Grinding to a Halt:
Evaluating Canada's Worst Bottlenecks

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Acknowledgments

This study was conducted by CPCS on behalf of the Canadian Automobile Association. The study's analysis relied on a variety of data sources. Notably, the vehicle speed data were provided by HERE North America, LLC (HERE), a leading supplier of digital maps, location-based services and traffic management data. Traffic volume data were provided by various provincial and local government departments of transportation.

The CPCS team would like to thank the CAA for commissioning the study as well as HERE and the government departments that provided the data necessary for our analysis.

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Executive Summary

This Study, the first of its kind in Canada, collected and analyzed speed and volume data on highways in urban areas across the country to identify the worst highway bottlenecks across the country. Specifically, we collected and analyzed data from the following Census Metropolitan Areas (CMA) for this purpose: Vancouver, Calgary, Edmonton, Regina, Winnipeg, Toronto (including the Hamilton and Oshawa CMAs), Ottawa, Montreal, Quebec City and Halifax.

How this study is different from others

While other studies have attempted to estimate congestion levels at the city or region-wide level, this Study is unique in that it identifies and compares congestion levels on specific stretches of highway across Canada. These bottlenecks were identified as stretches of highway that are routinely and consistently congested throughout the course of a weekday, as opposed to stretches that are congested only at limited times of day or days of a week. To identify the bottlenecks, we compared actual average hourly speeds to a baseline speed on each segment for each hour of the day. This Study uses a baseline speed which makes our estimate of the congestion costs associated with the top bottlenecks conservative relative to other studies that have calculated congestion costs region-wide. A key point is that this methodology is applied consistently across all urban areas, allowing for a comparative ranking of top bottlenecks across the country.

Canada's Worst Bottlenecks

Canada's worst highway bottleneck is the stretch of Highway 401 that cuts across the north part of the City of Toronto. This bottleneck alone costs commuters over 3 million hours annually. In total, five of the top ten bottlenecks are found in the Toronto area. The stretch of Highway 40 into downtown Montreal is the third worst bottleneck in the country, costing commuters nearly 2 million hours of delay annually. Although the City of Vancouver does not have non-signalized highways serving the downtown core, stretches of two main arteries (Granville St. and West Georgia St.) are congested enough to fall within the top ten bottlenecks in the country.

Our estimates of total delay are significantly impacted by the choice of the baseline speed to which actual speeds are compared. For example, we selected the main artery that serves Vancouver's downtown core in order to make the results broadly comparable to Canada's other large cities, despite the fact that it is signalized. These and other main arteries have significantly lower maximum speeds and throughput potential than limited access highways. As such, our estimate of total delay on these arteries are much lower than they would have been if they were compared with the throughput potential of a limited access highway. In other words, although the ranking of the Vancouver bottlenecks are not as severe as they are in Toronto and Montreal, the actual vehicle speeds that drivers experience into and out of

downtown Vancouver are in fact as bad as or worse than they are in those two cities.

Region-Wide Congestion

Although calculating region-wide congestion measures is not the primary focus of this Study, our data also allows for developing such measures. In order to do so, we calculated Travel Time Indices (TTI) for each of the urban areas that were included in our dataset. The TTI is the travel rate during a specified period of time relative to the travel rate in free-flow conditions. For example, if it takes 45 minutes to travel between points A and B during the morning peak and it takes 30 minutes to travel between the same points during free-flow conditions, the TTI is 45 / 30 = 1.50.

The TTI can be used to estimate how much the typical motorist's commute time would be reduced in each city if free-flow conditions prevailed (noting the free-flow conditions at all hours is not a reasonable expectation).

Unsurprisingly, the typical Toronto area motorist spends the most additional time per day relative to a two-way 60 minute free-flow commute. In typical peak period traffic conditions, what would be a 60 minute two-way commute becomes a 96 minute commute (for 36 additional minutes in total). Hamilton (which is part of the Greater Toronto and Hamilton Area) appears next (25.3 minutes), followed by Montreal (24.2 minutes) and Vancouver (24 minutes).

Comparison With US Bottlenecks

Compared with US bottlenecks, the 401 bottleneck ranks among the top ten (Canada and US combined), while Montreal's top bottleneck ranks among the top 20. In terms of total hours of delay, the 401 bottleneck compares with the worst bottlenecks in the New York metro area, while the Highway 40 bottleneck compares with the worst bottleneck in Boston.

Acronyms

AADT	Average Annual Daily Traffic
AHUA	American Highway Users Alliance
ATRI	American Transportation Research Institute
CMA	Census Metropolitan Area
DVP	Don Valley Parkway (or Don Valley Parking Lot)
FFS	Free-Flow Speed
FHWA	US Federal Highway Administration
GIS	Geographic Information Systems
GTHA	Greater Toronto and Hamilton Area
HCM	Highway Capacity Manual
HOV	High Occupancy Vehicle
MTS	Maximum Throughput Speed
VKT	Vehicle Kilometres Travelled

Key Messages

- This Study, the first of its kind in Canada, identifies the worst highway bottlenecks across the country.
- These bottlenecks were identified as those stretches of highway that are routinely and consistently congested throughout the course of a weekday, as opposed to stretches that are congested only at limited times of the day or days of a week.
- Canada's worst highway bottleneck is the stretch of Highway 401 that cuts across the north part of the City of Toronto. This bottleneck alone costs commuters over 3 million hours annually. In total, five of the top ten bottlenecks are found in the Toronto area.
- The stretch of Highway 40 into downtown Montreal is the third worst bottleneck in the country, costing commuters nearly 2 million hours of delay annually.
- Although the City of Vancouver does not have non-signalized highways serving the downtown core, stretches of two main arteries (Granville St. and West Georgia St.) are congested enough to fall within the top ten bottlenecks in the country.
- Compared with US bottlenecks, using a similar methodology, the 401 bottleneck ranks among the top ten (Canada and US combined), while Montreal's top bottleneck ranks among the top 20.
- In terms of total hours of delay, the 401 bottleneck compares with the worst bottlenecks in the New York metro area, while the Highway 40 bottleneck compares with the worst bottleneck in Boston.
- Although it is not the primary purpose of the Study, our data also allows for developing region-wide congestion measures. According to these measures, what would be a 60 minute two-way commute in free-flow conditions becomes a 96 minute commute in the Toronto area, an 84.2 minute commute in Montreal and an 84 minute commute in Vancouver.

Project Objective

Traffic congestion studies often publish region-wide estimates of congestion. These aggregated estimates are helpful for comparisons between cities [1, 2]. However, alleviating congestion requires a more detailed understanding of precise bottlenecks or chokepoints, to enable specific targeted interventions. The American Highway Users Alliance (AHUA) recently commissioned such a study of bottlenecks on US highways, garnering nationwide policy and media attention [3].

The objective of this Canadian National Bottleneck Study ("Study") is therefore to identify and rank the top highway congestion bottlenecks, the first of its kind to do so in Canada. Specifically, we collected and analyzed data from the following urban areas for this purpose: Vancouver, Calgary, Edmonton, Regina, Winnipeg, Toronto, Ottawa, Montreal, Quebec City and Halifax. The Study estimates the impacts of congestion for major bottlenecks in terms of time (hours lost), monetary cost (economic opportunity cost of the lost time), and environmental effects (excess fuel consumption, total CO2 emissions). This nationwide analysis of Canadian highway bottlenecks will help policymakers further investigate and develop solutions for those locations where congestion is the most severe.

Purpose of this Report

In this report, we summarize the approach we followed to identify the major highway bottlenecks. We discuss the concept of congestion and its effects, the Study methodology, how it differs from other studies, and the congestion impacts of the major bottlenecks.

Study Key Questions

At the start of the project, we developed a number of key questions to help guide the Study effort. These questions shaped how we looked at the data, and how we present the results. The key questions are:

- What are highway bottlenecks?
- How do we measure congestion?
- What causes highway congestion?
- What are the effects of congestion?
- Why study congestion now?
- Which roads should we include?
- How should the results of this Study be used?
- How should we identify, classify, and rank bottlenecks nationally?
- What are the specific impacts of these bottlenecks, and the potential benefits of alleviating them?

What are highway bottlenecks?

Bottlenecks are severe traffic chokepoints where demand far exceeds available highway capacity. As an example, the United States Federal Highway Administration (FHWA) states that recurring bottlenecks account for the largest share of road delay in the US (40%), far exceeding traffic incidents (25%), inclement weather (15%), construction (10%) or other causes.[4] This Study focuses on recurring bottlenecks in major urban areas across Canada. Note that we primarily examine highways (all limited-access expressways, a few signalized highways) in this Study, leaving out local roads and highway access roads and ramps. Highways are our primary focus because in most urban areas the majority of vehicle kilometers travelled (VKT) occur on highways. Furthermore, free-flow and maximum throughput speeds (MTS) are generally similar across highways, whereas free-flow speeds (FFS), or the average speed at which motorists would travel if there was no congestion or other adverse conditions (such as construction or poor weather), and MTS vary considerably across arterial, collector and local roads. As such, the choices regarding the calculation of free-flow speeds and MTS will heavily influence any comparisons across different road types, rendering the comparisons less objective.

We think of highway bottlenecks as stretches of highway that are routinely and consistently congested. The delays in these stretches are generally more than just a peak-period or rush hour problem. The large number of vehicles passing through bottlenecks experience severe delays, over the 24-hour course of a weekday. Even though bottlenecks are commonly associated with gridlocked conditions, there are many stretches of highway where even minor delays of a few minutes per vehicle add up across the many vehicles traveling those stretches. For example, in its 2014 Cost of Congestion report, the American Transportation Research Institute (ATRI) determined that 89% of truck-related congestion costs were associated with only 12% of the road miles. The case for passenger vehicles is analogous. In fact, in this Study we examined traffic flows and speeds on approximately 3,000 kilometres of highways across Canada, but the total length of the top 20 bottlenecks found is only 65 kilometres.

How do we measure congestion?

A key component of congestion measurement is the baseline speed to which actual speeds are compared. When motorists experience congestion they are likely comparing their actual travel speed to FFS. However, the use of free-flow conditions as a baseline for congestion cost estimates, while practical and familiar, has been questioned by practitioners. Rather, practitioners are interested in the level of "excess" congestion. Economic measures of congestion identify congestion costs and benefits from the reduction of congestion. "Optimal" congestion is the congestion level that would remain after excess congestion was eliminated. This optimal congestion level would vary considerably by time and place. Because achieving free-flow speeds at all times of day is simply not practical in most urban areas, economists have warned against the use of free-flow as a baseline.

We can see the existence of optimal congestion at work in the form of lineups for many goods and services provided by the private sector (e.g., morning lineups at popular coffee shops, lineups for popular rides at amusement parks). The market response comes in the form of a combination of higher prices for the desired services (generally limited by competitive forces) and an increase in capacity to meet demand. But lineups still persist because it would typically be too expensive to increase fixed capacity to completely eliminate the difference between peak and off-peak period demand. In other words, the users themselves do not see the value of doing this, relative to the costs of doing so. The private service provider makes investment decisions based on the signals given by the lineups, and the willingness-to-pay of customers for faster services balanced against the costs of capacity increases at peak times.

Developing baseline travel speeds based on optimal congestion levels, however, is challenging. True marginal congestion pricing would vary by time and place, depending on individual tolerances for congestion levels and the cost of mitigating congestion with investment in capacity or other remedies.

As such, studies that attempt to measure congestion costs often rely upon rough estimates of optimal travel speeds, based for example on a fraction of observed FFS. Our Study uses the MTS as the baseline speed, which in turn is estimated from FFS, using familiar methodology from the Highway Capacity Manual (additional details are provided in Appendix A). While MTS is not technically an optimal speed, it is likely much closer to the optimal speed than FFS. Furthermore, the use of MTS as a baseline speed is intuitively easy to understand, as it technically represents the speed at which throughput is maximized on the road network. In other words, it's the speed that allows the largest volume of motorists to use a highway at any given time.

We also note that our method of estimating FFS itself (also described in Appendix A) is more conservative than what has been used by some other studies. Further, we acknowledge that there are other potential costs of congestion that are not included in our analysis. For example, while our actual speeds are based on average speeds in each hour of the day, there is naturally some variability in these speeds from day-to-day, making travel times less predictable. This variability likely adds a cost of congestion that is not captured by the delay costs based on average speeds.

These factors combined with the use of the MTS (as opposed to FFS) as the baseline speed makes our estimate of the congestion costs associated with the top bottlenecks a conservative measure. A key point is that this methodology is applied consistently across all urban areas, allowing for a comparative ranking of top bottlenecks across the country.

We also note that FFS, while usually related to the posted speed limit, do not necessarily equal the posted speed limit. Because FFS is based on true observations of actual travel speeds during off-peak (non-congested) periods, FFS may be higher or lower than the posted speed limit, depending on the characteristics of the specific roadway under observation.

What causes highway congestion?

Congestion is a mismatch between highway capacity and demand. In other words, congestion occurs when there are many more motorists attempting to drive a stretch of highway than the available capacity of that stretch. Under these conditions, motorists are forced to reduce speed to accommodate a larger number of vehicles. In addition to the number of vehicles, highway design features such as merging lanes, ramps, and reduced visibility around curves also contribute to congestion as they cause drivers to quickly decrease speed. Weather, visual distractions, accidents, construction and maintenance, and special events may further affect the smooth flow of vehicles. In most cases, these factors do not operate in isolation; a number of them interact to exacerbate congestion [5].

What are the effects of congestion?

Congestion increases the time it takes to get from point A to B, what we commonly refer to as "delays". The lost time impacts both quality of life for individuals and the overall economy. Motorists and passengers give up productive work hours, and precious personal and family time. When trucks are stuck in traffic, the goods they are moving become more costly to businesses and consumers. The lost productivity from delayed passenger trips and freight deliveries harms regional and national economic competitiveness. Along with delays, congestion increases fuel consumption and greenhouse gas emissions. Vehicles idling in traffic consume far more fuel than they otherwise would. And by extension, vehicles emit more greenhouse gases in congested conditions.

Why study congestion now?

Transportation planners have long relied on computer models to predict how passenger cars and trucks would use the highway system, and would design the system accordingly. A number of planning and engineering studies informed these designs, but the costs and effort required made these infrequent. More importantly, there is a missing feedback loop on the difference between the predictions and how drivers actually use the system. This Study is an example of how empirical data, i.e. real-time system wide observations, can close the gap and provide a much-needed feedback loop for both highway planning and operations.

Many public and private actors in the transportation community are now routinely collecting data on traffic and system-wide conditions. Improved sensors and other information and communications technologies have significantly lowered the costs of collecting, storing and sharing these data, popularly called "big data". The collection of real-time probe data from smartphones, personal navigation devices (PNDs) and vehicles provides rich insights on highway speeds, a major input into congestion analysis.

This empirical approach – using data and observations as inputs into models, instead of outdated assumptions - is a substantial improvement over previous analyses of congestion. In fact, the new GPS probe-based data enables more accurate and precise identification of highway bottlenecks. Collecting data year-round enables analysts to hone in on the stretches of highway that routinely experience low speeds, leading to congestion. In sum, the frequency, low-cost, and high reliability of new traffic and speed data dramatically improve our understanding of congestion, and enables congestion analyses to be repeated often.

Which urban roads do we include?

The geographical focus is on urban expressways and some key signalized highways as well as urban arterials. We defined urban areas using the limits of the Census Metropolitan Areas (CMA) for the cities shown in Figure 1. The figure also summarizes their population in 2015 and the approximate highway road kilometers (one-way centerline) we analyzed within these urban areas.

Our algorithms used a boundary of each CMA which is large enough to ensure that the analysis retained any congested stretches near and around a core urban area. We also removed nearby local roads, expressway access ramps and exits so that the lower speeds on those nearby roads did not "contaminate" the congestion analysis, for reasons described earlier.

What data did we use?

This Study uses many different disparate data sources. Much of the analytical work involves cleaning these data, pre-processing them to filter the most useful components, and then combining different data sets so that the information is in one place and used consistently. While this may seem like a linear process, the analysis actually involves many iterations until we are satisfied with the results. We obtained speed observations (described below), volume estimates (Average Annual Daily Traffic), and combined these with other proprietary spatial and map data.

Figure 1. Coverage of urban areas in this Study

CMA	Province	Population (millions)	Total Highway Length (kms)
Vancouver	British Columbia	2.5	206.4
Calgary	Alberta	1.44	245.13
Edmonton	Alberta	1.36	352.18
Regina	Saskatchewan	0.24	146.85
Winnipeg	Manitoba	0.79	168.24
Greater Toronto	Ontario	7.7	641.84
Ottawa-Gatineau	Ontario	1.33	259.69
St. Catharines	Ontario	0.13	73.33
Montreal	Quebec	4.06	561.21
Quebec City	Quebec	0.8	206.03
Halifax	Nova Scotia	0.42	115.26

Source: CPCS analysis of Statistics Canada and proprietary data
*Includes Toronto, Hamilton and Oshawa CMAs

We used speed data collected from GPS probes that are averaged for each five-minute interval in a day, across many weeks in the year. These data were provided by HERE North America, LLC (HERE), a leading supplier of digital maps and traffic management data. In these data sets, the GPS probe-based speeds are allocated to a road network layer called Traffic Message Channel (TMC). We combine these data with other location information from a proprietary CPCS highway data set through a process known as conflation, described below.

We used empirical GPS observations from the year 2015. To eventually develop estimates of delays for weekday travel, we first needed to understand the 24-hour weekday speed profile of different stretches of highway. The 5-minute speed data were averaged for every weekday hour (60 min / 5 min = 12 observations) for weekdays from eight weeks (5 weekdays/week x 8 weeks = 40 weekdays). Thus the average consists of 480 observations. Two weeks for each quarter of the year 2015 were chosen to account for seasonal choices in driving behavior, as well as to avoid statutory holidays. These sampling time periods were: February 2 - 15, May 4 - 17, August 10 - 23, and November 2 – 15. In total, we examined over 15,000 urban segments and almost 180 million speed observations!

The inset box shown on page 8 provides an overview of our approach. Mathematical details are in the Technical Appendix.

How should you use the Study results?

Many provincial and local transportation agencies have begun to rely on similar empirical data to identify localized bottlenecks. Our Study does not intend to replace these local efforts; instead we want to help make visible the most severely congested stretches of the nation's highways. These are the segments we identified that incur more than fifty thousand hours of annual delay. By focusing on the nation's most intensely congested segments, this report is intended to help direct resources to solutions that could add the most value in relieving congestion. This report also reinforces provincial and local efforts to address the most congested areas.

Furthermore, since most highway planning and investment is conducted at the provincial (and to a lesser extent, local) level in Canada, analysis and comparisons of specific highway bottlenecks are usually conducted within provincial or local boundaries. This Study makes these comparisons across the country, using a consistent methodology and traffic speed data from the same source. Nationwide comparisons may be of particular interest for Federal Government, which has increased its involvement and investment in local transportation infrastructure for the purpose of reducing road congestion.

The results are, of course, of interest to individual motorists as well. Using consistent methodology and the same data source to identify and rank bottlenecks across the country allow individual motorists who regularly drive in those bottlenecks to put their own commutes into a Pan-Canadian context.

Our approach to identifying, classifying and ranking highway bottlenecks

CPCS has developed a proprietary screening and prioritization framework for identifying bottlenecks using observed vehicle speeds. Our chosen method allows us to systematically compare and rank highway bottlenecks nationwide. We applied our proprietary approach in six steps:

1. Speed Profiles

We filtered a very large vehicle speed data set to first hone in on the highways of interest, and then filtered further based on time, selecting specific weeks in the year. We applied this process to a highway network comprising over 15,000 highway segments in major cities across Canada, and 180 million speed observations. For each highway segment, we developed a speed profile, i.e. a representation of speeds on a "typical weekday". In other words, the speed profile gives the speed at which a driver could expect to drive on a stretch of highway in a particular hour on a weekday.

2. Delay Estimates

We estimated delays by comparing the observed speed profile for each highway segment to the Maximum Throughput Speed for the same segment. Delay estimates were then adjusted for the relative lengths of highway segments, as well as the estimated volume of vehicles (both cars and trucks) on those segments. The resulting delay metric is Daily Total Delay, measured in hours. See the Technical Appendix of this report for mathematical details.

3. Network Conflation

The aggregate estimate of delay for a freeway segment needs not only the speed profile of vehicles driving that stretch but also the volume of vehicles that could potentially experience delays, denoted by Average Annual Daily Traffic (AADT). Often the relevant variables are stored in different spatial datasets. Conflation is the process of merging spatial data from two or more networks using Geographic Information Systems (GIS) tools and techniques. We merged the speed profiles, congestion estimates, vehicle volumes and observed speeds with CPCS's proprietary data on Canada's highway system to harmonize both congestion-related calculations and spatial and location information. The adjoining Figure 3, shows an example of conflation for two different speed-related data sets.

4. Bottleneck Adjacency Analysis

We first identified the most congested highway segments in each urban area, and then looked upstream and downstream to capture the full effect of a queue, or zone of congestion. The Daily Total Delay for the entire queue is used for the nationwide rankings (see maps).

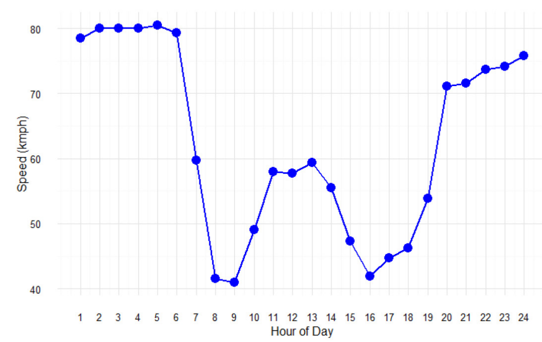
5. Validation of Results

We expected to see slight differences in our results and the congestion studies of provinces and local agencies. There are differences both in the precise locations and estimated lengths of the top-ranking bottlenecks, because of the differences in data and methods. We sought detailed feedback from agencies and representative regional organizations to validate our own findings. We leveraged local knowledge to prepare the profiles for the top 20 bottlenecks.

6. Bottleneck Impacts

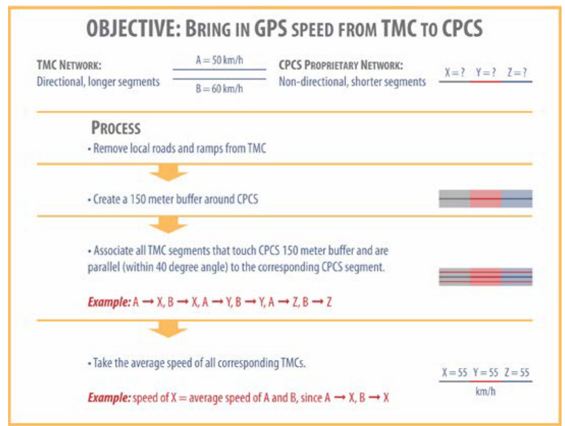
Finally, we calculate the cost of congestion ($), and potential fuel and emissions savings, for each bottleneck. The mathematical relationships for cost impacts and benefits calculations were drawn from peer-reviewed and published materials.

Figure 2. An example of a speed profile for a highway segment



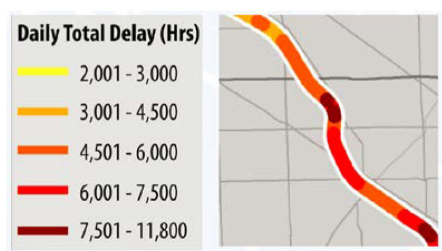
Source: CPCS analysis

Figure 3. Network Conflation Process for Speed Data



Source: CPCS analysis

Figure 4. An example of a bottleneck "queue" of highway segments with different congestion intensities, shown in the legend



Source: CPCS analysis

Figure 5. Multi-dimensional Congestion Impacts, including costs of congestion (lost value of time), potential fuel and emissions savings

Source: CPCS analysis

Canada's Worst Bottlenecks in 2015

This table lists the worst bottlenecks we found in our analysis. The twenty most severe bottlenecks are in just four cities – Toronto, Montreal, Vancouver, and Quebec City. We also calculated the congestion cost in terms of lost value of time, and the potential emissions and fuel savings from eliminating these bottlenecks. Altogether, the delay costs from these bottlenecks is close to $300 million per year. Eliminating these bottlenecks could save over 22 million litres of fuel per year, or roughly 500 thousand trips to the gas station!

Appendix C contains maps depicting daily hours of delay per kilometer across the entire highway network in each Census Metropolitan Area (CMA) we analyzed.

