Appendix 3.1 - CANADA / Québec – Montréal – tunnels Ville-Marie & Viger

1. SUMMARY

The Ville-Marie and Viger tunnel complex is part of the A 720's east-west freeway. It is located in the heart of downtown Montréal, metropolis of Québec and the second-largest city in Canada. There are over two million inhabitants on Montréal Island and a further two million in the surrounding urban area.

The complex is an underground interchange with multiple floors, composed of two main tubes of three to five traffic lanes and six secondary connecting tubes of one or two traffic lanes. There are five access ramps and seven exit ramps. In addition, several kilometres of emergency corridors run throughout the Montréal underground system **(Figure 1).**

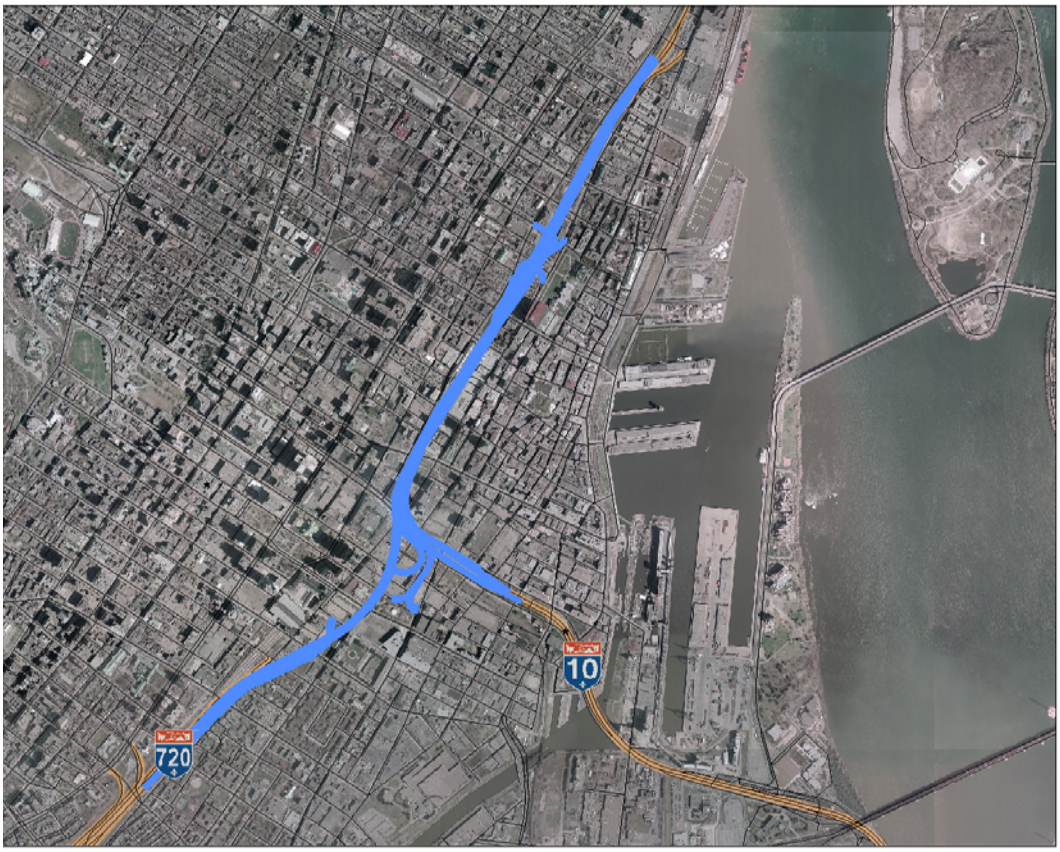

Figure 1 – Localisation of Ville-Marie Tunnel in downtown Montréal

The tunnel system comprises two tunnels, Ville-Marie and Viger, separated by a section of depressed freeway with five overpasses **(Figure 2).**

The complex includes eight technical buildings called "vent shafts" that include heavy mechanical and electrical equipment such as fans, pumps, transformers, power generators and electronic equipment for telecommunication and surveillance, such as programmable controllers and networking systems.

