Downtown Ottawa (Truck) Tunnel

Feasibility Study

PARSONS

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Feasibility Study

prepared for:

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Executive Summary

Truck traffic on the King Edward-Rideau-Waller-Nicholas (KERWN) Corridor has been an issue for many years. The corridor is the major truck route connecting the highway networks in Ontario and Quebec. As the cities have grown, so have traffic demands. Community concerns about the local impacts have been focussed on finding a potential solution to reduce the impacts of both pass through truck and car traffic and find a better option to connect the Macdonald-Cartier Bridge to Highway 417.

The Vanier Parkway solution proposed in the 1970s was to provide an alternate corridor. The southern portion of the corridor was constructed, but is limited to car use only with truck use prohibited. The northern section was delayed and ultimately removed from the City's Official Plan and Transportation Master Plan in response to local community concerns. Various development plans for King Edward Avenue also looked at ways to improve the corridor and reviewed a number of tunnel options that would have seen a lower level roadway or tunnel located primarily under King Edward implemented as part of the road reconstruction. The ultimate reconstruction plan did not include a grade-separated truck route but rather opted for a 6-lane surface route, improving the northern portions of the truck route.

Most recently the Inter-provincial Crossing Environmental Assessment (EA) Study looked at an additional river crossing as a solution to capacity constraints across the Ottawa River. The study did not look at a KERWN Corridor tunnel, but rather focussed on a region-wide person-trip capacity improvement strategy. The proposed bridge would have created a new connection to the east of downtown and would have diverted a significant number of trucks from the study area. The recommendations of this incomplete EA study are not currently moving forward.

All of the previous studies have noted that the truck traffic is composed of three types:

- Local trucks, which make deliveries in the study area and would not benefit from a direct bridge-to-highway tunnel connection,
- Through trucks, which would benefit from a direct tunnel connection as they do not need to make any local or intermediate stops between the bridge and the highway, and
- Hazardous or dangerous goods trucks, which are challenging to accommodate in tunnels and as such, are typically prohibited.

This mix of truck traffic indicates that any alternate route or tunnel would only divert a portion of the trucks. Surveys undertaken for prior studies indicate that approximately 65% of trucks are through trucks while 35% are local, indicating that a truck route could divert a substantial portion of the trucks from the current route. While previous studies did not look at the benefits for car traffic, diverting car traffic from the KERWN Corridor could also provide benefits in terms of lower total traffic volumes.

If a tunnel was to be constructed, it is estimated that about 1,700 trucks per day would be attracted to the facility. This is only two thirds of the total number of trucks in the corridor, as one third of the trucks on the network are considered to be local and would not make the direct Macdonald-Cartier Bridge to Highway 417 connection. A typical lane of traffic can accommodate in the order of 2,000 vehicles per hour per direction, whereas directional truck volumes within the tunnel would be in the order of 100 per hour based on the existing data sources. A tunnel just for trucks would be significantly underutilized.

Based on this finding, the question of feasibility is based on a tunnel designed to accommodate both trucks *and* cars.

In 2015, with a lack of action on other potential solutions, the City of Ottawa and Ministry of Transportation of Ontario decided to co-fund and advance this Feasibility Study to examine the potential for the construction of a tunnel to divert truck traffic through downtown Ottawa linking the Macdonald-Cartier Bridge with Highway 417. The Official Plan and Transportation Master Plan provide direction that "*The City will explore alternative means to accommodate interprovincial truck travel to minimize the impacts on the Central Area, in particular along and in the vicinity of King Edward Avenue*".

Feasibility, for the purpose of this study, is defined as the ability to construct a tunnel between the Macdonald-Cartier Bridge and Highway 417. The degree of feasibility, ranging from least to moderate to high is based on a set of criteria such as physical constraints and constructability. Other criteria related to social impacts such as land use impacts, costs and safety features were considered as well.

This study area was initially smaller, and did not include lands east of the Rideau River, but it was expanded at an early stage in the study to permit the development of more potential tunnel alternative routes. As such, the study area boundary is generally defined as land indicated within Sussex Drive and Nicholas Street to the west, Boteler Street to the north, Highway 417 to the south, and Vanier Parkway and Rideau River to the east (see **Figure 1**).

The study methodology process included the following major tasks:

1. Inventory – Several background reports were drafted and research was conducted to understand the needs, aspects, major constraints and impacts to constructing a tunnel;
2. Identify preliminary tunnel alternatives;
3. Consultation with the Technical Consultation Group (TCG) to confirm findings, identify gaps, and refine alternatives;
4. Analyze and evaluate each alternative using a set of evaluation criteria;
5. Select a technically preferred alternative(s) and prepare a conceptual design;
6. Highlight other considerations that will affect the feasibility of a tunnel such as ownership, construction, dangerous goods and comparative costs (among others);
7. Summarize findings to support a Staff Report to the City's Transportation Committee and MTO Regional Staff.

After ongoing research, consultation, and analysis and evaluation of possible alternatives, the project team determined that constructing a tunnel from the Macdonald-Cartier Bridge to Highway 417 is feasible. The Cross Country alternative was deemed the 'most feasible alternative' (see **Figure 2**) for the following reasons:

- The alignment results in a high geometric standard;
- The alignment has minimal to no impact development on adjacent development;
- Anticipated impacts at portals can be mitigated; and
- There appears to be opportunities to modify / refine the design to improve the performance of the solution.

This Cross Country alternative connects the Macdonald-Cartier Bridge with the Vanier Parkway interchange to Highway 417. It runs in a south-easterly direction under the neighbourhoods of Lowertown and Sandy Hill, before running parallel to the Rideau River and eventually crossing the River to connect to the Vanier Parkway.

Cost estimates prepared as part of this study provide an indicative cost to design and construct a twin bore, four-lane facility connecting the south end of the Macdonald-Cartier Bridge to the Highway 417 / Vanier interchange via a cross-country route. Parametric costs for various items were developed. Soft costs for design, engineering management and oversight were added, and a range of contingency costs applied. The likely project cost, with a low and high contingency range, is $1.7 to $2 billion ($2015).

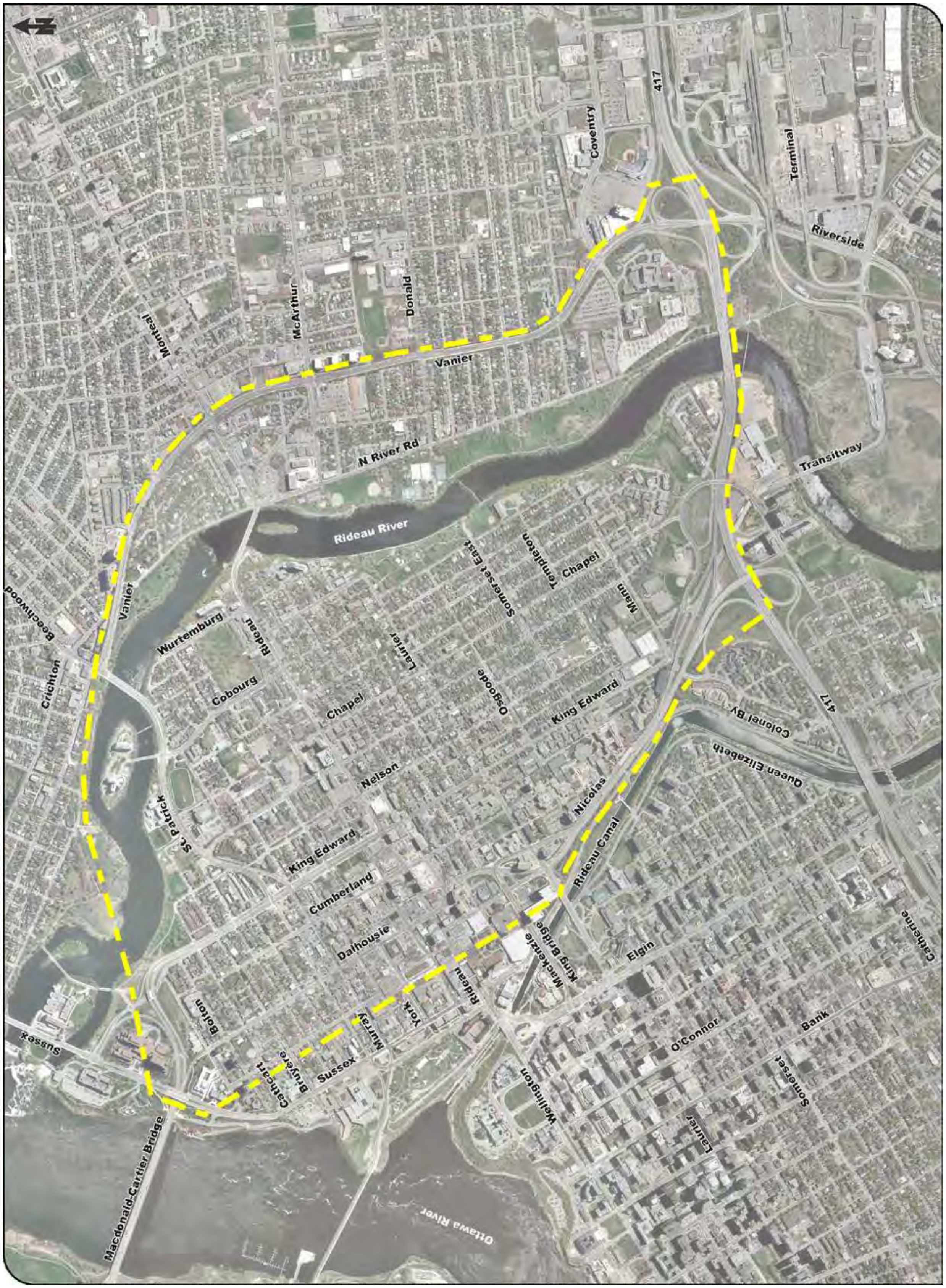

Figure 1: Study Area

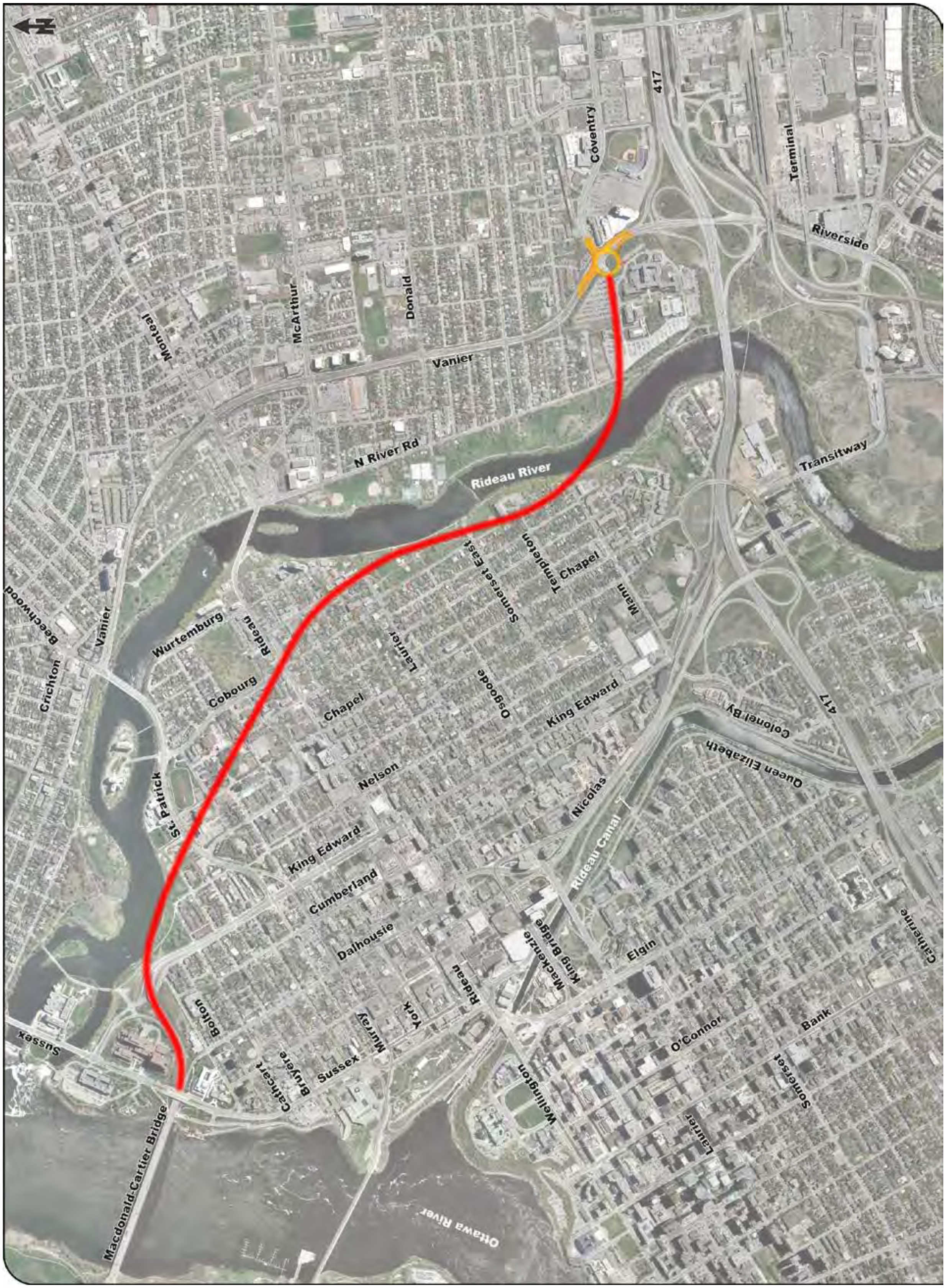

Figure 2: Most Feasible Alternative

These study findings will be presented to the City of Ottawa's Transportation Committee and Council. The future of this topic will be determined by these decision makers.

