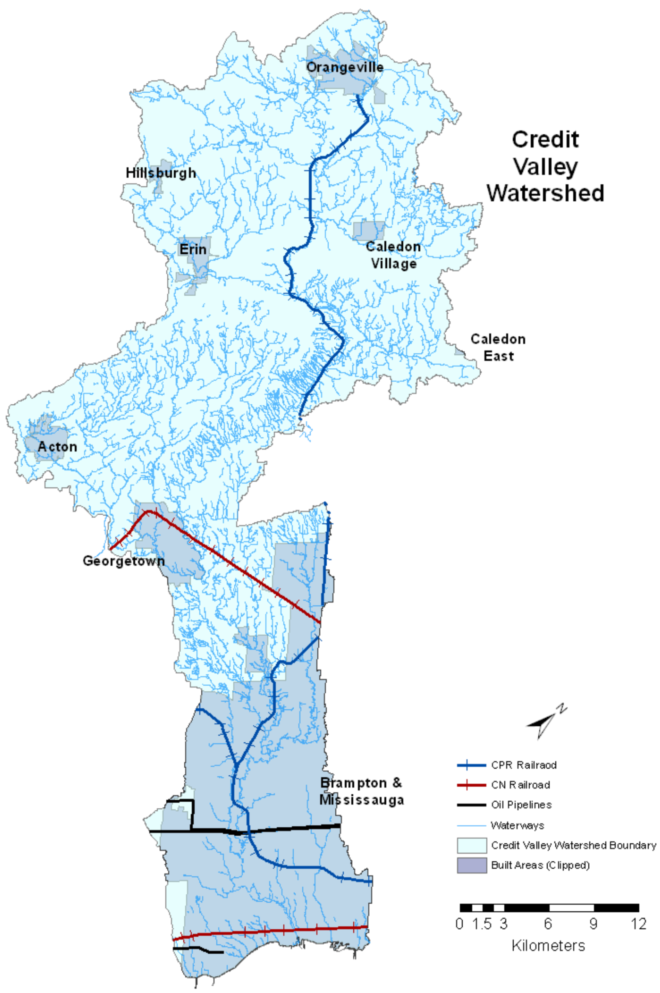
In some ways, the task to assess dangerous goods movements by rail is less involved because the networks involved are less complicated than is the case for road. Also, road involves a fairly involved interplay between urban arterial roads and major highways. With road, there are many more short distance trips. In terms of data, by far the most important sources are Transport Canada and Statistics Canada. The former is the recipient of compulsory detailed data from rail companies in Canada and the latter reports on rail movements with publications such as Rail in Canada (Statistics Canada, 2006, 2010) which is released each year, and monthly car loadings which is released 12 times a year. None of these data sources deal overtly with dangerous goods moved by rail, although there are certain insights to be gleaned and also, the level of geographical detail for these data sources is not finer than the provinces. The competitive interests of the rail companies and the need for some confidentiality are taken into account. Attempts to source data directly from CN and CP for this project were unsuccessful, especially due to the sensitive nature of movements involving dangerous goods.

Exhibit 32 outlines the CN and CP networks within the watershed and shows quite clearly that it is a good deal less complex, in a network sense, than the road network that covers the area. Exhibits 41 and 42 (see Appendix) show the two rail networks for a wider area to provide more context. This observation is related to the fact that rail is geared towards moving goods over long distances. With regard to the Lakeshore Route, CN is the owner but an agreement is in place which provides CP access.

Overall, there are three key lines that are crossing the watershed with two of them being south of Hwy 401. The CP line to Orangeville is not high volume. It is the other CP line which crosses the southern watershed which is the main line. Locations of key rail facilities which handle the trains are well-known and are largely to the east of the watershed. Examples include the CN Brampton and CP Vaughn inter-modal facilities and the CN McMillan yard which is in Concord, Ontario.

With this brief background in mind, the best source for dangerous goods movement in Canada is a Transport Canada report (Provencher, 2008) which was already exploited in the derivation of the road results. In that report, there are several tables that are focused on rail and these will be exploited in deriving estimates of tonnages flowing across the watershed. The discussion will largely focus on tonnage and the amounts that might be expected to cross on the typical day. Data are available in the same source to infer something about dangerous goods crossings in terms of number of carloads and trains. Since the data for that report dates back to 2004, an effort is made to check other more recent data to get an idea of potential changes since 2004.

Exhibit 32 Rail and Pipeline Crossing the Watershed



4.1 Dangerous Goods Rail Patterns

A good starting point for deriving localized rail tonnages of hazmat is Exhibit 33 below from Provencher (2008). This table illustrates flows for hazardous materials between the main regions of Canada for rail. Originally, this data will have been derived from waybill data which are provided to Transport Canada as a mandatory condition of moving freight by rail in Canada.

Exhibit 33 Inter-Regional Tonnages of Dangerous Goods (2004) (000's)

Region	Maritimes	Quebec	Ontario	Manitoba	Saskatchewan	Alberta & Territories	BC
Maritimes	174	69	34	2	2	7	0
Quebec	466	2,451	2,822	80	41	249	454
Ontario	270	1,204	1,197	185	79	669	608
Manitoba	0	49	462	28	13	19	64
Saskatchewan	5	32	33	79	40	37	31
Alberta & Territories	15	182	792	237	258	842	1,631
BC	22	742	1,353	60	21	331	743

It is evident from this table that the distance decay effect for rail is much less severe than it is for trucking. For example, we see that more hazmat moves from Ontario to Quebec than moves within Ontario. For trucking, the reverse would be true. The same goes for Quebec relative to Ontario. Some further insight is derived in Exhibit 33 which shows 2004 data (Statistics Canada, 2005) with more detail about specific substances and in reference to movements to and from Ontario. As well as being more focused on Ontario, the table provides detail on hazmat exchanges between Ontario and the NAFTA partners. The vast majority of that tonnage relates to the United States. Note that in the Rail in Canada report, dangerous goods are not specifically identified so it has been left to us to select certain product categories that are most associated with dangerous goods. There is a good possibility that at least some of the information will reflect goods that are not considered dangerous. For example, Exhibit 33 shows internal hazmat movements of 1.197 million tonnes of hazmat within Ontario whereas Exhibit 34 shows 1.339 million tonnes. Since Exhibit 33 is specifically linked to hazmat, we would defer to the former total as being more accurate.