Figure 2 – East entrance of Ville-Marie Tunnel

This infrastructure enables users to cross the city centre within four or five minutes. It offers quick access to the central business district and to the A10 and A15 motorways, even during peak hours.

The main tunnel, Ville-Marie, was opened in 1974, while the Viger Tunnel is in service since 1985.

The Ville-Marie tunnel was extended between 1996 and 2002, as part of the construction of the Quartier International de Montréal.

The depressed freeway between the two tunnels was partially covered (extending the Ville-Marie tunnel) for the construction of the Montréal Convention Centre and the Caisse de Dépôt et Placement du Québec. **(Figure 3).**

Considerable maintenance and refurbishment works have been carried out by the Québec Ministry of Transport to ensure acceptable safety levels in this aging tunnel system.

Despite its complexity, the incident and accident record of this tunnel system is lower than the national average. A prize was awarded in 2006 by the PIARC-Québec committee for the smoke-extraction strategies implemented for fire incidents.

The condition of the tunnel complex was evaluated. Refurbishment and upgrading works continue in accordance with best practice, taking advantage of recent technological developments.

Figure 3 – Open area between tunnel Viger (at the bottom) and Ville-Marie Tunnel (at the top)

2. TUNNEL FEATURES

Tunnels Ville-Marie and Viger form an underground interchange **(Figure 4)** with multiple levels and varying vertical clearances in different sections of the tunnel. It is connected to the surface network through eight access tunnels, each with one or two traffic lanes. The two main tubes have between three and five traffic lanes in each direction. These tubes are superimposed over a length of 1,220 metres, which represents over half the length of the main segment.

This complex is adjacent to the Montréal underground network which consists of pedestrian tunnels, subway tunnels, shopping centres and parking lots.

The proximity with other underground infrastructure and the intertwining with municipal service networks have posed a challenge in terms of design and construction, and still contribute to the complexity of the operation today.

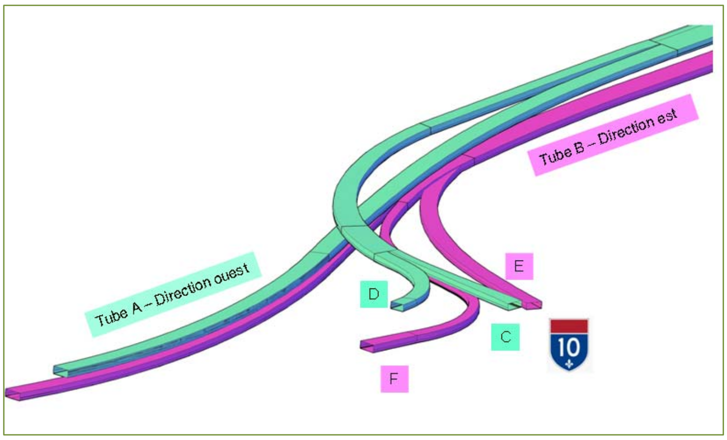

Figure 4. Simplified 3D model showing the layout of the tubes of tunnel Ville-Marie.

The tunnel sections were cast on site in trenches which were dug in the bed of an old river and then covered **(Figure 5).** The lowest point of the tunnel is located at a depth of 42 metres below ground level. Large portions of the tubes are below ground water levels. Additionally, the water table tends to rise due to runoff from the south side of Mont-Royal nearby..