Through the study process the team found that:

- There is sufficient potential to divert truck traffic from the current KERWN Corridor to consider a tunnel, however not all trucks using the corridor would choose to use the tunnel as many trucks need to make local deliveries within the study area
- The volume of trucks is not sufficient to warrant their own tunnel, leading the team to evaluate the potential use by car traffic
- More than 25,000 vehicles per day are likely to use a tunnel facility to make the connection between the bridge and highway, with the Regional TRANS model indicating an even higher usage, drawing traffic to the improved highway network connection
- While existing and proposed storm and sanitary sewers, as well as the LRT and CSST tunnels, present constraints to the development of a tunnel, the constraints are manageable and can be cost-effectively mitigated
- The most feasible alternative is a twin-bore tunnel carrying two traffic lanes each connecting form the south end of the bridge to the Vanier/Coventry intersection via a cross-country route under parts of Lowertown and Sandy Hill.

If a decision is made to advance with future steps in the design process, they would include:

- Additional geotechnical investigations to understand the local geotechnical conditions along the proposed alignment, allowing for the design to be refined
- Conducting an environmental assessment to understand the impacts of the facility on the community and determine effective mitigation measures to minimize any potential impacts
- Integration of the tunnel option into the broader transportation planning processes being considered for the National Capital Region, including the comparison of the effects and benefits of a tunnel-based solution to other network enhancements including a new inter-provincial bridge

This study was designed to review the potential for a tunnel to alleviate truck traffic issues on the KERWN corridor. They study found that a tunnel solution can effectively address the truck traffic issue and provide additional network capacity to address broader travel demand issues. The solution proposed will form the basis of future work, but has clearly demonstrated that a feasible solution exists.

Résumé

La circulation de camions dans le couloir King Edward/Rideau/Waller/Nicholas (KERWN) pose problème depuis de nombreuses années. En fait, ce couloir est la principale route pour camions reliant les réseaux routiers de l'Ontario et du Québec, et l'expansion des villes environnantes a entraîné une augmentation des besoins en circulation. La communauté s'inquiète des répercussions locales de la circulation des voitures et des camions; elle cherche une solution pour en atténuer les effets ainsi que de nouvelles et meilleures possibilités pour relier le pont Macdonald-Cartier et l'autoroute 417.

La solution de la promenade Vanier proposée dans les années 1970 consistait à créer un autre couloir. Sa partie sud a été construite, mais seules les voitures peuvent y circuler. La construction de la partie nord a été reportée, puis retirée du Plan officiel et du Plan directeur des transports de la Ville en réponse aux préoccupations de la communauté locale. Dans le cadre de différents plans d'aménagement de l'avenue King Edward, on a examiné diverses façons d'améliorer le couloir ainsi que plusieurs scénarios de construction d'un tunnel où l'on aurait abaissé la chaussée et construit un tunnel principalement sous l'avenue King Edward. Le dernier plan de reconstruction ne comprenait pas de voie dénivelée pour les camions, mais plutôt six voies de surface qui amélioraient la partie nord de la route pour camions.

Plus récemment, dans le cadre d'une étude d'évaluation environnementale (EE) sur les liaisons interprovinciales, on a examiné la possibilité d'aménager un pont supplémentaire pour résoudre les problèmes de capacité de déplacement d'un côté à l'autre de la rivière des Outaouais. L'étude ne portait pas sur la construction d'un tunnel pour le couloir KERWN, mais plutôt sur une stratégie d'amélioration de la capacité de déplacement des personnes dans la région. Le pont proposé aurait créé un nouvel accès à l'est du centre-ville et aurait permis à de nombreux camions d'éviter le secteur à l'étude. Les recommandations de cette étude d'EE incomplète ne sont pas mises en œuvre.

Comme l'ont souligné les études précédentes, il y a trois catégories de camions sur les routes :

- les camions locaux, qui font des livraisons dans le secteur à l'étude et n'utiliseraient pas le tunnel reliant directement le pont et l'autoroute;
- les camions de passage, qui utiliseraient le tunnel étant donné qu'ils ne feraient aucun arrêt local ou intermédiaire entre le pont et l'autoroute;
- les camions transportant des marchandises dangereuses, qui ne conviennent pas réellement aux tunnels et y sont généralement interdits.

La construction d'une nouvelle route ou d'un tunnel permettrait donc de rediriger seulement une partie de ces camions. Les enquêtes menées dans le cadre d'études précédentes ont révélé qu'environ 65 % des camions sont des camions de passage, et 35 %, des camions locaux, ce qui signifie qu'une route pour camions redirigerait une grande partie des véhicules. Les études précédentes n'ont pas examiné les avantages pour la circulation des voitures, mais le fait de rediriger ces véhicules du couloir KERWN pourrait aussi diminuer le débit de circulation total.

Si un tunnel devait être construit, quelque 1 700 camions l'utiliseraient chaque jour, ce qui représente seulement deux tiers des camions qui circulent dans le couloir; le tiers restant comprend des camions locaux qui n'ont pas à circuler entre le pont Macdonald-Cartier et l'autoroute 417. Une voie de circulation ordinaire peut accueillir environ 2 000 véhicules à l'heure dans chaque direction, mais les sources de données existantes indiquent qu'environ 100 camions à l'heure emprunteraient dans chaque direction un tunnel qui leur serait réservé : il serait donc sous-utilisé. À la lumière de ces renseignements, un tunnel conçu pour les camions *et* les voitures est le scénario le plus faisable.

En 2015, comme aucune solution potentielle n'avait été mise en œuvre, la Ville d'Ottawa et le ministère des Tranports de l'Ontario (MTO) ont décidé de cofinancer et de mener cette étude de faisabilité afin d'examiner la construction potentielle d'un tunnel reliant le pont Macdonald-Cartier et l'autoroute 417 pour détourner les camions du centre-ville d'Ottawa. Le Plan officiel et le Plan directeur des transports indiquent que *« la Ville explorera des solutions de rechange pour permettre les déplacements interprovinciaux des camions tout en réduisant les effets de ces véhicules sur le secteur central, et plus particulièrement le long et dans les environs de l'avenue King Edward ».*

Dans le cadre de l'étude, la faisabilité est la capacité à construire un tunnel entre le pont Macdonald-Cartier et l'autoroute 417. Le degré de faisabilité – faible, moyen ou élevé – est établi d'après un ensemble de critères, comme les contraintes physiques et la constructibilité. Ont aussi été pris en compte d'autres critères liés aux répercussions sociales, comme le coût et les dispositifs de sécurité.

Au départ, le secteur à l'étude était plus petit et ne comprenait pas les terrains à l'est de la rivière Rideau. Il a été élargi dans les premières étapes de l'étude pour offrir de nouvelles possibilités de tracés pour un tunnel. On considère généralement que le secteur à l'étude est délimité par la promenade Sussex et la rue Nicholas à l'ouest, la rue Boteler au nord, l'autoroute 417 au sud et la promenade Vanier et la rivière Rideau à l'est (voir la **Figure 1**).

La méthodologie utilisée pour l'étude comprenait les principales tâches suivantes :

1. Inventaire – Rédaction de plusieurs rapports circonstanciels et réalisation de recherches pour comprendre les besoins, les aspects, les contraintes importances et les répercussions de la construction d'un tunnel.
2. Proposition de concepts préliminaires de tunnel.
3. Discussions avec le groupe de consultation technique pour confirmer les conclusions, cibler les lacunes et peaufiner les solutions envisagées.
4. Analyse et évaluation de chaque possibilité d'après des critères d'analyse.
5. Sélection des solutions à privilégier au plan technique, et préparation d'un plan de conception.
6. Présentation des autres considérations qui influenceront la faisabilité du tunnel, notamment les droits de propriété, la construction, les marchandises dangereuses et les coûts comparatifs.
7. Résumé des conclusions pour un rapport du personnel présenté au Comité des transports de la Ville et au personnel en région du MTO.

Après l'exécution des étapes de recherche, de consultation, d'analyse et d'évaluation des possibilités, l'équipe de projet a jugé qu'il était faisable de construire un tunnel reliant le pont Macdonald-Cartier et l'autoroute 417. Le tracé dans les champs a été considéré comme « la possibilité la plus faisable » (voir la Figure 2) pour les raisons suivantes :

- Son écart-type géométrique est élevé.
- Il a peu ou pas de répercussions sur les aménagements adjacents.
- Il est possible d'atténuer les effets prévus sur les portails.
- Il semble exister des possibilités de modifier ou de raffiner la conception pour améliorer l'efficacité de la solution.

Le tracé proposé relie le pont Macdonald-Cartier et l'échangeur de la promenade Vanier vers l'autoroute 417. Les véhicules y circuleront en direction sud-est, sous la Basse-Ville et Côte-de-Sable, longeront la rivière Rideau, puis la traverseront pour atteindre la promenade Vanier.

L’estimation des coûts préparée dans le cadre de l’étude inclut le coût de conception et de construction du tunnel bitube et de la route à quatre voies reliant l’extrémité sud du pont Macdonald-Cartier à l’échangeur de la promenade Vanier vers l’autoroute 417. On a aussi calculé le coût paramétrique de différents éléments, et ajouté le coût accessoire des étapes de conception, de gestion de l’ingénierie et de supervision, ainsi que les coûts des éventualités. En tenant compte des coûts minimum et maximum des éventualités, le coût approximatif du projet varie entre 1,7 à 2 milliards de dollars (montant de 2015).