Exhibit 34 Dangerous Goods Tonnage by Type to and From Ontario (2004)

from Ontario 2004	Atlantic	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	BC	NAFTA	Total
Gasoline and Aviation	0	2,745	38,168	0	0	93	95	86	41,188
Fuel Oils and Crude Petroleum	43,912	90,595	62,660	0	0	110	83	71,622	268,982
Gaseous Hydrocarbons	195,135	367,923	410,270	0	10	3	0	1,095,485	2,068,825
Other refined petroleum and coal	13,441	100,926	258,868	18,434	12,995	152,869	39,887	408,481	1,005,901
Sulphuric Acid	82,079	154,853	243,414	2,136	0	0	0	975,915	1,458,397
Other basic chemicals	54,807	224,822	217,790	22,321	9,576	50,176	29,541	627,495	1,236,527
Fertilizers	552	9,699	67,006	224	1,423	1,393	203	170,315	250,815
Other Chemical Products and Preparations	5,291	25,002	41,258	2,001	1,516	17,420	6,397	198,517	297,400
Total	**395,217**	**976,565**	**1,339,434**	**45,116**	**25,520**	**222,064**	**76,206**	**3,547,916**	**6,628,035**
to Ontario 2004									
Gasoline and Aviation	0	622,136	38,168	103,814	0	5,023	0	1,897	771,037
Fuel Oils and Crude Petroleum	242	651,354	62,660	226,547	0	56,178	9	167	997,158
Gaseous Hydrocarbons	17,629	50,805	410,270	8,673	234	82,342	0	65,200	635,153
Other refined petroleum and coal	334	29,398	258,868	91	611	57,331	240	243,418	590,290
Sulphuric Acid	973	20,888	243,414	2,016	0	0	67	50,265	317,624
Other basic chemicals	5,688	421,052	217,790	45,420	3,097	599,803	13,358	1,070,000	2,376,188
Fertilizers	0	1,738	67,006	46,601	52,757	248,500	361	327,217	744,180
Other Chemical Products and Preparations	465	3,029	41,258	696	0	3,390	1,948	178,690	229,475
Total	**25,331**	**1,800,400**	**1,339,434**	**433,858**	**56,699**	**1,052,567**	**15,983**	**1,936,854**	**6,661,105**

What are some other observations that can be made from this information? One very important observation is that international flows of dangerous goods are relatively much more significant for rail than they are for truck. In 2004, it appears that greater than 50% of movements of dangerous goods originations in Ontario by rail are destined for NAFTA partners. For movements to Ontario, the result is about 30% in 2004. The results need to be taken with some caution as we are not sure that the totals are purely hazmat. For Ontario exports to NAFTA partners, nearly two thirds of the total is explained by gaseous hydrocarbons (1.095 million tonnes) and sulphuric acid (0.976 million tonnes). For these two substances in particular, far more leaves Ontario for the NAFTA partners than arrives in Ontario from the partners.

A second major observation is that with the exception of Atlantic Canada, BC and of course the NAFTA partners, more dangerous goods appear to be flowing into Ontario from other regions than are flowing out. Gasoline, aviation fuel and fuel oils are of interest since they are so prominent for the road mode. Clearly, the substances are relatively less important for rail than they are for trucking and also, with respect to these substances, Ontario is much more of a destination than an origin for rail movements. The absolute totals for rail for these substances are actually quite trivial compared to the amount that moves by road.

Provencher (2008) provides information that leads to the development of Exhibit 35 for rail movements by the nine transport Canada classes. It is important to note that this figure reflects movements for all of Canada as opposed to Ontario only. With respect to tonnage it can be seen that the pattern is much more evenly distributed across the classes than is the case for trucking. Class 3 Flammable liquids is the most important class for rail as for trucking but not by a large amount over Class 2 gases. Class 8 corrosives is another important category. In comparing Exhibit 35 to Exhibit 34, there is little evidence that the national distribution holds for Ontario. In Ontario, movements of gases by rail appear to be relatively more important than flammable liquids in contradiction to the overall Canadian pattern.

Exhibit 35 Estimated Rail Tonnages by Dangerous Goods Class - Canada (2004)

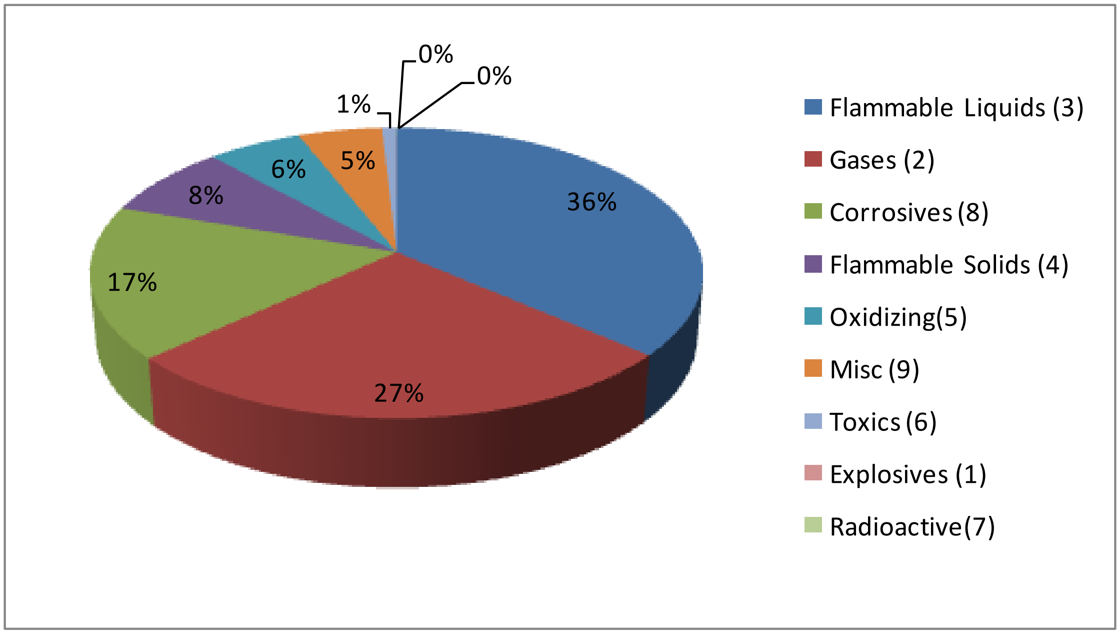


Exhibit 36 Prominent Dangerous Goods Imported by Rail into Ontario (by tonnage)