Figure 6. Canada's worst bottlenecks, 2015

Rank	CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
1	Toronto	Hwy 401 between Hwy 427 & Yonge St	15.3	3,218	82.28	5,721	15,250
2	Toronto	DVP/404 between Don Mills Rd & Finch Ave	10.5	2,174	55.51	3,478	9,209
3	Montreal	Hwy 40 between Blvd Pie-IX and Hwy 520	10.6	1,956	45.60	4,197	10,901
4	Toronto	Gardiner Expy between S Kingsway & Bay St	7.4	1,076	27.51	1,671	4,447
5	Montreal	Hwy 15 between Hwy 40 & Chemin de la Côte-Saint-Luc	3.9	812	18.93	1,653	4,273
6	Toronto	Hwy 401 between Bay-view Ave & Don Mills Rd	3.3	485	12.40	934	2,510
7	Toronto	Hwy 409 between Hwy 401 and Kipling Ave	1.6	274	6.99	553	1,486
8	Montreal	Hwy 25 between Ave Souligny & Rue Beaub-ien E	2.1	259	6.04	591	1,525
9	Vancouver	Granville St at SW Ma-rine Dr	1.6	245	6.08	679	1,700
10	Vancouver	W Georgia St between Seymour St & W Pender St	1.2	149	3.70	603	1,477

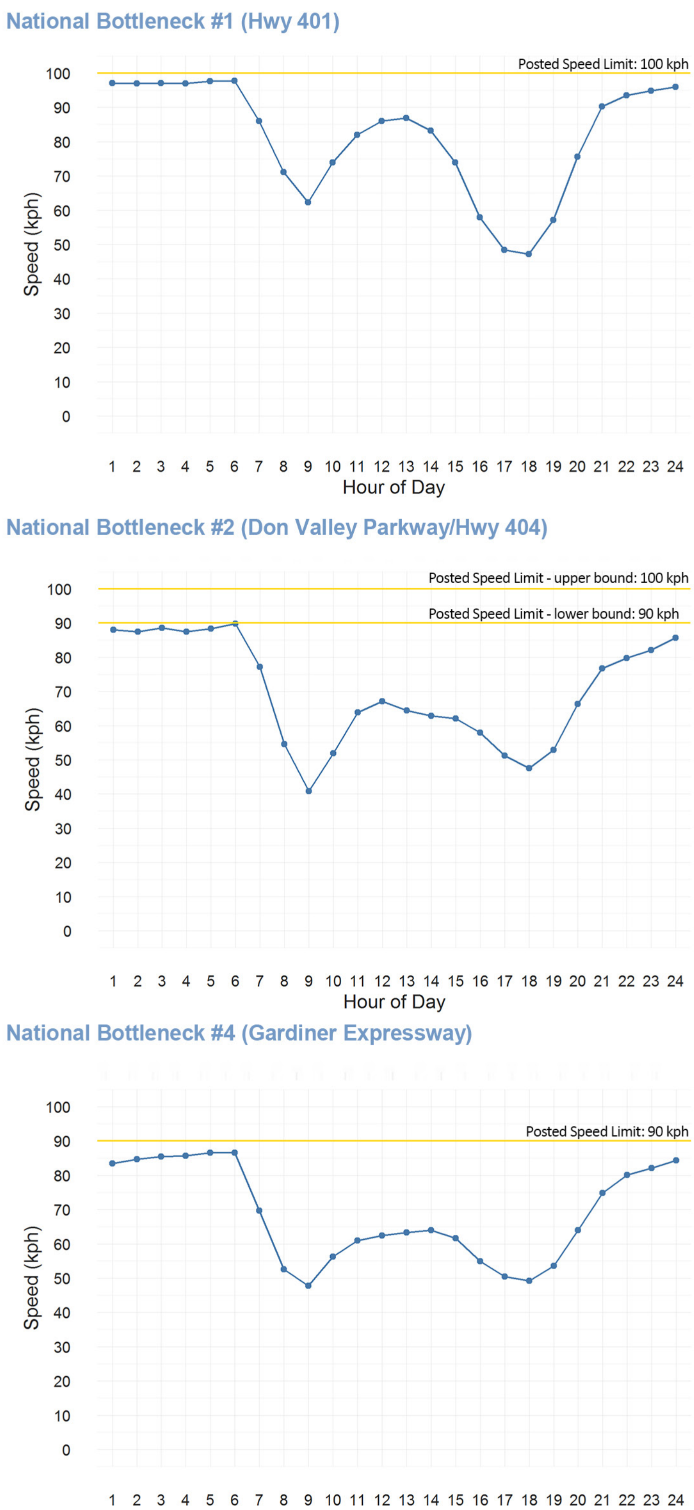
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 7. Canada's worst bottlenecks, 2015

Rank	CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
11	Toronto	Hwy 401 between DVP & Victoria Park Ave	1.3	143	3.66	395	1,064
12	Toronto	Black Creek Dr between Weston Rd & Tretheway Dr	0.8	114	2.91	391	986
13	Toronto	Hwy 401 between Mavis Rd & McLaughlin Rd	0.8	103	2.63	164	437
14	Montreal	Hwy 40 between Hwy 520 & Blvd Cavendish	0.9	96	2.23	207	544
15	Vancouver	Granville St between W Broadway St & W 16th Ave	0.6	88	2.19	276	683
16	Montreal	Hwy 20 near 1re Avenue	0.8	84	1.97	174	463
17	Quebec City	Hwy 73 between Chemin des Quatre Bourgeois & Exit to Ave Dalquier	0.7	78	1.81	127	329
18	Toronto	Hwy 401 interchange at Hwy 427	0.6	73	1.87	194	518
19	Toronto	Hwy 400 at Hwy 401	0.6	62	1.60	216	575
20	Vancouver	George Massey Tunnel on Hwy 99	0.6	60	1.50	97	255
Total			65.2	11,546	287	22,322	58,634

Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 8. Toronto 24 Hour Average Speed Profiles



Greater Toronto Area Bottlenecks

#1, #2, #4, #6, #7, #11, #12, #13, #18, #19

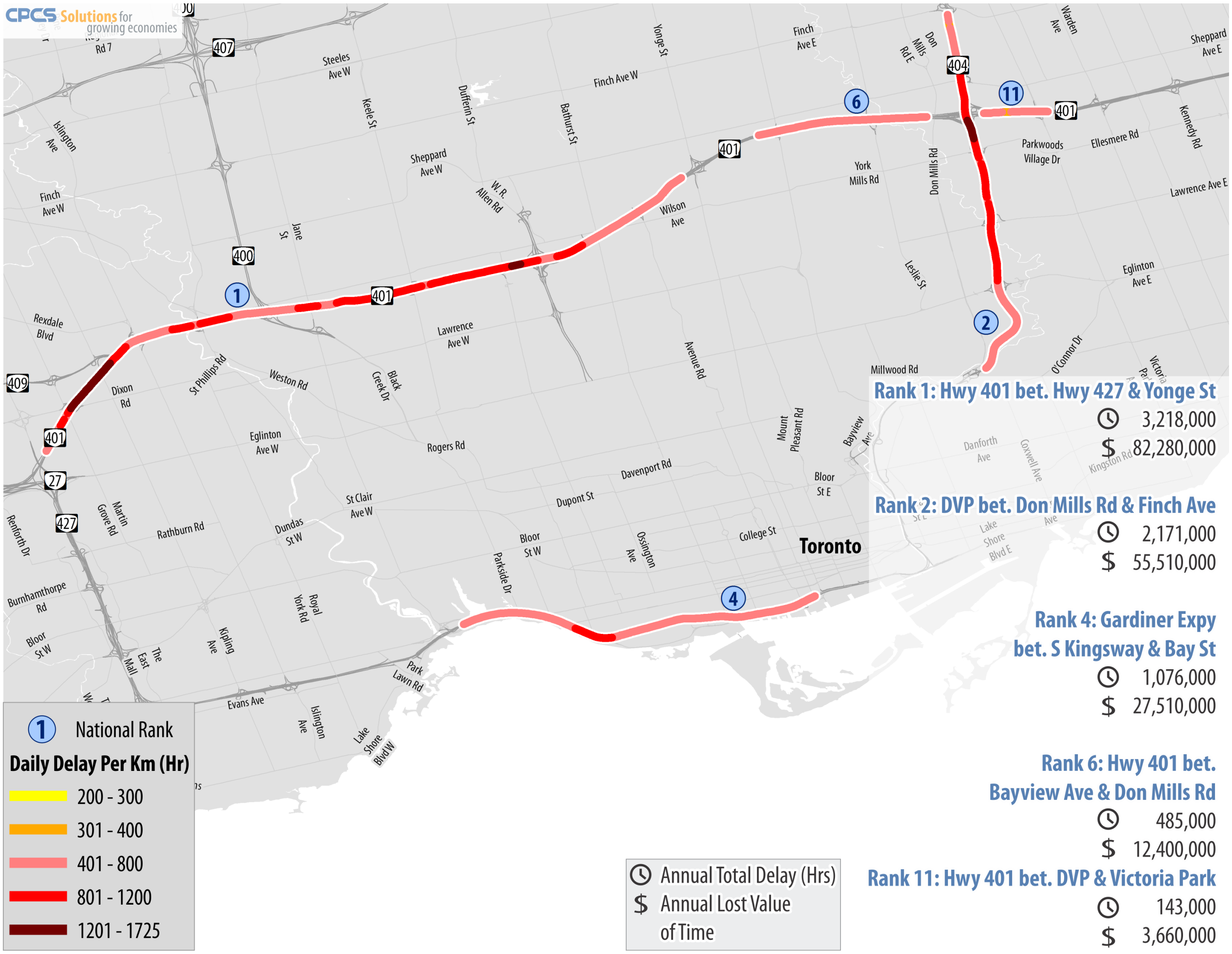
Canada's worst bottleneck is in Toronto – a 15 km stretch of Highway 401 between Highway 427 and Yonge Street. Originally constructed in the 1960s as a bypass to downtown Toronto to the south, activity around Highway 401 quickly flourished to become one of the most developed areas in the country. Today, the bottleneck costs drivers over 3.2 million hours in lost time every year, or $82 million in the lost value of time at average local wage rates.

The second-worst bottleneck, the Don Valley Parkway (DVP) between Don Mills Road and Finch (at which point it is Highway 404), is not far behind. This bottleneck is about 10.5 km long, creating a loss of almost 2.2 million hours annually. Originally planned as one of a series of expressways between downtown Toronto and the growing suburbs in the 1960s, the DVP has instead become the only north-south expressway into downtown. Due to the persistent congestion throughout the day, the DVP has earned the nickname "Don Valley Parking Lot" by local motorists for good reason.

The third-worst bottleneck in the GTHA (and fourth-worst in the country) is the portion of the Gardiner Expressway between South Kingsway and Bay St. in downtown Toronto.

The total hours of delay on the DVP and the Gardiner are not as large as they are on the 401 because they are not nearly as wide and as such, do not carry as much volume. However, the average speeds on the DVP and the Gardiner are lower and more persistently low throughout the day (see Figure 8). While average speeds do drop below 50 kph in the PM peak on the 401, average speeds are below this level in both the AM and PM peak on the DVP and the Gardiner. Further, the travel speeds remain low throughout the day on both the DVP and the Gardiner.

Figure 9. Top Greater Toronto Area Bottlenecks

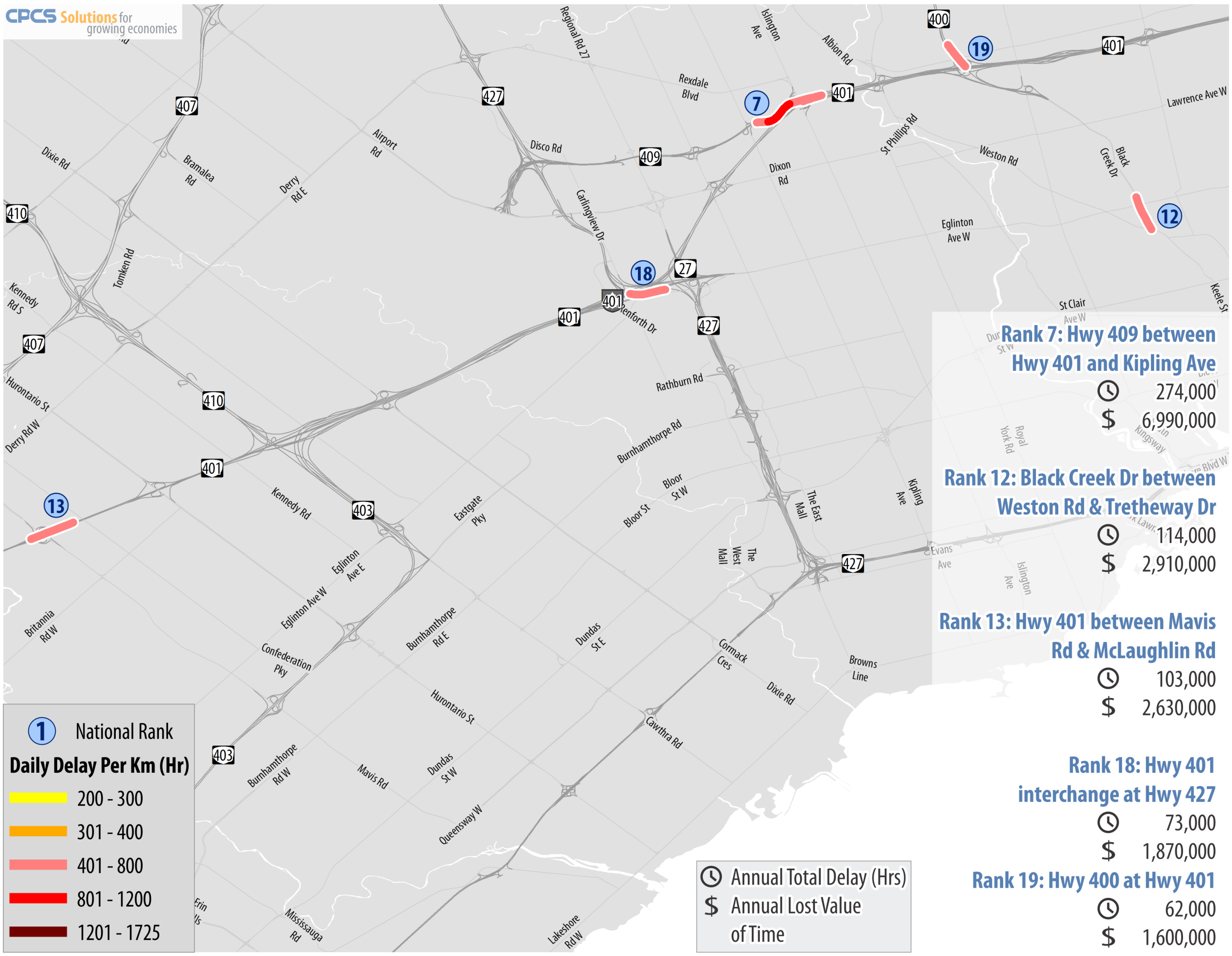


Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Notably absent from the bottlenecks are any stretches of 407 ETR, a 108 kilometre barrier-free all-electronic toll highway that runs north of the City of Toronto. Our analysis shows no excess congestion whatsoever on 407 ETR, which is itself a result of the impact of road tolls. As such, 407 ETR can easily be called the longest "non-bottleneck" in the GTHA.

Another stretch of highway that is notably absent is any portion of the QEW, which runs west of Toronto through Mississauga towards Hamilton. This highway has recently undergone a significant expansion, with new High Occupancy Vehicle (HOV) lanes added in both directions towards the end of 2010. Although the highway still sees congestion, it appears as if this new capacity has helped to reduce congestion levels enough so the highway does not rank among the worst bottlenecks in the GTHA.

Figure 10. Additional Bottlenecks in the Greater Toronto Area



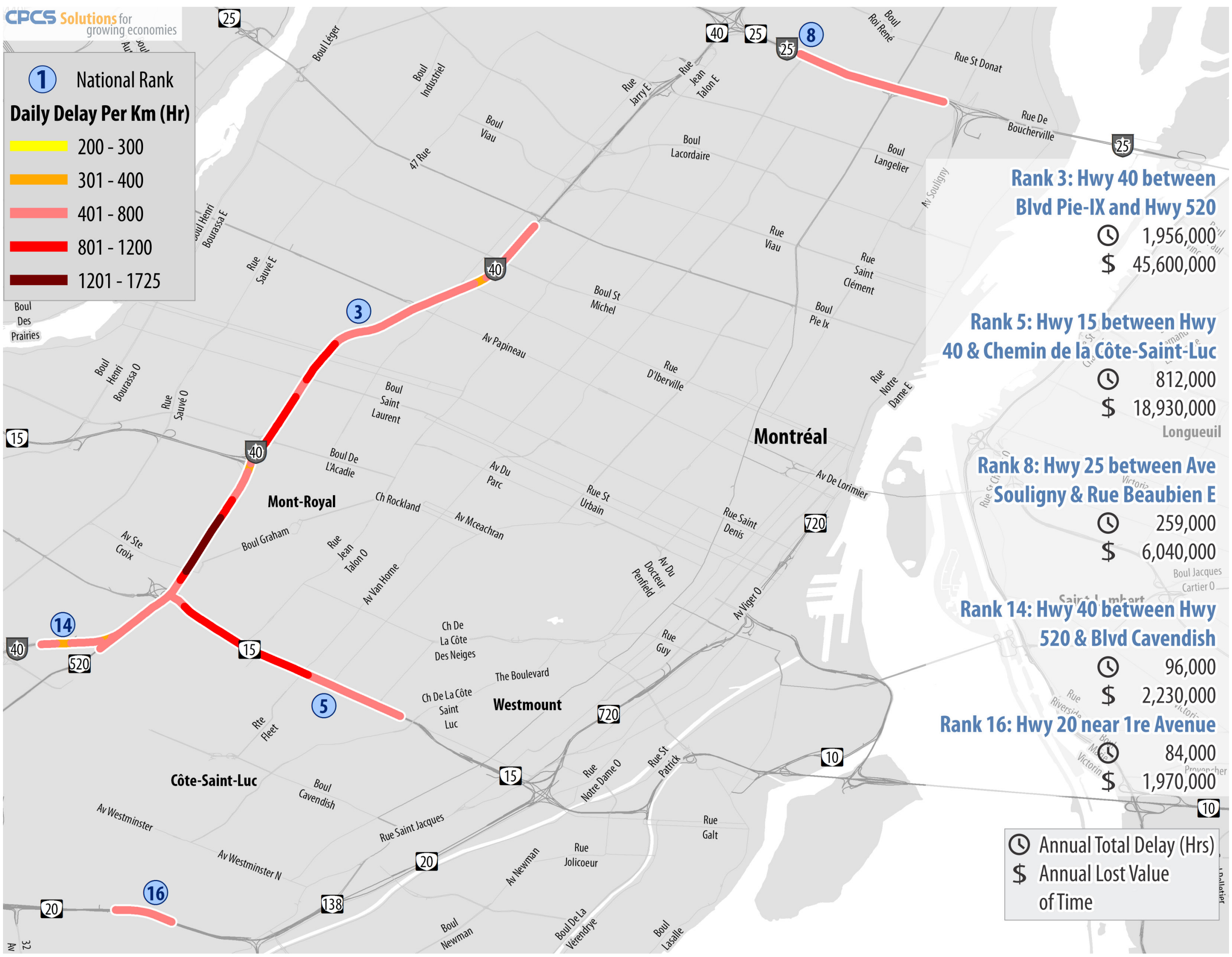
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Montreal Bottlenecks

#3, #5, #8, #14, and #16

Montreal has five of the top twenty most severe bottlenecks in Canada. The worst of these is a 10 km stretch on the Metropolitan Autoroute (Autoroute 40) between Boulevard Pie-IX and Autoroute 520. On this highway, the busiest section of the Trans-Canada Highway, drivers lose slightly under 2 million hours in delays annually, costing them about $45 million is the lost opportunity cost of time. They could altogether save almost 1.3 million liters of fuel, avoiding over 11 million kilograms of emitted CO2.

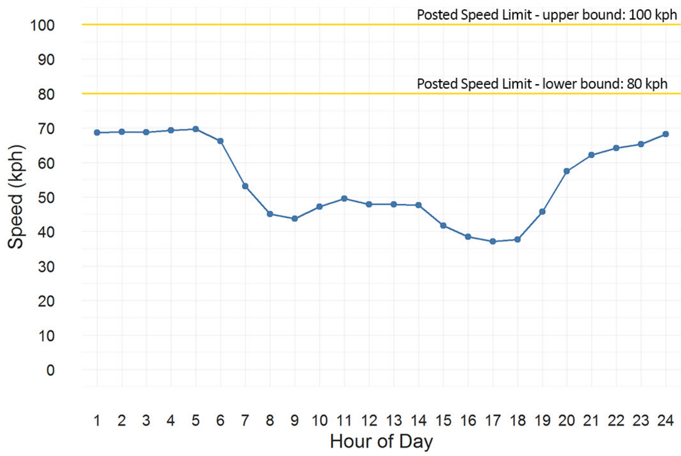
Figure 11. Greater Montreal's Top Bottlenecks



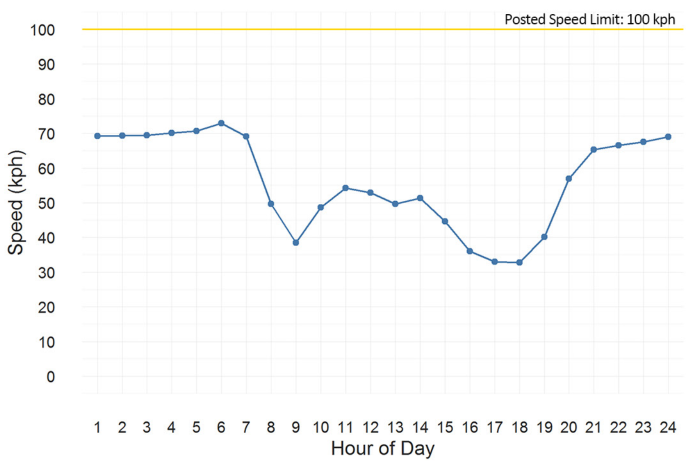
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 12. Montreal 24 Hour Average Speed Profiles

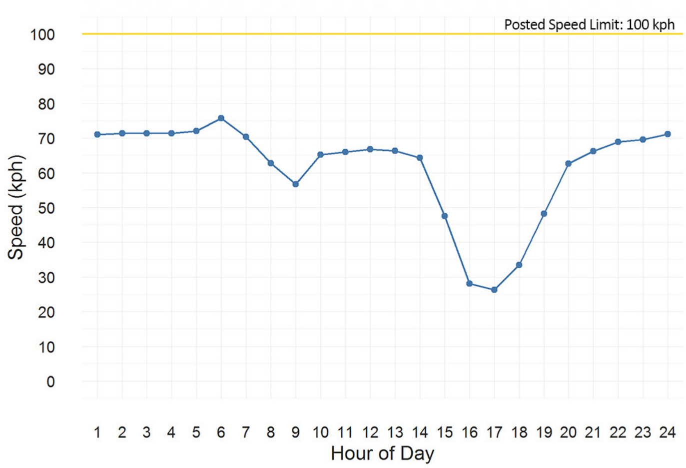
National Bottleneck #3 (Hwy 40)



National Bottleneck #5 (Hwy 15)



National Bottleneck #8 (Hwy 25)



Montreal's other four bottlenecks are shorter, ranging from 800 meters to about 4 kilometers, however they still exacerbate local driving conditions and impose losses. In total, Montreal's five bottlenecks are responsible for over 3 million hours in annual delay, worth about $75 million in lost time. If these bottlenecks were to be addressed, drivers would save almost 7 million liters in fuel per year, or enough to save about 140 thousand trips to the gas station. Related potential emission reductions would be 18 thousand tonnes of CO2, the equivalent of about 4,500 elephants!

Although Montreal's bottlenecks rank behind Toronto's worst bottlenecks generally, the travel speeds on Montreal's bottlenecks are in fact worse (see Figure 12). For example, on the Metropolitan Autoroute average travel speeds are consistently at or below 50 kph throughout the entire business day. In fact, there is almost no distinction between the AM, midday and PM peak periods on this stretch. Rather, that entire period can almost be considered as a single peak traffic period.

In terms of our calculations of total delay, because free-flow and MTS travel speeds are also much lower on Montreal's bottlenecks (than on Highway 401, for example), the total delay relative to MTS on the Montreal bottlenecks is not as severe. In other words, given the road design, urban environment and other factors, the maximum achievable speeds on the Montreal bottlenecks are not as high as they are on Highway 401. Therefore, the total delay relative to these speeds are also not considered to be as severe (although this certainly is no cause for relief for Montreal's motorists!).

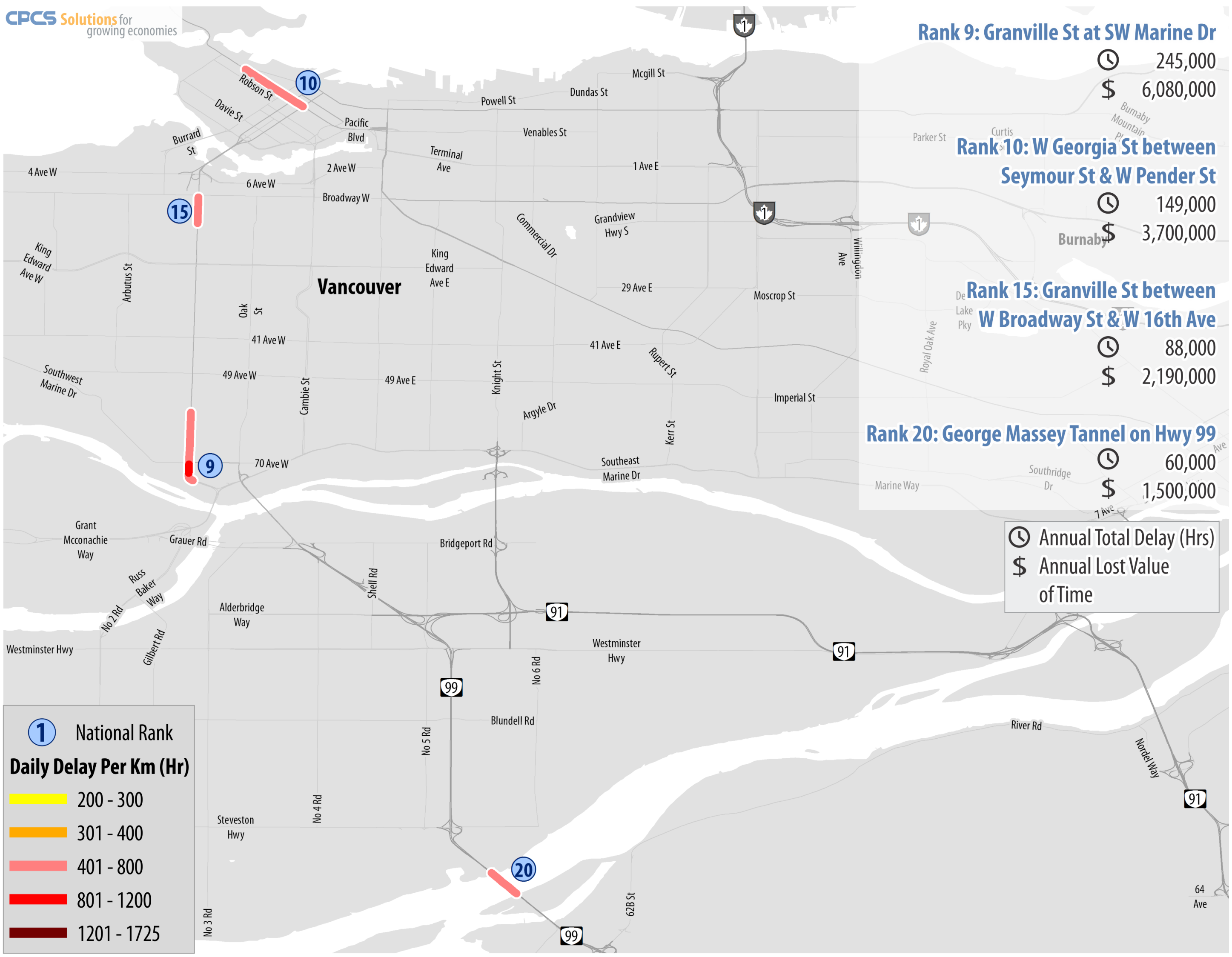
Vancouver

#9, #10, #15 and #20

As already noted, this Study focused on expressways. Unlike Toronto and Montreal, Vancouver does not have any expressways directly serving its downtown area. As such, we choose to include the signalized portion of Highway 99 that runs through downtown Vancouver.

Two of Vancouver's four bottlenecks are on Granville St (part of the signalized portion of Highway 99). The longer of the two (#9) is at SW Marine DR, and about a kilometer and a half in length. The shorter (#15) one is only about half a kilometer long, stretching between W Broadway St and W 16th Avenue.