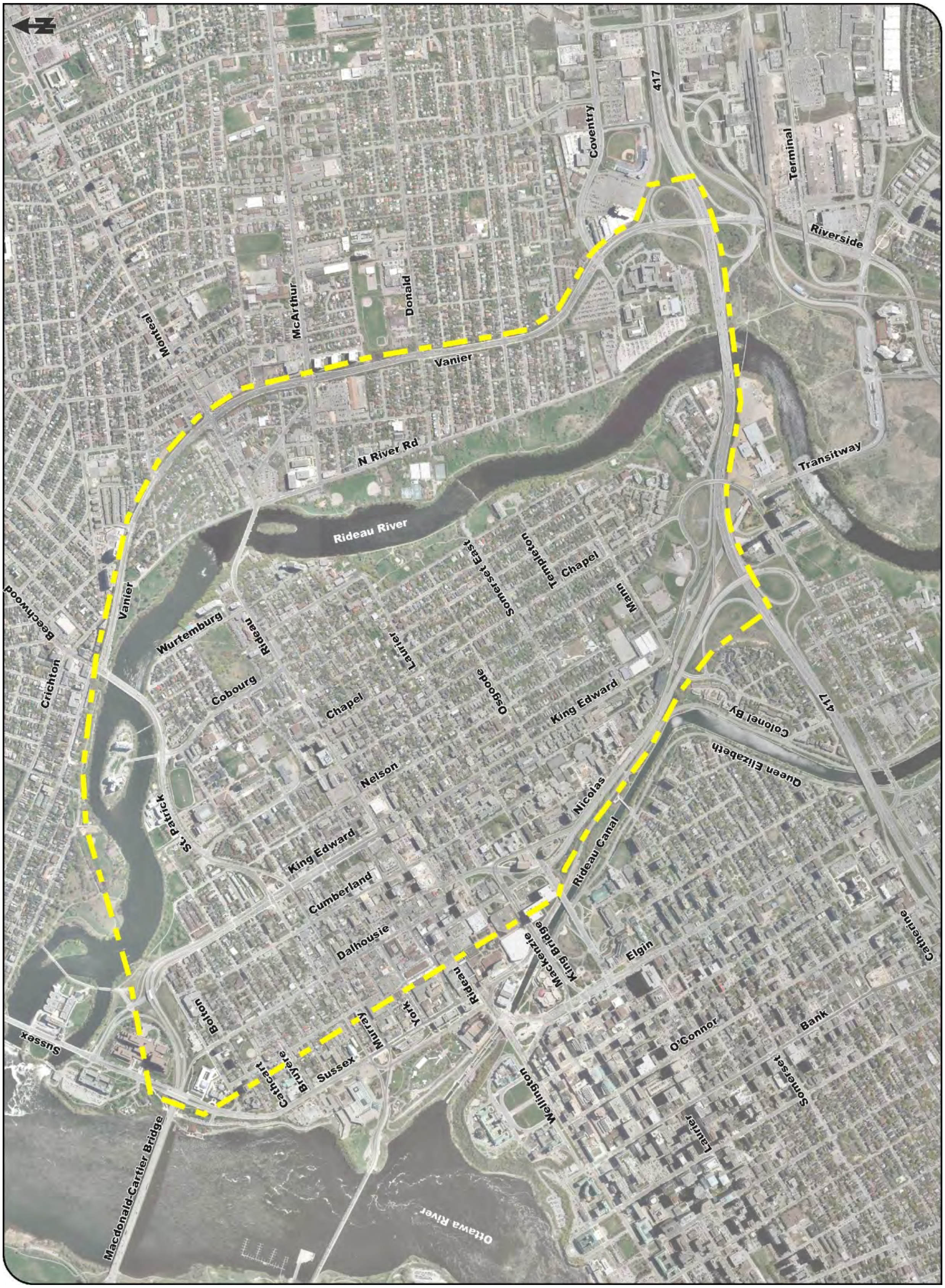

Figure 3: Secteur à l'étude

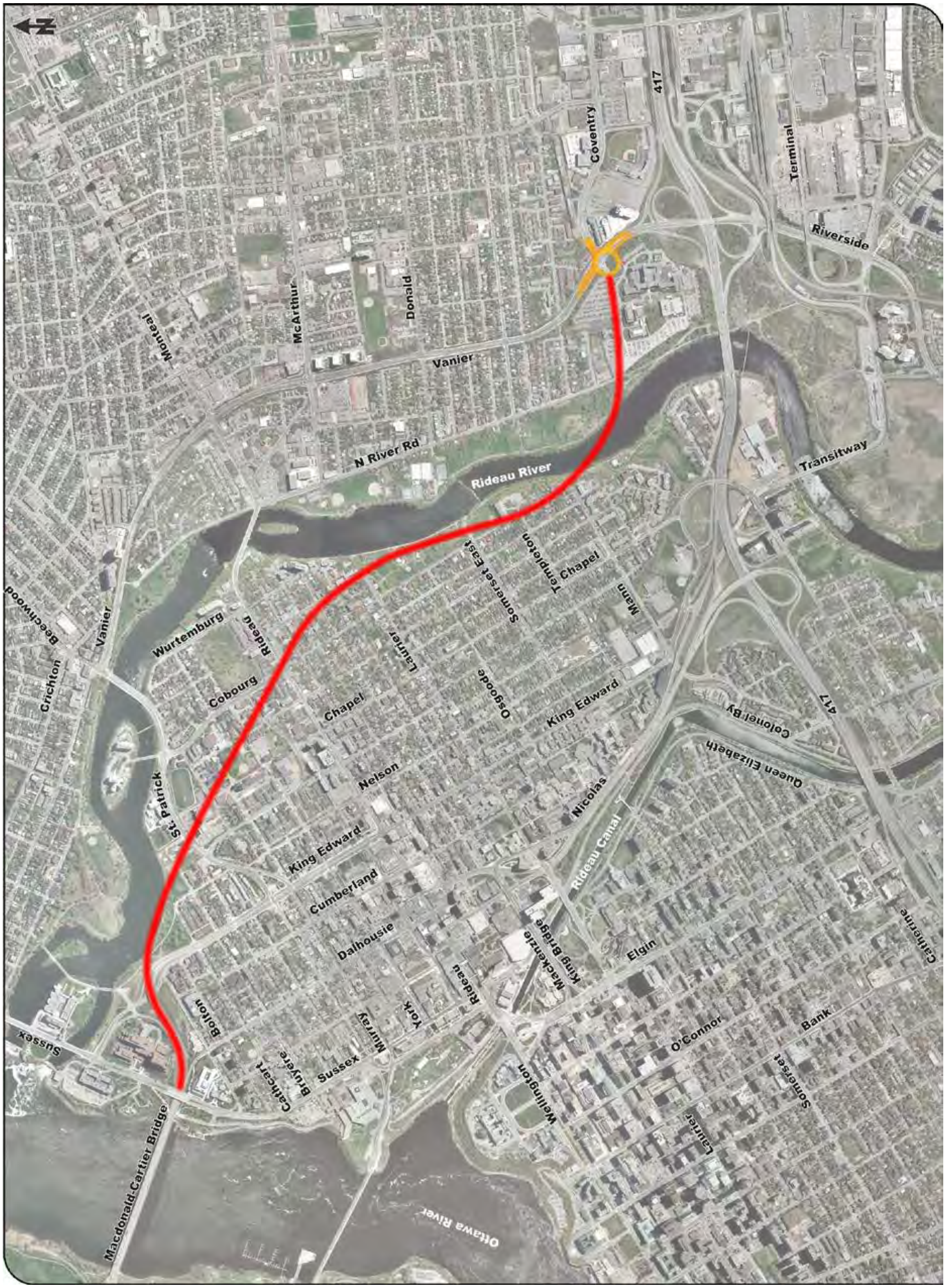

Figure 4: Possibilité la plus faisable

Les conclusions de l'étude seront présentées au Comité des transports et au Conseil de la Ville d'Ottawa.

Voici les conclusions :

- Le nombre de camions circulant dans le couloir KERWN actuel peut justifier la construction d'un tunnel. Cependant, ce ne sont pas tous ces camions qui utiliseront le tunnel, car bon nombre d'entre eux doivent faire des livraisons locales dans le secteur à l'étude
- Le nombre de camions n'est pas suffisant pour justifier la construction d'un tunnel qui leur serait réservé, ce qui a mené l'équipe à étudier la possibilité d'un tunnel aussi accessible aux voitures.
- On estime que plus de 25 000 véhicules par jour pourraient utiliser le tunnel reliant le pont et l'autoroute; le modèle régional TRANS suggère même un nombre supérieur, car la liaison améliorée pourrait attirer les usagers de la route.
- Les égouts pluviaux et sanitaires existants et proposés ainsi que les tunnels de train léger et de stockage des égouts unitaires pourraient entraver l'aménagement d'un tunnel, mais ces contraintes sont gérables et peuvent être atténuées à faible coût.
- La possibilité la plus faisable est un tunnel bitube à deux voies reliant le sud du pont à l'intersection de la promenade Vanier et du chemin Conventry par une route passant sous des portions de la Basse-Ville et de Côte-de-Sable.

Si on décide de procéder avec les prochaines étapes du processus de conception, ces dernières pourraient comprendre :

- des études géotechniques supplémentaires pour mieux comprendre les conditions géotechniques locales de l'aménagement proposé et ainsi améliorer la conception;
- une évaluation environnementale pour comprendre les effets d'une telle installation sur la communauté et déterminer les mesures d'atténuation qui les réduiront de manière efficace;
- l'intégration du tunnel dans les processus de planification globale des transports dans la région de la capitale nationale, y compris la comparaison des effets et des avantages d'un tunnel par rapport à d'autres améliorations du réseau routier, comme un pont interprovincial.

L'étude visait à examiner la possibilité d'aménager un tunnel pour atténuer les problèmes liés à la circulation des camions dans le couloir KERWN. Elle a montré que la construction d'un tunnel pourrait régler ces problèmes de circulation de manière efficace et augmenter la capacité du réseau à répondre aux besoins accrus en transport. La proposition, qui servira de référence aux futurs travaux, démontre clairement qu'il existe une solution faisable.

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1. Introduction

1.1 Context of the Study

The construction of Quebec provincial Highway 5 and the six-lane Macdonald-Cartier Bridge across the Ottawa River in the 1960s resulted in significant increases in the number of motor vehicles on King Edward Avenue and downtown Ottawa roadways leading to Highway 417. In response to the growing demands for both cars and heavy trucks in the 1970s, plans were made for the construction of the “Vanier Arterial” that would link directly from the north end of King Edward Avenue and the off ramps from the Macdonald-Cartier Bridge, then cross east over the Rideau River and run along a former railway line to Highway 417. This controlled access roadway would offer an alternative north-south route to the King Edward Avenue and Nicholas Street Corridor for vehicles traveling between the Macdonald-Cartier Bridge and Highway 417. Federal and municipal parties involved in the construction of the “Vanier Arterial” ultimately made an agreement that trucks would be prohibited on that road; this requirement remains in force today.

The northern end of the now named Vanier Parkway, from Beechwood Avenue across the Rideau River to the bridge off ramps, was never built. It was removed from the road network plans of the former Regional Municipality of Ottawa-Carleton as part of the 1997 Regional Official Plan as approved by the Ontario Municipal Board. As a result, the King Edward-Rideau-Waller-Nicholas (KERWN) corridor remains the main connection and truck route between Highway 417 and the Macdonald-Cartier Bridge.

The current City of Ottawa Official Plan addresses the issue of truck traffic on King Edward Avenue in several policies as follows:

> Section 2.3.1, Transportation, policy 32
>
> The City will explore alternative means to accommodate interprovincial truck travel to minimize impacts on the Central area, in particular along and in the vicinity of King Edward Avenue. The City will, working with other levels of government, remove Rideau Street and King Edward Avenue from the City’s identified truck route system upon the completion of a new interprovincial corridor to accommodate trucks.
>
> Section 3.6.6, Central Area, policy 7h) and 8c)
>
> 7h) King Edward Avenue, also designated a Traditional Mainstreet in its extent beyond the Central Area, is a major entrance gateway into Ottawa from Quebec, with significant potential for residential and other types of intensification and a new role as a unifying element between East and West Lowertown once the truck route is relocated to a new inter-provincial bridge.
>
> 8c) The City will, working with other levels of government, remove Rideau Street and King Edward Avenue from the City’s identified truck route system upon the completion of a new interprovincial corridor to accommodate trucks.

Similar policies, including specific reference to a truck tunnel, are reflected in the City’s updated Transportation Master Plan (2013):

Action 7-7:
Interprovincial bridges. The Ottawa River is spanned by five roadway bridges under federal jurisdiction. This plan projects a substantial increase in total peak hour travel demand across these bridges by 2031, and despite higher levels of transit ridership, one or more new river crossing(s) will be warranted by that time. A primary consideration in the planning of a new crossing is its effectiveness as a truck route, because restrictions on existing bridges have concentrated trucks on King Edward Avenue and the Macdonald-Cartier Bridge, leading to industry inefficiencies and negative community and environmental impacts along King Edward Avenue and elsewhere in the Central Area.

Toward a new bridge. The federal government, in conjunction with both provincial governments and affected municipalities, undertook a comprehensive evaluation of possible crossing locations but without reaching a consensus recommendation among the partnering agencies. Until a new Ottawa River crossing is built, the City will continue to prohibit development in locations that could hinder the implementation of a potential crossing.

The City will work with provincial and federal governments to develop a transportation system that supports the City's growth management objectives. The City will explore alternative ways to accommodate interprovincial truck travel. Once a safe and efficient alternative to the downtown truck route is found, the City will remove Rideau Street and King Edward Avenue from the City's identified truck route system.

Action 7-17:
Reducing impacts in the Central Area. As discussed in Section 7.2 [of the TMP], the volume of truck traffic passing through Ottawa's downtown to and from the Macdonald-Cartier Bridge has substantial negative impacts on local neighbourhoods and businesses. The City will work with other governments and the private sector to explore ways that through truck traffic in the Central Area, particularly King Edward Avenue, can be reduced while ensuring the safe and efficient movement of goods. This may include efforts to develop a tunnel solution for connecting the Macdonald-Cartier Bridge with Highway 417, or other measures.

While the Interprovincial Crossings EA was not completed in 2014, the technical work undertaken is still valid and revealed interesting details pertinent to this study. A significant finding related to truck and goods movement and the overall transportation demands between Ottawa and Gatineau was the truck data and analysis along the KERWN corridor.

In 2011, there were in the order of 2600 trucks (two-way) that crossed the Macdonald-Cartier Bridge over a 24 hour period. Data was collected through an extensive tube and video count system to determine the origins and destinations of these trucks.

There are three groups of trucks: local trucks making one or more stops in the study area, regional trucks that are passing through the study area without needing to stop and dangerous goods trucks which are typically not allowed in tunnels. The split between local and regional truck trips was 35% and 65% respectively. This means that over 900 trucks require access to locations in Ottawa's downtown core and need to use sections of the KERWN corridor. This results in about 1700 trucks that could benefit from a direct connection between the Ministère des Transports du Québec (MTQ) highway system in Gatineau and the MTO's Highway 417.

When the Interprovincial Crossings EA study was cancelled in 2014 before it was completed, there was no longer a planned solution for these trucks. As such, the City of Ottawa initiated, with funding assistance from MTO, this study which examines the feasibility of constructing a truck tunnel between the Macdonald-Cartier Bridge and Highway 417.

The long standing issue of truck traffic on the KERWN Corridor in Ottawa remains unresolved.

The City retained Parsons Inc. to conduct a study to look for a feasible solution to remove truck traffic from affected roads and divert some or all of it into a truck tunnel. While the City is leading the project management aspects of the work, a Technical Consultation Group made up of various experts and approval groups was formed to help guide the study to an appropriate technical conclusion.

1.2 Project Scope

The following report documents the background research conducted, presents various alignment alternatives and their analysis, and discusses issues such as construction techniques, all leading to an answer if a tunnel is feasible.

Feasibility, for the purpose of this study, is defined as the ability to construct a tunnel between the Macdonald-Cartier Bridge and Highway 417. The degree of feasibility, ranging from least to moderate to high is based on a set of criteria such as physical constraints and constructability. Other criteria related to social impacts such as land use impacts, costs and safety features were considered as well. Section 3.0 documents the analysis and evaluation process undertaken to determine the most feasible tunnel option.

1.3 Study Area

The study area boundary is generally defined as land indicated within **Figure 3**, that being, Sussex Drive and Nicholas Street to the west, Boteler Street to the north, Highway 417 to the south, and Vanier Parkway and Rideau River to the east.

The study area was originally intended to exclude examination of a potential tunnel crossing east of the Rideau River. However at an early stage of work on tunnel alignment constraints it was recommended that it would be useful to expand the study area east of the river to the Vanier Parkway corridor and the study's Technical Consultation Group agreed as this would provide more options for developing potentially feasible tunnel alternatives.