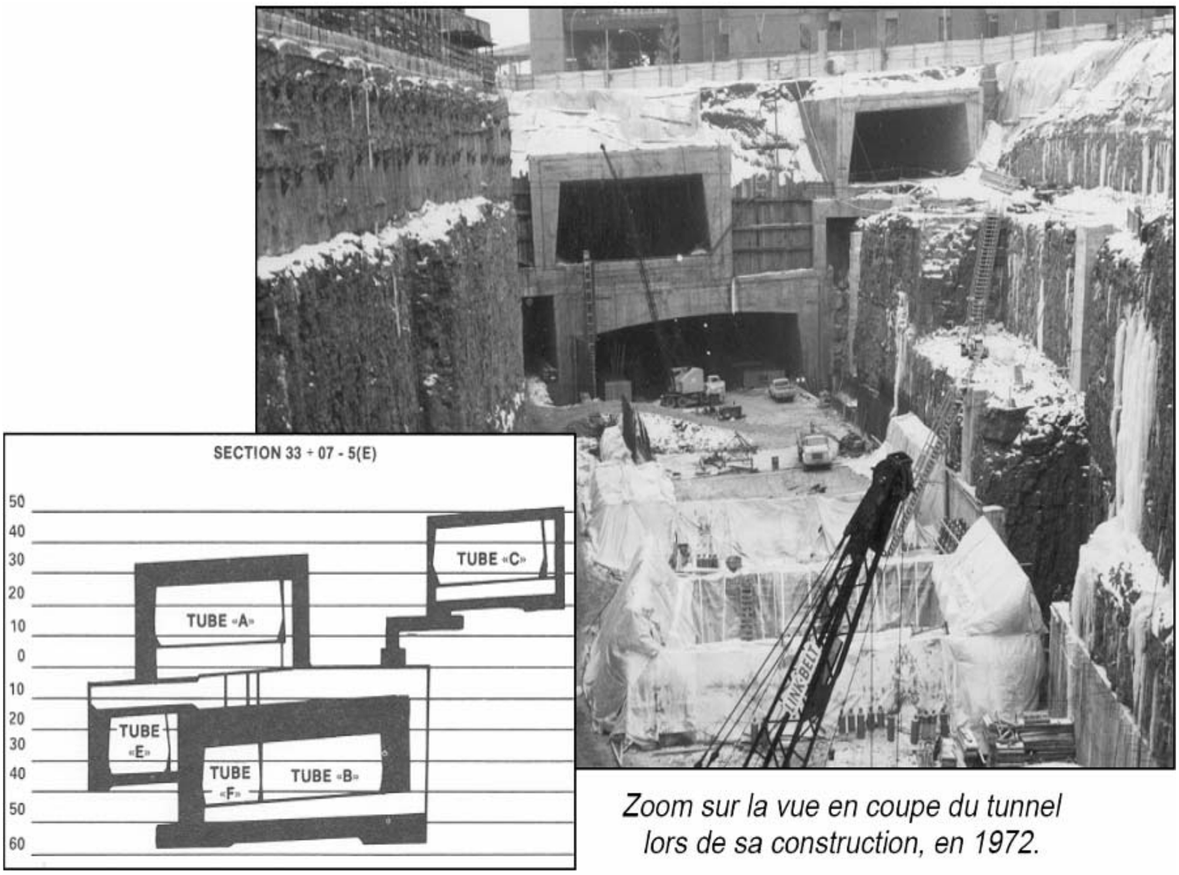

Figure 5. *Photograph of the construction site of tunnel Ville-Marie during winter 1972*
(Inset: Diagram of the tunnel *cross section at the time of construction*)

3. GEOMETRY

3.1 HORIZONTAL AND VERTICAL ALIGNMENT

The combined length of the tubes in the tunnel complex is 7,776 m. The Ville-Marie tunnel is 6,497 m long, and the Viger Tunnel is 1,379 m long. The longitudinal profile features gradients of between -3.26% and +7.49% in the westbound bore and between -5.07% and +3.66% eastbound bore **(Figure 6).**

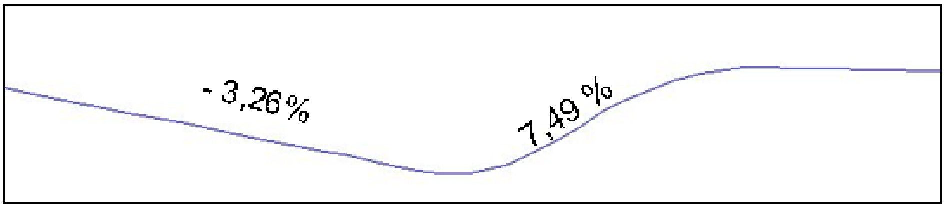

Figure 6. *Longitudinal profile of the westbound bore of the Ville-Marie tunnel.*

The complexity of the underground interchange is due to significant differences between the longitudinal profiles of each tube, and in the layout of these tubes over the whole tunnel. The traffic tubes have dimensions varying between 6.9 m and 21.1 m in width and between 4.39 and 4.90 m in height. The following **figures 7 & 8** present typical cross sections to highlight the complexity of the tunnel's cross sectional profile.