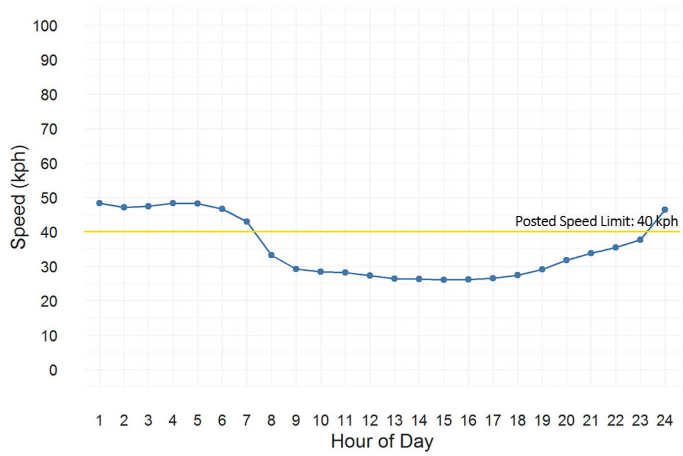
Figure 13. Greater Vancouver's Top Bottlenecks



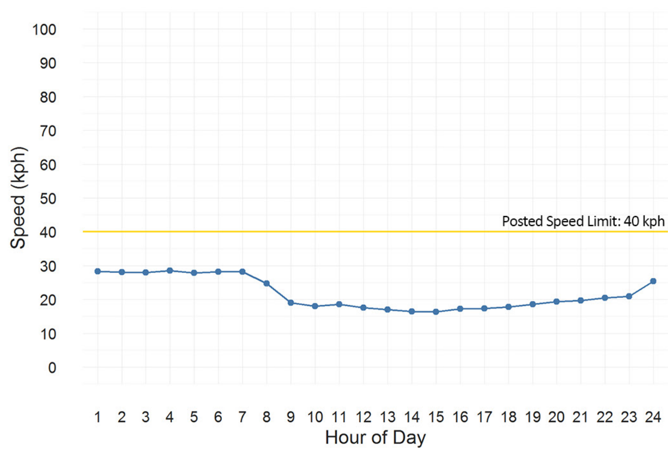
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 14. Vancouver 24 Hour Speed Profiles

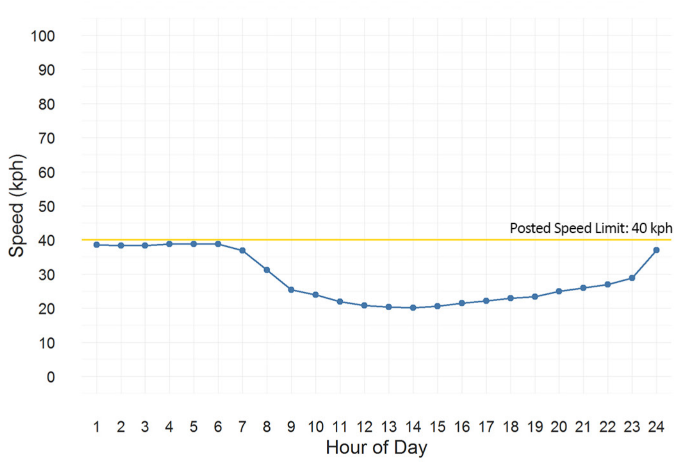
National Bottleneck #9 (Granville St.)



National Bottleneck #10 (W Georgia St.)



National Bottleneck #15 (Granville St. (2))



The other two bottlenecks are on W Georgia St between Seymour and W Pender (also part of the signalized portion of Highway 99), and the George Massey tunnel corridor on the non-signalized portion of Highway 99 (which contrary to recent media reports does not appear to be the worst bottleneck in the area).

As noted, we selected the main artery that serves Vancouver's downtown core in order to make the results broadly comparable to Canada's other large cities, despite the fact that it is signalized. These and other main arteries have significantly lower maximum throughput potential than limited access highways. As such, our estimate of total delay on these arteries are much lower than they would have been if they were compared with the throughput potential of a limited access highway. In other words, although the ranking of the bottlenecks are not as severe as they are in Toronto and Montreal, the actual vehicle speeds that drivers experience into and out of downtown Vancouver are in fact as bad as or worse than they are in those two cities.

This point is illustrated by the speed profiles shown in Figure 14. Travel speeds throughout the day on these bottlenecks are consistently at or lower than 30 kph. In the case of W Georgia St. which runs through the downtown core, average travel speeds remain at approximately 20 kph throughout the entire business day.

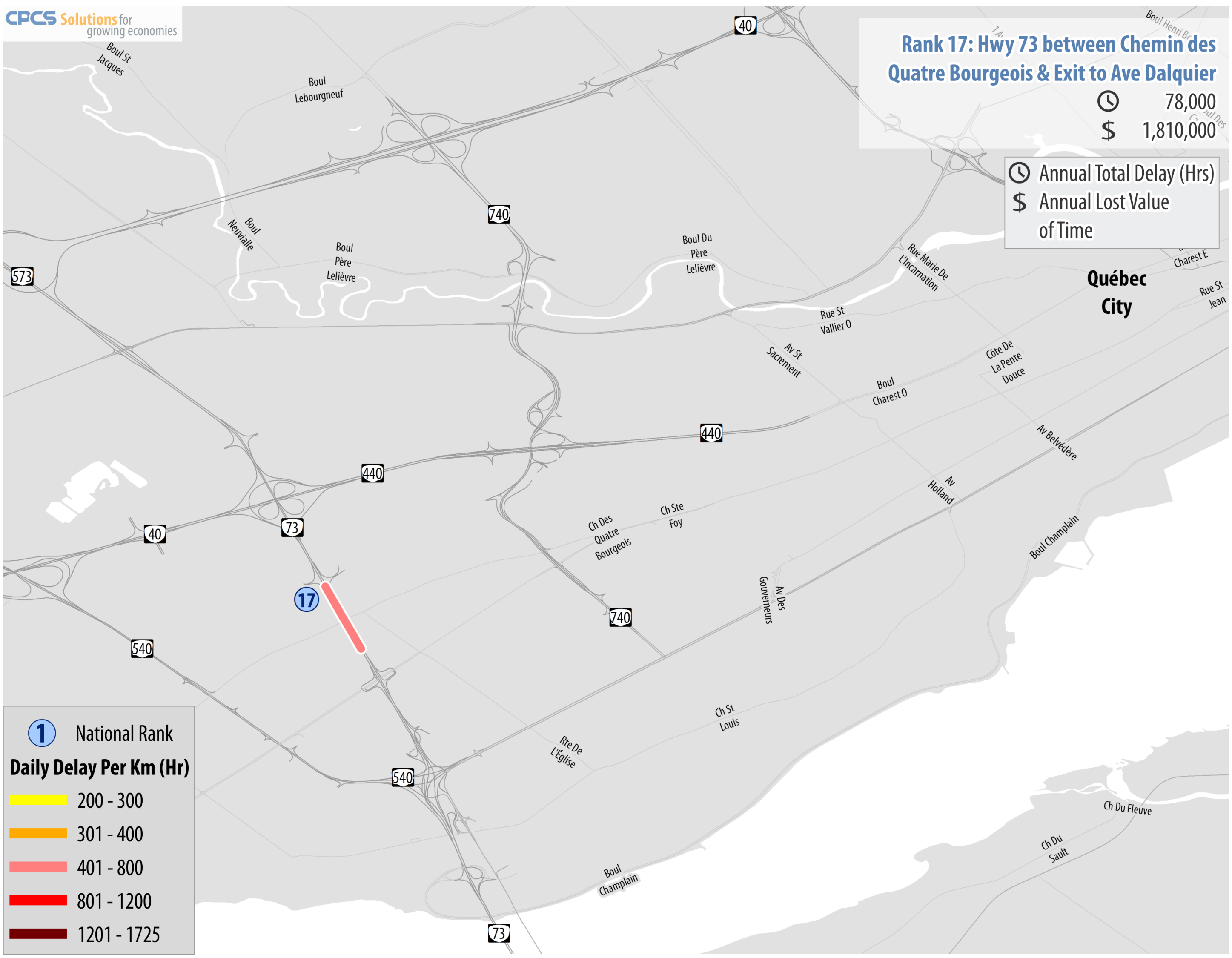
The four kilometers of severe congestion across the four bottlenecks identified cost Vancouver's drivers over $13 million annually. Eliminating these bottlenecks could help recover about half a million hours in lost time and save over 1.5 million liters of fuel per year, which is about 30 thousand trips to the gas station. The related CO2 emissions equal over four thousand tonnes annually, which is approximately the same weight as two thousand cars!

Quebec City

#17

Quebec City is the only medium-sized city in Canada to have a major bottleneck severe enough to rank in the top twenty worst congestion zones in Canada. This bottleneck is less than a kilometer long, on Highway 73 between Chemin des Quatre Bourgeois and the exit to Avenue Dalquier. This single stretch delays drivers by about 78,000 hours annually, at a cost of 1.8 million in the opportunity cost of time. These drivers could save over 1,000 thousand liters of fuel a year, if the congestion were to be relieved in this area.

Figure 15. The Quebec City Area's Worst Bottleneck



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Other Bottlenecks of Note

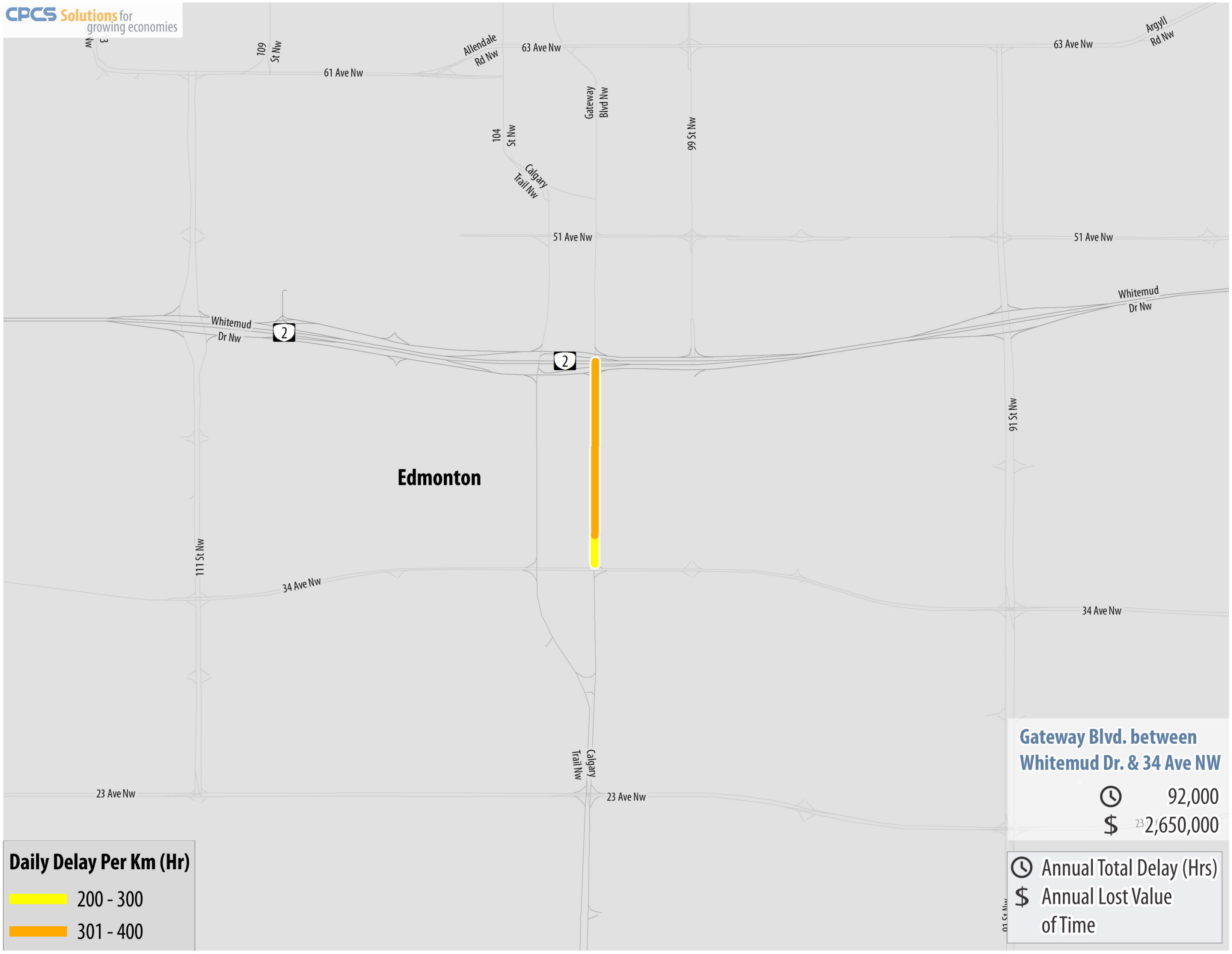
We also found bottlenecks in other cities that were not severe enough in their intensity in any given stretch to rank in the twenty worst. But drivers in these stretches also experience significant congestion. These five bottlenecks are in the Ottawa-Gatineau, Calgary, and Edmonton areas, and shown in the table below as well as the maps that follow.

Figure 16. Other Bottlenecks of Note in Canada

CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
Ottawa-Gatineau	Hwy 417 between O'Connor St & Bayswater Ave	2.4	127	3.24	277	740
Calgary	Crowchild Trail between University Dr NW & Memorial Dr NW	1.7	114	3.30	436	1,139
Ottawa-Gatineau	Vanier Pkwy between Hwy 417 & Montreal Rd	1.9	106	2.72	449	1,153
Edmonton	Gateway Blvd. between Whitemud Dr. & 34 Ave NW	1.2	92	2.65	374	966
Calgary	Crowchild Trail at 24th Ave NW	0.6	36	1.04	107	282

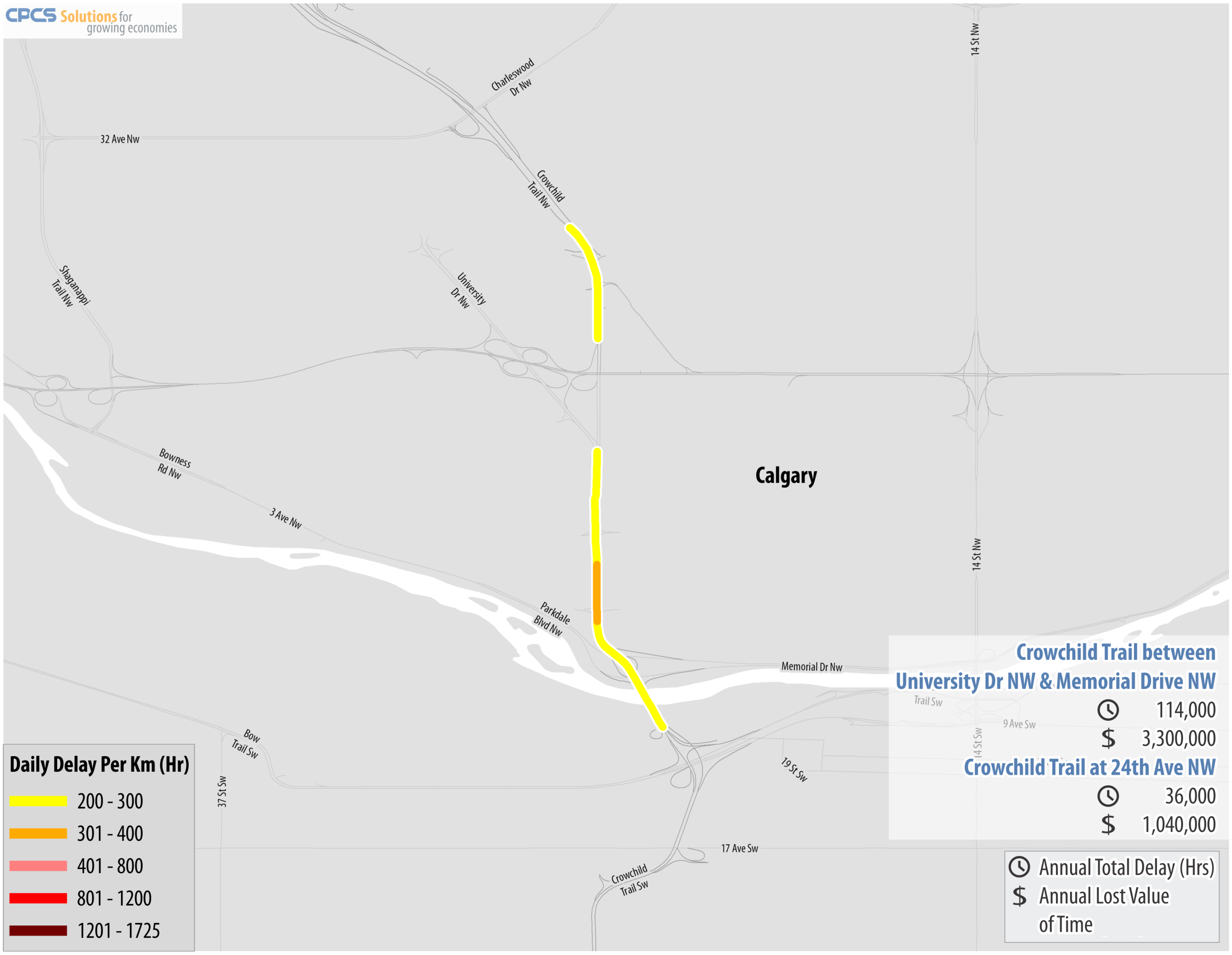
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 17. Edmonton's Worst Bottleneck



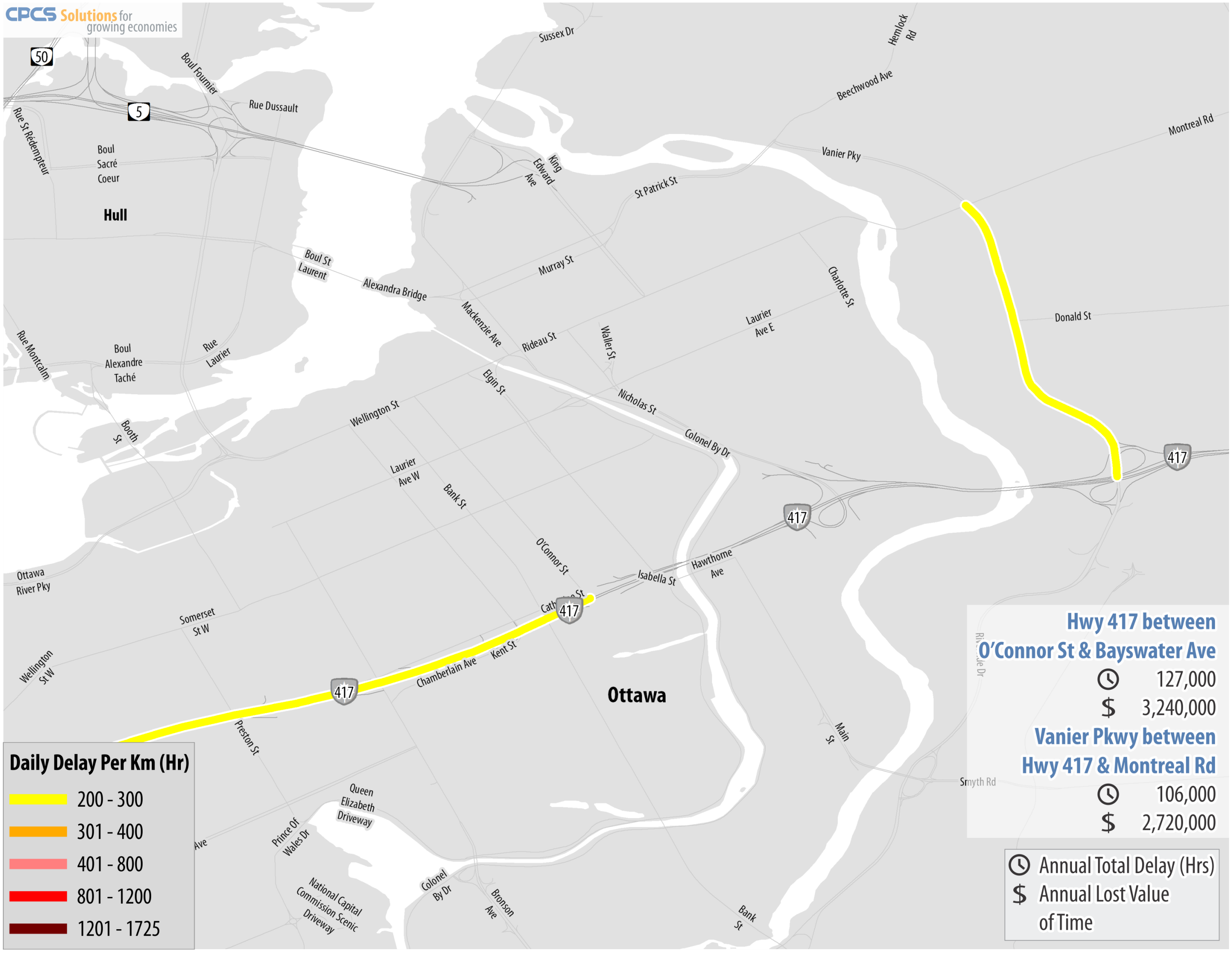
Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 18. Calgary's Worst Bottlenecks



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Figure 19. Ottawa's Worst Bottlenecks



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Region-wide Measures of Congestion

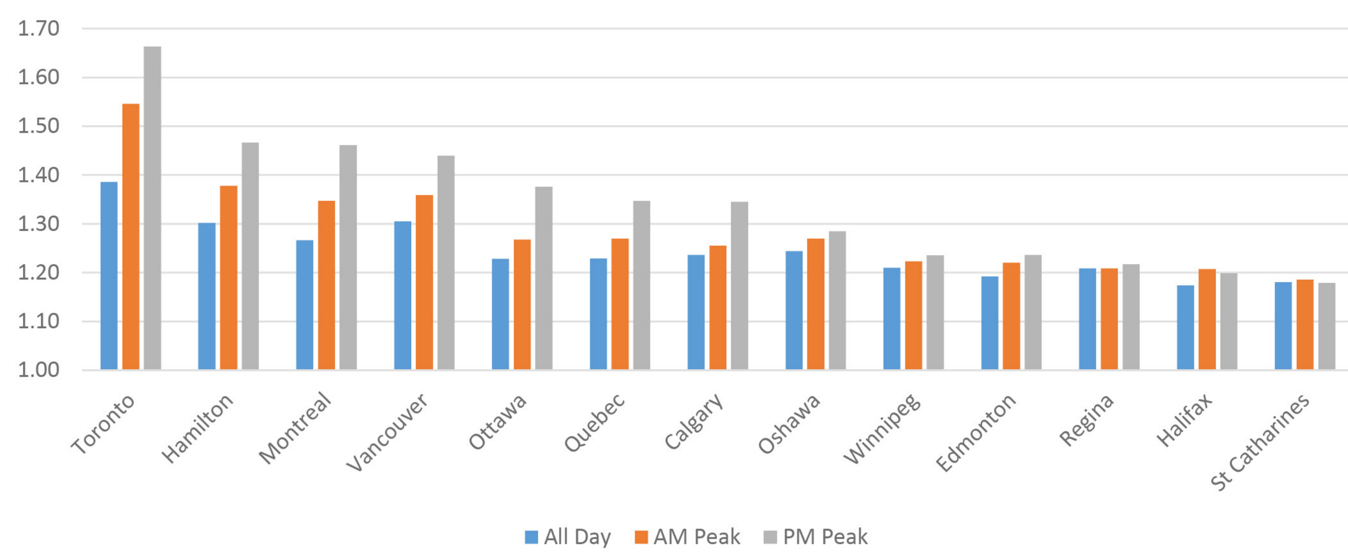
Our analysis has focused primarily on identifying the worst bottlenecks, which are specific stretches of highway as opposed to region-wide measures of congestion. As noted in the introduction, other studies have estimated region-wide measures of congestion. Although doing so is not the primary focus of this Study, our data also allows for developing region-wide congestion measures.

In order to do so, we have calculated Travel Time Indices (TTI) for each of the urban areas that were included in our dataset. The TTI is the travel rate during a specified period of time relative to the travel rate in free-flow conditions. For example, if it takes 45 minutes to travel between points A and B during the morning peak and it takes 30 minutes to travel between the same points during free-flow conditions, the TTI is 45 / 30 = 1.50. The TTI can be calculated as an all-day average or as an average during a more specific period of time (morning or afternoon peak, for example).

The TTI differs from our method of estimating bottlenecks in a few key ways:

- The bottleneck analysis measures the level of congestion for specific stretches of highway, whereas the TTI measures average congestion levels region-wide.
- The bottleneck analysis uses MTS as the baseline speed, whereas the TTI uses FFS as the baseline speed (with the FFS being higher than the MTS). Further, the TTI as we calculate it here uses a slightly more liberal estimate of FFS.
- The bottleneck analysis takes the total volume of traffic into account to determine the rankings, with higher volume highways showing up as more severe bottlenecks. The TTI is not affected by volume, except to weigh different speed observations in each hours in order to arrive at a single TTI for each city.

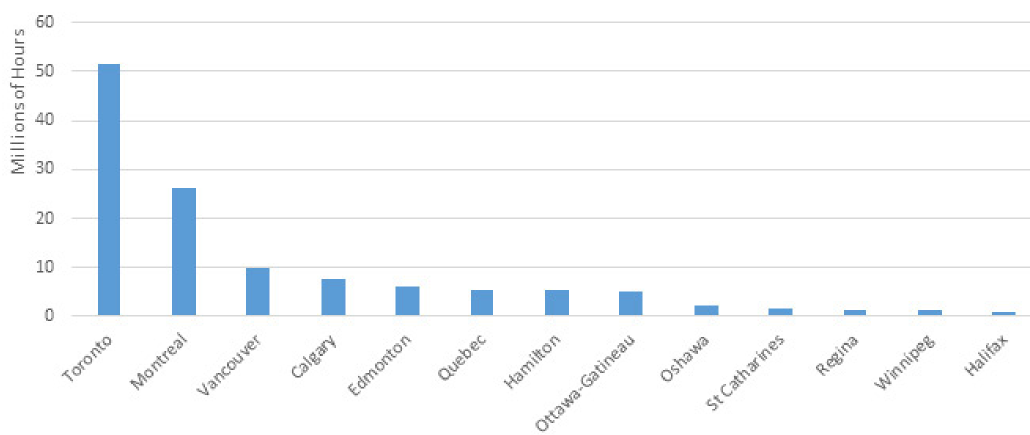
Figure 20. Weekday Travel Time Indices by Census Metropolitan Area



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

The TTI for each CMA included in our analysis is shown in Figure 20 (shown in order of highest to lowest All Day TTI). For each CMA, the average TTI throughout the day is shown, as well as the AM Peak (7 – 9am) and PM Peak (4 – 6pm) TTIs. For example, the All Day TTI for Toronto is 1.39. This means that on average during a weekday a trip in the Toronto Area highways takes 39% longer than it would under free-flow conditions. During the morning peak that trip would take 55% longer than it would under free-flow conditions, increasing to 66% longer during the afternoon peak. Because the All Day average is calculated using a weighted-average of volumes throughout the day, it places greater weight upon the peak periods than it does to the off-peak periods (which is why the All Day average is usually close at least to the morning peak, if not both).