Figure 5: Study Area

1.4 Study Methodology

The Downtown Ottawa (Truck) Tunnel Feasibility Study was conducted following the decision process highlighted below:

(1) Inventories and several background reports were drafted and research was conducted to understand the needs, aspects, major constraints and impacts to constructing a tunnel;
   a. Transportation Demands: The Regional Transportation Model (EMME/3) used by the City of Ottawa, along with transportation reports from other studies and data collection were examined and used as inputs to understand the potential use of a tunnel by both heavy vehicles and autos.
   b. Tunnel Research: 24 transportation tunnels throughout the world were researched to provide an understanding of their context in relation to this project.
   c. Major Constraints: Several major pieces of existing, under construction or planned infrastructure are found in the study area including the Combined Sewage Storage Tunnel (CSST), Confederation Line / LRT and Interceptor Outfall Sewer along with other local facilities. These are considered constraints and tunnel alternatives need to avoid them if possible.
   d. Cross Sections: Based on MTO, City and the geometric design of other tunnels, typical cross sections and design standards for various tunnel and lane configurations were developed.
   e. Geotechnical Considerations: The feasibility of a tunnel will hinge on the depth and hydrogeology of the ground conditions in the study area. Background information on local geotechnical and hydrogeological conditions were compiled, particularly the depth to bedrock and the likely depth of weathered rock at this interface.

(2) Identified preliminary tunnel alternatives;
   a. Understanding the long list of study area constraints, design criteria and needs, a series of tunnel alternatives (plans and profiles) were developed. This initial set of alternatives highlighted the many challenges to overcome. This fed into the next step in the process.

(3) Consultation occurred with the Technical Consultation Group (TCG) to confirm findings, identify gaps, and refine alternatives;
   a. The TCG met in a workshop format to review the background information and provide guidance to the study team. The guidance helped refine the study's direction with respect to the overall study area, portal locations, alignments and cross sections and the overall design criteria.
   b. The purpose of the workshop was to develop a short list of alternatives to be analyzed and evaluated. As a result of very significant effects such as community impacts or conflicts with major infrastructure, many alternatives were not carried forward. Those that were, underwent refinement.

(4) An analysis and evaluation of each alternative was conducted;
   a. The analysis and evaluation process considered criteria that helped differentiate the alternatives leading to the ability to rank each alternative between least, moderate or most feasible. Section 3.0 of this report provides the detailed analysis and evaluation exercise and results.

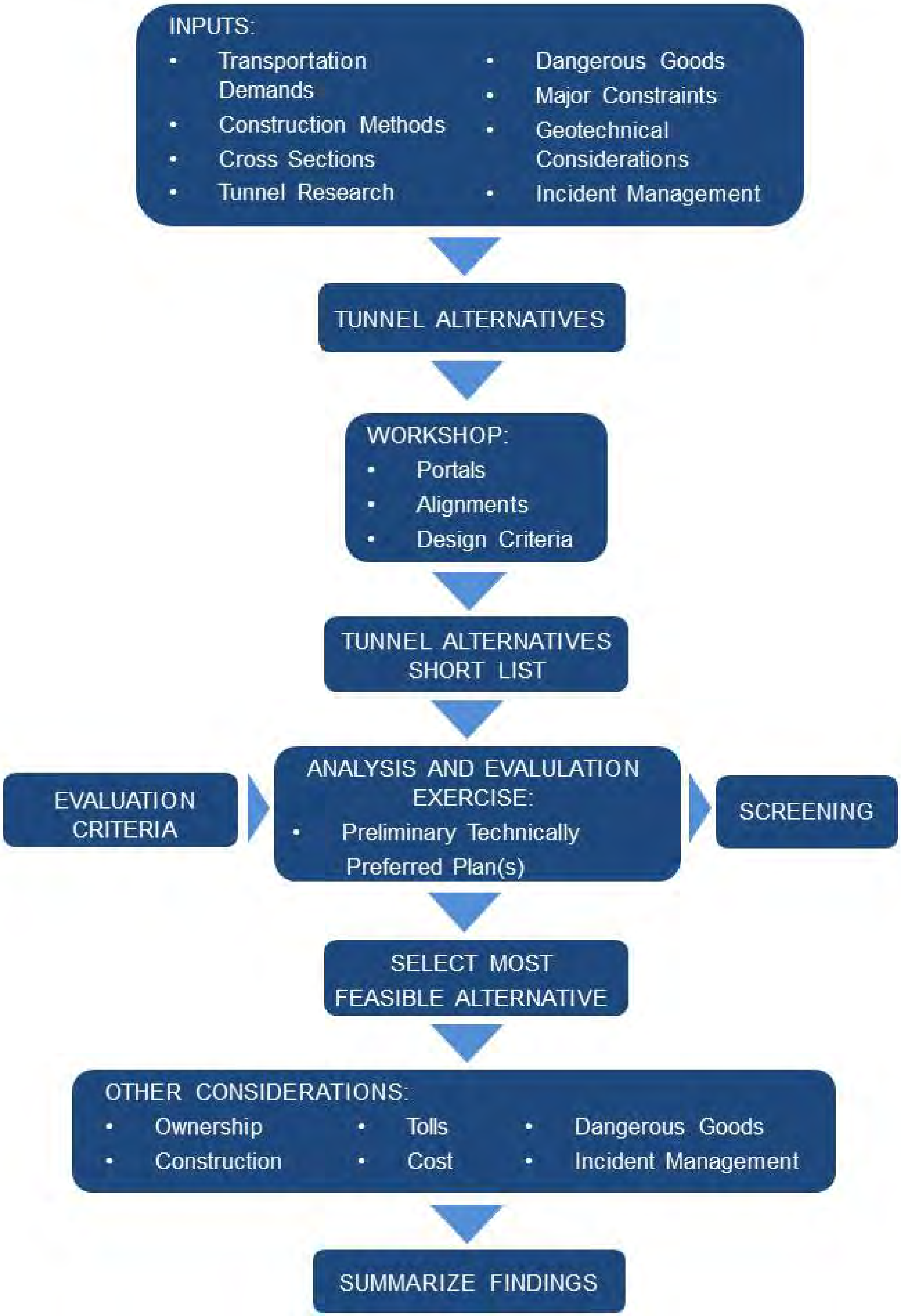
(5) Selected a technically preferred alternative(s) and prepared a conceptual design;
   a. The analysis and evaluation exercise produced the alternative that is considered to be the most feasible. This alternative provides the necessary connectivity, capacity and constructability while avoiding several major constraints. However, it does have impacts to property and major utilities. The most feasible alternative is the option on which the considerations in the following section are based.

(6) Highlighted other considerations that will affect the feasibility of a tunnel;
   a. Ownership: Who should own and operate the tunnel and how could/should they be organized?
   b. Construction: What is likely the best construction technique to control known risks?
   c. Tolls: Are tolls appropriate? What might their impacts be? How is this related to ownership and construction?
   d. Incident Management: What systems and plans will be required to maintain public safety?
   e. Dangerous Goods: How will dangerous goods movement be accommodated?
   f. Comparative Costs: What is the likely cost range for this type of facility?

(7) Summarized findings to support a Staff Report to the City's Transportation Committee and MTO Regional Staff.

Figure 4 summarizes the study methodology process from its initial start-up to a preferred most feasible tunnel alternative with considerations.

Figure 6: Tunnel Feasibility Decision Process



2. Background Information

As background context for this study, research was conducted in order to determine the need for a tunnel, study area conditions, and construction methods. This background is provided in the following sections.

2.1 Transportation Demand

Several sources of transportation data and counts were considered for truck traffic and overall people movement along the King Edward – Rideau – Waller – Nicholas (KERWN) Corridor. Appendix A contains a technical memorandum which provides the data, analysis and estimated demand for a tunnel.

In 2011, there were in the order of 2600 trucks (two-way) that crossed the Macdonald-Cartier Bridge over a 24 hour period. Data was collected through an extensive tube and video count system to determine the origins and destinations of these trucks.

If a tunnel was to be constructed, it is estimated that about 1,700 trucks per day would be attracted to the facility. This is only two thirds of the total number of trucks in the corridor, as one third of the trucks on the network are considered to be local and would not make the direct Macdonald-Cartier Bridge to Highway 417 connection. A typical lane of traffic can accommodate in the order of 2,000 vehicles per hour per direction, whereas directional truck volumes within the tunnel would be in the order of 100 per hour based on the existing data sources. A tunnel just for trucks would be significantly underutilized.

No existing information was available documenting car travel through the study area, particularly how many cars make a through trip and would benefit from a tunnel if one were available. A Bluetooth survey was performed along the KERWN Corridor to gauge travel patterns through the study area and estimate how many vehicles would potentially use a tunnel. Sensors were deployed at seven locations over a 2-week period, as outlined in Appendix A. This exercise revealed that in the order of 25,000 vehicles per day would likely benefit from a tunnel connection. For travel from the MacDonald-Cartier Bridge to Highway 417, the Bluetooth data indicated approximately 10,500 daily vehicle trips, with Nicholas Street/King Edward Avenue corridors being the predominant route choice. An estimated 25% of this Ottawa inbound traffic was destined to the west on Highway 417 with the balance destined to the east. For travel between Highway 417 and the MacDonald-Cartier Bridge, the Bluetooth data indicated approximately 14,000 daily vehicle trips. The data suggested that approximately 90% of the Ottawa outbound traffic through the study area (from Highway 417 to MacDonald-Cartier Bridge) originates from east of Nicholas Street on Highway 417. This is not unexpected given that that the MacDonald-Cartier Bridge is the most easterly bridge crossing of the Ottawa River, and there are other river crossing opportunities for traffic originating from the west.

Based on the foregoing Bluetooth data, it is estimated that 1,000 to 1,500 vehicles per hour per direction would likely benefit from the addition of a tunnel connection during the commuter peak hours. The tunnel link was added to the TRANS Regional Model (a regional transportation planning model used in the National Capital Region) to assess the area-wide impacts of the new infrastructure. The model is forecasting potential usage of up to 2,400 vehicles per hour in the peak direction at the 2031 planning horizon, essentially filling the tunnel to capacity, in part by adjusting flows on other routes. In this case, the car versus truck modal split would be about 93% cars and 7% trucks. In particular the model indicates that some vehicle flow would divert from competing inter-Provincial bridges as a result of the enhanced connection to/from the Highway 417 Corridor. This initial finding would require additional testing and research in future stages of planning.

Based on this finding, the question of feasibility is based on a tunnel designed to accommodate both trucks *and* cars.

Data to analyze the potential for dangerous goods movement is not readily available. Two sources have been reviewed as input to the study:

- Interprovincial Roadside Truck Study (1999-2000) (Appendix A) conducted for the TRANS Model team in Ottawa collected information on trucks crossing the Ottawa River. The study recorded information over a 24-hour period, which indicates that between 4% and 12% of the trucks are carrying goods considered dangerous or hazardous. The report provides a general classification of truck loads with the low end of 4% of trucks noted as carrying petroleum products, compressed gasses, fertilizer, pesticides and other goods definitively classified as dangerous or hazardous. An additional 8% of trucks carry loads which may or may not be considered dangerous or hazardous, such as lumber, wood pellets and truck tires.
- A Statscan summary which summarizes "trucking dangerous goods in Canada, 2004-2012" (Appendix A), provides an overview of truck activity in Canada and draws several conclusions from patterns in truck-based shipping
    - o While the tonnage of goods carried by trucks grew by 17% over the study period, dangerous goods shipments increased by 32%,
    - o Trucks carry more than four times as much tonnage of dangerous goods as rail, however the volumes in individual trucks and the average distance carried is much less,
    - o More than 80% of the total tonnage of dangerous goods falls into four categories (petroleum products, gas and aviation fuel, fuel oils and non-metallic minerals)
    - o While some provinces have seen an increase in the tonnage carried, Ontario and Quebec have seen the total weight of dangerous goods handled by truck reduce over the period

The snapshot of dangerous or hazardous goods movement provided by these two reports indicates that the total volume of trucks carrying these materials is relatively small, and appears to be reducing in Ontario and Quebec. There is not sufficient information to indicate how this will impact the estimated 1700 trucks per day that could take advantage of a tunnel based on their travel pattern, but at 4% to 12% of total truck traffic the impact could be in the order of 70-200 trucks per day. This may be offset by some local trucks making use of the tunnel to serve areas south of Highway 417 or towards the west end of downtown where the longer freeway route would avoid downtown congestion.

Additional data collection and analysis will be required to understand the magnitude of trucks carrying these materials in this corridor.

2.2 Tunnel Research Precedents

The project team undertook a review of similar tunnel properties in other cities. A total of twenty-four (24) examples were selected and researched based on their similarity to the Downtown Ottawa Tunnel project.

The following tunnel projects were examined:

1. Port Miami Tunnel	**9.** Detroit-Windsor Tunnel	**17.** Ville-Marie and Viger Tunnels (Montreal)
2. Dublin Port Tunnel	**10.** Louis-Hippolyte Lafontaine	**18.** Wacker Drive Chicago

Bridge-Tunnel

3. Blanka Tunnel Complex (Prague)

4. Seattle Alaskan Way Viaduct Replacement Tunnel

5. Oakland Caldecott Tunnel

6. Auckland Waterview Connection Tunnel

7. Brisbane Clem Jones Tunnel

8. Calgary Airport Trail Tunnel

11. Robertson Tri-Met Tunnel (Portland)

12. New Portsmouth Midtown Immersed Tunnel

13. George Massey Tunnel (Vancouver)

14. Vancouver Trans-Canada Cassiar Connector Tunnel

15. Joseph-Samson Tunnel (Quebec City)

16. Palm Jumeirah Vehicular Tunnel (Dubai)

19. Thorold Stone Road Tunnel

20. Dulles International Airport AeroTrain Tunnel

21. Al Salam Street Tunnel (Abu Dhabi)

22. Fraser Canyon Highway Tunnels

23. East-West Access Road (Algeria)

24. Laerdal Tunnel (Norway)

Information was primarily collected via the internet. All websites where information has been collected was recorded.