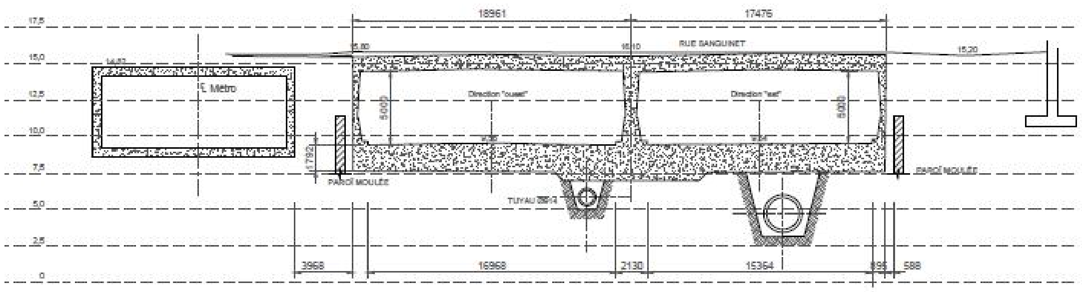

Figure 7. *Example of a cross section and of the proximity of the Montréal subway*

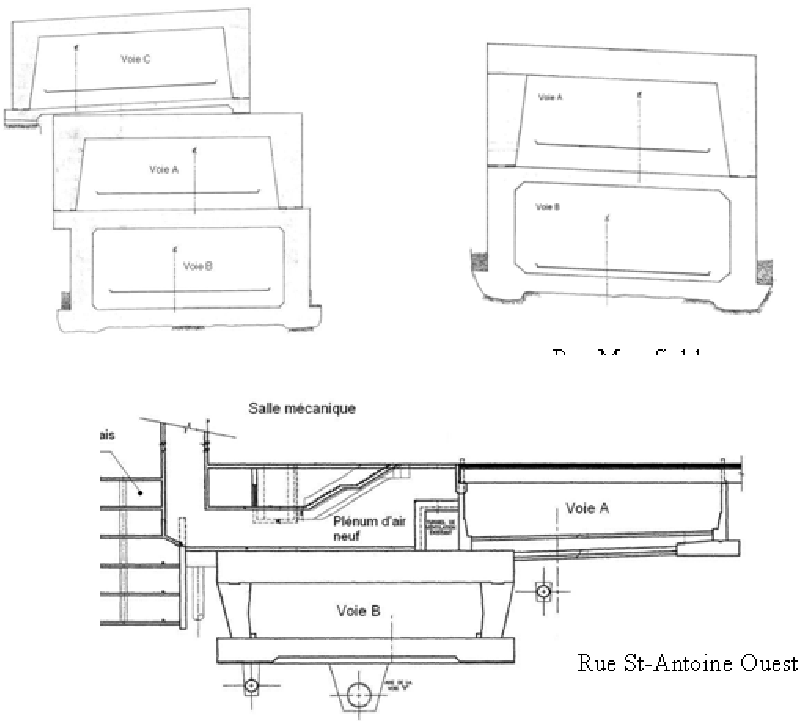

Figure 8. *Example of a cross section and of tubes superposition*

3.2 VENTILATION SHAFTS

Vent shaft No. 9 **(Figure 9)** is particularly complex as it serves six underground levels and hosts the control centre of the urban motorways network of Montréal.

With six underground levels, vent shaft No. 9, close to the University Street, presents specific configuration complexity **(Figure 9).** Furthermore the highest level of the shaft hosts the control centre of the urban motorways network of Montréal.