Figure 21. Additional Minutes of Travel Time per Year Relative to Free-Flow (60 Minute Baseline, AM and PM Peak)



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

For the purpose of measuring congestion costs, the FFS is not a suitable measure for the baseline speed. In the example above, the presence of a TTI of 1.50 does not suggest that the actual travel time "should" be 30 minutes instead of 45 minutes. As noted in our opening discussion regarding the purpose of this Study, the optimal level of congestion varies by time and place, and depends on the cost of reducing congestion in those specific areas. However, FFS and by extension the TTI can be useful for making general comparisons of the total traffic level across urban areas, which is why it is commonly used.

Using the same data, we can also estimate the cumulative amount of time spent in traffic by motorists, relative to the amount of time that would have been spent in traffic if free-flow conditions prevailed. To do this, we multiplied our hourly estimates of net travel times (actual travel times minus free-flow travel times) for each day on each highway segment by 250, the approximate number of non-holiday weekdays in the year. The results are shown in Figure 22. In total, motorists across all CMAs spent an additional 125 million hours in traffic, relative to the time that they would have spent in free-flow conditions.

Figure 22. Additional Annual Hours of Travel Time Relative to Free-Flow

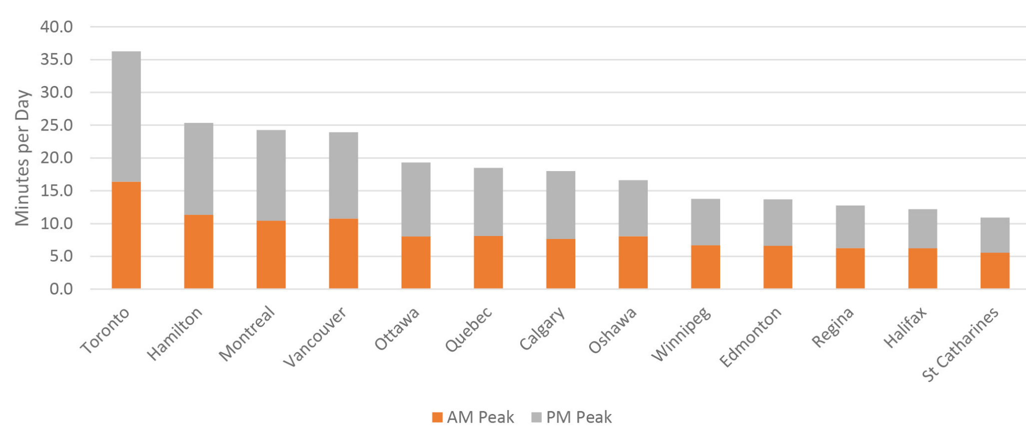
CMA	Millions of Hours
Toronto	51.6
Montreal	26.3
Vancouver	10.0
Calgary	7.8
Edmonton	6.2
Quebec	5.3
Hamilton	5.2
Ottawa-Gatineau	5.2
Oshawa	2.3
St Catharines	1.5
Regina	1.1
Winnipeg	1.1
Halifax	0.9
Total	124.4

Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Interpreting the TTI

The TTI can be used to estimate how much the typical motorist's commute time would be reduced in each city if free-flow conditions prevailed (again noting the free-flow conditions at all hours is not a reasonable expectation). For example, if the typical motorist spends 75 minutes per day commuting to and from work, and the TTI was 1.25, that time would be reduced to 75 / 1.25 = 60 minutes (a difference of 15 minutes) if free-flow conditions prevailed. In the chart below, we refer that difference as additional minutes of travel time relative to free-flow.

Figure 23. Additional Minutes of Travel Time per Day Relative to Free-Flow (60 Minute Baseline, AM and PM Peak)



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

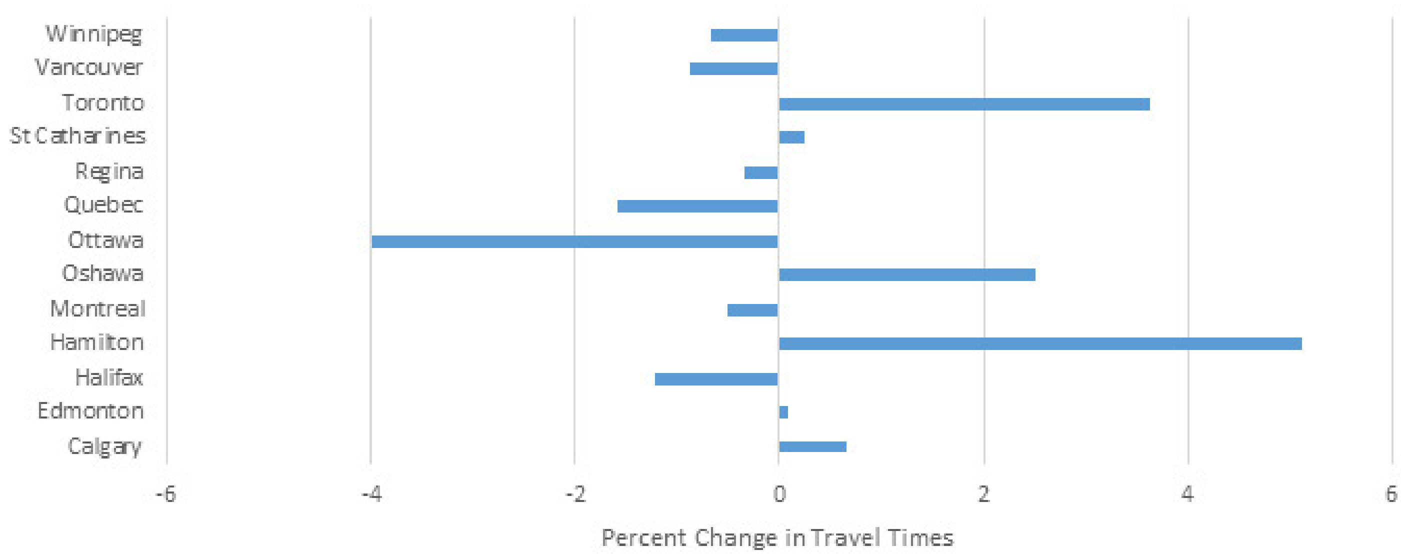
Unsurprisingly, the typical Toronto area motorist spends the most additional time per day relative to a two-way 60 minute free-flow commute. In typical peak period traffic conditions, what would be a 60 minute two-way commute becomes a 96 minute commute (for 36 additional minutes in total). Hamilton (which is part of the GTHA) appears next, followed by Montreal and Vancouver.

No top bottlenecks were found in the medium sized cities due in part to the smaller volumes of traffic found on their highways (recall that the bottleneck analysis takes both speed and volume into account). As indicated by Figure 23, however, motorists in those cities also face considerable delays, relative to free-flow speeds. For a typical Ottawa area motorist, for example, what would be a 60 minute two-way commute in free-flow conditions becomes a 79 minute commute during peak periods.

Although there are some exceptions, PM peak period traffic is more severe than AM peak period traffic on average. This is due in part to the fact that commuters usually leave home at more variable times in the morning (spreading the traffic to some extent) than they leave work in the afternoon (which tends to be more clustered closer to 5pm).

As noted, the AM and PM peak periods in the figures above are defined as 7 – 9am and 4 – 6pm, respectively. By fixing the length of the peak periods across all urban areas, we do not see how the length of the peak periods vary. While there are many ways of showing this, one way of showing the difference between the urban areas in this regard is to show the TTI values for a one specific hour relative to another.

Figure 24. Change in Average Travel Times Between 5 – 6pm and 6 – 7pm



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

For example, Figure 24 shows the change in the TTI from 5 – 6pm to 6 – 7pm in each urban area. If the TTI does not change from 5 – 6pm to 6 – 7pm, this suggests that travel speeds and overall traffic levels are consistent between the two hours. However, if the TTI for 6 – 7pm is lower than the TTI for 5 – 6pm, this suggests that traffic is dissipating. Urban areas with TTIs that are considerably lower for 6 – 7pm relative to 5 – 6pm then have shorter peak periods overall relative to those urban areas that do not.

As shown in Figure 24, average travel times in some urban areas (notably Toronto, Oshawa and Hamilton – all part of the GTHA, and Calgary) are actually longer (speeds are slower) during the 6 – 7pm period than they are during the 5 – 7pm period. In these urban areas, the afternoon "rush hour" clearly extends into the early evening. In other urban areas, particularly Ottawa and to a lesser extent Quebec City and Halifax, there is a significant drop in travel times (speeds are faster) during the 6 – 7pm period. This suggests that peak hour congestion does not last as long in these urban areas.

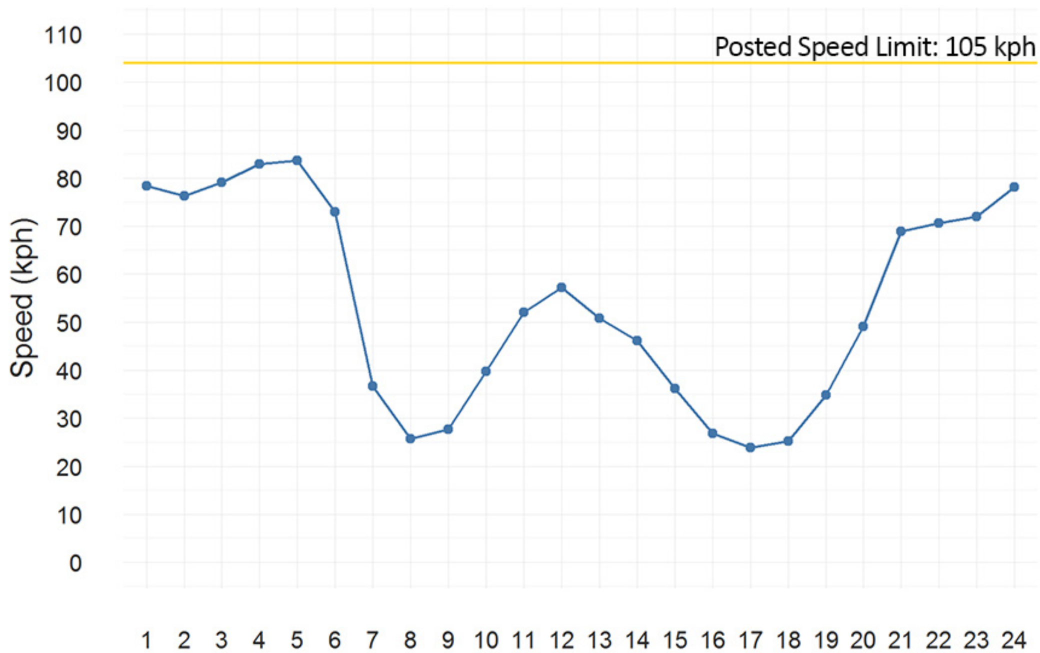
Comparison With Top US Bottlenecks

Comparisons With Top US Bottlenecks

In 2015, CPCS completed an analysis of top highway bottlenecks in the US, using broadly similar methodologies and data sources. The new Canadian analysis allows for a comparison of the worst bottlenecks across both countries.

Through this comparison we find that Canada's worst bottleneck (the stretch of Highway 401 through Toronto) ranks among the ten worst across Canada and the US. In terms of total hours of delay, it compares with the worst bottlenecks in the New York metro area. Only New York, LA and Chicago have bottlenecks that are worse than Toronto's.

Figure 25. Additional Minutes of Travel Time per Day Relative to Free-Flow (60 Minute Baseline, AM and PM Peak)



Source: CPCS analysis of data provided by HERE and provincial/local departments of transportation.

Meanwhile, Montreal's worst bottlenecks falls within the 20 worst across both countries. Specifically, this stretch of Highway 40 is comparable to the worst bottleneck in Boston, and is among the worst bottlenecks on the Eastern seaboard.

Despite the severe levels of congestion in Toronto and Montreal, the I90 between Roosevelt Rd. and N Nagle Ave. in Chicago is found to be the most severe bottleneck due to the extremely low travel speeds in the AM, midday and PM peak hours (see Figure 18). In both the AM and PM peaks, average travel speeds fall well below 30 kph, while during the midday average travel speeds remain between 40 and 60 kph at best. These low speeds combined with the length of the highway segment that sees such consistently low speeds make it the worst ranking bottleneck.

Figure 26. Canadian bottlenecks compared with worst US bottlenecks in 2015

Rank	CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
1	Chicago	I90 between Roosevelt Rd and N Nagle Ave	19.3	16,900	543	24,113	60,320
2	Los Angeles	I405 between SR22 and I605	6.6	7,100	248	6,887	16,640
3	Los Angeles	I10 between Santa Fe Ave and Crenshaw Blvd	11.1	6,900	243	8,448	21,320
4	Los Angeles	I405 between Venice Blvd and Wilshire Blvd	8.4	6,300	220	7,427	18,200
5	Los Angeles	US101 between Franklin Ave and Glendale Blvd	7.1	5,400	189	6,668	16,640
6	Los Angeles	I110 between Exposition Blvd and Stadium Way	6.9	5,400	188	7,025	17,160
7	Los Angeles	US101 between Sep-ulveda Blvd and Laurel Canyon Blvd	6.1	3,600	124	3,966	10,140
8	New York and Union City	Lincoln Tunnel between 10th Ave and John F Kennedy Blvd	4.2	3,400	113	6,550	15,860
9	Toronto	Hwy 401 between Hwy 427 & Yonge St	15.3	3,218	82	5,721	15,250
10	New York	I95 between I895 and Broadway	5.0	3,000	106	5,851	14,300
11	Austin	I35 between East Riv-erside Dr and E Dean Keeton St	4.8	3,000	95	6,724	17,420
12	Los Angeles	I5/I10 between N Mis-sion Rd and US101	3.2	2,300	81	3,659	9,360

Source: CPCS analysis of data provided by HERE and US state / CA provincial / local departments of transportation.

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Figure 26. Canadian bottlenecks compared with worst US bottlenecks in 2015 (continued)

Rank	CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
13	San Francisco	I80 between US101 and Bay Bridge	3.1	2,200	76	3,020	7,280
14	Toronto	DVP/404 between Don Mills Rd & Finch Ave	10.5	2,171	56	3,478	9,209
15	Los Angeles	I10 between La Brea Ave and National Blvd	3.5	2,100	74	2,088	5,200
16	Los Angeles	I5 between S Eastern Ave and Euclid Ave	3.2	2,100	73	3,756	9,620
17	Boston	I93 between I90 and US1	3.1	2,100	75	7,498	18,200
18	Montreal	Hwy 40 between Blvd Pie-IX and Hwy 520	10.6	1,956	46	4,197	10,901
19	Oakland	I80 between I580 and Ashby Ave	3.2	1,900	65	2,619	6,500
20	Seattle	I5 between Madison St and Exit 168A	2.6	1,600	59	2,346	5,980
21	Fort Lee	I95 between SR4 and Palisades Interstate Pkwy	1.4	1,500	49	3,069	7,540
22	Newark and Kearny	Pulaski Skyway between I95 and Central Ave	1.8	1,400	47	3,244	7,800
23	Miami	Palmetto Expy between 41st St and Dolphin Expy	2.7	1,400	39	2,451	6,240
24	New York	I678 between Queens Blvd and Liberty Ave	2.3	1,400	48	1,942	4,680

Source: CPCS analysis of data provided by HERE and US state / CA provincial / local departments of transportation.

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Figure 26. Canadian bottlenecks compared with worst US bottlenecks in 2015 (continued)

Rank	CMA	Location	Length (km)	Annual Total Delay ('000 hours)	Annual Delay Cost (CAD millions)	Potential Annual Fuel Savings ('000 litres)	Potential Emissions Savings ('000 kg CO2)
25	Houston	I610 between Richmond Ave and Post Oak Blvd	2.1	1,300	41	1,928	4,940
26	Chicago	I90 Between I55 and W Pershing Rd	1.9	1,300	41	2,569	6,760
27	Atlanta	I75/I85 between Freedom Pkwy NE and North Ave NE	2.1	1,200	35	1,486	3,900
28	Houston	I69 between Hazard St and Buffalo Speedway	2.1	1,100	36	2,321	5,980
29	DC	I395 between Washington Blvd and George Washington Memorial Pkwy	1.8	1,100	35	1,221	2,860
30	Dallas	Woodall Rodgers Freeway	1.8	1,100	34	1,782	4,420
31	Toronto	Gardiner Expy between S Kingsway & Bay St	7.4	1,076	28	1,671	4,447
32	Boston	I93 between Edge Hill Rd and West St	19	1,000	36	1,373	3,380
33	Los Angeles	I405 between Burbank Blvd and Ventura Blvd	1.6	1,000	34	1,286	3,120
34	Los Angeles	US101 between SR110 and Alameda St	1.6	1,000	34	1,644	4,160
35	Montreal	Hwy 15 between Hwy 40 & Chemin de la Côte-Saint-Luc	3.9	812	19	1,653	4,273

Source: CPCS analysis of data provided by HERE and US state / CA provincial / local departments of transportation.

Appendix A: Mathematical Formulations

Calculating normalized hour-indexed delays

We calculated length-normalized hour-indexed delays (hours per mile) for every urban freeway segment i using this relationship:

$$Delay\ (d_{ji}) = Vehicles\ per\ hour_{ji} * \left(\frac{1}{Observed\ Speed_{ji}} - \frac{1}{Baseline\ Speed_{i}}\right)$$

Where,

Observed Speed is the weekday profile speed for every hour j in the day in every freeway segment i;

Baseline Speed is the Maximum Throughput Speed (MTS) for that freeway segment i, a counterfactual speed based on ideal travel conditions. We develop this for each segment using relationships published in the Transportation Research Board's Highway Capacity Manual (HCM);

Vehicles per hour is the hourly volume estimated as above.

The relationship above holds ONLY in weekday hours when the observed speed is lower than the Maximum Throughput Speed (ideal conditions). In other words, the conditions for calculating congestion are met when drivers experience slowdowns. When observed speed exceeds MTS, there is no congestion – delay in those hours and segments in 0.

Calculating Maximum Throughput Speed (MTS)

The Maximum Throughput Speed is the speed corresponding to optimal vehicle volume flow, i.e. the speed at which a maximum number of vehicles can pass through a road segment. Imagine an empty stretch of highway with a few vehicles passing through at the Free Flow Speed (FFS). As more vehicles enter the stretch, the volume (number of vehicles passing through a road segment at a given time) increases and the speed decreases due to lane changes, fluctuating separation distance, and other behavioral and design factors. As more and more vehicles enter the freeway, the volume reaches a theoretical maximum throughput – the speed at this stage in the traffic flow process is the MTS. Additional vehicles beyond this level of throughput start to reduce the speed leading to slow downs and congestion. Even though drivers experience slowdowns, this may still be far from "sitting in traffic" or jam conditions.

Although the MTS baseline is lower than the FFS, it represents a better use of available freeway capacity and is therefore an improved reference point for estimating delays due to congestion. Assuming a constant volume of vehicles in this range of speeds, using the MTS as a baseline also gives us a more conservative estimate of congestion. In other words, we most likely underestimate hourly delays.

To calculate the MTS (in mph):

$$MTS_i = 39 + 0.2 * FFS_i$$

Where,

FFS is the free flow speed as estimated by the 95th percentile of calculated weekday average hourly speeds. Because the hourly speeds themselves are average speeds, the calculated FFS is lower than the true 95th percentile speed. Our method of calculating FFS can be roughly interpreted as the average vehicle speed in the best or second-best hour of the day (which is usually an overnight or early morning hour when traffic volumes are low).

Ranking bottlenecks

We ranked bottlenecks by the metric Daily Total Delay (hours), defined as the sum of the estimated delays in all hours experienced by all vehicles entering and leaving a congestion queue on a representative non-holiday weekday.

To go from the length-normalized hour-indexed delay (hours per mile, as above) to the Daily Total Delay (hours), we followed a four-step process:

1. Adjustment to Daily Delay: We first calculated the length-normalized daily delay (hours/km) for all urban freeway segments i

$$Daily\ Delay\ (D_i) = \sum_{j=1}^{24} Delay\ (d_{ji})$$

2. Adjacency Analysis: We then defined a bottleneck as a group of contiguous highway segments i that are each above a certain Daily Delay threshold. For major bottlenecks, a cut-off of 400 hours/km of Daily Delay was chosen based on the Di distribution across all freeway segments with non-zero delays. In iterative analysis we found that a cut off of 300 hours/km did not change the list of bottlenecks, rather added some new adjacent segments to the existing list, thus 400 hours/km appeared to be a natural break in the distribution. The chosen cut-off represents the 90th percentile, meaning the top 10% of congested freeway segments qualified for national bottlenecks. If two bottlenecks were located within 0.5 km of each other, they, along with the segments in between were considered as being part of one corridor. NOTE: We did not apply this 0.5 km for the bottlenecks located in two different freeways near an interchange.

3. Length-weighting: The Daily Total Delay for each bottleneck was calculated as the sum-product of Daily Delay (Di) and length of individual segments i in a bottleneck.

$$Daily\ Total\ Delay_A = \sum_{i=1}^{n} Daily\ Delay\ (D_i) * Length_i$$

Where,

i represents a freeway segment that is part of bottleneck A, and n is the number of segments in that bottleneck. This resulting metric accounts for both length of the bottleneck and the expected volume of vehicles through that bottleneck over a 24-hour period. The corresponding queue length (in kilometers) for bottleneck A is LA, given by

$$Queue\ Length\ (L_A) = \sum^{n} Length_i$$

4. National Ranking: In the final step, we rank ordered all the bottlenecks identified in the adjacency analysis in Step 2, using the Daily Total Delay (hours) calculated in Step 3. We identified 240 hours of Daily Total Delay (or about 60,000 hours annually) as a natural break in the distribution of top-ranked bottlenecks. The final output of this analysis is the curated list of top 20 bottlenecks shown in the results.

Calculating the lost value of time due to delays

We valued each hour of delay using the province-specific estimate of the average hourly wage (CA $/hour). This value is a weighted average of employment wage rates across many labor and skill sectors, and based on data collected by Statistics Canada. This approach most likely underestimates the lost value of time, because it doesn't full include the value of an hour's work to the economy and its multiplying effects.

Calculating the benefits of alleviating congestion

We estimated the excess fuel spent due to congestion and potential fuel savings (liters) using relationships between vehicle speed (kilometers per hour, kph) and fuel economy (kilometers per liter, mpg) published by the Oak Ridge National Laboratory [6]. These relationships are based on lab tests as well as observed data from a large fleet of vehicles. Only the excess fuel used when vehicles are traveling at slow speeds during congested conditions are counted.

We then calculated the potential emissions avoided (kg CO2) using standard parameter values published by the Environment Canada [7]:

CO2 Emissions from a gallon of gasoline (for cars): 2.289 kg CO2/ litre

CO2 Emissions from a gallon of diesel (for trucks): 2.663 kg CO2/ litre

Appendix B: Comparison with Previous Estimate of Congestion Costs in the GTHA

Introduction

The purpose of this Study is to identify and rank the top highway congestion bottlenecks in urban areas in Canada. Although the purpose is not to explicitly calculate total congestion costs in each urban area, as a result of the process of identifying the top highway bottlenecks we are able to sum the total delay and associated delay costs across all highways in order to arrive at an estimate of total delay costs on those highways. This total can be compared to past estimates of congestion costs after adjusting for differences in scope in methodology.

The most notable past research conducted to identify congestion costs in Canada is a study completed by HDR for Metrolinx in 2008. [8] This HDR study is the source for the estimate of $6 billion in annual congestion costs in the Greater Toronto and Hamilton Area (GTHA) that is often cited by analysts and media. This appendix compares the HDR methodology to our methodology, identified key differences in data sources and reconciles the differences in the two estimates of total delay costs in the GTHA.

Comparison of Methodology

The HDR report estimated the following components of congestion costs in the GTHA for 2006:

- Time (delay) costs (auto and transit users)
- Vehicle operating costs
- Accidents
- Vehicle emissions

In addition, the HDR report estimated the cost in terms of a reduction in regional GDP (due to lost employment, etc.). These costs are not explicitly added to the above congestion costs but it is implied by the report that they are additive (the $6 billion total cost figure that is frequently cited is the sum of both the congestion costs above and the reduction in regional GDP).

In terms of coverage, the HDR report includes the following municipalities:

- Hamilton
- Halton Region
- Peel Region
- City of Toronto
- Region of York
- Durham Region

The analysis covers expressways, arterials, collectors and "important" local roads.

The key data source for VKT was Metrolinx modelling that was conducted in support of the Draft Regional Transportation Plan. The modelling covered the AM peak period (the values were then extrapolated to cover the PM peak period as well by HDR). Travel speeds were estimated from VKT from speed-flow functions (based on US Bureau of Public Road functions).

Relative to our methodology, the HDR methodology:

- Covered a broader range of congestion costs, by including estimates of transit user time costs, accident costs, vehicle operating costs (beyond fuel costs) and reductions in regional GDP. For a rough comparison, these costs can be scaled relative to auto user time costs to make the estimates more comparable, as excess travel times are at the core of all costs estimated by HDR.
- Covered a larger portion of the road network (arterials, collectors and important local roads). This difference can roughly be addressed by estimating the portion of VKT that occurs on expressways relative to other roads. The HDR report notes that the majority of VKT occurs on expressways.
- Used modelled rather than observations of actual travel speeds. The HDR report estimated travel speeds based on observed traffic volumes using the standard BPR function. Our analysis used observations of actual travel speeds by road segment. This is an important distinction as actual travel speeds can deviate substantially from modelled travel speeds.

Reconciling the Data

At the core of HDR's estimates of congestion costs is the estimate of auto user travel delay. Their estimates of auto user travel delay and other congestion cost components are shown below.

Figure A1. Summary of Components of Congestion Costs from HDR Report

Component	Annual Cost ($million)
Time cost- auto users	2,245
Time cost- transit riders	337
Vehicle operating costs	479
Accidents	256
Vehicle emissions	29
Cost of Congestion (all of the above)	3,346
Reduction in Regional GDP	2,733
Total of Congestion and Reduction in Regional GDP*	6,079*

Source: HDR, Page 3, Table 1.

*The Cost of Congestion and Reduction in Regional GDP are not explicitly added together in the HDR report.