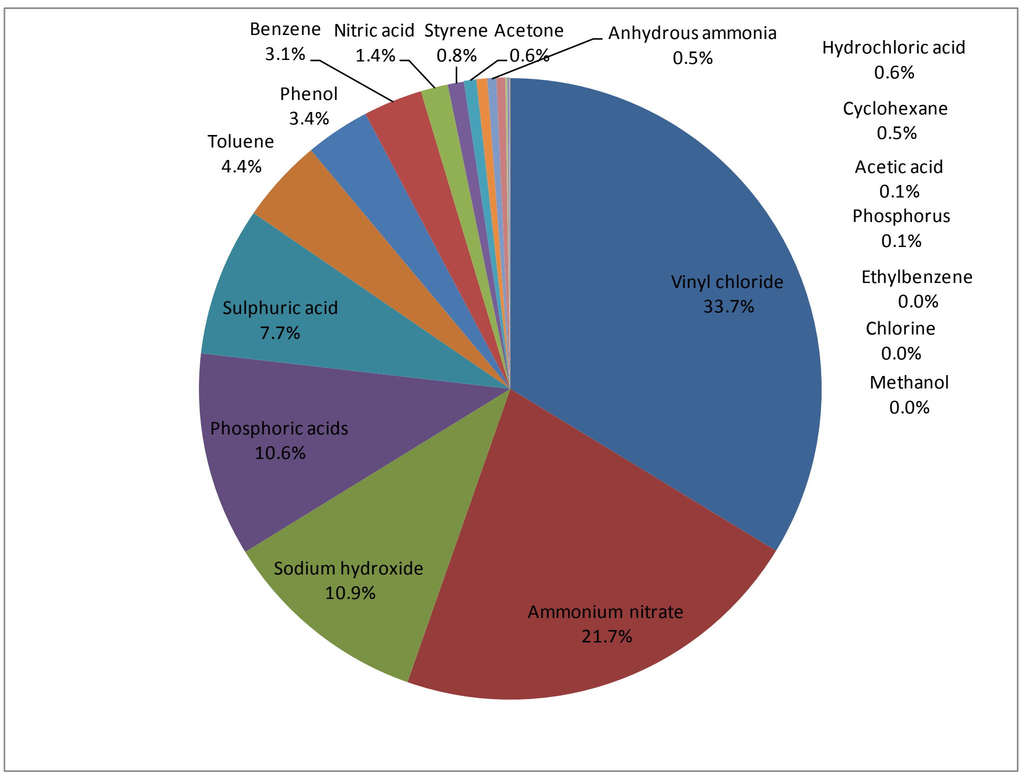
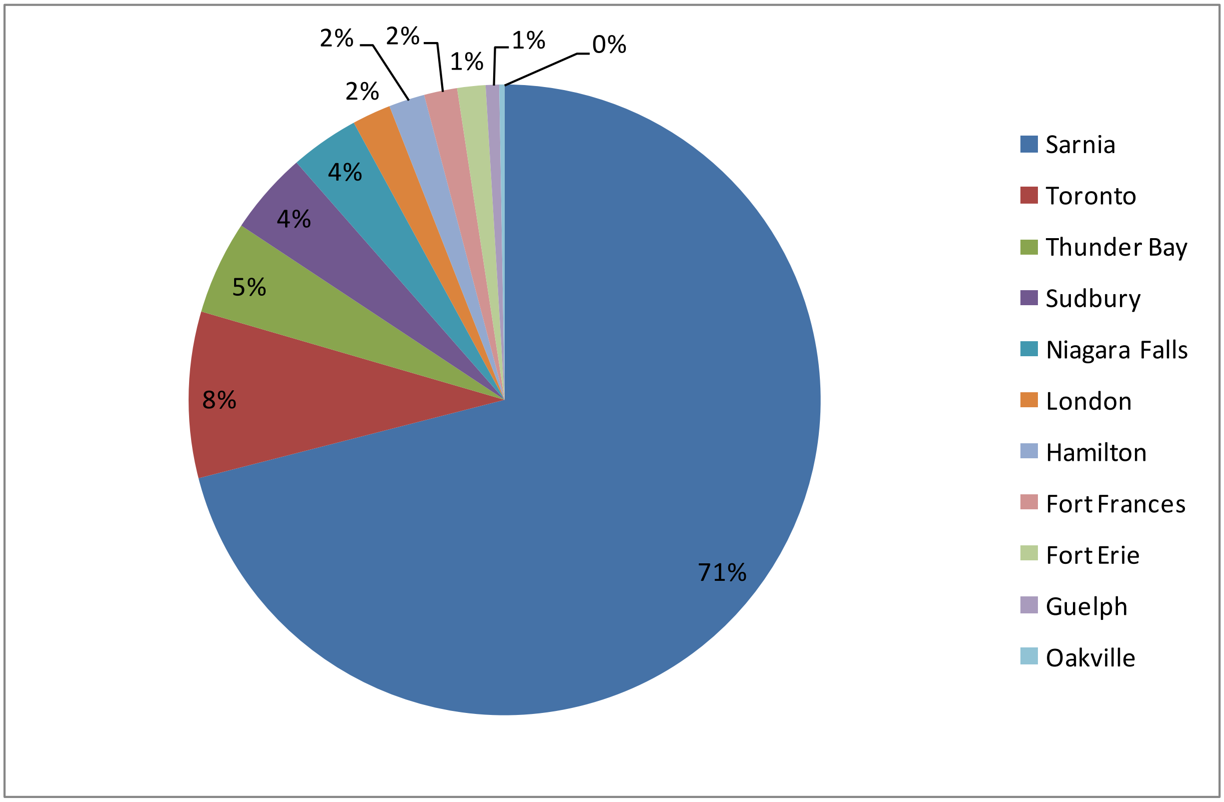


Exhibit 36 focuses on specific substances that are being imported into Ontario for the year 2010. These data are provided by the Canadian Border Services Agency and Statistics Canada. Note that total rail imports into Ontario for the identified substances in Exhibit 34 is 528,673 tonnes for 2010 in contrast to the total of 1.937 million tonnes shown in Exhibit 32 for 2004. That is a substantial gap and it is probably accurate to say that Exhibit 36 is much more focused on the most toxic of substances as opposed to Exhibit 34. The dominant import substance into Ontario is vinyl chloride which is used in the manufacturing of PVC materials. It is likely that the vast majority of this raw material is processed in the Sarnia petrochemical complex and thus never reaches the Credit Valley Watershed. Other prominent rail substances include ammonium nitrate, sodium hydroxide, phosphoric acids and sulphuric acid. The latter, as we saw, is exported from Ontario much more than it is imported.