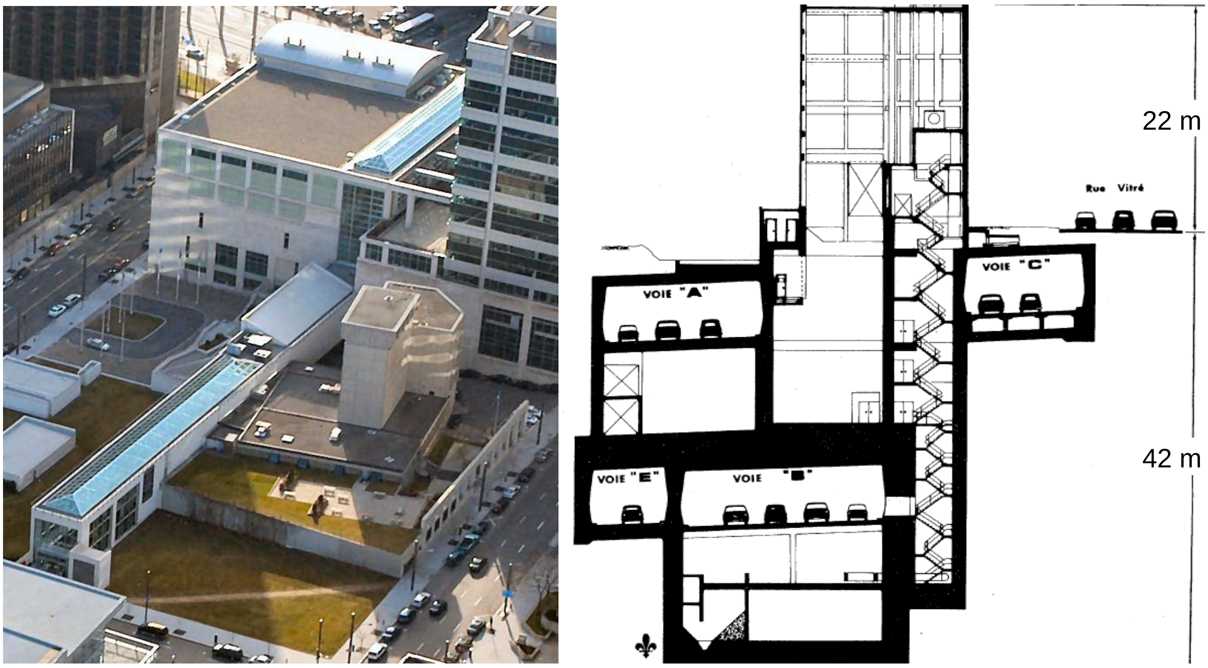

Figure 9. *Vent shaft No. 9 :Exterior view and cross-sectional view of the structure.*

3.3 EMERGENCY ACCESSES AND ESCAPE ROUTES

The tunnels feature over 5 km emergency exit routes to street level, and connections to underground parking and adjacent buildings. 71 emergency exit doors, accessible at average intervals of 94 m, provide access to the emergency exit tubes.

4. TRAFFIC PROFILE – BREAKDOWNS AND INCIDENTS

4.1 TRAFFIC CONDITIONS

Traffic in the tunnel is unidirectional. For safety purposes, the maximum speed limit is 70 km/h and transport of dangerous substances is prohibited in the tunnel.

Congestion appears at certain exit ramps and tubes on weekdays. Queues of 100 to 200 m long form for up to 90 minutes in the morning and 135 minutes in the afternoon. Occasional evening congestion occurs during cultural and sporting events in downtown Montréal. However, the main tubes of the tunnel are rarely congested because of the large number of lanes available.

The annual average daily traffic (AADT) is quite stable, with around 100,000 vehicles per day in 2012 (all tubes). The lowest traffic flow occurs in August, with 89,000 vehicles daily, while the highest traffic flow is in May, with 104,000 vehicles per day.