The auto user time costs are a function of actual travel speeds, "optimal" travels speeds, total traffic volumes and the value of time. Their optimal speeds in the morning peak period are estimated to average 74.6 kph for the region compared to their estimated average actual speeds of 50.6 kph. Excess hours of travel are estimated to total over 93 million annually, broken down by region/city as shown below. Also shown are estimates of AM Peak VKT.

Figure A2. Summary of Auto User Travel Delay Estimate from HDR Report

Municipality	Hours per Year (thousands)	AM Peak VKT
Hamilton	2,340,523	1,791,463
Halton Region	6,321,584	3,606,596
Peel Region	23,099,566	6,421,952
City of Toronto	42,463,052	9,296,614
Region of York	16,794,912	6,134,044
Durham Region	7,909,060	3,874,073
GTHA Total*	98,928,697*	31,124,742

Source: HDR, Page 12 (Table 1), Page A1-1 (Table 12).
*The sum of all municipality shown in the report does not equal the GTHA Total shown in the report. The GTHA Total shown in this table is the sum of the hours from each of the municipalities.

In order to contrast HDR's estimates of total congestion costs with our own, the key component is the total hours of travel delay for the GTHA, which is approximately 93 million hours annually (as noted, the GTHA total in the table above is calculated as the sum of hours across all municipalities, we refer to the 93 million figure to be consistent with the main text provided in the HDR report). After adjusting for the fact that the 93 million hours are based on travel on most of the road network in the GTHA, as opposed to travel primarily on expressways, we have an estimate that is roughly comparable to that of our own.

Total and Expressway VKT in the GTHA

As noted, HDR estimated that the majority of VKT in the GTHA occurs on expressways. Our own analysis conducted by estimating VKT on the highway network (AADT per road segment multiplied by segment length) and comparing this total to estimates of total VKT for the whole city or region (from the Transportation Tomorrow Survey) confirm this to be the case. For example, our estimate of VKT on the expressways in the GTHA (including the Hamilton, Toronto and Oshawa CMAs) is 19.4 billion annually. Meanwhile VKT by households (which excludes business VKT) for the TTS area (which is larger than the GTHA) is estimated to be 22.6 billion annually.

The estimate from the TTS is likely an underestimate as it was calculated by multiplying total trips by median trip length (whereas the mean trip length is likely longer than the median trip length). Furthermore, there is a significant amount of commercial vehicle activity that is not captured by the TTS. Despite these differences in survey coverage, these results confirm that at least the majority of VKT in the GTHA occurs on expressways.

Although the majority of VKT occurs on expressways, it is not necessarily the case that the majority of time is spent on expressways. This is due to the fact that despite the presence of road congestion, average travel speeds on expressways remain higher than on other road types, even during peak hours. Although our raw speed data set is primarily constrained to expressways, we were able to conduct a rough analysis of travel speeds for a sample of expressways and arterial roads in the GTHA using HERE's and other sources' online travel planners available in the public domain, combined with assumptions of the number of lanes by road type and vehicles per lane hour. According to this rough analysis, we estimated that approximately 68% of the travel delay in the GTHA occurs on expressways. If this analysis included a sample of collector or local roads, the portion of travel delay that occurs on expressways would be smaller. However, the high number confirms at the very least that a large portion and perhaps the majority of travel delay does indeed occur on expressways.

Our Estimates of VKT and Total Hours of Delay

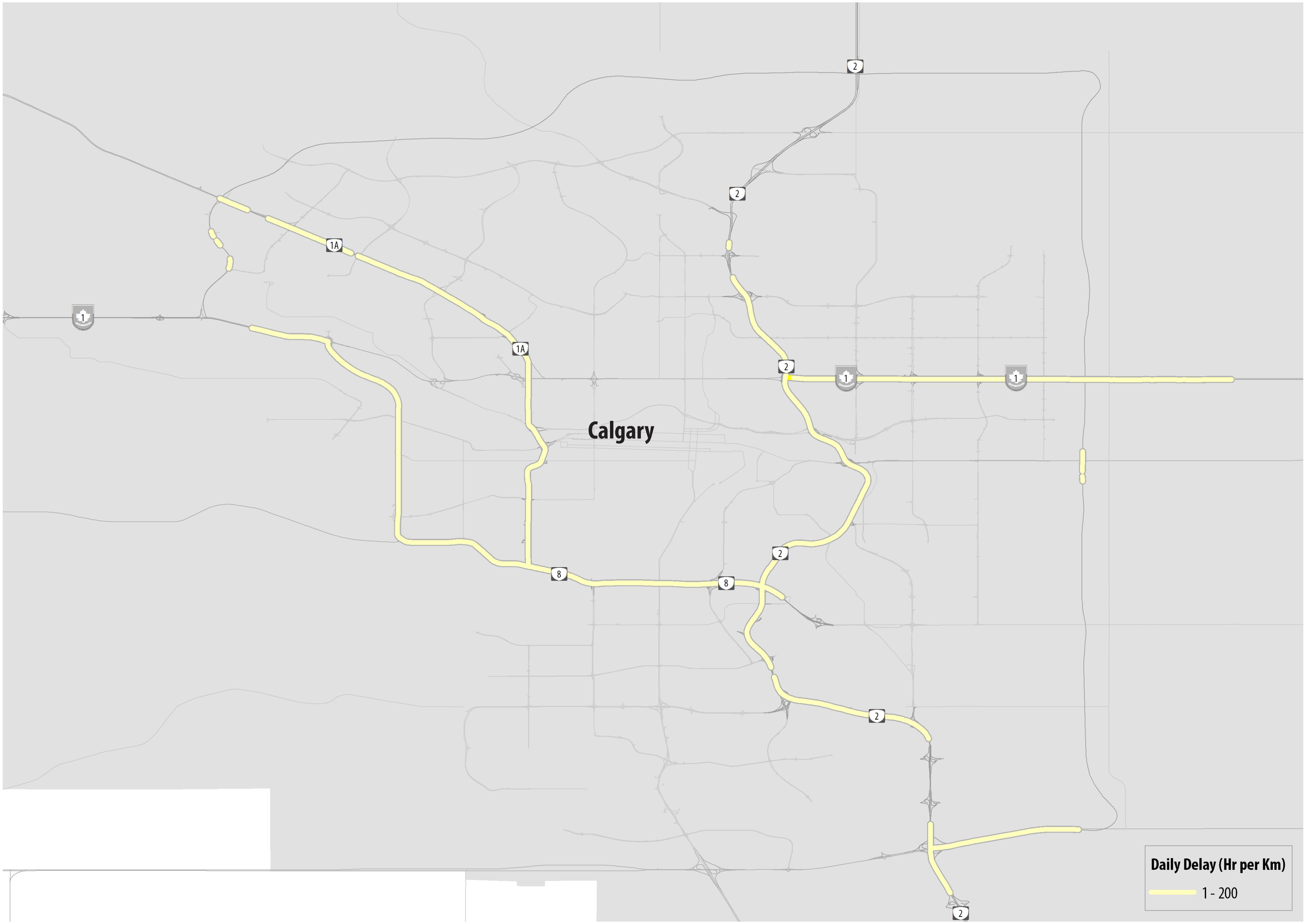
Given the above analysis, if we were to assume that half of the travel delay occurs on expressways, we would be able to sum the travel delay across all expressways in our analysis and multiply that sum by two to arrive at an estimate of auto user travel delay that is comparable to the total auto user travel delay estimated by HDR. Our estimate of total auto user travel delay on expressways is 13.4 million hours annually. Multiplying by two gives us an estimate of 26.8 million hours annually, a number that is far lower than the 93 million hours estimated by HDR (despite the fact that HDR's base year was 2006 and our base year was 2012 for the volume data and 2015 for the speed data). Assuming that the hourly Value of Travel Time savings have remained similar, this implies a much lower total cost of congestion from our analysis.

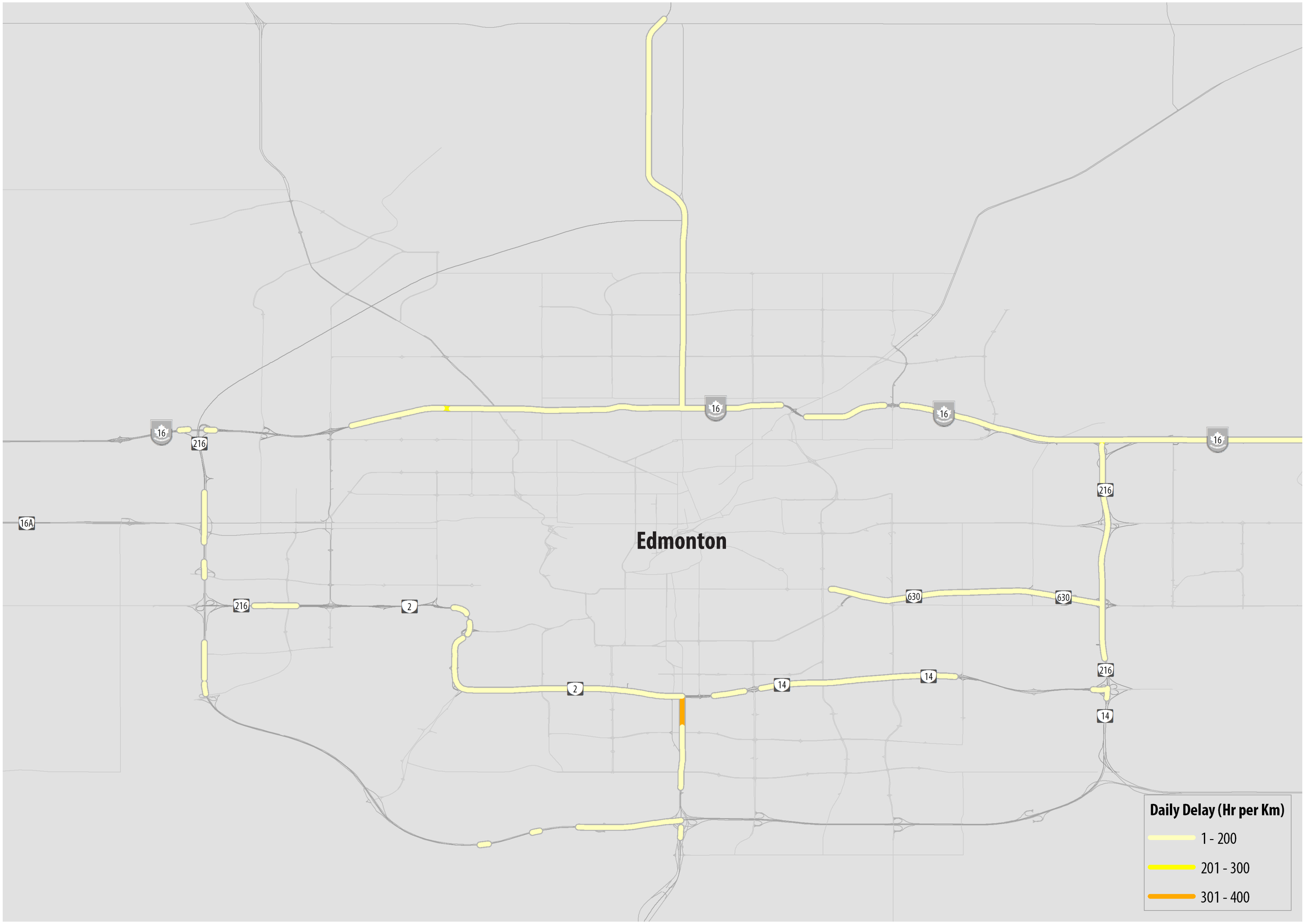
There are likely two key areas which contribute to the difference in the estimates of total delay costs. One is that HDR's travel speeds were modelled from volumes, whereas our travel speeds were based on observations of actual speeds. As noted, modelled speeds could diverge significantly from actual speeds.

The other key difference is the assumption in the baseline travel speed to which estimates of actual speeds are compared in order to arrive at the estimate of total delay. HDR used an average baseline speed of 74.6 kph, which they considered to represent the "optimal" travel speed. Our average baselines speed was based on an estimate of Maximum Throughput Speed, in this case typically ranged between 70 – 83 kph for the GTHA. Note that these baseline speeds are not directly comparable because the HDR estimate is based on an average of travel speeds on expressways, arterials, collectors and important local roads. The fact that other road types are included in HDR's analysis seems to indicate that an optimal average travel speed of 74.6 kph in peak hours may be unreasonably high. In other words, if our analysis suggests that the MTS ranges between 70 – 83 kph on expressways, the optimal travel speed averaged across all road types is likely to be much lower than this range. This difference in the two approaches is likely the primary cause of the difference in the two estimate of auto user congestion costs.

Appendix C: Delay Maps for All CMAs

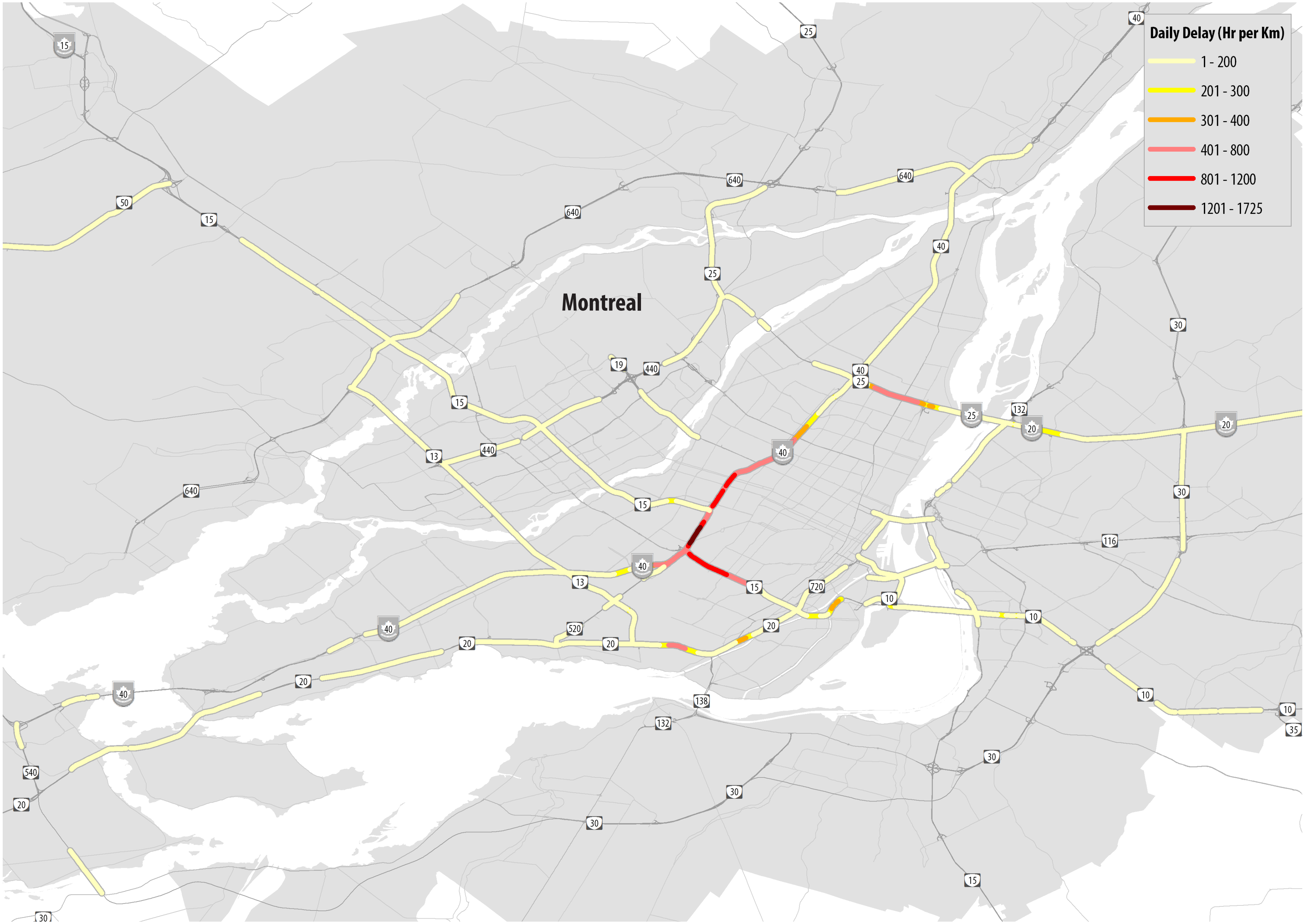
The following delay maps for each CMA show our estimates of the total daily delay (in hours) per kilometer on the highway networks that were included in our analysis. As indicated in the discussion of our methodology, the total delay takes into account both speed and traffic volumes. This means that the maps differ from maps that solely depict speed in that they indicate the stretches of highway where travel speeds are low and a large number of motorists are experiencing those low travel speeds.

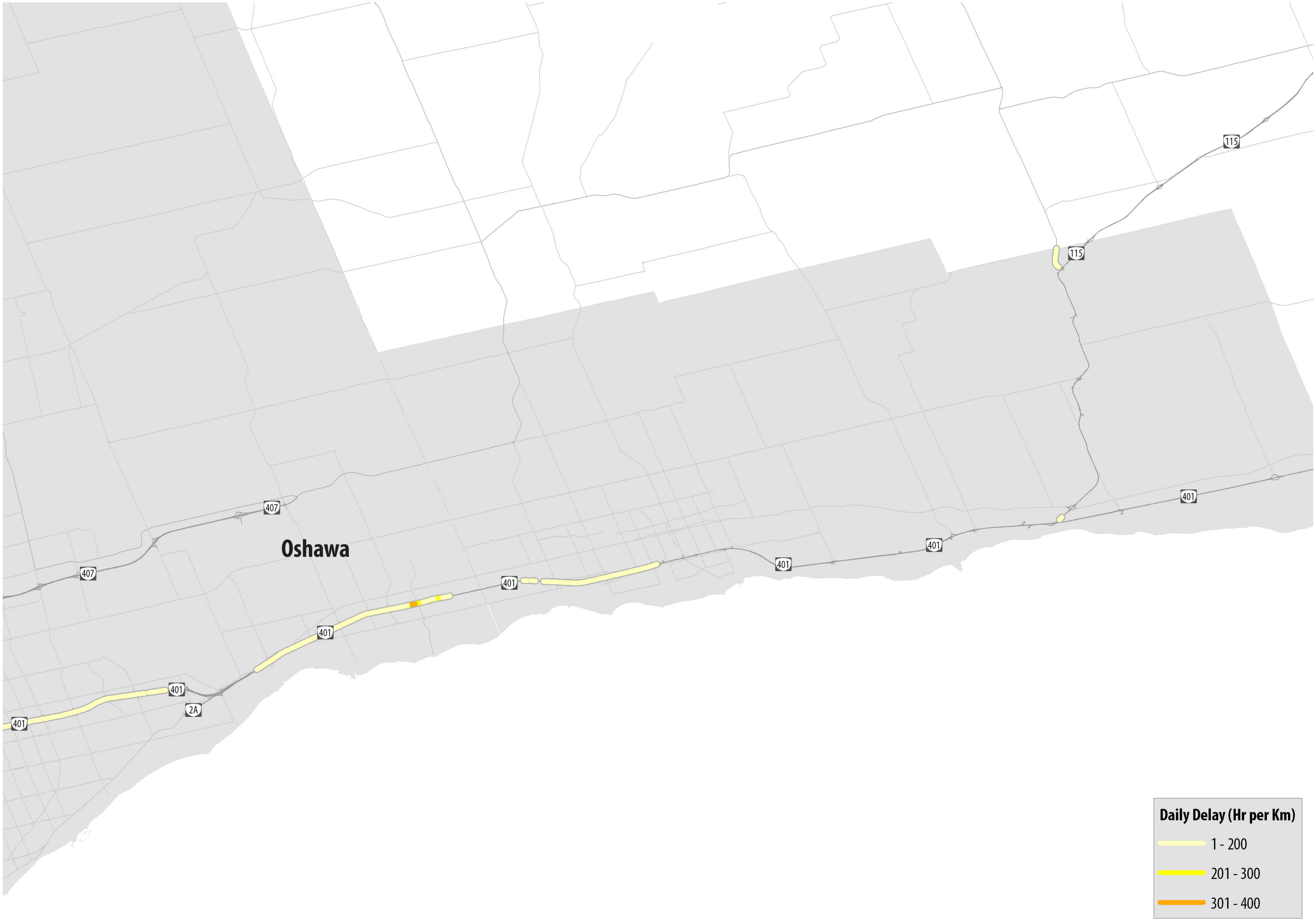

Calgary
Daily Delay (Hr per Km)
1 - 200
1A
1
2
8

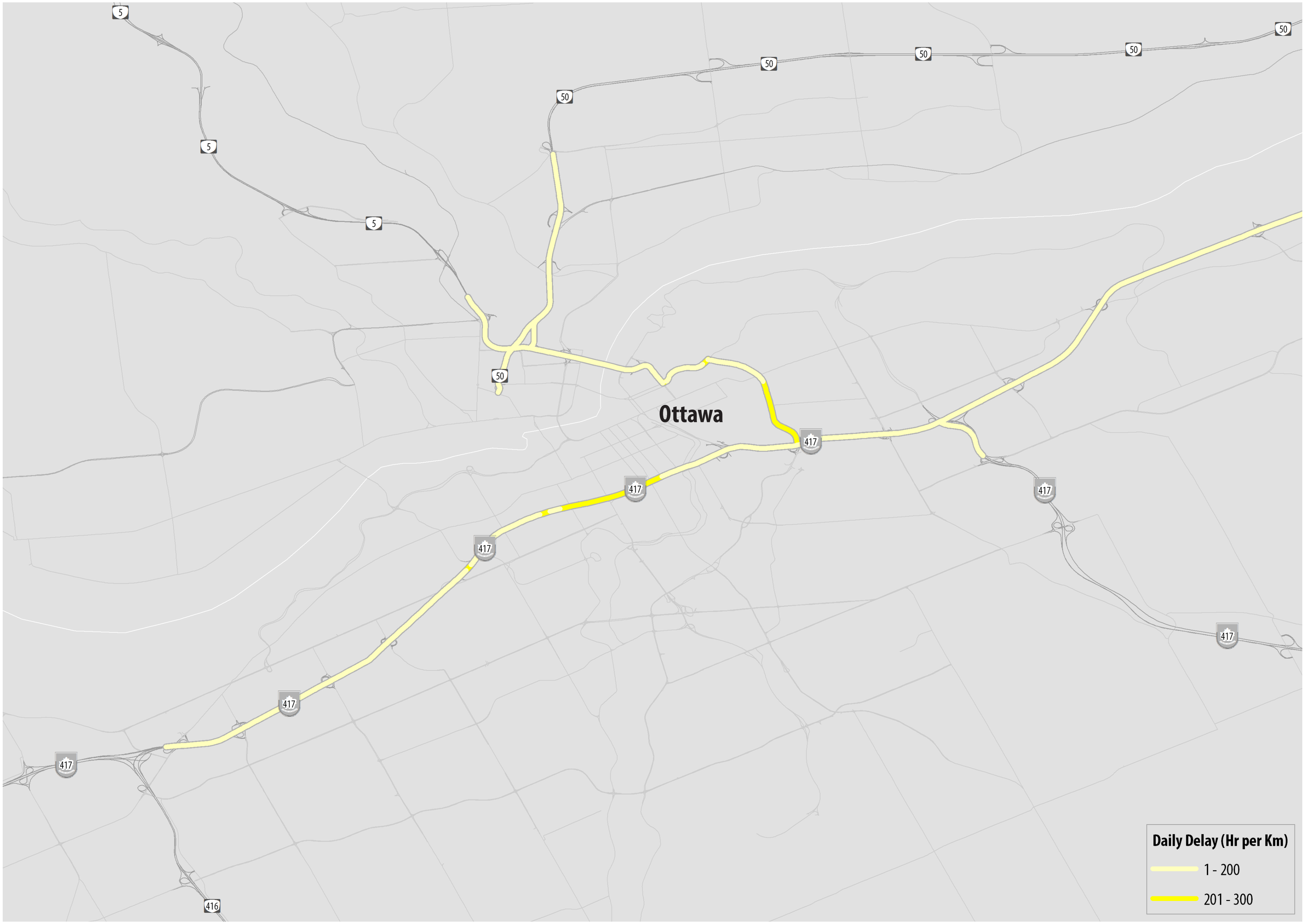

Edmonton
16
16
16
16
16A
216
216
216
216
2
2
630
630
14
14
14
Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400


101
101
102
102
102
102
118
118
118
107
107
Halifax
111
111
111
103
103
103
Daily Delay (Hr per Km)
1 - 200


407
403
403
403
Hamilton
403
6
6
Daily Delay (Hr per Km)
1 - 200


Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400
401 - 800
801 - 1200
1201 - 1725
Montreal