Exhibit 37 Prominent Ontario Ports of Entry for Dangerous Goods Rail Imports (by tonnage)



The geographical picture with respect to the port of entry for dangerous goods by rail is quite striking (Exhibit 37). For the main Ontario ports of entry, about 71% is arriving from the NAFTA partners at the Sarnia crossing. The major CN tunnel to the U.S. is at Sarnia which may explain much of this pattern. Toronto, Thunder Bay and Sudbury are all significant ports of entry for dangerous goods but they pale in importance relative to Sarnia. Meanwhile, the Niagara crossings, which are quite important for dangerous goods movements by truck, are much less important by rail. One other significant note is that the results show no dangerous goods clearing at Windsor which is interesting since a main CP line crosses to the U.S. via Windsor. This outcome seems hard to justify but it can be noted that the original Canadian Border Services data on which Exhibit 37 is based captures where goods clear as opposed to where it crosses the border. In the case of rail, it would be much more likely than with truck that the goods would clear in non-border locations such as Toronto.

4.2 Tonnages Crossing the Watershed

The process to assess tonnages crossing the watershed by rail is similar to what was done for road. The primary goal in this section is to produce a rail counterpart to Exhibit 21 which was derived for road. The re-aggregation that takes place follows a similar path with the only real difference being that the initial aggregated hazmat flows for rail (Exhibit 33) are utilized. Since the behavioural patterns are different for rail, a different set of models were estimated using, as before, the techniques developed in Kanaroglou and Ferguson (1996). These models have different statistically estimated parameters that capture, for example, the much shallower distance decay associated with rail.

Exhibit 38 Re-Aggregated Interregional Tonnages of Dangerous Goods (2004) (000's)

Region	toronto	hamilton	oshawa	ont sw	ont north	east	west
toronto	0	39	17	410	17	758	835
hamilton	84	0	3	105	3	79	94
oshawa	38	3	0	33	2	35	37
ont sw	585	71	21	680	30	926	533
ont north	35	3	1	45	2	47	52
east	1,462	145	64	2,393	86	3,673	1,331
west	1,425	149	58	862	85	1,464	4,681

The results of this process are captured in Exhibit 38 which gives us all the required information to derive reasonable estimates of the hazmat tonnages crossing the watershed by rail. The shaded cells represent those flows associated with crossing the watershed. The cells shaded blue are involved with crossing the watershed in an eastbound manner while the other pink cells are associated with westbound trips. The eastbound totals amount to 2.359 million tonnes per year and the westbound totals sum to 4.083 million tonnes per year for a total of 6.442 million tonnes. This total can be contrasted with the quantity of 1.197 million tonnes from Exhibit 33 relating to all intra-Ontario rail movements of hazmat. It is not surprising that the estimated amount crossing the watershed is much larger since significant quantities of goods from other provinces and the United States will be included. In analyzing the quantities in each cell of Exhibit 38, it is important to keep in mind the composition of the seven zones as was discussed in detail in Section 3.1.

Exhibit 38 includes all tonnages, including those to and from the NAFTA partners which are quite substantial in the case of rail. The foreign tonnages are attributed to a Canadian port of entry or exit. Provencher (2008) indicates that 2.995 million tonnes exit Ontario for the U.S. and 1.331 million tonnes enter Ontario from the U.S. The data from Exhibit 37, as it relates to major points of entry, was used as a guide in allocating these exports and imports to specific border crossings. The role of the Sarnia crossing is quite prominent in the allocation. In terms of specific origins within Ontario for exports and specific destinations in Ontario for imports, a disaggregate version of Exhibit 38, absent the international flows, was used to guide the allocations.

In Exhibit 39 the final pattern for international flows in and out of Ontario, which is a subset of the quantities in Exhibit 38, are shown. The cells for this o-d matrix are zeros in cases where the pairing in question is not associated with any international movements. It can be seen that the Ontario SW region, which is very much associated with movements to and from the U.S. is extremely prominent. The "west" zone also figures in more modestly for rail movements to and from Northern Ontario (which is part of the west zone). It is interesting that the largest single flow is from the east region, which includes major centres like Montreal, to the Ontario SW region (e.g. Sarnia) where the goods leave the country.

Exhibit 39 Estimated Flow Patterns due to Imports/Exports

Region	toronto	hamilton	oshawa	ont sw	ont north	east	west
toronto	0	0	0	278	0	0	39
hamilton	0	0	0	69	0	0	9
oshawa	0	0	0	23	0	0	3
ont sw	321	37	12	552	17	564	110
ont north	0	0	0	31	0	0	4
east	0	0	0	1,730	0	0	225
west	50	5	2	144	2	79	13

Since this set of estimates is essentially based on 2004 data, it is reasonable to ask if the results might have changed a lot. Due to data availability issues, we are not able to derive a more recent version of Exhibit 38 but it is possible to study a more recent version of Exhibit 34.

The more recent counterpart to Exhibit 34 is Exhibit 40 above which is for the year 2008 (Statistics Canada, 2010). There is no doubt that there is some variation on a commodity basis between the two years. If anything, the grand totals in Exhibit 40 suggest that slightly lower quantities of dangerous goods were in circulation by rail in 2008. Since then, it is possible that shipments have bounced back so the 2004 estimates are likely to be fairly applicable even today. An update of these estimates will depend upon the release of more current data of the type available in Provencher (2008).