During the week, traffic flow varies between 99,000 vehicles per day, on Mondays, and 111,000 vehicles per day, on Fridays. On weekends, traffic decreases to 78,000 vehicles per day on Saturdays, and 67,000 vehicles per day on Sundays. Traffic in the tunnel reflects the schedule of people working downtown, with typical peak hour periods: from 7 a.m. to 9 a.m. **(Figure 10)** and from 4 p.m. to 6 p.m. .

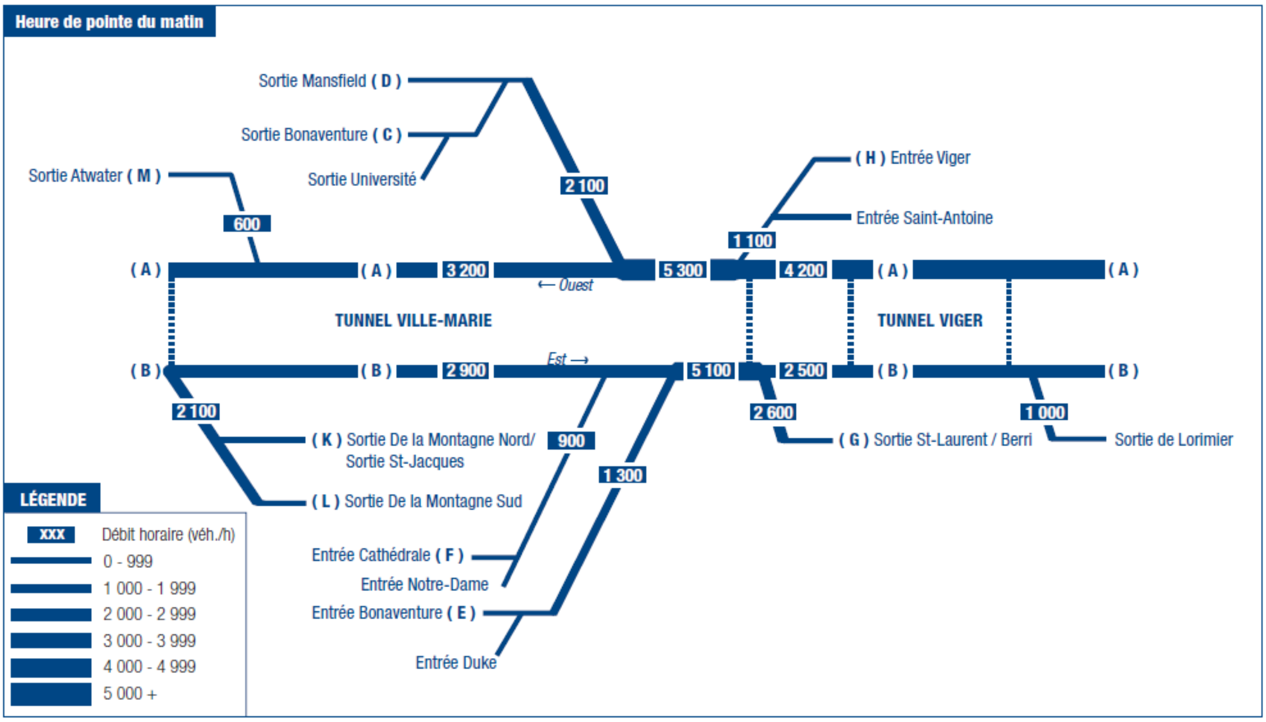

Figure 10. *Traffic flow distribution during the morning peak hour*

4.2 INCIDENTS STATISTICS

The most problematic sections for incidents feature winding roadway. Sharp bends can cause a loss of control and steep gradients encourage acceleration. The risk of these features is mitigated by a speed limit of 70 km/h.

However, the number of accidents in the tunnel is lower than the number of accidents recorded on an equivalent freeway segment (with the same traffic flow, same speed, etc.). The reasons may be users' increased level of alertness due to the confined environment, lighting in the tunnel and increased, continuous monitoring which enables rapid intervention.