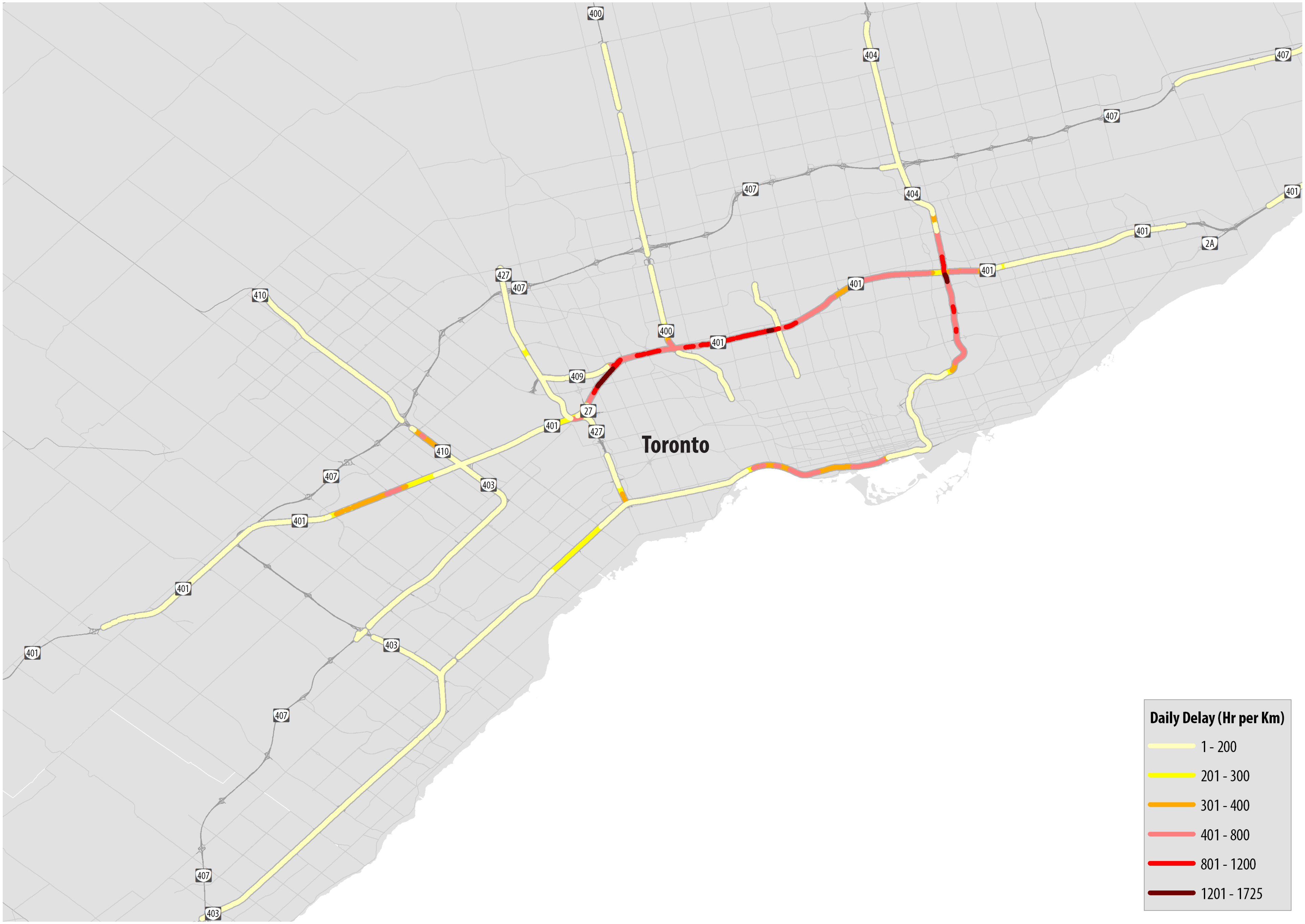

Oshawa
401
407
2A
115
Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400


Ottawa
5
50
417
416
Daily Delay (Hr per Km)
1 - 200
201 - 300

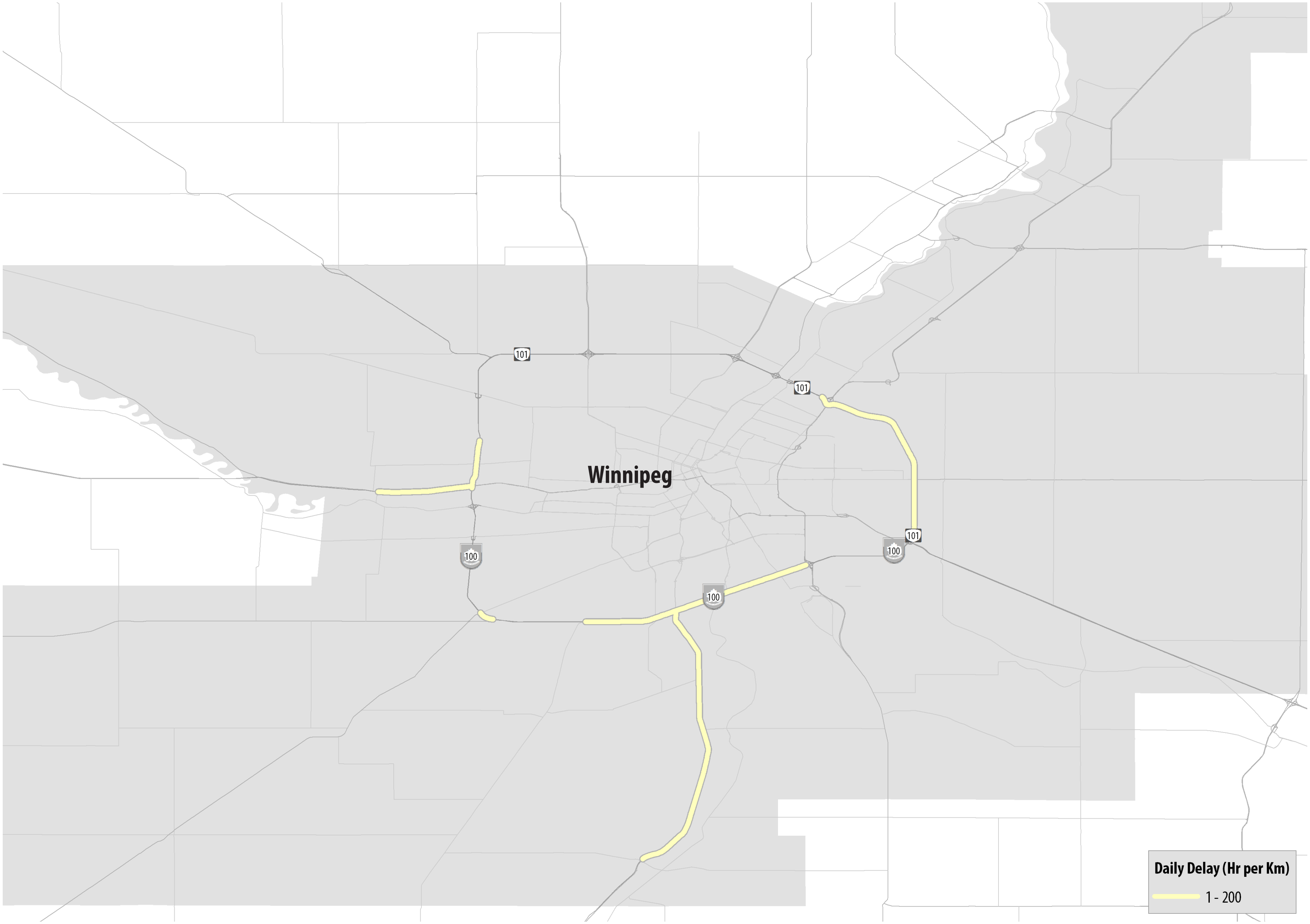

Quebec City
Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400
73
40
440
740
540
573
20


11
6
Regina
1
Daily Delay (Hr per Km)
1 - 200


St. Catharine's
406
406
406
405
405
58
420
Daily Delay (Hr per Km)
1 - 200


Toronto
Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400
401 - 800
801 - 1200
1201 - 1725


Vancouver
1
91
91A
99
Daily Delay (Hr per Km)
1 - 200
201 - 300
301 - 400
401 - 800
801 - 1200

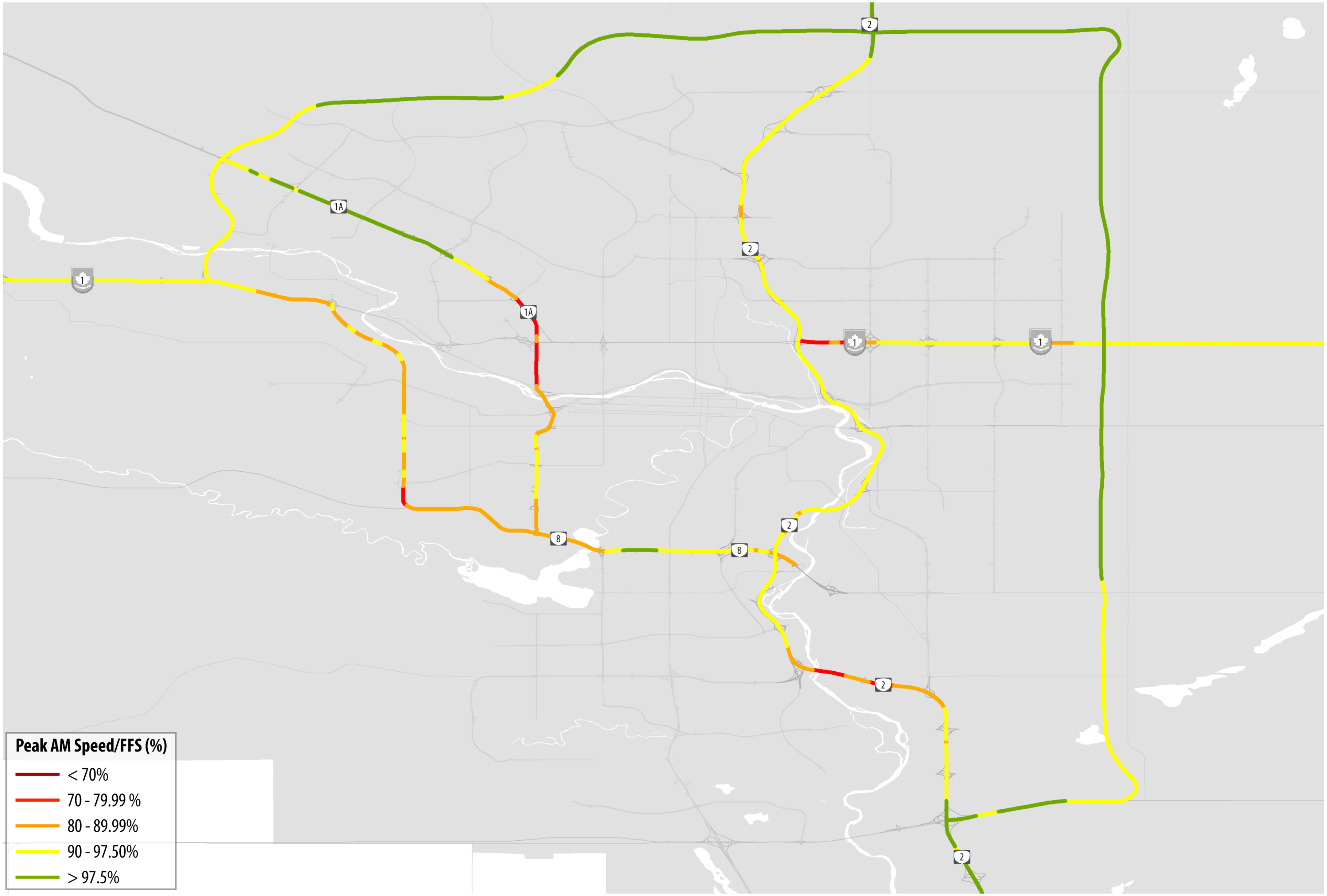

Winnipeg
101
101
101
100
100
100
Daily Delay (Hr per Km)
1 - 200

Appendix D: Speed Relative to Free Flow Maps

The following maps show the average AM or PM travel speeds relative to free flow speeds in each CMA.