A final quantity of interest is how these tonnages translate into railway cars (probably mostly tank cars). From Provencher (2008), it is possible to determine that 14.032 million tonnes of dangerous goods move to, from and within Ontario. This is associated with 454,571 rail cars which equates to about 31 tonnes of dangerous goods per car. Applying this latter figure to the 6.442 million tonnes which is estimated to cross the watershed suggests that 208,695 cars of dangerous goods will cross the watershed annually. Using the earlier convention of 300 days per year as a denominator we arrive at 695 rail cars per typical day that will cross the watershed or 21,473 tonnes. If this total were to be divided among the main Transport Canada classes, past data would indicate that 6671 tonnes would be class 2 gases, 7628 tonnes would be class 3 flammable liquids and 5,049 tonnes would be class 8 corrosives. The remaining 2,123 tonnes would be divided among the other classes with fairly small amounts in each. In terms of ranking the rail corridors, we are not privy to the data that would assist in dividing these totals among the lines that cross the watershed but would assume that the CN lakeshore line likely carries the most. Especially since the CN line is the main line between Sarnia and Toronto.

Exhibit 40 Dangerous Goods Tonnage by Type to and from Ontario (2008)

from Ontario 2008	Atlantic	Quebec	Ontario	Manitoba	Saskatchewan	Alberta	BC	NAFTA	Total
Gasoline and Aviation	0	3,847	34,117	0	0	1,298	3,829	0	43,091
Fuel Oils and Crude Petroleum	0	97,624	161,093	52,455	60	1,480	7,466	16,565	336,743
Gaseous Hydrocarbons	169,345	181,788	264,745	0	0	1,418	12	756,520	1,373,827
Other refined petroleum and coal	10,075	153,409	241,004	11,822	5,196	128,740	32,605	304,558	887,408
Sulphuric Acid	48,561	130,874	165,936	1,347	0	0	0	1,219,644	1,566,362
Other basic chemicals	68,098	66,239	107,100	7,016	7,710	17,550	20,445	349,868	644,026
Fertilizers	759	9,368	61,309	4,373	10,472	2,883	202	167,472	256,837
Other Chemical Products and Preparations	1,970	3,185	30,980	441	539	7,717	4,282	265,229	314,342
Total	**298,808**	**646,334**	**1,066,284**	**77,454**	**23,977**	**161,086**	**68,841**	**3,079,856**	**5,422,636**
to Ontario 2008									
Gasoline and Aviation	0	785,544	34,117	10,507	5,901	37,321	0	5,335	878,726
Fuel Oils and Crude Petroleum	7	863,630	161,093	86,406	10,928	21,539	0	7,561	1,151,164
Gaseous Hydrocarbons	7,458	77,293	264,745	689	9,027	119,208	241	98,786	577,447
Other refined petroleum and coal	487	21,304	241,004	414	6,368	45,844	575	316,196	632,192
Sulphuric Acid	575	16,969	165,936	545	0	0	204	25,767	209,996
Other basic chemicals	6,045	416,809	107,100	66,649	6,831	104,439	16,456	980,829	1,705,159
Fertilizers	1,431	10,639	61,309	38,545	10,875	123,125	211	351,350	597,484
Other Chemical Products and Preparations	417	1,890	30,980	347	59	12,376	3,683	168,569	218,320
Total	**16,420**	**2,194,078**	**1,066,284**	**204,102**	**49,989**	**463,852**	**21,370**	**1,954,393**	**5,970,488**

5

Conclusions

This study has derived estimates of the movements of dangerous goods across the Credit Valley Watershed by road and rail. The general approach has been to understand the nature and quantities of movements over a much wider area than the watershed itself. For movements by truck a national origin-destination matrix of inter-provincial dangerous goods movements has been used as a building block along with a similar matrix which is available for rail movements. To further assist efforts, a detailed matrix based on over 2,000 zones has been developed for the Greater Toronto Hamilton Area. This extra level of detail is necessary for trucking since associated movements are often more localized with many different combinations of origins and destinations being possible. This matrix has been fed into a traffic assignment algorithm which determines the likely routes that are taken in moving the goods from origin to destination. In this way, a simulation of dangerous goods traffic patterns on highway and arterial routes has been derived. For rail, there are fewer origin-destination permutations that need to be considered and patterns of movements are less complex. Thus, a similar but less involved process has been used to estimate movements across the watershed.

The main quantitative conclusions of the research are that in the typical year, an estimated 8.857 million tonnes of dangerous goods cross the Credit Valley Watershed by road and an estimated 6.442 million tonnes of dangerous goods cross by rail. Road hazmat is more oriented to local distribution of flammable liquids such as gasoline and diesel. Rail hazmat is somewhat more diversified between flammable liquids, gases and other substances. These estimates do not particularly relate to any specific point in time but are meant to characterize the recent past years and the near term. The processes used are not sufficiently accurate to really differentiate one year from another at a level of geography as low as the watershed. There is some evidence that dangerous goods volumes have declined somewhat from peak volumes in the years leading up to the financial crisis and subsequent severe recession.

Various data challenges were encountered in the course of this research. The primary rail carriers (CN & CP) preferred not to provide information due to the sensitivity of the topic. On the truck side, the best data are collected by Statistics Canada via the trucking commodity origin destination survey (TCOD) but that survey covers for-hire firms of a minimum size. Some very useful data were contributed by the Ontario Ministry of Transportation through selected intersects of their 2006 Commercial Vehicle Survey. This information assisted substantially in the validation of the road results.

Some observations that arose from the work are as follows:

- There is the potential for further work to be done in relation to substance-specific dangerous goods movements. To really do a detailed job at the substance level, it is necessary to have a detailed understanding of the industrial geography that gives rise to the hazmat flows. It is necessary to have detailed knowledge of which types of manufacturers are likely to use which types of input and the exact locations of the players in a given process. By going into greater detail in this way, it would be possible to develop more refined results than those of this report.

- Some government reports (e.g. Transportation in Canada) are more geared towards the economic value of the goods that are moved. In the context of dangerous goods, economic value is fairly meaningless. It is all about the tonnage and the nature of the goods. To assist municipalities in understanding exposure to certain substances, there could be more emphasis on tonnage in certain publications.

- Examination of cross-border data is a useful tool for determining which transportation corridors are likely to be utilized in traversing geographical areas such as the watershed. One source of distortion that was observed in the Statistics Canada data developed with the Canadian Border Services Agency is that the location where the goods clears is often not the border. Clearly, the goods will have crossed the border at some point but the data itself might show clearance in Toronto.