Facts pertaining to this study's problem statement include:

- Of the twenty-four (24) examples studied, no tunnels were constructed and used exclusively for trucks. As can be seen in the above list, transportation tunnels have been constructed around the world under various physical constraints and with different purposes. The study team used this data to provide perspectives as they relate to the downtown Ottawa tunnel;
- In almost all cases, dangerous goods are prohibited in the tunnels. Where there are exceptions, time restrictions or advanced technology were used as mitigation. Typically in any general use / roadway transportation system, the percentage of heavy vehicles is in the order of 5% to 10%. Considering the relatively high cost to construct these facilities, it does not make economic sense to have single use tunnels. As noted, this study is considering mixing cars and trucks in the tunnel, as previously described in Section 2.1;
  - Notably the Detroit-Windsor Tunnel and the Joseph-Samson tunnel in Quebec City do not permit dangerous goods
  - The George Massey and Cassiar Connection tunnels in Vancouver permit dangerous goods within specific permit guidelines
  - Three tunnels in Montreal, the Louis Hipployte, Viger and Melocheville tunnels, permit the transport of dangerous goods only with prior approval and under special operating conditions whereby no other traffic is allowed in the tunnel at the same time
  - Many European tunnels do permit the handling of dangerous goods, but only after a thorough risk assessment as many of these mountain tunnels shorten trips by substantial distances making the provision for transport of dangerous goods economical
- Many examples were constructed to bypass urban environments. In these cases, the desired result was achieved. Based on this study's problem statement, the overall objective is to reduce the volume of heavy trucks in the downtown core. Considering the potential volumes projected in Section 2.1, it is anticipated that many social and environmental elements could be improved if a solution were deemed feasible;

- Most modern examples were constructed through Public Private Partnerships (P3) contracts given the value of the infrastructure; however, several other economic tools can be considered in the overall agreement such as tolls, design-build and creating a tunnel authority. These ideas are further explored in Section 6.0 of this report; and
- Ownership of the tunnels varies, however the majority are publically owned. Where the tunnels are part of the regional highway network they tend to be owned by the provincial or state government. In some cases the tunnels surveyed were developed by cities to serve local needs, in which case they tend to be owned by the city or cities who lead their development. A trend towards private ownership through some form of concession has also emerged in recent years, but the concessions are ultimately overseen by some public agency.

A technical memorandum documenting this work is included in Appendix B. The transport of dangerous goods in tunnels is discussed in more detail below (Section 2.6).

The City specifically asked that Chicago's Wacker Drive be reviewed. Downtown Chicago, Illinois has a number of double-decked and a few triple-decked streets immediately north and south of the Main Branch and immediately east of the South Branch of the Chicago River. The most famous and longest of these is Wacker Drive, which replaced the South Water Street Market upon its 1926 completion. The resulting bi-level street has an upper-level riverfront boulevard, a lower-level roadway for commercial and through traffic, and a recreational walkway at water level.

This configuration was due to geography and traffic patterns in the downtown Loop. Unlike the more suburban parts of the city, most of downtown streets crossed the river on a series of bascule bridges, which required height clearances at the approaches to, and over the river. Further necessitating clearances were many existing railroad tracks that were along the river or that extended as far as the edge of the river. The City established a clearance zone along the river's edge to accommodate the many closely spaced crossings. Many double-decked or triple-decked streets came into being as a result of falling within this clearance zone.

This also created an anomaly not only in the layout and uses of streets, but also planning of buildings. Generally, the upper levels of the multi-level streets usually serve local traffic. The primary entrances of buildings are usually located on this level. The lower levels generally serve through-traffic and trucks serving businesses along the roads. This level houses the receiving/shipping entrances to the buildings on these streets, so no loading docks are located at street level.

Wacker Drive runs along the south side of the main branch and the east side of the south branch of the Chicago River. The vast majority of it is double-decked; the upper level intended for local traffic, and the lower level for through-traffic and trucks servicing buildings on the road (and originally a dock). It is sometimes cited as a precursor to the modern freeway, though when it was built, the idea was that pleasure vehicles would use the upper level.

The upper level is normally known as **Upper Wacker Drive** and the lower level is **Lower Wacker Drive**. A short segment has a third level, sometimes called **Lower Lower Wacker Drive**.

The original double-decker road, replacing South Water and River Streets, was completed in 1926 at a cost of $8 million and named after Charles Wacker. The 1926 section stretched from Lake Street to Michigan Avenue, the latter of which was also rebuilt into a two-level road. An extension south to Congress Parkway and Harrison Street was built between 1948 and 1954, replacing Market Street, and extensions to the east were built in 1963 and 1975.

In 2001-2002, Wacker Drive was redesigned and reconstructed between Michigan Avenue and Randolph Street. The original upper deck was crumbling, and the entire roadway did not meet modern standards for road widths and clearances. Using a specially-developed "flat-slab, longitudinally post-tensioned, reinforced, high-performance concrete cast-in-place system", the new road deck was expected to have a lifespan of 75–100 years. Walkways along the river were meant to make the drive more pedestrian-friendly, while restoration of historic limestone elements and reproduction lighting evoked the drive's original 1926 appearance. The 20-month, $200-million project was completed on time and within budget.

In spring of 2010, work commenced on a $300 million rebuilding of the north-south section of Wacker, from Randolph Street to Congress Parkway, including the upper and lower levels. This is a continuation of the Revive Wacker Drive project started in 2001.

While a similar scheme can be envisioned for the KERWN corridor, the project would require not only the reconstruction of the road corridor to excavate and install the lower level (and rebuild of the surface level) but the removal and reinstatement of the major utilities that use the corridor. Connections to the lower levels of buildings, which allows for the street level to be free of loading bay facilities in Chicago, would need to be created for each building, requiring extensive reconfiguration of the buildings. Some buildings in the corridor do not have a basement level and would not be able to take advantage of the new lower level.

The street discontinuity at Rideau Street, which causes many of the traffic issues today, would need to be resolved through the development of an S-curve to connect the south end of King Edward with the north end of Waller. This would require removal of some existing buildings and would impact development potential.

To effectively use the two-level road for local and through traffic, a series of connecting ramps would be required. Along Wacker these are located in the centre of the 6-lane roadway, and would impact local pedestrian crossings in the ramp zones. The close spacing of cross streets in some segments of the KERWN Corridor would make the development of the necessary ramps challenging.

The facility would need to be constructed using an open cut or cut and cover construction method, which would be very disruptive for the duration of construction, and more disruptive than a tunneled route.

As there are a number of significant challenges related to implementation, and substantial costs to remove and reinstate relatively new infrastructure, this option has been documented for completeness, but will not be pursued as part of this feasibility study.

2.3 Utilities

In downtown Ottawa, various built and planned infrastructure pose conflicts to the potential design of a tunnel. Possible horizontal and vertical conflicts include the future LRT and utility networks.

LRT

The Confederation Line enters the study area along Rideau Street, with a relatively deep station under the street in front of the Rideau Centre. East of the station the LRT tunnel heads east and turns to the south-east under Waller, rising until just south of Laurier when it breaks the ground surface and runs in the former Transitway corridor, parallel to Nicholas Street. The LRT alignment is shown in **Figure 5**.

Figure 7: Future LRT Alignment

CSST

From west to east, as planned, the Combined Sewage Storage Tunnel (CSST) would move through the downtown area along Laurier Avenue, where it would connect to a midpoint launch shaft at the Laurier / Nicholas intersection. It would continue to travel east along Laurier Avenue, turning sharply under the Tabaret Lawn to then travel north under Cumberland Street. The CSST would head north-east and cross both King Edward Avenue and the Rideau River to head to an outlet chamber in the New Edinburgh Park area. The grade of the CSST would be very shallow and could not be altered. The tunnel is also relatively deep to maintain a cover of rock over the proposed TBM tunnel construction. The planned CSST alignment is shown in **Figure 6**.

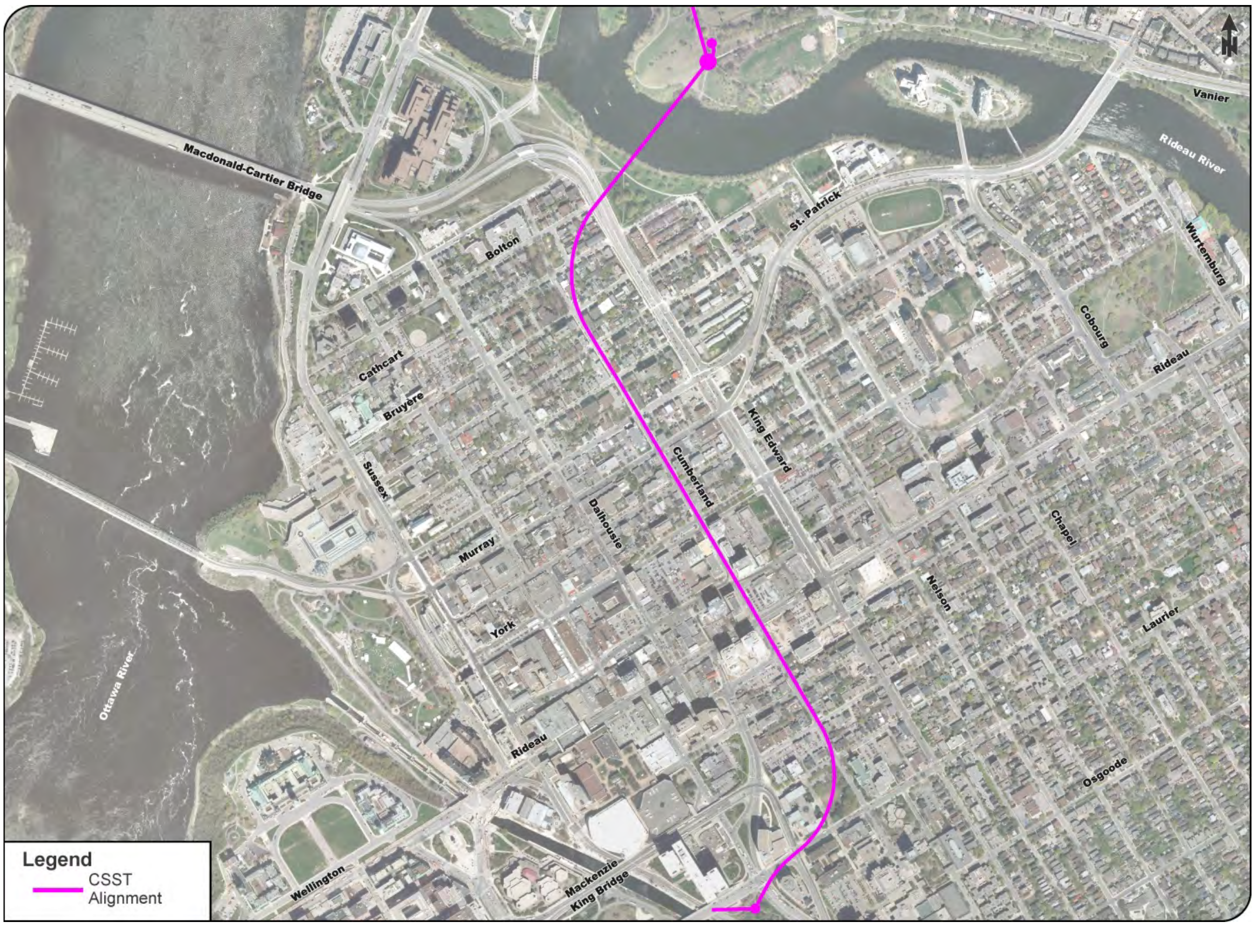


Figure 8: CSST Alignment

Interceptor Outfall Sewer

The Interceptor Outfall Sewer constructed in 1959 crosses the downtown area in a more "cross country" alignment, shown above in **Figure 5**. From west to east, the sewer moves through the downtown under Wellington and Rideau Streets, heading north along Mackenzie Avenue and begins to move in a north-east direction after passing the York Street intersection. The sewer continues in a north-eastern direction until it connects to the sewer access shaft and chamber by the Bolton Street, Cathcart Square intersection and crosses both King Edward Avenue and the Rideau River. The depth of the sewer is substantial, although it is slightly shallower than the CSST, (**Figure 7**).

Figure 9: Interceptor Outfall Sewer

Major Storm and Sanitary Sewers

With pipes ranging in size from 675mm to 1050mm, these sewers both cross and travel along the Macdonald-Cartier Bridge approach and are in the areas most suitable for the northern portal. Other major sewer networks that provide potential conflicts in the northern portion include storm collector pipe, storm outfall sewer, and sanitary sewer network. These networks are presented in **Figure 8**.

These three sewer networks travel primarily down King Edward Avenue in parallel until turning south-west onto Cathcart Street. The piping then turns north-west where the sanitary sewer network connects to the Interceptor Outfall Sewer. The two storm sewer networks cross the Interceptor Outfall Sewer's access shaft chamber on the Bolton Street, Cathcart Square intersection. The outfall sewer pipe continues along that alignment crossing the Macdonald-Cartier Bridge Approach before heading and outletting to the Ottawa River. The collector sewer pipe turns again to a south-west direction and travels along Bolton Street until it crosses Sussex Drive and Lady Grey Drive before moving and outletting to the Ottawa River.