Since 1995, 163 accidents have been recorded in the tunnel network per year. Of that number, 20 to 48 accidents involved injuries. Over the last 20 years, 10 fatalities have been recorded, including three in 1995, two in 2007 and one in each of the years 2001, 2005, 2006, 2012 and 2013. Three of these happened on the westbound lanes and seven in the westbound lanes. Accidents involving trucks decreased from an annual average of 18 in the 1990s to an annual average of 10 in the 2000s.

5. SURVEILLANCE, COMMUNICATION AND SIGNAGE

The safety of users and infrastructure is ensured by the deployment of specific monitoring measures and a combination of equipment which includes:

- A dedicated computer system, SCADA-iFIX®, to ensure continuous monitoring (24 hours a day, 7 days a week), control, data acquisition and remote equipment control;
- A control room enabling continuous remote supervision through 85 traffic cameras;
- A significant number of sensors, analysers, motion sensors, gas detectors (carbon monoxide and nitrogen dioxide) and temperature sensors;
- Nearly 300 emergency telephones installed near hose cabinets, on both sides of the roadway and in emergency corridors;
- Many illuminated and variable message signs are installed in the tunnel. Traffic lights are installed over each lane. Some 350 lights are controlled from the operation centre in response to accidents, stalls, or other traffic delays or road works in the tunnel.

6. SPECIFIC MECHANICAL EQUIPMENT

The tunnel is equipped with operating mechanical equipment:

VENTILATION

- 87 fans (31 air supply fans and 42 exhaust fans);

POWER SUPPLY

8 emergency backup generators:

- 5 in tunnel Ville-Marie: 4 of 800 kW, and 1 of 1 200 kW ;
- 3 in tunnel Viger, of 600 kW, 210 kW and 250 kW.

PUMPING STATIONS

2 pumping stations with a total of 9 pumps:

- 5 in tunnel Ville-Marie, including 3 vertical units and 2 submersible units. Pumps are identical. The total flow for vertical pumps operating in parallel is 896 l/s at 352 kPa (35.85 mce); for submersible pumps, the total flow is 574 l/s at 400 kPa (40.8 mce), and it is 1,470 l/s at 352 kPa for all pumps operating in parallel;
- 4 submersible pumps for the tunnel Viger sector, each with a nominal flow of 175 l/s at 172 kPa (17.6 mce) and a total flow for a parallel operation of 700 l/s at 172 kPa.

7. VENTILATION

Automatic and manual ventilation sequences to dilute pollution emissions and ensure adequate air quality in the tunnel are programmed according to the following thresholds:

Ventilation scenario	CO	NOx
Manual activation of fans	> 50 ppm	> 5 ppm
Manual shutdown of fans	> 30 ppm	> 3 ppm
Automatic activation of fans	> 80 ppm	> 8 ppm
Activation of an alarm signal and tunnel closure	> 150 ppm	> 15 ppm

The smoke-extraction system in the Ville-Marie section is semi-transverse, with fresh air supply at regular intervals and with high volume extraction points. The tunnel is divided into zones between 2 vent shafts. Out of the 73 fans installed in 6 vent shafts, 42 are used mainly to supply air and 31 are used for exhaust.

Smoke-extraction ventilation in the Viger section is longitudinal and comprises local extraction points. It consists of 14 fans, including 6 installed in 2 vent shafts (3 per shaft) and 8 jet-fans installed in the traffic tubes above the lanes (4 per direction).

A smoke-extraction sequence, determining the order of activation of fans, has been established based on the position of a fire identified by cameras. The activation and shutdown of a smoke-extraction sequence is done by an operator.

8. ENVIRONMENTAL ISSUES

The 87 fans are activated at least twice a week for 30 minutes for preventive maintenance purposes. Because of the proximity to residential areas, some of the fans are activated from 10 a.m. to 1 p.m. on Mondays and Wednesdays, while the rest of the fans are activated at night.

The storm water from the tunnel Ville-Marie is directed to a settling pond at the lowest point of the tunnel. A primary treatment involving decanting of solids and the segregation of sludge is done before water is sent back to the storm water drainage network and to the water treatment facility.