- Attempts to make assessments of dangerous goods by road-side observation has its challenges. Unless one actually stops the truck, one is often not certain about the cargo. In cases where dangerous goods placards are visible, most often on tanker trucks, the process is easier but most tanker trucks do not display such placards. While placard violations do occur, mostly this reflects that many tanker trucks are not carrying dangerous goods. Apart from food products, there are substances such as some petroleum products and chemicals which are also not considered hazardous. For example, the Clarkson Lubricants plant near the border of Mississauga and Oakville gives rise to many tanker trips but they are carrying blended lubricants and process oils that are high flash materials (i.e. not flammable) and are not considered toxic. Many are white oils which are actually used in health care products.

- One other challenge is that some proportion of hazmat truck trips moves around as less than truckload cargo. The hazmat component may fill a part of a large trailer which is otherwise carrying non-hazmat cargo. Totes or containers may be getting used. In some cases, these trailers are not showing a hazmat placard and thus are not possible to indentify. Perhaps more work can be done in this area to clarify hazmat components of certain cargos.

- Some of the challenges encountered in this research suggest that need for a specialized publication in Canada along the lines of the U.S. Commodity Flow Survey special publication on hazardous materials. The Transport Canada Publication by Provencher (2008) is a step in the right direction but something more formalized is needed so that Canadian researchers and other stakeholders in this important area can have ready access to critical hazmat data .

6

Appendix

Exhibit 41 CP Rail Network - Wider Perspective

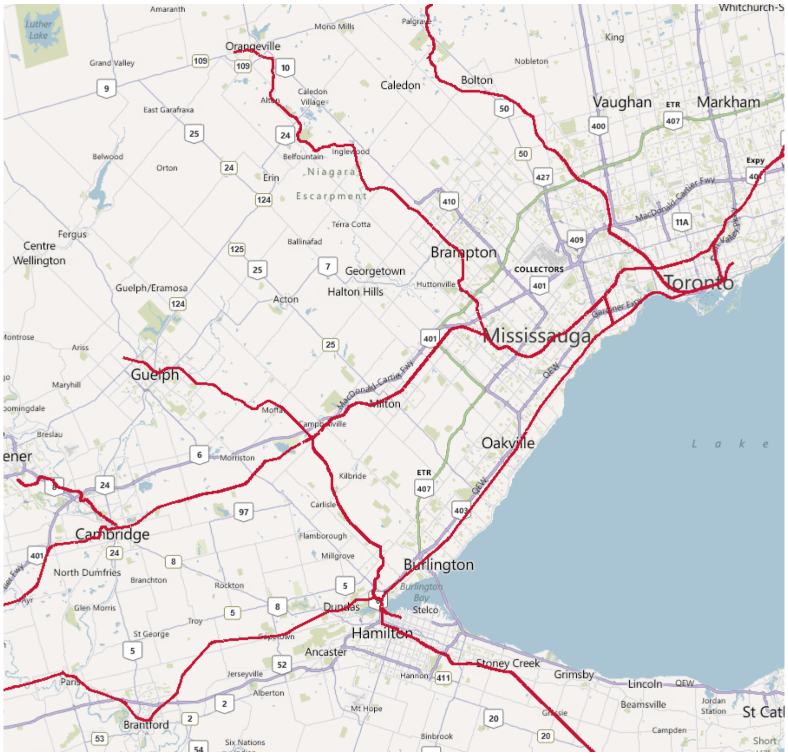
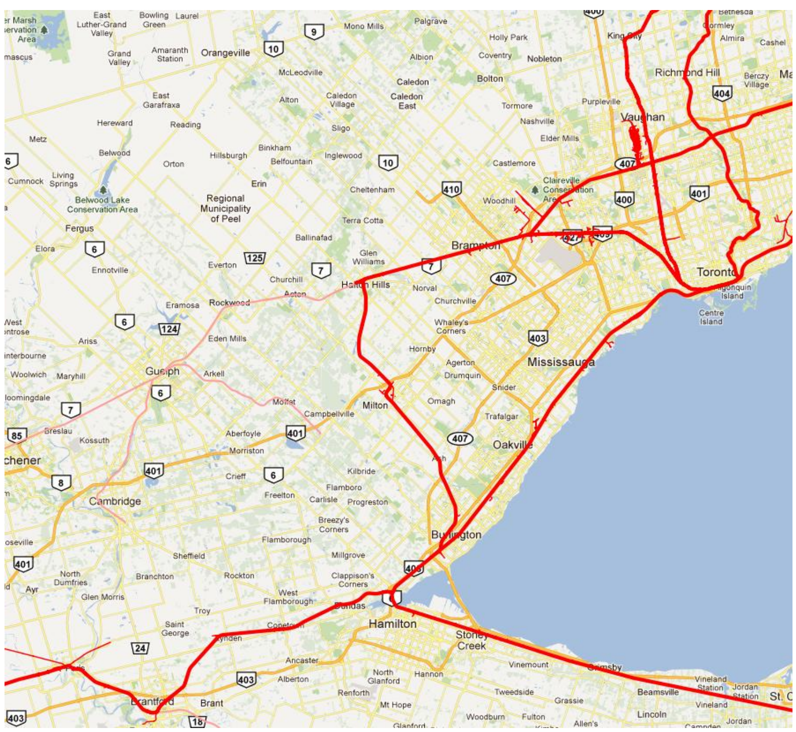


Exhibit 42 CN Rail Network - Wider Perspective



Exhibits 41 and 42 were sourced directly for the CP and CN websites. Below, the complete list of Dangerous Goods of interest is provided, along with details on their industrial uses, including associated NAICS.

Name	Use	Associated NAICS	Notes
Acetic acid	paints; adhesives; solvent; coatings; nitrocellulose; lacquers; varnish removers; wood stain; semiconductors; cellulose acetate (synthetic textile also used for film); TPA for polyester, food and beverage containers, and engineering resins; food additive (acidulant); other textiles; pharmaceuticals	31-33 Manufacturing; 325 Chemical Manufacturing	
Acetic anhydride	Cellulose acetate, for photo film and coatings; aspirin; acetaminophen; agri chemicals; pharmaceuticals; plastics; starch modifiers; triacetin; wood preservative	31-33 Manufacturing; 111 Crop Production; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing	
Ammonia	Fertilizer; plastics; resins; adhesive; explosives; nitric acid; potassium cyanate (an industrial feedstock); cleaner; hydrogen cyanide for mining	31-33 Manufacturing; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing; 111 Crop Production; 21 Mining, Quarrying, and Oil and Gas Extraction	
Ammonium nitrate	Fertilizer; explosives; freezing mixtures; laughing gas; rocket propellant; herbicide; insecticide	111 Crop Production; 31-33 Manufacturing; 325 Chemical Manufacturing	
Benzene	Ethyl benzene for styrene & polystyrenes: widely used plastics; acetone; other plastics; resins; pharmaceuticals; paint thinner; nylon; insulating foam for buildings and refrigerators; synthetic rubber; herbicide; adhesive; detergent; minor component of gasoline	326 Plastics and Rubber Products Manufacturing; 325 Chemical Manufacturing; 313 Textile Mills; 31-33 Manufacturing	
Butyraldehyde	Manufacturing plasticizers, alcohols, solvents, and polymers (maybe fuel and fertilizer as well); pharmaceuticals, agri chemicals; rubber; textiles;	31-33 Manufacturing; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing; 111	