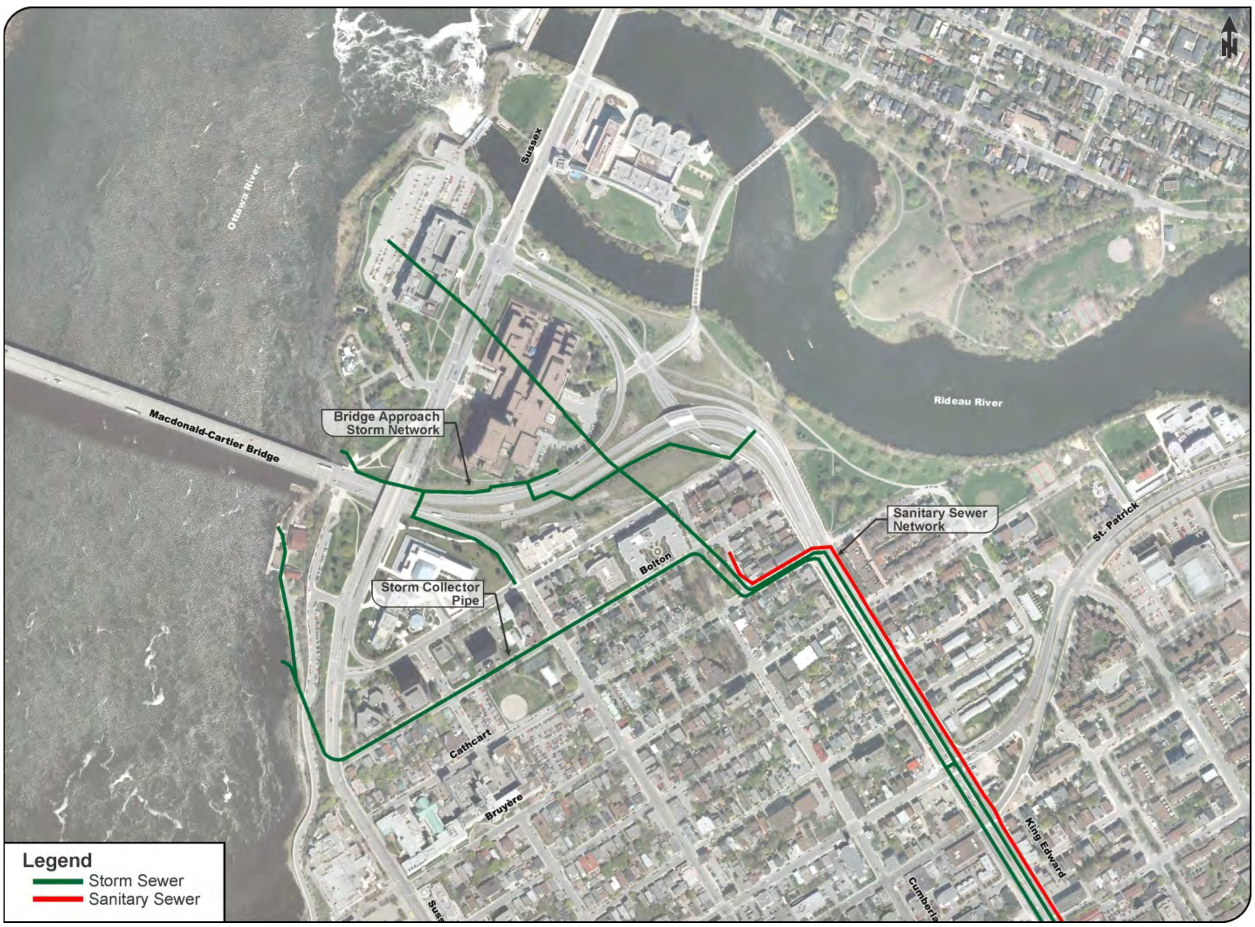


Figure 10: Major Storm and Sanitary Sewer Alignments – North End

Another conflict exists in the form of an 1800mm combined sewer pipe and 675mm storm sewer network in the south end of the study area, shown in **Figure 9**. The combined sewer crosses Queen Elizabeth Drive, Rideau Canal, Colonel By Drive, Nicholas Street, and King Edward Avenue eventually travelling under Templeton Street heading east. The 675mm storm network on King Edward Avenue (between Laurier Avenue and Mann Avenue) and Mann Avenue outlet to this pipe.

Figure 11: Major Storm and Sanitary Alignments - South End

The southeast portion of the study area just west of the RCMP site also has substantial utility constraints. Multiple utilities exist at this location, including the sanitary Rideau River Collector sewer and connecting 900mm pipe, a 600mm watermain, and two storm outfalls, sizes 600mm and 2700mm. **Figure 10** illustrates the utilities at a portion of the south end of the study area. Both the Rideau River Collector and 600mm watermain are relatively shallow and measures would be required to keep both undisturbed during construction. The 900mm sanitary sewer, 600mm storm outfall, and 2700mm storm outfall could be relocated if necessary. The 600mm storm outfall current services the RCMP buildings could also be relocated.

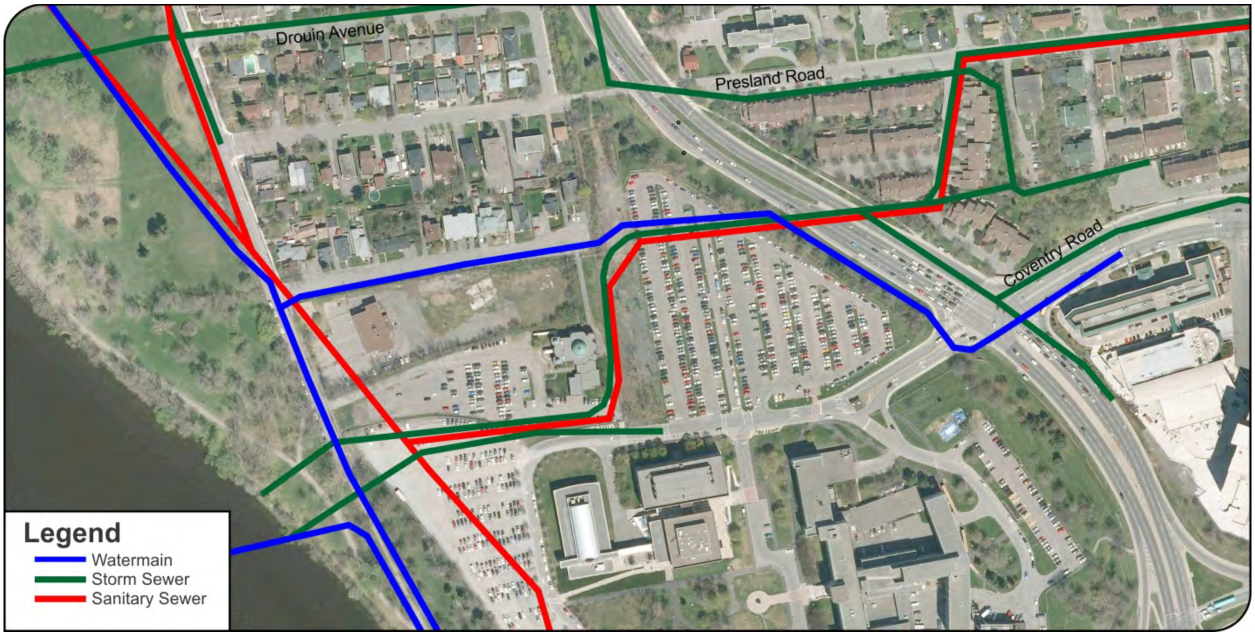


Figure 12: Major Storm and Sanitary Alignments - South End

The City is planning several service upgrades in this area, which should be coordinated with the tunnel planning if possible to reduce or eliminate potential conflicts.

2.4 Land Use Considerations – Deep Foundations and Significant Properties

Central Ottawa contains many buildings and properties that will need to be considered in the design process. Downtown, particularly the west end of the study area includes many buildings (commercial and residential) with deep foundations that may conflict with routing of a tunnel. There are also several foreign embassies located within the Lowertown and Sandy Hill neighbourhoods that may prove challenging for tunnel alignment near these sites.

Deep foundation sites can be classified into three categories:

- Commercial/Office buildings with multiple levels of underground space for loading and parking, including those built on large raft foundations, which are susceptible to differential settlement and may impose loads on the soil that approach the limit of capacity,
- Older buildings, which may be founded on shallower footings and may be more susceptible to movement given their more fragile construction,
- Residential towers with substantial underground parking facilities, which in addition to having similar foundation issues to commercial/office buildings are also more sensitive to noise and vibration transmission.

Significant properties would include historic buildings, university buildings and embassies. Special care would need to be taken to pass under or close to these sites, particularly embassy sites.

2.5 Geotechnical Considerations

A broad summary of the general subsurface conditions was developed based on available geologic mapping and experience in the Ottawa area. The background of the downtown Ottawa area and the subsurface conditions including a list of geotechnical issues for consideration were compiled in a technical memorandum completed by Golder Associates and are summarized below. The comments were based on available geologic mapping and general knowledge of the study area. A full report of the report is found in Appendix C.

- The presence of existing tunnels within the downtown core may restrict the feasible profile and alignment of the truck tunnel. As a general guideline, a minimum (horizontal and vertical) separation of at least two tunnel diameters should be maintained from existing tunnels, including the Interceptor Outfall Sewer, Ottawa Light Rail Transit, and Combined Sewage Storage Tunnel. If tunnel construction under private property or along narrow right-of-ways is proposed, there may be potential conflicts with existing or proposed basements/foundations.

- The profile of any fully-tunneled option should ideally be picked to keep the tunnel fully within either soil or bedrock (i.e., to avoid mixed faced or transitional conditions). Ideally the tunnel should have two to three diameters of crown cover to maintain adequate stability. Depending on the size of the proposed tunnel, this may mean that sections of the tunnel may be more cost-effectively constructed as cut and cover, rather than as a bored tunnel. If the alignment crosses under the Rideau River the potential for hydraulic connectivity will be high, particularly if there is less than ideal rock cover.

- In areas of significant overburden thickness, shaft excavations (or those for cut-and-cover construction) may require costly excavation shoring. Impacts on adjacent structures resulting from ground movements due to shoring or tunnel construction will need to be considered. The selected excavation and support methods will need to consider the presence of boulders in the glacial till, as well as the potential for flowing ground conditions below the groundwater table in sandier zones (as frequently encountered at the transition between the Champlain Sea Clay and underlying glacial till).

- In areas overlain by (or in close proximity to) Champlain Sea Clay deposits, the extent of groundwater level drawdown resulting from excavation activities will need to be evaluated, including the potential for widespread underdrainage of the clay via the bedrock. Widespread lowering of the piezometric pressure in the clay deposits, particularly in areas of the city with heavy structures founded on raft slabs on clay, would result in increased loading of the sensitive silty clay which, if stressed close to or beyond its pre-consolidation pressure, could result in damaging consolidation settlements.

- Both the north portal area and any potential crossing of the Rideau River are in zones with little overburden. In the Rideau River bedrock is visible within the river bed when river levels are at their lowest. Bedrock is also clearly visible at the south end of the Macdonald-Cartier Bridge.

- Depending on the selected alignment and profile of the tunnel, excavations may extend into or be tunneled entirely within bedrock. In the Verulam and Lindsay limestones (expected along the northern portion of the tunnel alignments), discontinuity controlled wedges and blocks and the intrinsic hardness of the formation will constitute the main geotechnical concerns, as the rock is expected to be competent and strong to very strong. In the south part of the study area, the tunnel could encounter weak to medium strong Billings shale, which consists entirely of black shale. The main issues in this rock would be time-dependent deformation behaviour, swelling, and slaking that could have an impact on the design and construction of the tunnel lining. Depending on the size, depth, and means of construction, feasible methods of excavation within the bedrock could include drill and blast, sequential excavation method (as is currently being undertaken for the OLRT project), or tunnel boring (as is planned for the CSST project). Blasting or other ground vibrations associated with rock excavation can likely be controlled, but impacts to surrounding utilities and structures should be considered.

- Known faults within the Ottawa area can sometimes be associated with deep overburden zones and potentially areas of poor quality rock. It is expected that Nicholas Avenue parallels a large offset fault along much of its length (between at least Laurier Avenue East and Somerset Street East) and a deep buried valley is known to exist along Nicholas Street between Waller to north of Laurier Avenue East. A similar deep erosional valley is known to exist east of the Rideau Canal near the intersection of Rideau and Sussex Streets with the bedrock surface mapped at over 33 metres depth. The existing Interceptor Outfall Sewer was designed to skirt these features. The OLRT Rideau Station excavation passes through this buried valley.

- Depending on the expected tunnel profiles, alignments may encounter soil or groundwater contamination.

- Potential tunnel alignments could traverse areas of past industrial activity, so it is possible that any groundwater level lowering could mobilize contaminated groundwater from sites above and adjacent to the tunnel alignment and draw it towards/into the tunnel. Areas of potential concern identified at this early stage include: a former Gas Plant west of King Edward Avenue between York and George Streets; poor fill quality along the Nicholas Street alignment (which follows old railway lines); and three former landfills, one near Highway 417, one east of King Edward Avenue and south of Templeton Street, and one northeast of Rose and Bruyere Streets. There are also several gas stations and dry cleaners along King Edward Avenue and in the market area.