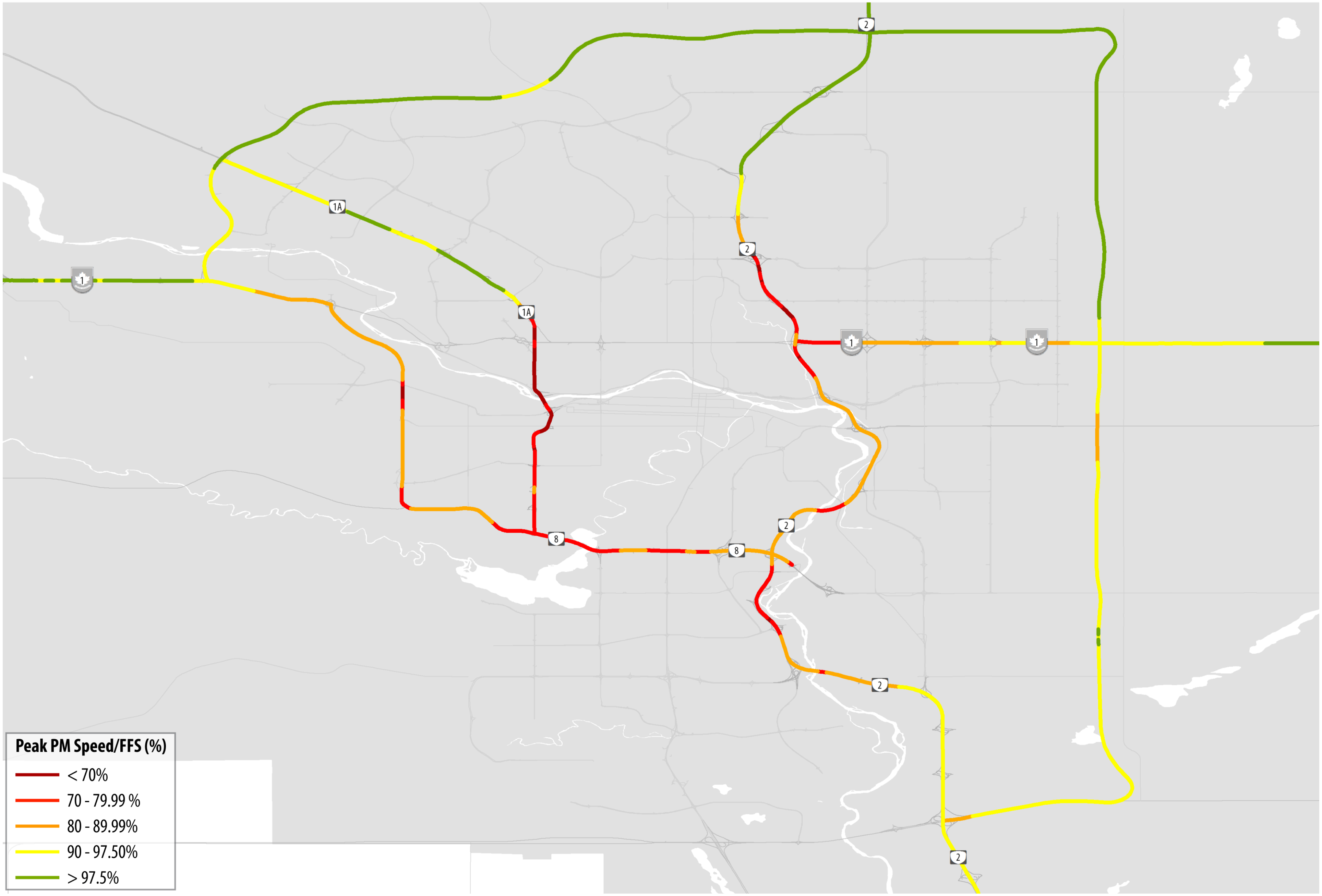
CPCS Solutions for growing economies

Calgary: Peak AM Speed (7:00 - 9:00AM)/FFS



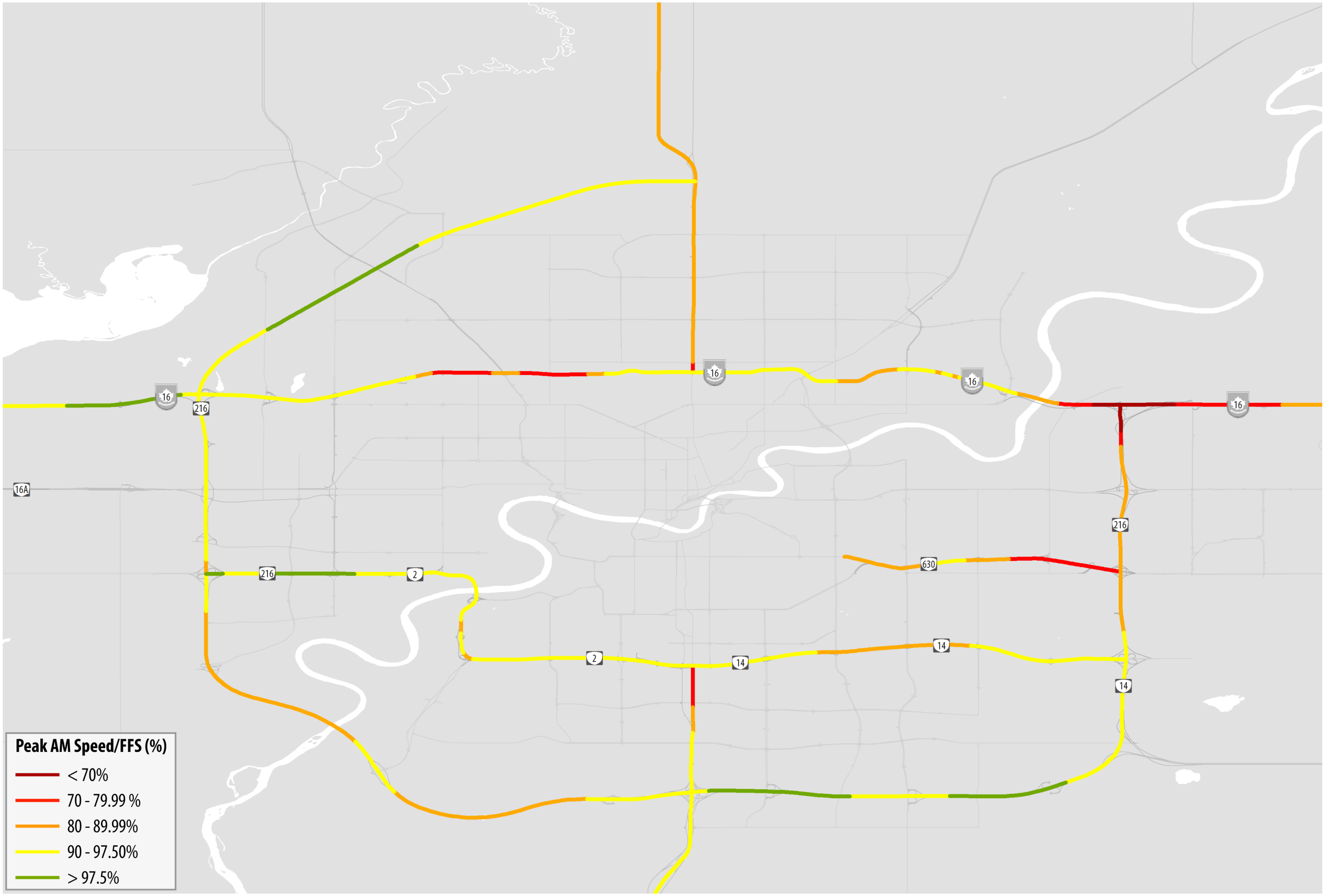
CPCS Solutions for growing economies

Calgary: Peak PM Speed (4:00 - 6:00PM)/FFS



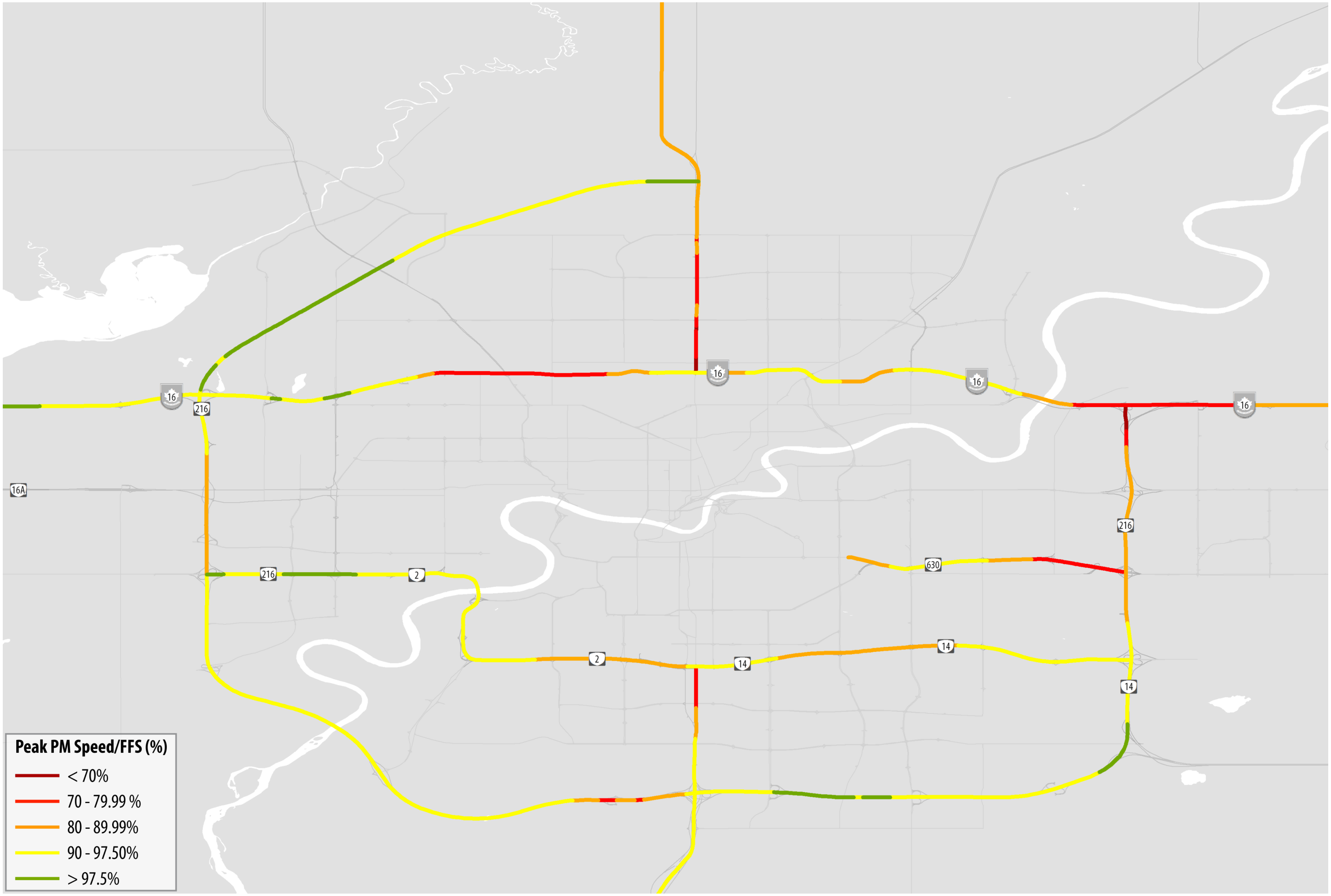
CPCS Solutions for growing economies

Edmonton: Peak AM Speed (7:00 - 9:00AM)/FFS



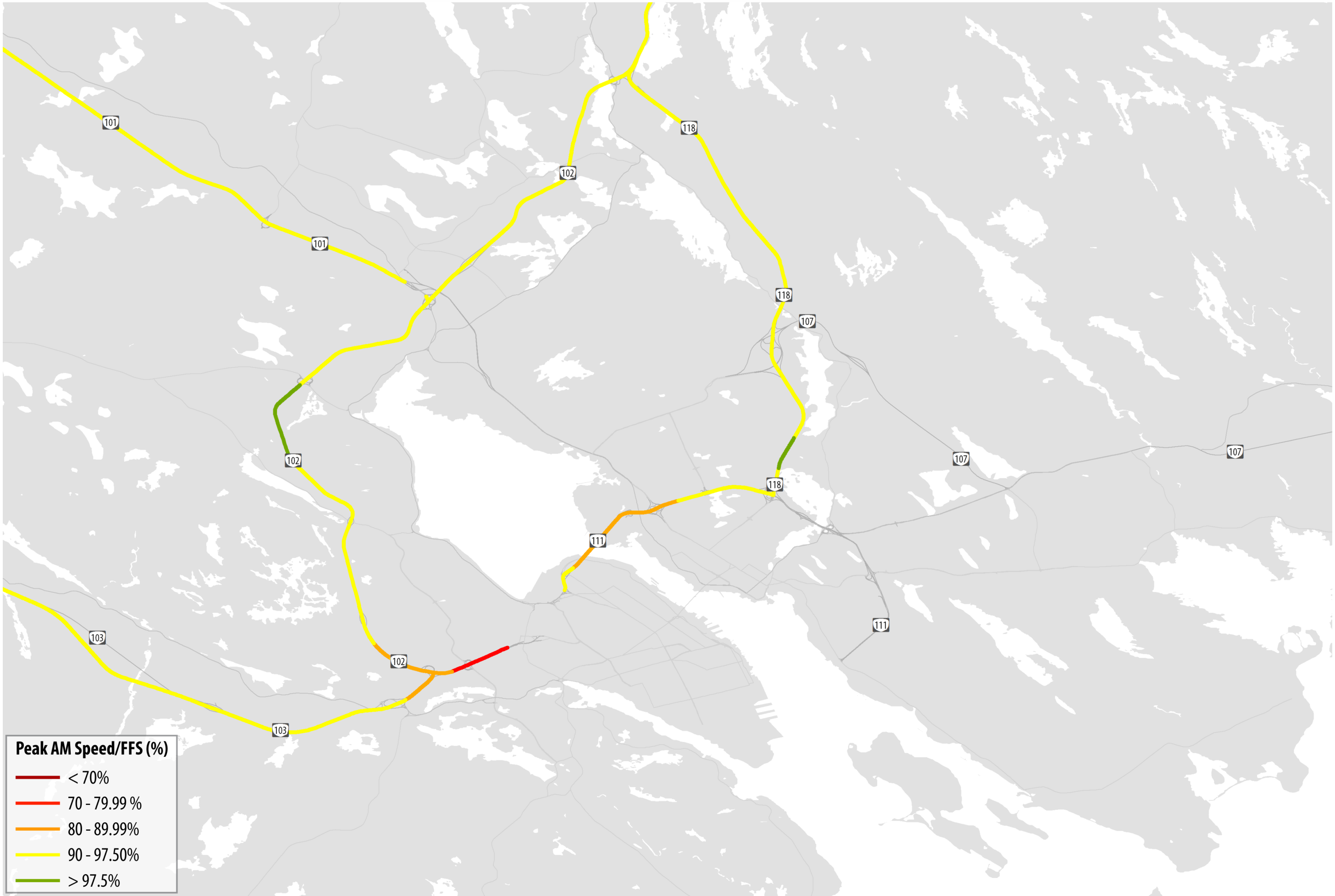
CPCS Solutions for growing economies

Edmonton: Peak PM Speed (4:00 - 6:00PM)/FFS



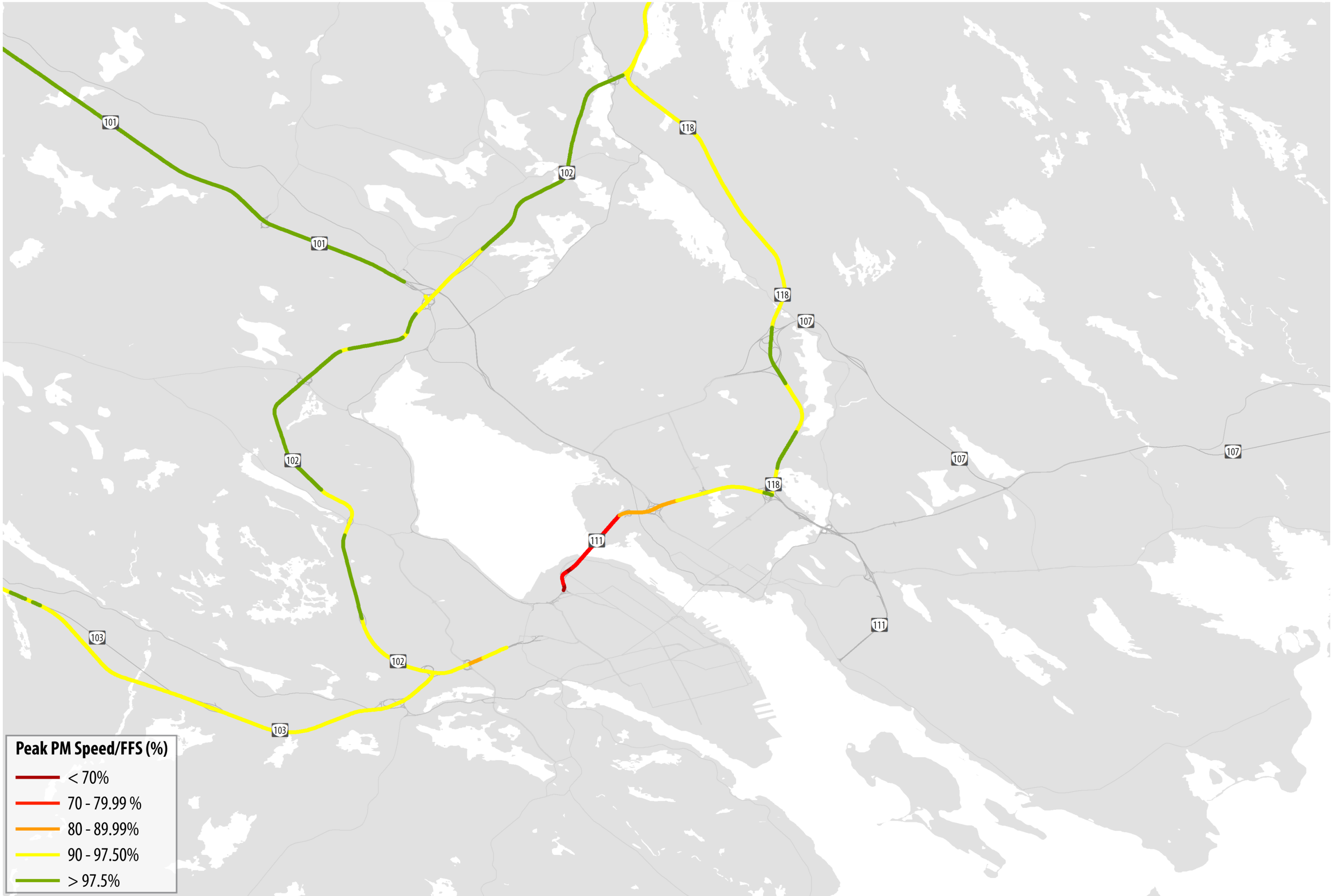
CPCS Solutions for growing economies

Halifax: Peak AM Speed (7:00 - 9:00AM)/FFS



CPCS Solutions for growing economies

Halifax: Peak PM Speed (4:00 - 6:00PM)/FFS



CPCS Solutions for growing economies

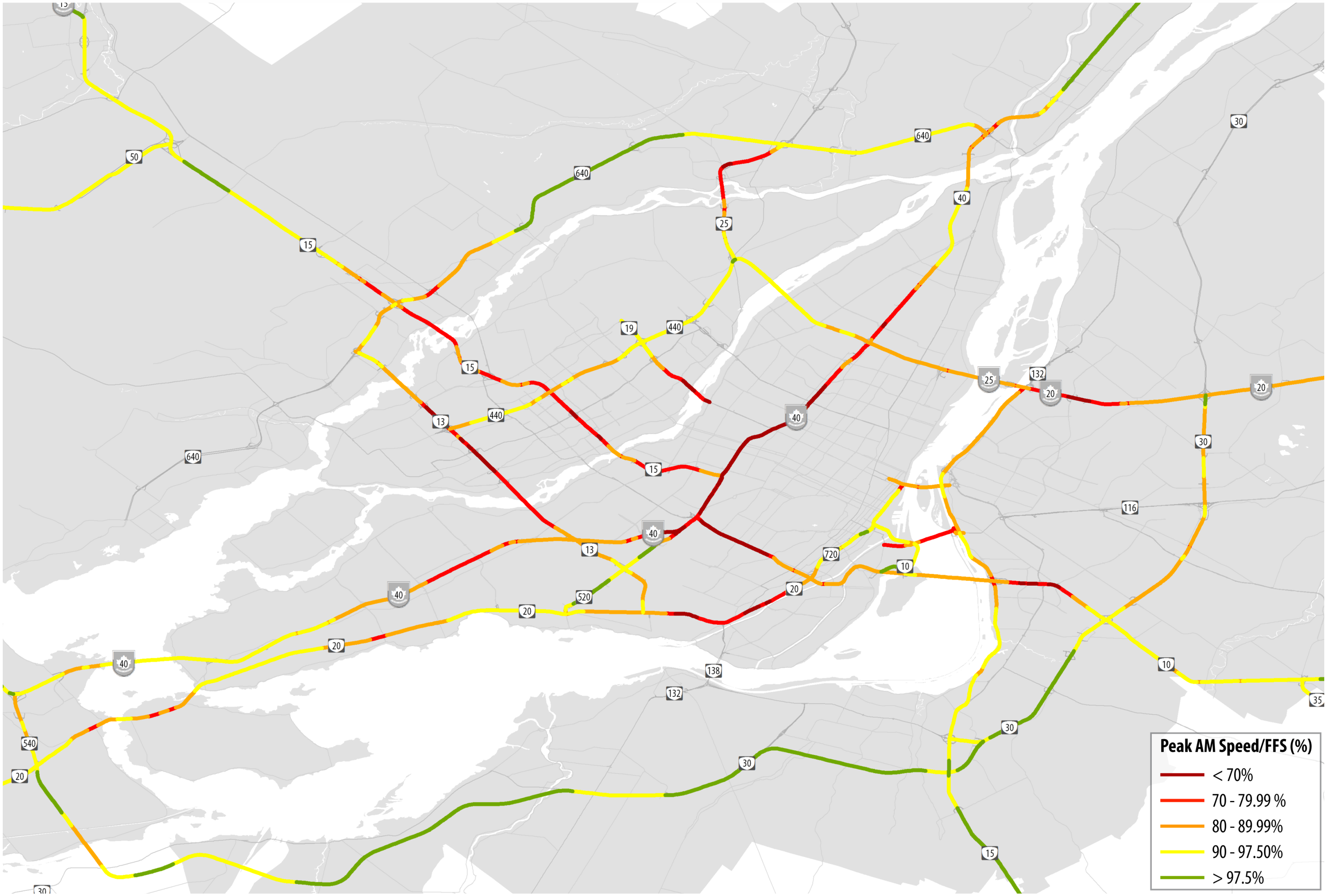
Hamilton: Peak AM Speed (7:00 - 9:00AM)/FFS

CPCS Solutions for growing economies

Hamilton: Peak PM Speed (4:00 - 6:00PM)/FFS

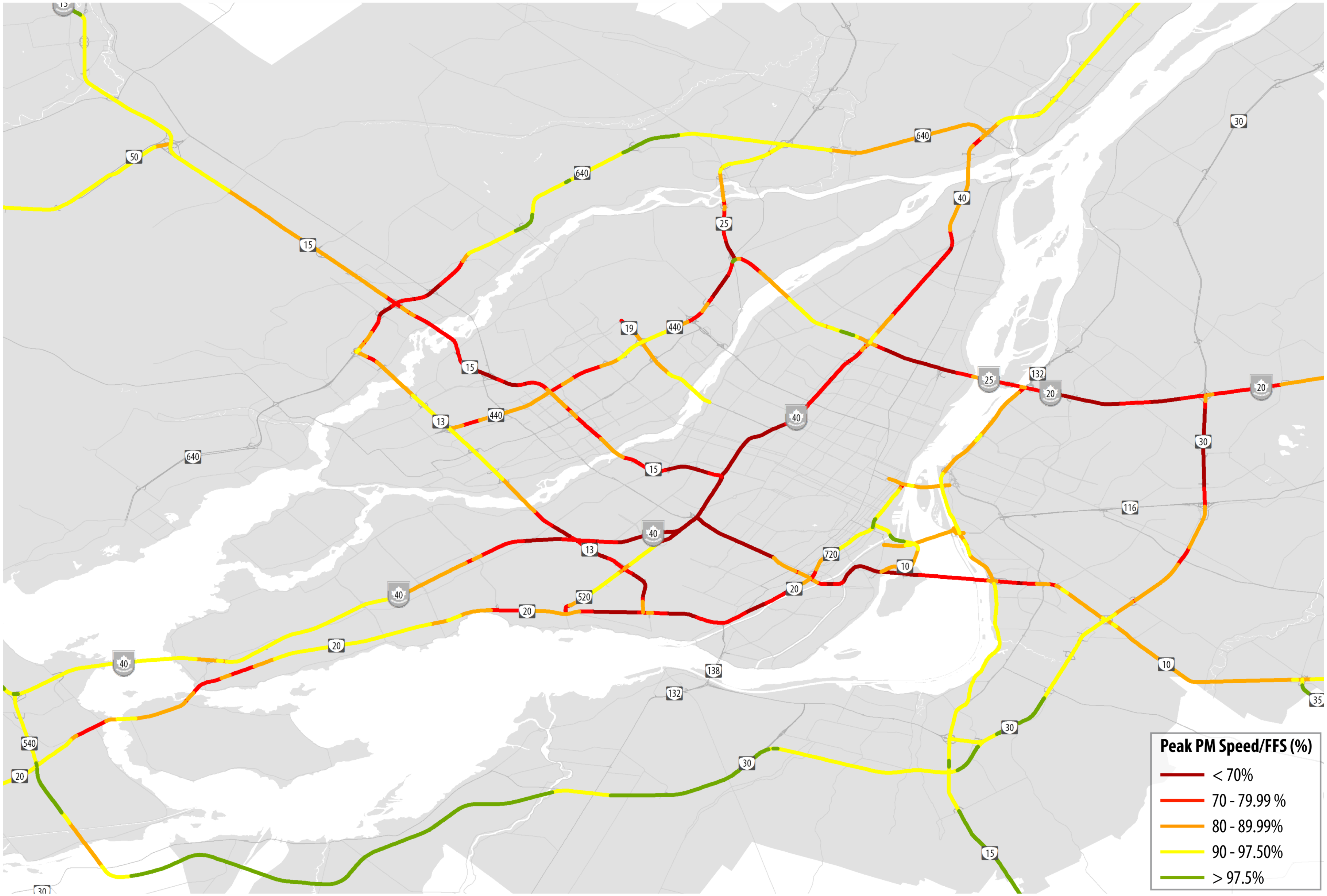
CPCS Solutions for growing economies

Montréal: Peak AM Speed (7:00 - 9:00AM)/FFS



CPCS Solutions for growing economies

Montréal: Peak PM Speed (4:00 - 6:00PM)/FFS



CPCS Solutions for growing economies

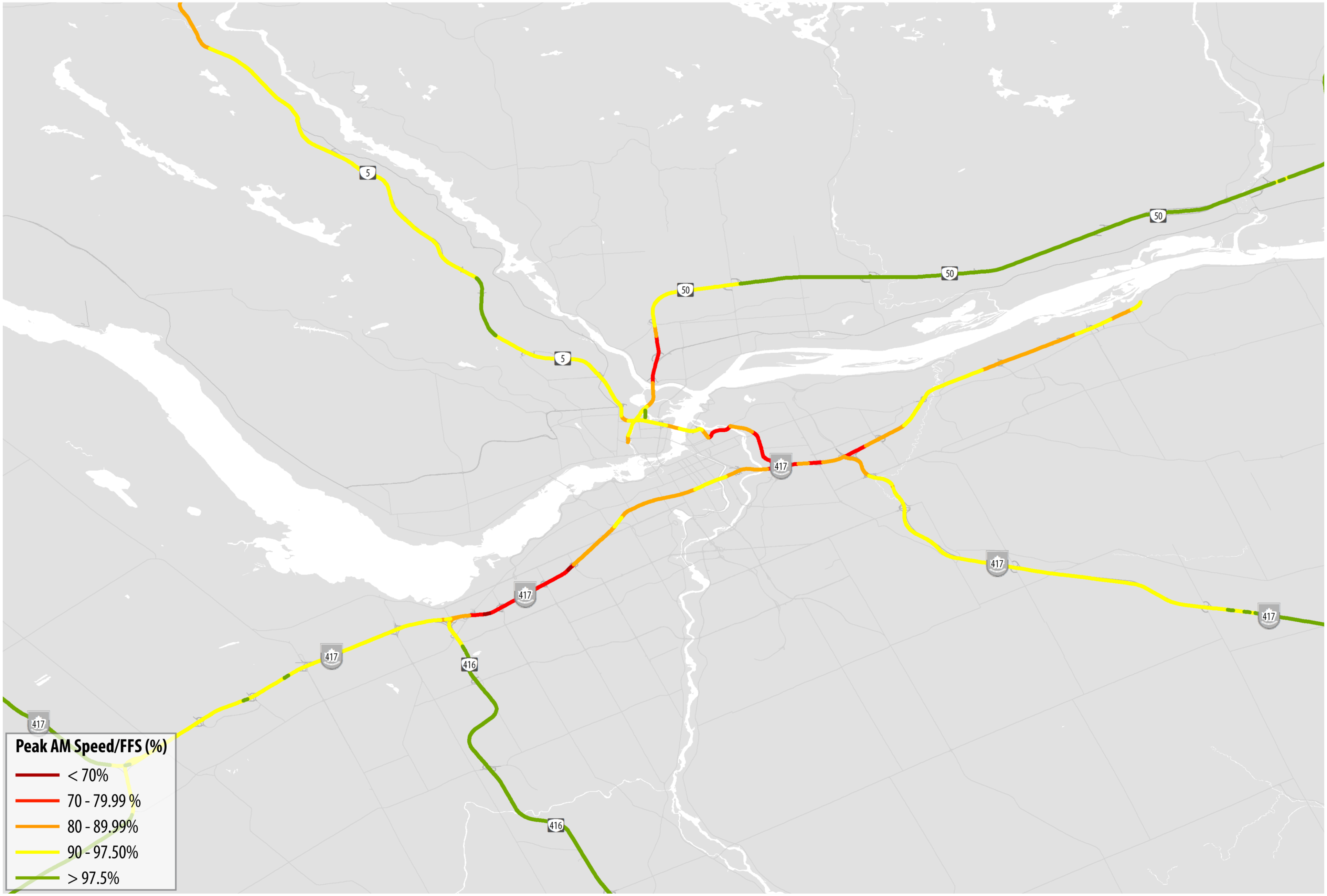
Oshawa: Peak AM Speed (7:00 - 9:00AM)/FFS