	perfume; flavours (food)	Crop Production	
Chlorine	PVC; other organic chemicals; inorganic chemicals; water treatment; pulp and paper	31-33 Manufacturing; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing; 322 Paper Manufacturing; 22 Utilities	Chlorine is used in a huge range of industrial processes, from medicines, to bullet proof vests, to disinfectants
Cyclohexane	Manufacture of nylon; solvents; insecticides; plasticizers (concrete, plastics); PVC; polyurethane (ex skateboard wheels)	326 Plastics and Rubber Products Manufacturing; 325 Chemical Manufacturing; 3273 Cement and Concrete Product Manufacturing; 31-33 Manufacturing	
Ethylbenzene	Styrene for large variety of plastics; solvent; resin; fuel	325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing	
Ethylene	Making ethylene oxide, ethylene dichloride, ethylbenzene, polyethylenes for use in plastics, resins, plasticizers, detergents, lubricants, styrene, polyester; anesthetic agent; agriculture (fruits); welding gas	31-33 Manufacturing; 1113 Fruit and Tree Nut Farming	Ethylene is the most produced organic compound in the world; 2005 production exceeded 107 million tonnes (wiki)
Ferric Chloride	Sewage treatment, waste water treatment; water treatment; copper ethcant (circuit boards); PVC production	22 Utilities; 31-33 Manufacturing; 334 Computer and Electronic Product Manufacturing	did not have recent data on consumption pattern
Formaldehyde	Sugar industry; automobile manufacture; textiles; plywood adhesive; carpeting adhesive; sanitary paper products; insulation; paints; explosives; vaccines (preservative); other medical use; embalming agent; woodworking; counters; cabinets; wood veneer; resins	8121 Death Care Services; 31-33 Manufacturing; 622 Hospitals	Formaldehyde and derivatives account for 1.2% of US and Can GDP, incl 4 million employees and 11,900 plants in US and Can
Hydrochloric acid	Brine treatment for chloralkali; steel pickling; food (incl corn syrop, aspartame); calcium chloride; oil well acidulation; chlorine; swimming pools;	31-33 Manufacturing; 322 Paper Manufacturing; 324 Petroleum and Coal Products Manufacturing; 325	Also called hydrogen chloride

	metal recovery from used catalysts; pH control; sludge removal; sand and clay purification; PVC production; other plastics; resins; synthetic glycerine; pharmaceuticals; sewage treatment; drinking water; paper production; road salt; battery production	Chemical Manufacturing; 327 Nonmetallic Mineral Product Manufacturing; 331 Primary Metal Manufacturing; 21 Mining, Quarrying, and Oil and Gas Extraction; 22 Utilities	
Mercury	manufacture of chlorine and caustic soda; electrical and electronic applications; measuring and control instruments; dental amalgams; cosmetics	31-33 Manufacturing	Mercury seems to be only classified with TC as a compound (and there are many, usually with class 6.1)
Methanol	feedstock for other chemicals, including formaldehyde, acetic acid, for later use in plastics, plywood, paints, explosives, textiles; fuels; fuel additive; solvent; antifreeze; pipelines; windshield washer fluid	31-33 Manufacturing; 325 Chemical Manufacturing; 486 Pipeline Transportation	
Nitric acid	ammonium nitrate, for fertilizers, explosives, metal etching, gold extraction; cyclohexanone; dinitrotoluene; nitrobenzene; rocket fuel; chemical reagent; woodworking	31-33 Manufacturing; 325 Chemical Manufacturing; 21 Mining, Quarrying, and Oil and Gas Extraction	multiple forms (spent; red fuming; other)
Phenol (Carbolic Acid)	resins (ex bakelite); plastics; nylon; pharmaceuticals (aspirin); herbicides	31-33 Manufacturing; 325 Chemical Manufacturing	also known as carbolic acid, produced on a large scale
Phosphoric Acid	fertilizer; animal feed; food additive (colas); rust remover; dentistry	111 Crop Production; 31-33 Manufacturing; 6212 Offices of Dentists; 3121 Beverage Manufacturing	
Phosphorous	water treatment; plant medicine	22 Utilities; 325 Chemical Manufacturing	only info is on 'phosphorous acid' which is different than above, more toxic
Propylene oxide	polyurethane plastics; foams; food industry (fumigant); lubricant;	31-33 Manufacturing; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing; 311 Food Manufacturing	also made into propylene glycol (NOT SURE WHAT THIS IS)
Sodium chloride	road salt; food industry;	22 Utilities; 325	used in every industry

	home use; agriculture; pulp and paper; textiles; soaps; detergents; production of industrial chlorine and sodium hydroxide; firefighting and fire extinguishers	Chemical Manufacturing; 311 Food Manufacturing; 322 Paper Manufacturing	due to production of chlorine
Sodium hydroxide	principle strong base in the chemical industry; pulp and paper; textiles; drinking water; soaps and detergents; drain cleaner; food industry; petroleum	325 Chemical Manufacturing; 322 Paper Manufacturing; 311 Food Manufacturing; 324 Petroleum and Coal Products Manufacturing; 22 Utilities	also known as lye and caustic soda
Sodium hypochlorite	household bleach; industrial disinfectant; food industry; water treatment	22 Utilities; 31-33 Manufacturing; 311 Food Manufacturing; 4246 Chemical and Allied Products Merchant Wholesalers	known as 'bleach'
Styrene	plastics; rubber; insulation; textiles; fibreglass; pipes; automobile and boat parts; food containers; carpet backing	31-33 Manufacturing; 325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing	also known as vinyl benzene
Sulphuric acid	fertilizers; detergents; explosives; dyes; other acids; parchment paper; glue; petroleum industry; metal pickling; pulp and paper; car batteries; plastics; ore processing; steel industry; nylon; wastewater processing	31-33 Manufacturing; 21 Mining, Quarrying, and Oil and Gas Extraction	
Vinyl chloride	chemical intermediate mainly used to produce PVC for use in a variety of manufacturing; resins; adhesives	325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing	
Xylenes	intermediate for the production of fibers, plastics, coatings, inks; paints; gasoline additive; resins; varnishes; adhesives; food additive; leather industry; pharmaceuticals	325 Chemical Manufacturing; 326 Plastics and Rubber Products Manufacturing; 316 Leather and Allied Product Manufacturing	
Diesel Fuel	Domestic heating; industrial heating; power for heavy unit transportation; chemical synthesis; pesticide	31-33 Manufacturing; 48 Transportation and Warehousing	