- At Somerset Street east of Range Road, a deep borehole was advanced to approximately 12 metres elevation. At this location, the bedrock at the tunnel horizon (i.e., between elevation 31 and 43 metres) is indicated to be Lindsay and Verulam Formation limestone. At the south end of the alignment, the bedrock consists of shale bedrock, which is indicated in the published mapping to be Carlsbad Formation.

The geotechnical investigation undertaken for this feasibility study looked at existing information only. No additional field work was completed. The following key geotechnical and hydrogeological considerations will need to be addressed in future stages:

- General bedrock condition investigations to identify/evaluate;
    - General bedrock profile, to confirm the adequacy of cover over the tunnel crown
    - Bedrock quality to determine the impact on roof support requirements, overall tunnelling methodology, and productivity
    - Bedrock strength, hardness, abrasivity, and geochemistry which could impact on machine selection and performance, ventilation and muck management.

- Fault zones: To assess rock quality and groundwater inflow which could impact on the local stability of the tunnel and machine performance.

- Zones of low bedrock cover: Adequacy of the bedrock cover needs to be confirmed/defined in greater detail, particularly at any proposed Rideau River crossing, and just south of potential north portal locations.

- Zones of poor rock quality: To assess the need for additional rock support.

- Zones overlain by clay: To assess risks associated with clay consolidation settlement resulting from tunnel drainage and to confirm any constraints on tunnelling methodology.

- Portals and Cut and Cover Tunnels: Overburden, bedrock, and groundwater conditions need to be defined to evaluate excavation conditions, shoring requirements, water inflow and cut-off requirements, and potential for impacts on surrounding structures.

It is generally not feasible to fully investigate a tunnelling project, and address all of the above issues, in a single phase of investigation; a staged approach is generally required so that the scope of the subsequent more focused investigations can be developed.

2.6 Dangerous Goods Movement Considerations

The review of example tunnels and studies described in Section 2.2 and documented in Appendix B examined several criteria. One that is particularly important to the design criteria for this study is the consideration of dangerous goods movement.

The review undertaken concluded that most examples did not allow dangerous goods to be transported through the tunnels. Where they were allowed, several different mitigation and safety measures were implemented ranging from complicated monitoring equipment to time restrictions. Details on the volume of dangerous goods movements and the potential impact on the number of trucks that would use a tunnel is included above (Section 2.1).

A review of the literature found a report by the OEDC and the PIARC World Road Association (in Appendix D), which provides a comprehensive package covering both regulatory and technical issues concerning the transport of dangerous goods through road tunnels. The report proposes harmonised regulations to facilitate compliance by road transport operators and enforcement, thus improving safety. A quantitative risk assessment (QRA) model was developed as part of the research in the report, which compares the risks of transporting dangerous goods through a tunnel to using an alternative route. A decision support model (DSM) was also developed as part of the research which allows decision makers to combine the results from the QRA with other relevant data (which are not of a scientific or technical nature but rather of a subjective or political nature). The DSM will help the decision-maker to determine the preferred route for the transport of dangerous goods or upgrades to existing tunnel infrastructure and other measures required to meet safety objectives. Finally, the report details the effectiveness of measures that can be taken to reduce the risks of incidents in tunnels.

To ease regulation and improve compliance, the system proposed in the report suggests that all dangerous goods loadings would be split into a small number of groupings. This should be done in such a way that all loadings referred to in the same grouping could be accepted together in the same tunnel. The number of groupings must remain reasonably low for the system to be practicable.

The proposed grouping system is based on the assumption that there are three major hazards in tunnels which may cause numerous victims and possibly serious damage to the structure: explosions, releases of toxic gas or volatile toxic liquid, and fires. The main consequences of these hazards, and the efficiency of possible mitigating measures, are roughly as follows:

- Large explosions, divided into two subclasses,

    - "Very large" explosion, typically of a full load of LPG heated by a fire (Boiling Liquid Expanding Vapour Explosion – BLEVE – followed by a fireball, referred to as "hot BLEVE"),
    - "Large" explosion, typically the explosion of a full loading of a non-flammable compressed gas in bulk heated by a fire (BLEVE with no fireball, referred to as "cold BLEVE"),
- Large toxic gas releases from a tank containing a toxic gas (compressed, liquefied, dissolved) or a volatile toxic liquid, and
- Large fires which may serious damage the tunnel.

The order of these hazards: explosion, toxic release (gas or volatile toxic liquid), fire, corresponds to the decreasing consequences of an incident and the increasing effectiveness of the possible mitigating measures. From the above assumptions, a system with five groupings can be derived, ranked A to E in order of increasing restrictions concerning goods permitted in tunnels:

- Grouping A – All dangerous goods loadings authorised on open roads
- Grouping B – All loadings in grouping A except those which may lead to a very large explosion
- Grouping C – All loadings in grouping B except those which may lead to a large explosion
- Grouping D – All loadings in grouping C except those which may lead to a large fire
- Grouping E – No dangerous goods (except those which require no special marking on the vehicle)

Analysis of which groups of dangerous goods may be allowed in a specific tunnel are based on a quantitative risk assessment (QRA) and a decision support method (DSM).

The report outlines a series of accident scenarios that represent typical incidents for each of the events noted above. The report develops a model (QRAM model) to assess the impacts of each accident scenario to allow for an objective require of the risks and consequences.

When making decisions about which groupings are to be permitted in tunnels, decision makers must keep in mind that the goods prohibited in the tunnel must be transported on some alternative route. The risk and inconvenience on the alternative route will directly influence which grouping is the best from a societal point of view. This implies that it might not be rational to give the same grouping to two identical tunnels carrying the same traffic if the alternative routes differ significantly, e.g. in terms of length and population density along the route.

One of the primary objectives for the decision on which grouping to permit in a tunnel is to minimise the risk to human life. Apart from the risks to human life, there are several other factors that need to be taken into account when taking a decision on the routing of dangerous goods. The decision process is a complex procedure and a decision support model (DSM) is therefore required to ease and assist rational decision making. The attributes that are evaluated and weighted by the DSM include:

- Injury and fatality risks to road users and the local population,
- Material damage due to possible incidents on tunnel or detour route,
- Environmental impact due to an incident on tunnel or detour route,
- Direct expenses (investment and operational cost of tunnel risk reduction measures as well as possible additional costs in the transport of dangerous goods),
- Inconvenience to road users due to a possible incident (time lost during repair works after an incident in the tunnel), and
- Nuisance to local population (environmental impact of dangerous goods traffic, with the exclusion of possible incident consequences, but possibly including psychological impact).

Any other attribute found relevant by the decision maker can also be included in the decision problem. The report develops a computerised tool, making it possible to take account of the above attributes in a rational manner.

The report also notes that there are several measures that can be implemented in tunnels which will reduce either the probability or the consequences of an incident in a tunnel. These will influence the regulations governing the restriction of dangerous goods transport through a tunnel, including:

- Tunnel design and maintenance (cross section, visual design, alignment, lighting, maintenance procedures, road surface),
- Traffic and vehicles (speed limit, prohibition to overtake, escort, vehicle checks),
- Alarms, information and communications (CCTV, incident detection, fire detection, radio communication, vehicle identification, emergency telephone, signs/signals, loudspeakers, evacuation protocols, emergency exits, smoke control, fire-resistant equipment, failure management),
- Reduction of accident importance (equipment, rescue teams, drainage, emergency action plan, escort), and
- Reduction of consequences on the tunnel (fire-resistant or explosion-resistant structure).

Through discussion with the Technical Consultation Group for this study, the group concluded that transporting dangerous goods through this tunnel would not be appropriate considering the significant challenges of managing an incident in the enclosed and relatively inaccessible confines of a tunnel. In addition managing dangerous goods events on surface streets, while potentially disruptive to local traffic, residents and businesses, is substantially easier as:

- Access is less restricted (site can be accessed from several directions, space adjacent to road available),
- Existing training of emergency services personnel is in place (these types of events are rehearsed regularly as part of emergency preparedness), and
- Existing resources can be used (no additional or special equipment is needed).

2.7 Tunnel Cross-Sections and Construction Methods

Typical tunnel cross-sections for a variety of configurations were developed to understand the potential impacts on construction and constructability as well as operation of the tunnel. The provision of shoulders, safety by-pass lanes and emergency walkways influences the selection of an optimal configuration. The selected construction technique also impacts the most feasible configuration.

2.7.1 Tunnel Cross Sections

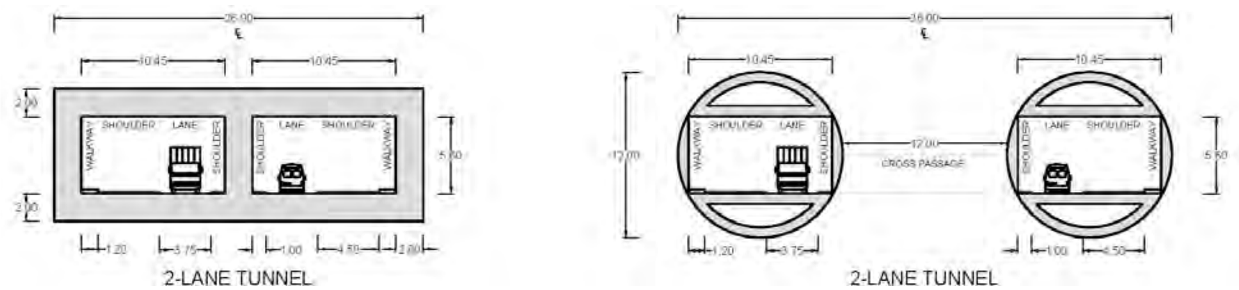
2-Lane Tunnel

Standards for lane widths are based on level of activity and posted speed. For a major arterial connection such as the proposed tunnel, a 3.75-metre lane width is proposed. Where a single traffic lane is provided a shoulder will be required which will allow for vehicles to pull completely out of the travel lane to avoid blocking traffic. Considering the length of this tunnel, its geometry and higher order arterial or freeway design criteria, a wide shoulder (in the order of 4.5 metres) should be included where there is only one travel lane per direction to ensure that a stopped or broken down vehicle can pull completely out of the travel lane (**Figure 11**).

In a tunnel, space is at a premium. Where more than one travel lane is provided in each direction, narrower shoulders can be considered to reduce tunnel size. This will require that a vehicle breakdown will occupy the outside shoulder and most of the right hand lane. Traffic can bypass the breakdown in the remaining lane. Where more than one lane is provided, the shoulder can be narrowed to 1.2 metres.

With the need for a 3.75-metre travel lane and a 4.5-metre shoulder, a two-lane tunnel is not considered economical as a 4-lane tunnel, which will only require a marginally wider road surface. Additionally, a 4-lane facility would accommodate all of the safety and capacity needs of the corridor.

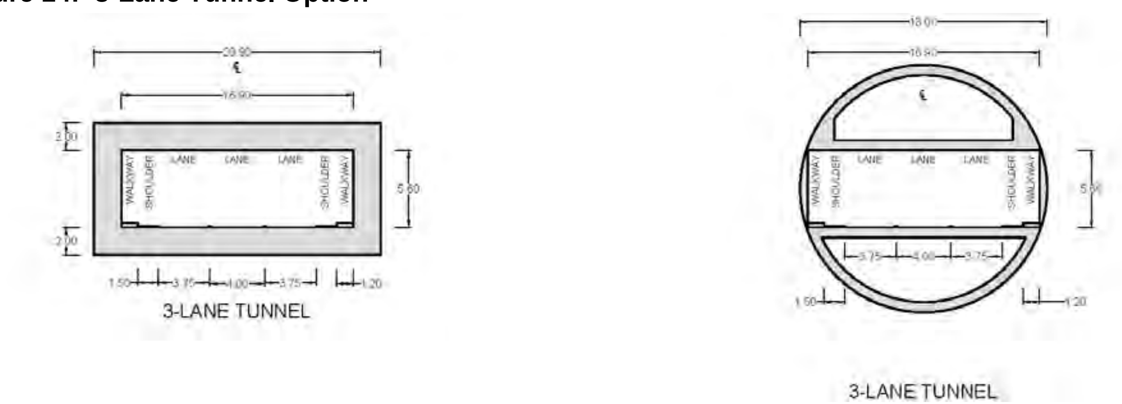
Figure 13: 2-Lane Tunnel Option



3-Lane Tunnel

A 3-lane scenario was also examined but discounted given the safety issues of a reversible lane and the additional technology required for lane management. In addition, the projected traffic flows through the tunnel are equal in both directions, for which a 3-lane configuration would not be suitable (**Figure 12**). Note that a 4.0m center lane was assumed to account for the opposing traffic effects.