CPCS Solutions for growing economies

Oshawa: Peak PM Speed (4:00 - 6:00PM)/FFS

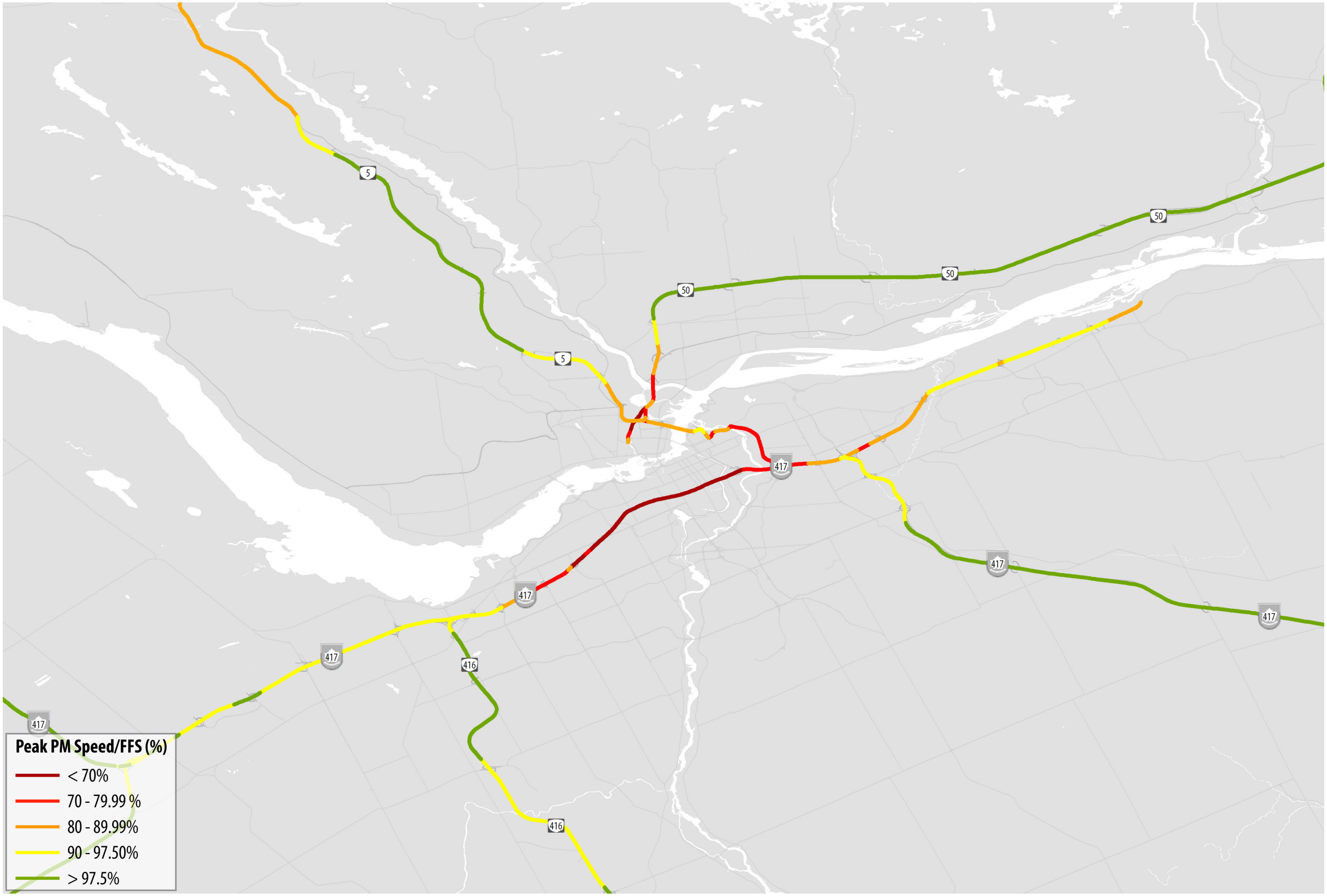
CPCS Solutions for growing economies

Ottawa: Peak AM Speed (7:00 - 9:00AM)/FFS



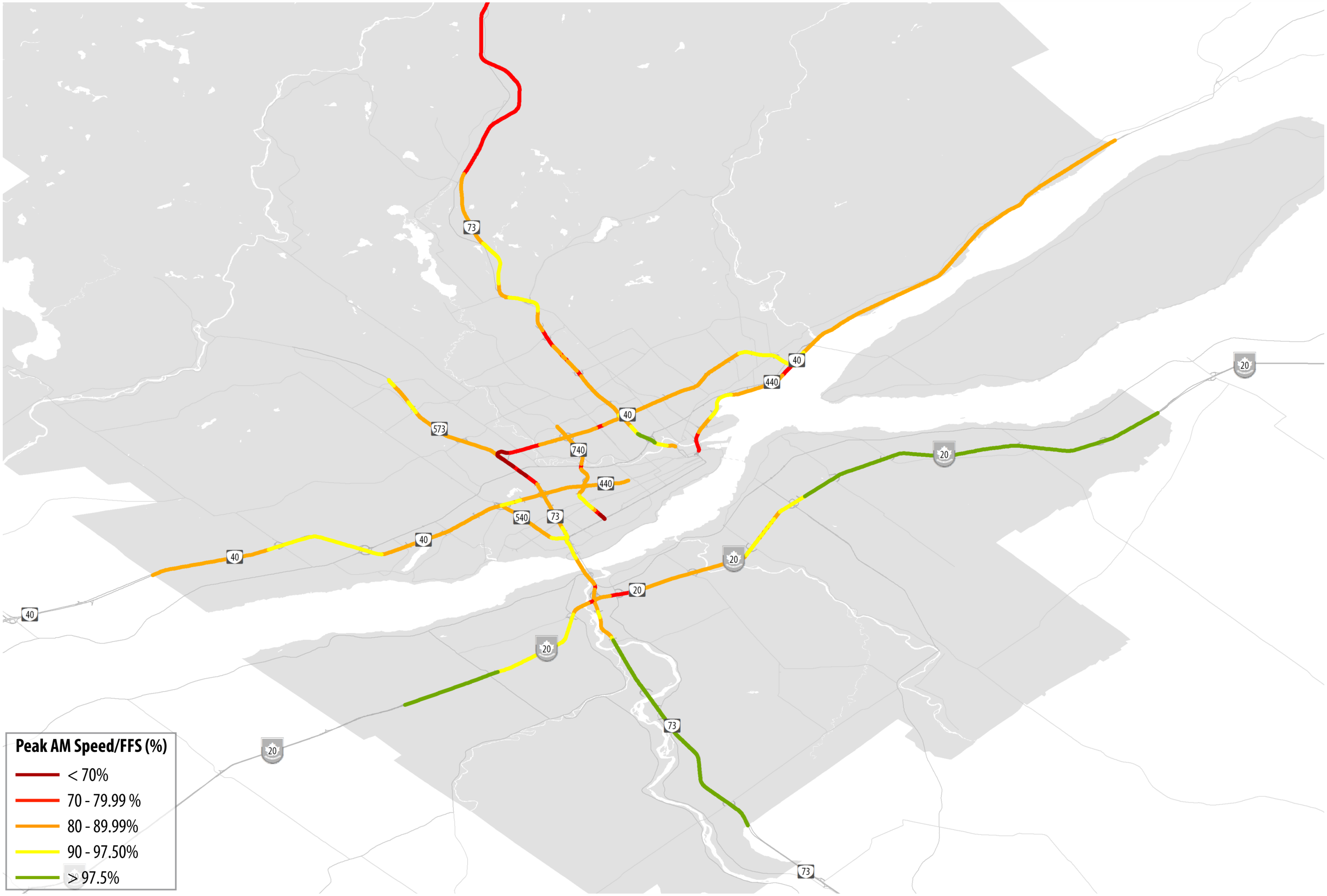
CPCS Solutions for growing economies

Ottawa: Peak PM Speed (4:00 - 6:00PM)/FFS



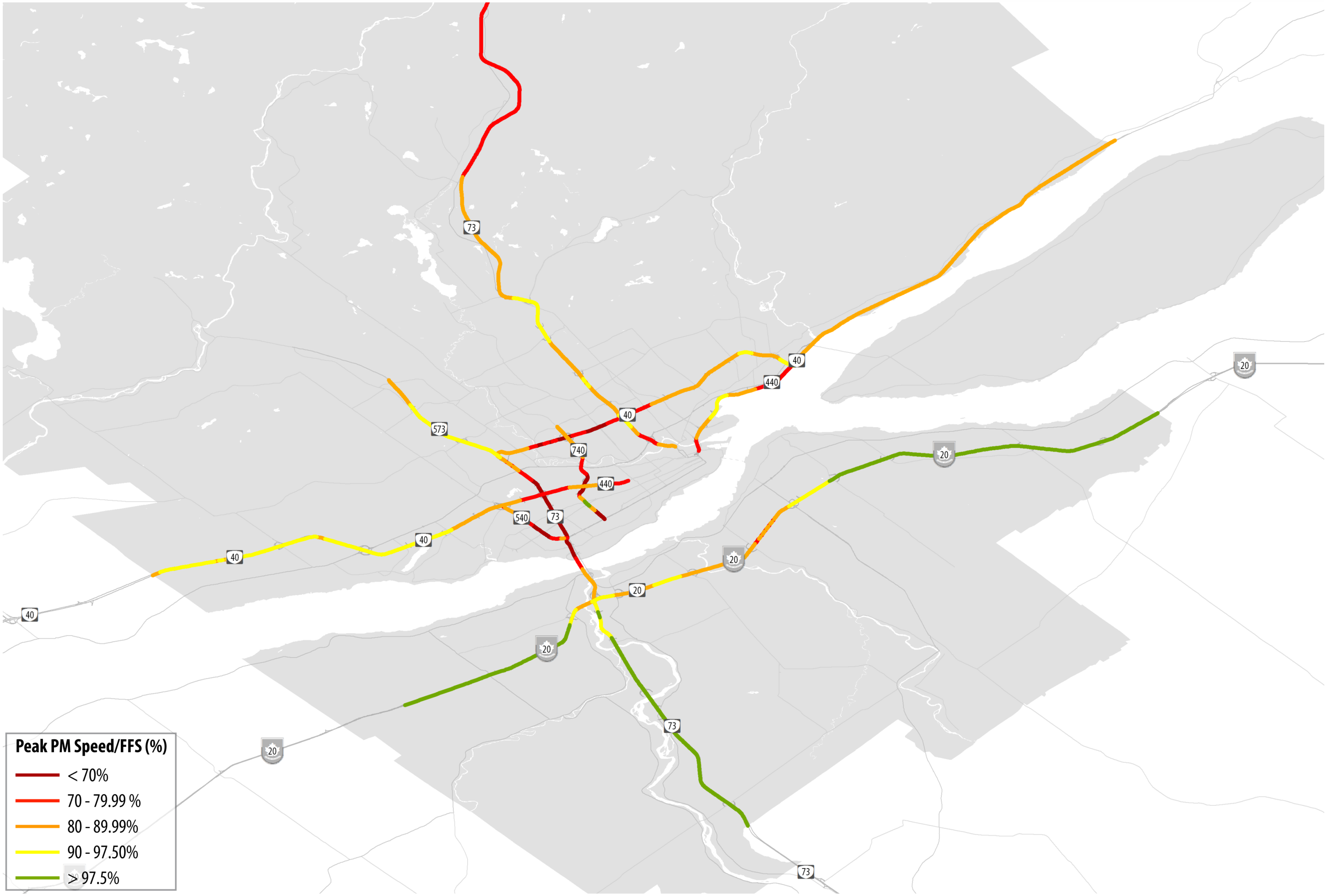
CPCS Solutions for growing economies

Québec City: Peak AM Speed (7:00 - 9:00AM)/FFS



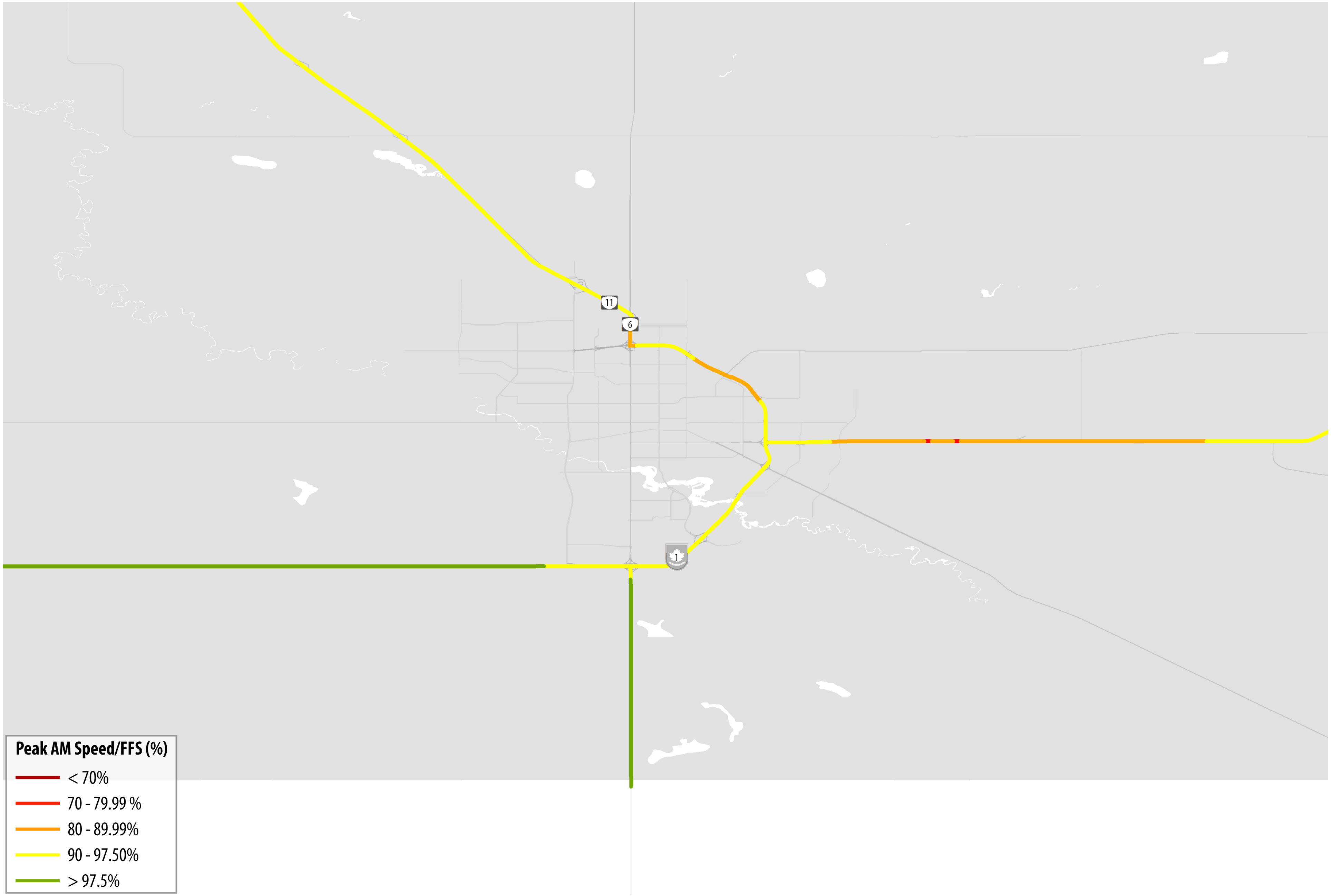
CPCS Solutions for growing economies

Québec City: Peak PM Speed (4:00 - 6:00PM)/FFS



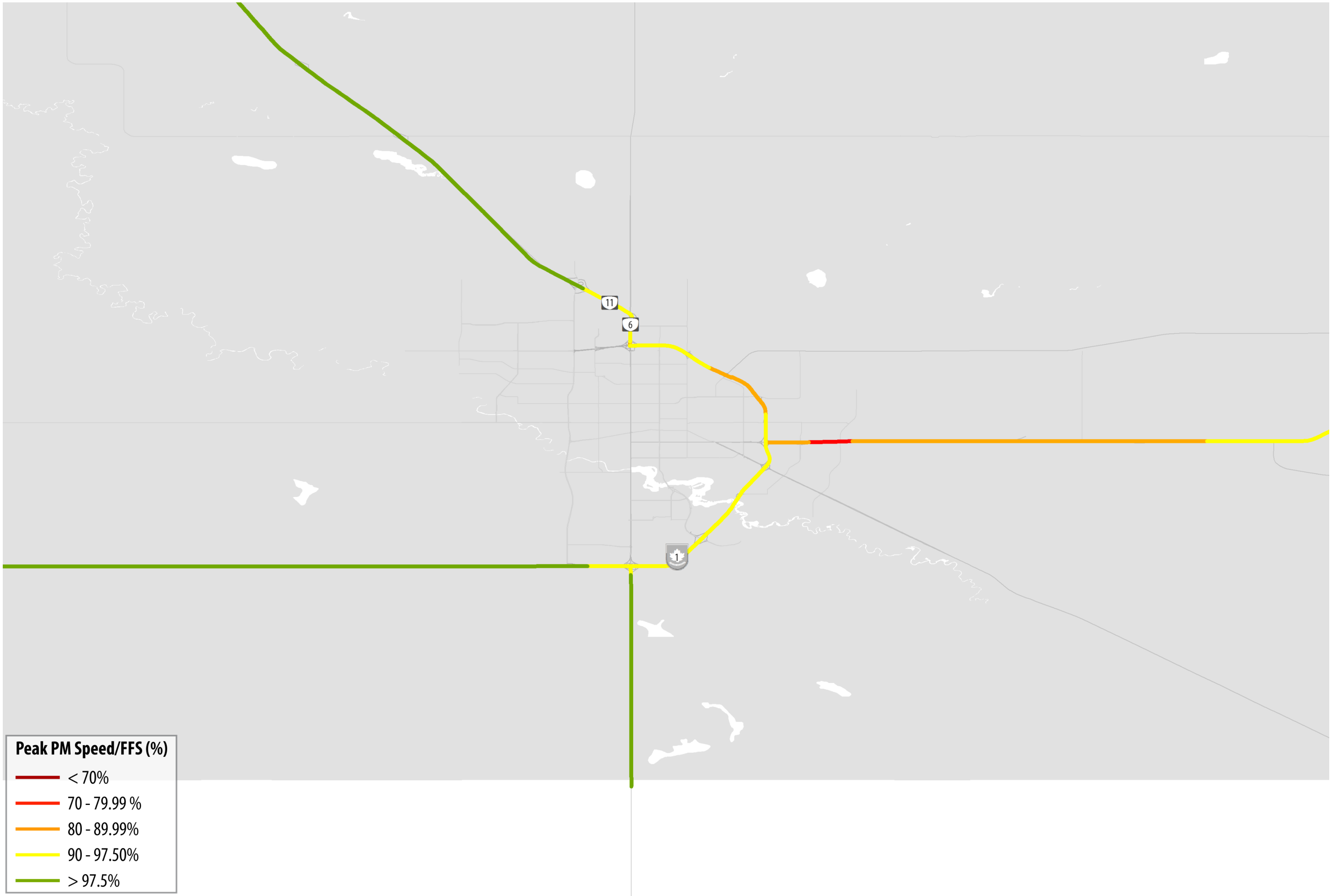
CPCS Solutions for growing economies

Regina: Peak AM Speed (7:00 - 9:00AM)/FFS



CPCS Solutions for growing economies

Regina: Peak PM Speed (4:00 - 6:00PM)/FFS



CPCS Solutions for growing economies

St. Catharine's: Peak AM Speed (7:00 - 9:00AM)/FFS

CPCS Solutions for growing economies

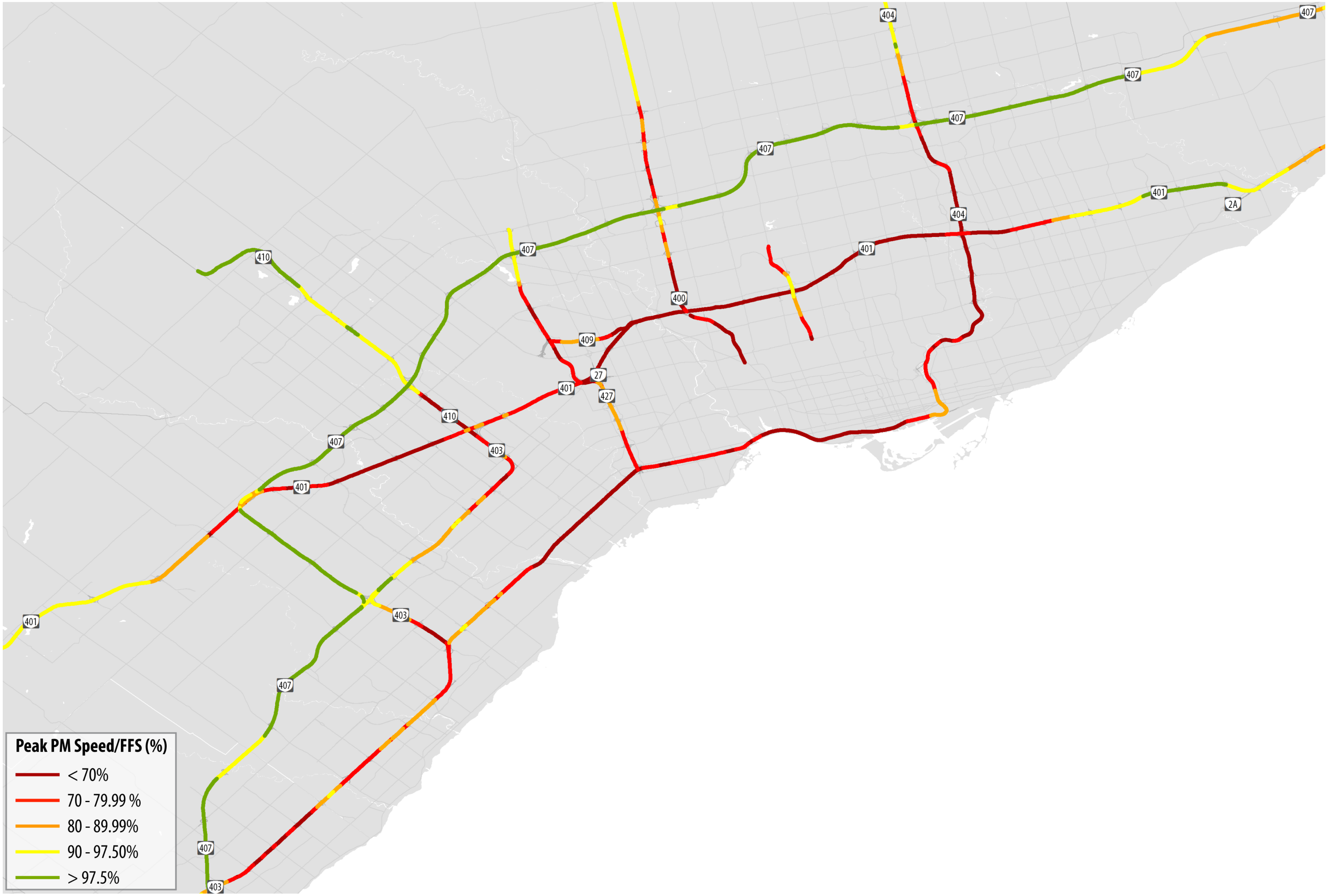
St. Catharine's: Peak PM Speed (4:00 - 6:00PM)/FFS

CPCS Solutions for growing economies

Toronto: Peak AM Speed (7:00 - 9:00AM)/FFS

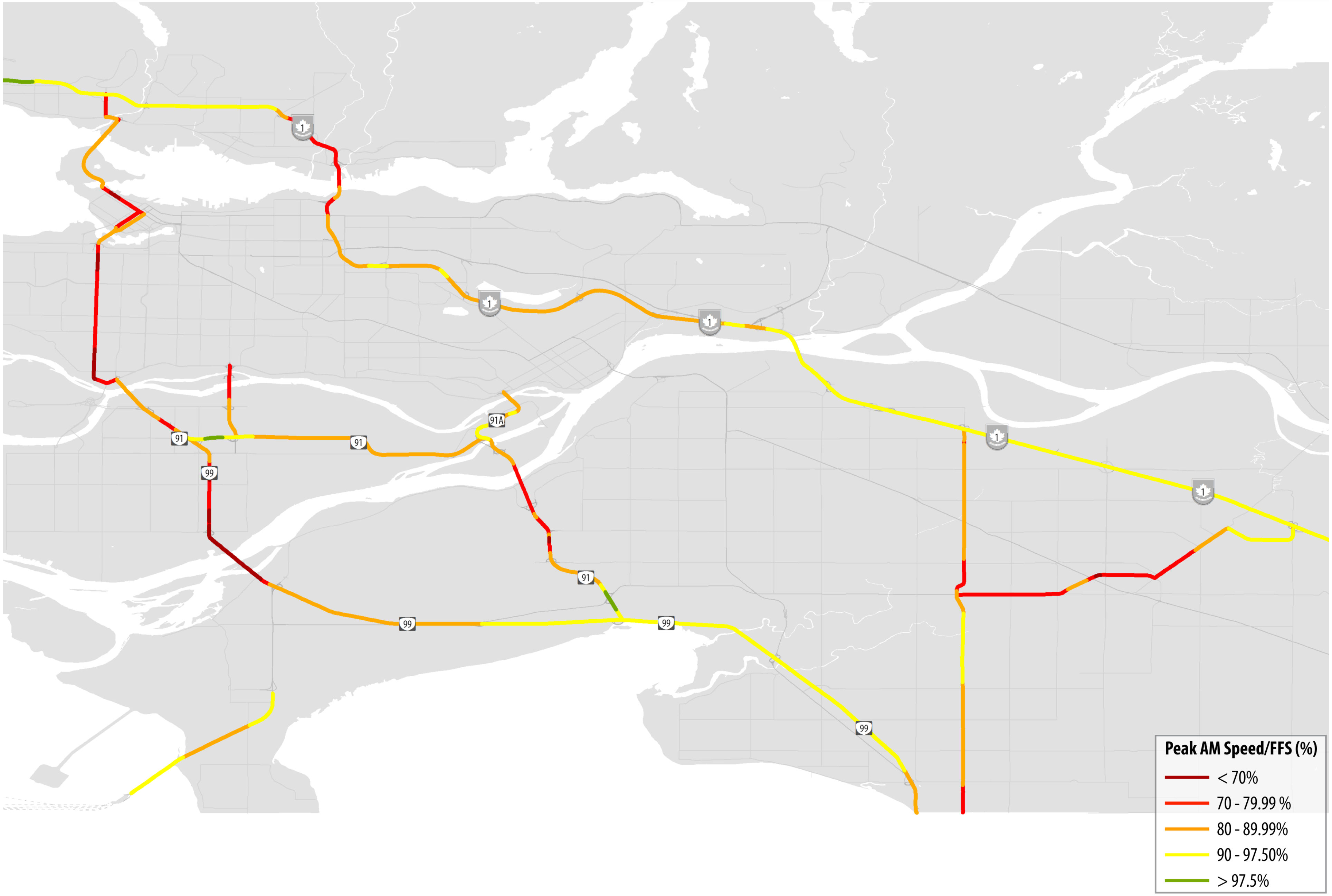
CPCS Solutions for growing economies

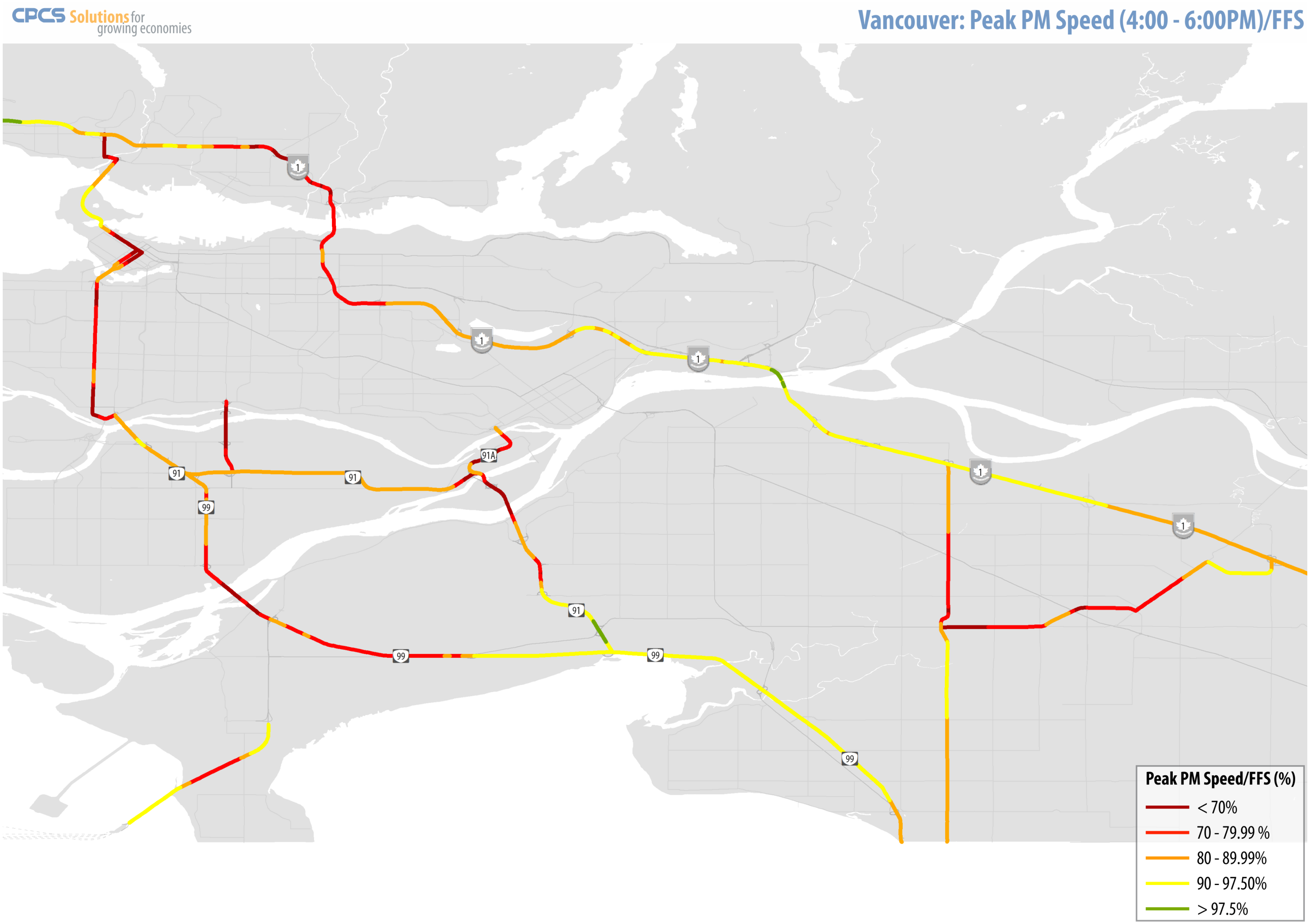
Toronto: Peak PM Speed (4:00 - 6:00PM)/FFS



CPCS Solutions for growing economies

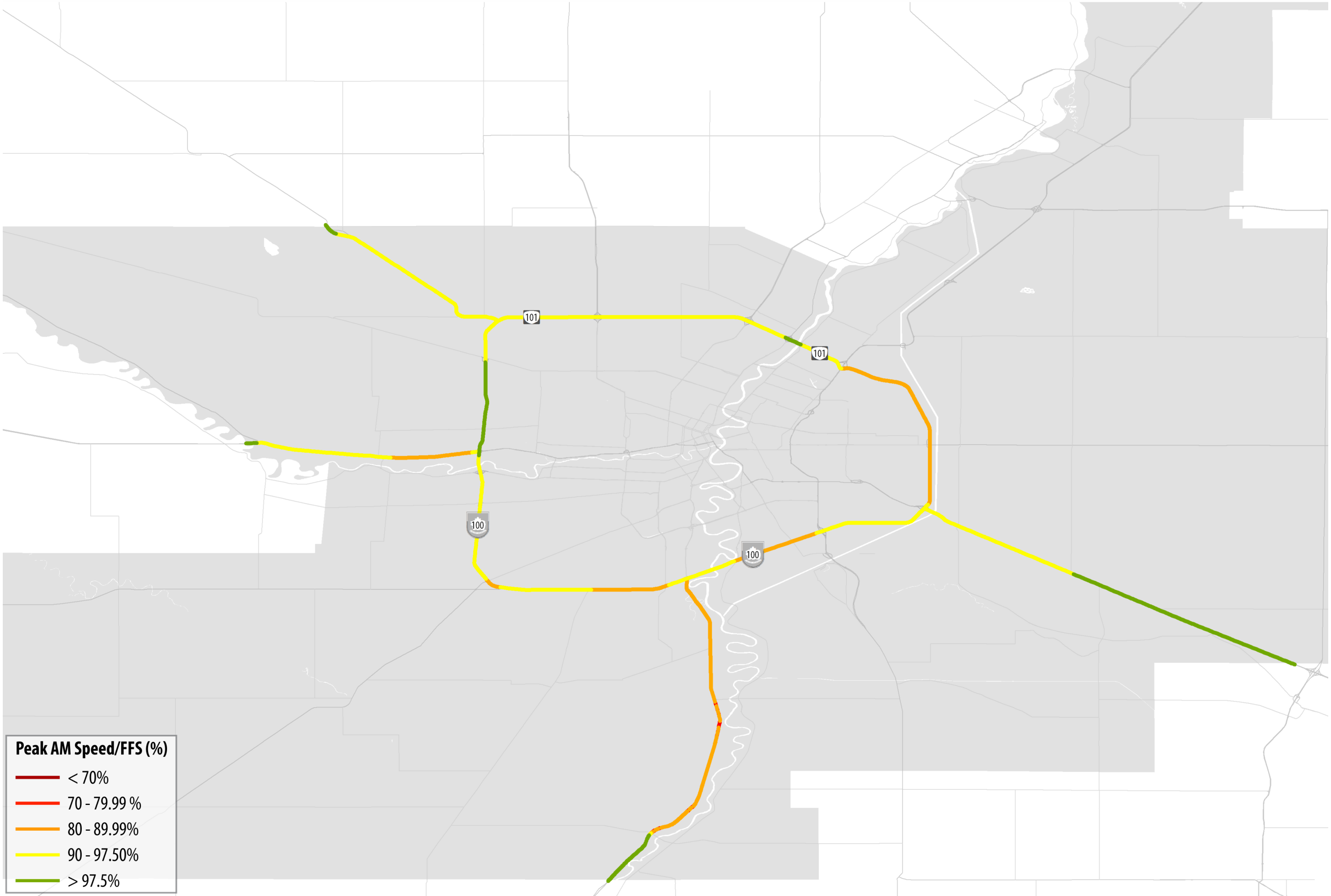
Vancouver: Peak AM Speed (7:00 - 9:00AM)/FFS




CPCS Solutions for growing economies
Vancouver: Peak PM Speed (4:00 - 6:00PM)/FFS
1
91
91A
99
Peak PM Speed/FFS (%)
< 70%
70 - 79.99 %
80 - 89.99%
90 - 97.50%
> 97.5%

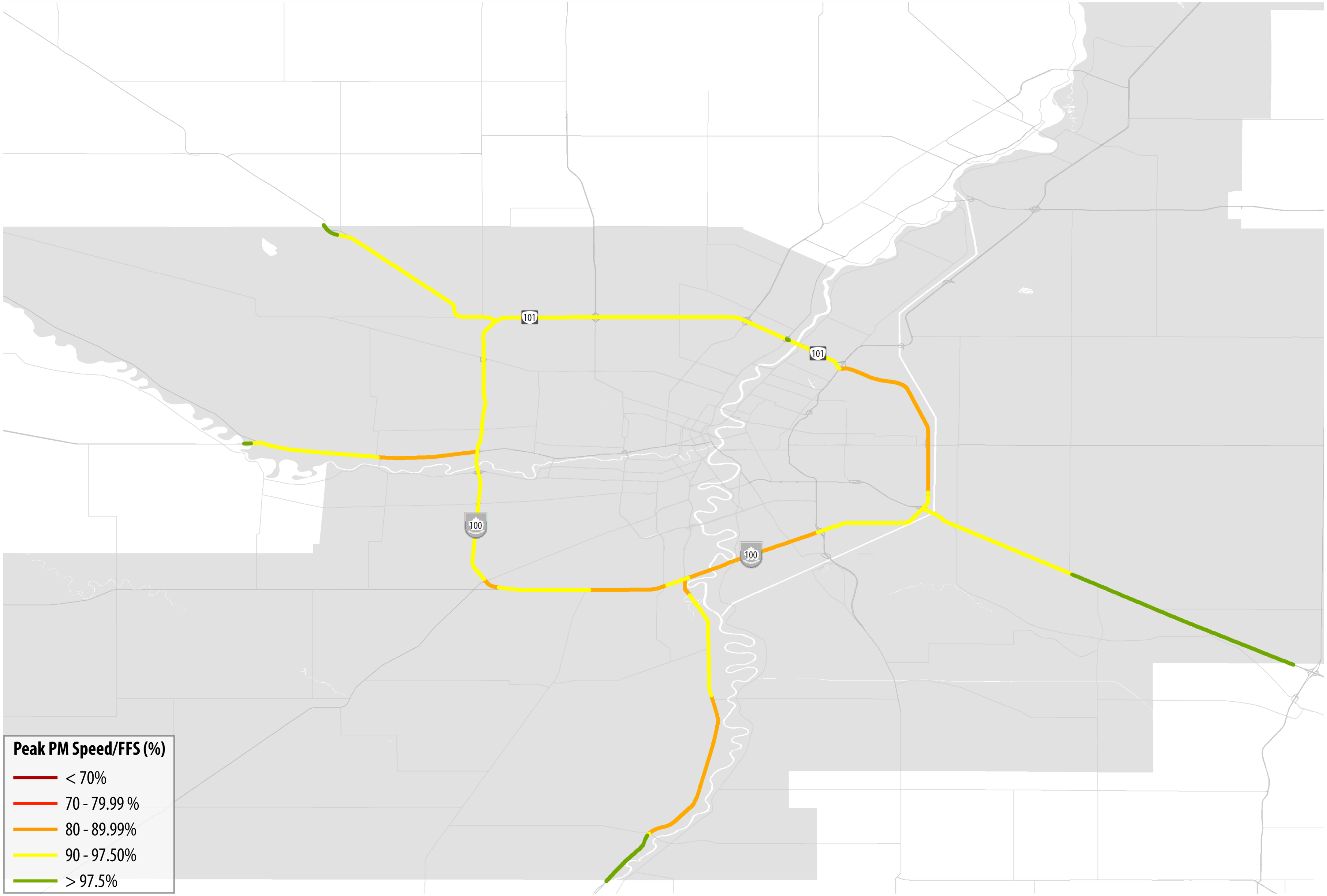
CPCS Solutions for growing economies

Winnipeg: Peak AM Speed (7:00 - 9:00AM)/FFS



CPCS Solutions for growing economies

Winnipeg: Peak PM Speed (4:00 - 6:00PM)/FFS



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