Ethanol	chemical intermediate for ethyl acetate etc; toiletries and cosmetics; scents and flavours; solvent; vinegar; household cleaners; detergents; pharmaceuticals; inks; paints; fuel; fuel additive; alcoholic beverages; antiseptic	31-33 Manufacturing; 325 Chemical Manufacturing; 3121 Beverage Manufacturing	
Gasoline	fuel for cars and trucks; solvent		
Fuel oil			Same info as for diesel; fuel oil may refer to the heaviest extract of crude oil
Kerosene oil	rocket and jet engine fuel; domestic heating; solvent; tractor fuel; household and industrial sprays	481 Air Transportation; 31-33 Manufacturing	also known as paraffin oil
Toluene (Acetone)	chemical intermediate for benzene production; gasoline production, additive; solvents; explosives; dyes; extractant	325 Chemical Manufacturing; 324 Petroleum and Coal Products Manufacturing	

Source: Compiled from Hazardous Substances Data Bank see: http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB and Research by MITL

References

Anand, P. (2005). "Environmental Risk Analysis of Chemicals Transported in Railroad Tank Cars" University of Illinois at Urbana-Champaign Working Paper.

Cole, Sherman and Associates (1988). *The Metropolitan Toronto Goods Movement Study*. Metropolitan Toronto Roads and Traffic Department, Toronto, Ontario.

Cambridge Systematics. (2003). *Accounting for Commercial Vehicles in Urban Transportation Models*. *Distribution* (p. 117).

Ferguson, M., Maoh, H., Kanaroglou, P., & Ryan, J. (2010). *Estimating Urban Commercial Vehicle Movements in the Greater Toronto-Hamilton Area*. *Area* (p. 61). Hamilton, Ontario.

Glickman, T. S., & Rosenfield, D. B. (1984). Risks of Catastrophic Derailments Involving the Release of Hazardous Materials. *Management Science*, *30*(4), 503-511. doi:10.1287/mnsc.30.4.503

Gorys, J. (1990). Transportation of Dangerous Goods in the Province of Ontario. *Transportation Research Record*, *1264*.

Hunt, J., & Stefan, K. (2007). Tour-based microsimulation of urban commercial movements. *Transportation Research Part B: Methodological*, *41*(9), 981-1013. doi:10.1016/j.trb.2007.04.009

Kanaroglou, P. S., & Ferguson, M. R. (1996). Discrete spatial choice models for aggregate destinations. *Journal of Regional Science*, *36*(2), 271-290.

Mitchell, J. T., Hill, A., Baker, M., Jones, S., & Cutter, S. (2002). Transitory trouble: inter- and intra-state hazardous materials flow in South Carolina. *Middle States Geographer*, *35*(1), 13-21.

Oggero, A., Darbra, R. M., Muñoz, M., Planas, E., & Casal, J. (2006). A survey of accidents occurring during the transport of hazardous substances by road and rail. *Journal of hazardous materials*, *133*(1-3), 1-7. doi:10.1016/j.jhazmat.2005.05.053

Provencher, M. (2008). *The Movement and Handling of Dangerous Goods in Canada for the Year 2004*. *Statistics* (p. 57).

Quarantelli, E. L. (1991). Disaster planning for transportation accidents involving hazardous materials. *Journal of Hazardous Materials*, *27*, 49-60.

Racca, D. P. (2002). HAZARDOUS MATERIAL TRANSPORTATION STUDY Prepared for The State of Delaware Emergency Response Commission By. *System*, (December).

Scott, D. M. (1996). Estimating Risk Costs per Unit of Exposure for Hazardous Materials Transported by Rail. *The Logistics and Transportation Review*, *32*(4), 351-376.

Statistics Canada. (2006). *Rail in Canada - 2004*. *Statistics* (p. 87).

Statistics Canada. (2008). *Canadian Vehicle Survey : Annual*. *Statistics* (p. 43).

Statistics Canada. (2010). *Rail in Canada - 2008*. *Statistics* (p. 91).

Stefan, K., McMillan, J., & Hunt, J. (2005). Urban Commercial Vehicle Movement Model for Calgary, Alberta, Canada. *Transportation Research Record*, *1921*(1), 1-10. doi:10.3141/1921-01

Stewart, A., & Van Aerde, M. (1990). An Empirical Analysis of Canadian Gasoline and LPG Truck Releases. *Journal of Hazardous Materials*, *25*, 205-217.

Transport Canada. (2011). *Transportation in Canada (Addendum)*. *Transportation* (p. 128).

Trépanier, M., Leroux, M.-H., & de Marcellis-Warin, N. (2009). Cross-analysis of hazmat road accidents using multiple databases. *Accident; analysis and prevention*, *41*(6), 1192-8. doi:10.1016/j.aap.2008.05.010

U.S. Departments of Transportation and Commerce. (2010). *United States : 2007 - Hazardous Materials - Commodity Flow Survey*. *Transportation* (p. 103).

Verter, V., & Kara, B. Y. (2001). A GIS-based framework for hazardous materials transport risk assessment. *Risk analysis*, *21*(6), 1109-20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11824686

Warner, J. E., Protopapas, A. A., Jasek, D. L., Morgan, C. A., & Huang, J. J. (2009). *Understanding and Managing the Movements of Hazardous Material Shipments through Texas Population Centers*. *System* (Vol. 7, p. 120).

iTRANS. (2004). *Goods Movement in Central Ontario : Trends and Issues Technical Report*. *Transportation* (p. 395).