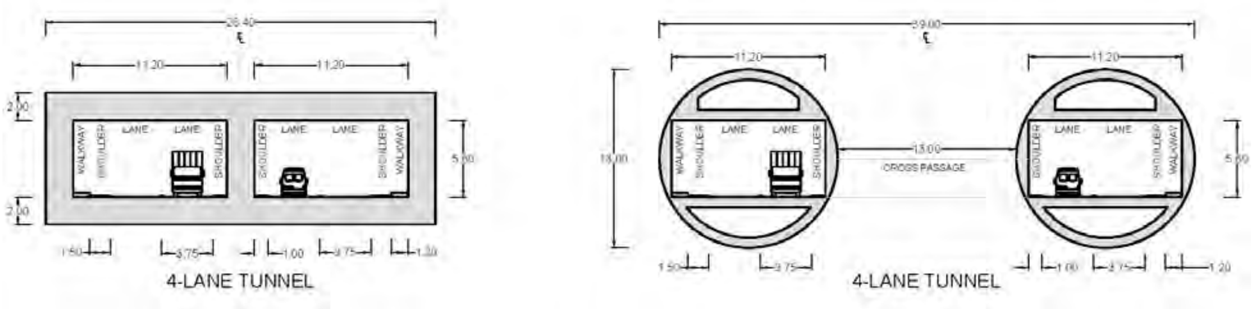
Figure 14: 3-Lane Tunnel Option



4-Lane Tunnel

A 4-lane configuration would best suit the environment of the study area. A 4-lane, horizontal box constructed using a cut and cover technique would significantly impact adjacent properties and in many cases, where the tunnel needs to be deep to avoid major infrastructure like the CSST, would not be an appropriate solution (**Figure 13**). While a 4-lane, vertical (stacked) box would be narrower and have less property impact at full depth, it again would need to be deep to avoid other infrastructure and have a longer portal for the lower level, resulting in difficult geometric constraints with other infrastructure.

Figure 15: 4-Lane Tunnel Option



Considering the obstacles described above, it is concluded that a 4-lane tunnel would be the appropriate solution. A 4-lane tunnel provides for good flow under normal conditions and allows for a single lane to continue operating if a vehicle breaks down and occupies the shoulder and right hand lane.

2.7.2 Tunnel Construction Methods

Tunnels can be constructed using three major techniques: cut and cover, tunnel boring machine (TBM), and sequential excavation by road header.

- The cut and cover technique excavates the tunnel from the surface and is completed by reinstating the ground level uses. It is suitable for projects where the tunnel is not deep; as such, conventional construction equipment can be used. However, during construction the impacts to the ground level can be significant particularly in cases where other infrastructure is present, particularly major water mains and sewers.
- TBMs are ideal in cases where the tunnel is long, with a relatively straight alignment and in a rock environment. The cross section resulting from this technique is circular, which provides space for utilities, ventilation and other needs but results in excavating more material than necessary. The staging areas for TBMs at the portals can be disruptive to the ground level, particularly the launch site where the machine must be lowered into the shaft in sections, the excavated material is removed and placed in trucks and the tunnel liners are stored and delivered to the machine. A smaller, but still substantial, site is needed at the other end of the TBM tunnel to accept the machine and extract it from the ground. A tunnel constructed with a TBM will need a cut and cover portal section to create the transition from grade to the depth where the TBM can be launched and extracted.
- A third technique is often used where the shape that is cut for the tunnel is optimized. A road header, or a truck-mounted auger, is used to excavate the tunnel. As work progresses, the exposed rock is secured with rock bolts and shotcrete before a final lining is placed. While not as efficient as a TBM, the technique provides much greater flexibility for the geometry, allows for a more optimal cross-section reducing the amount of rock to be excavated and simplifies construction techniques of the tunnel and its portals. A launch site is needed, but the site does not have to be as large as the site required for a TBM operation. A small site is needed at the end of the tunnel segment to connect to the portal. Multiple faces can be created by adding additional intermediate launch shafts, thereby improving productivity. A tunnel constructed with a road header will need a cut and cover portal section to create the transition from grade to the depth where the road header can be launched and extracted.

Appendix E contains a summary of the techniques that can be considered for the Downtown Ottawa Tunnel.

2.8 Incident Management

2.8.1 Incident and Fire Detection Systems

The following elements are considered the essentials to assure safety in tunnels:

- Loop detection systems are presence and speed monitoring devices using wire loops installed in slots cut in roadway at periodic intervals. Loops sense vehicle presence by changes in inductance as the vehicle passes over the embedded loop. Speed is measured between consecutive loops. Experience with loop detection systems in tunnels indicates that they provide accurate incident alarms during peak traffic conditions and catch up situations.
- Incident Detection Systems based on CCTV (Optical Systems)
    - Video surveillance equipment including automatic incident detection (AID) cameras installed in tunnels, centrally located video monitors located at a central location, pan/tilt/zoom equipment, video switchers, video recording equipment, AID software, AID processing equipment and communication network transmitting video signals between cameras and monitors.
    - Closed Circuit Television, Closed Circuit Video Equipment and Automatic Incident Detection are both mandatory systems for Class I and Class II tunnels in the European tunnel directive, and are recommended for all other tunnels.
    - Automatic fire detection systems should be able to detect a tunnel fire incident of 5MW or less within 90 seconds or better in a testing environment of 3m/s air velocity.
- Environmental and air quality monitoring devices include devices used to monitor environmental conditions and air quality inside vehicular tunnels (i.e. Carbon monoxide detectors, nitrous oxide detectors, beam).
- Automatic detection systems, including intelligent systems, are being installed in many new tunnels and being retrofitted into existing tunnels to speed up the recognition and response to incidents to manage the risk that they could escalate if unobserved or left unattended. Hardware, software and heuristic algorithms are being deployed to integrate information from various sources and notify the road authority of incidents as soon as they occur. Intelligent systems are able to maintain a high degree of attentiveness and are not susceptible to operator fatigue or information overload.

2.8.2 Control Centre

A tunnel traffic control centre will need to be established in order to monitor and control traffic and all equipment and safety systems such as:

- Power supply
- Ventilation
- Lighting
- Emergency call system
- Video monitoring
- Traffic analysis
- Traffic control
- Fire detection

- Fire fighting

If the tunnel control centre is not fully integrated with the City's traffic management system there will need to be an interconnection to allow the City to adjust other links in the network to compensate for closure events in the tunnel.

2.8.3 Emergency Exits and Service Facilities

The emergency exit(s) for tunnel users are established with the purpose of having a safe haven in case of harmful situations in the tunnel. The exits will mainly be used in connection with a fire in the tunnel. The emergency exits can be connected to the adjacent traffic tube, to a dedicated escape tube or out to the open air. The connection can be direct, or through a cross passage, or vertical shaft. In some cases shelters are arranged as safe havens, where tunnel users can stay for some time.

Given the depth of the tunnel and the preferred configuration of two parallel 2-lane tunnels, cross-passages between the two tunnels are the most likely solution. Cross-passages will need to be level to provide an appropriate degree of accessibility and closed at each end to assist in creating a safe haven in the event of an emergency. The use of cross-passages eliminates the need for intermediate exit shafts but requires that traffic in both tubes be stopped to permit safe evacuation.

2.8.4 Ventilation

Length, depth and characteristics of the tunnel will dictate the requirements for mechanical ventilation. Ventilation design has a major impact on the overall tunnel design as:

- Longer tunnels require either additional space in the tunnel for ventilation equipment and air handling, or introduce a number of vent shafts up to the ground surface. Unlike LRT or subway tunnels, the vehicles using the tunnel do not provide for enough air handling to satisfy operational requirements. LRT and subway tunnels also typically operate with electrically-powered trains that do not produce any exhaust fumes.
- Shallow tunnels may provide greater opportunities for vertical shafts to exhaust and/or supply fresh air as well as meet the needs for emergency events. Locating these shafts in urban areas can be challenging as they are considered a source of exhaust fumes, noise and in rare events smoke.
- The cross-sectional profile of the tunnel has an influence. The trade-off in size of the tunnel (to provide the air handling space) versus additional shafts will need to be explored. The size of the tunnel needed to accommodate the required number of traffic lanes could provide the required space, particularly if a circular tunnel is bored. The additional space above and below the traffic zone can be used for ventilation.

Both a normal operations phase and an emergency (fire) operations phase must be considered for dimensioning of the system. The three main aims are to:

1. Enable self-rescue through smoke mitigation including smoke discharge from the tunnel;
2. Ensure reasonable conditions for rescue staff; and
3. Reduce overall harm to people, vehicles and the tunnel structure.

Ventilation of Escape Routes:

Enclosed escape routes such as a dedicated escape tunnel or cross-passages have to be kept free from smoke by ensuring a somewhat higher pressure than in the incident tube and a flow of velocity of at least 1 m/s in openings connecting to the tube with the fire.

Suggested Ventilation Strategies:
Typically tunnels with a length exceeding 2 km, with truck traffic and in an urban location have semi-transverse ventilation systems with jet fans. An intermediate ventilation shaft could be introduced to reduced tunnel suction and increase safety level. Tunnel ventilation fans, their motors, dampers and all related components will need to be designed to remain operational for a minimum of 1 hour in an air stream temperature of 250 degrees Celsius.

2.8.5 Fire Fighting Facilities

2.8.5.1 Hand held Extinguishers

Hand held extinguishers are regarded as an effective apparatus in the early stages of a fire. According to an investigation in Japan by the Sudo Highway Public Corporation, hand held extinguishers have been used more frequently than any other apparatus when extinguishing tunnel fires. It is suggested that 9 kg (maximum) extinguishers be used with a maximum spacing of 90 metres.

2.8.5.2 Water supply and hydrants

Pressurized fire hydrants are connected to the water mains or the tanks of water that are used by tunnel users or by the fire brigades. They have a greater capacity than hand held extinguishers. It is desirable that only trained persons handle the equipment because a novice could damage the equipment or hurt other people in the immediate vicinity.

The installation distance of fire hydrants should be considered in a range of 50-100m.

The water pressure and flow rate shall be 0.4–1.0 MPa and 1000–1200 L/min, respectively. Standpipe systems shall have an approved water supply that is capable of supplying the system demand for a minimum of 1 hour.

Winter weather will also need to be considered as the standpipes near the tunnel portals would be susceptible to freezing. Dry-standpipe systems would then be used, whereby the pipe is charged with nitrogen and water starts to flow when the system is activated and the gas is vented.

2.8.5.3 Fire Department Connections

Fire department connections are designed to provide fire fighters close to the accident with sufficient water to extinguish fires through water outlets installed outside tunnels. These connections usually consist of plumbing, water inlets, water outlets, water discharge apparatus, and pumps.

2.8.5.4 Fixed Fire Fighting System

Fixed fire suppression systems are defined as the firefighting equipment, such as sprinkler and deluge systems, which are designed and installed at the ceiling or wall of constructions in the tunnel, for purpose of suppression or control of fires. It is reported that fixed fire suppression systems have been installed in Australia, Austria, Japan, Korea, Norway, Sweden and USA. The decision to provide water-based fixed fire-fighting systems in these tunnels was motivated primarily by the fact that these tunnels were planned to be operated to allow the unescorted passage of vehicles carrying hazardous materials as cargo. The use of sprinkler systems is mandated in Japan and Australia. Europe does not have a regulation that requires a water system.

Water-based fixed fire-fighting systems can be used, however, to cool down vehicles, to stop the fire from spreading to other vehicles (i.e., to diminish the fire area and property damage), and to stop secondary fires in tunnel lining materials.

We propose the evaluation of a high-pressure mist-type deluge system also for sustainable purposes. It should be noted that the traditional suppression system used nearly three times more water over the same area as the mist system.

Systems that will use water also need to consider drainage and pumping requirements. Holding capacity at the low point of the tunnel and forcemains to pump water out of the tunnel will have to be designed to match potential inflow rates.

3. Alternative Development and Analysis and Evaluation

Throughout the course of the study, tunnel alternatives were established, screened out, refined, analyzed and evaluated. This was completed with the ultimate goal of determining which alternative was most feasible, based on the definition of 'feasibility' described in Section 1.2.

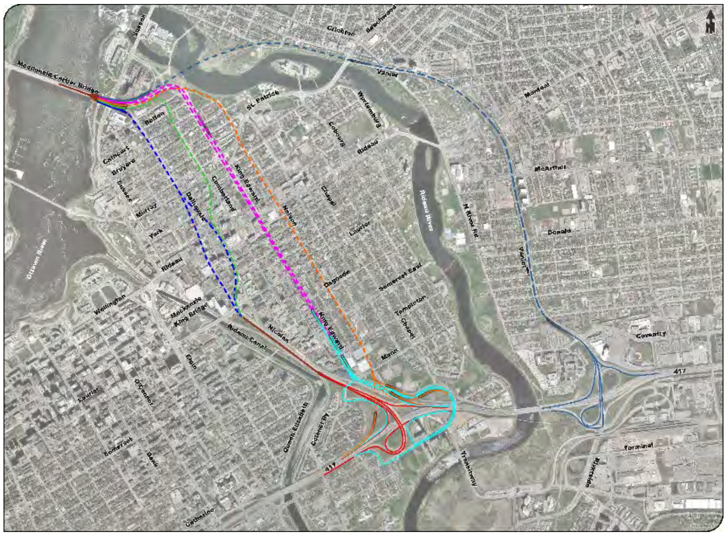
The Tunnel Feasibility Decision Process chart illustrates the various tasks undertaken to develop the study findings. There were three (3) key stages in developing a reasonable set of alternatives to evaluate.

1. Initial Set of Alternatives – The initial set of alternatives, also described as the 'pre-workshop' alternatives, were developed considering the background data collected, existing conditions and design criteria.
2. Technical Consultation Group (TCG) Workshop – This acted as a catalyst for the TCG members to arrive at a reasonable number of tunnel alternatives by ruling out those that had constraints that could not be mitigated and the workshop also confirmed the tunnel use (i.e., cars and trucks), design criteria and review of the alignments developed.
3. Alternatives Short List – Also known as the 'post-workshop' alternatives, those that did not have any insurmountable constraints and met the desired design criteria were carried forward for further refinement.

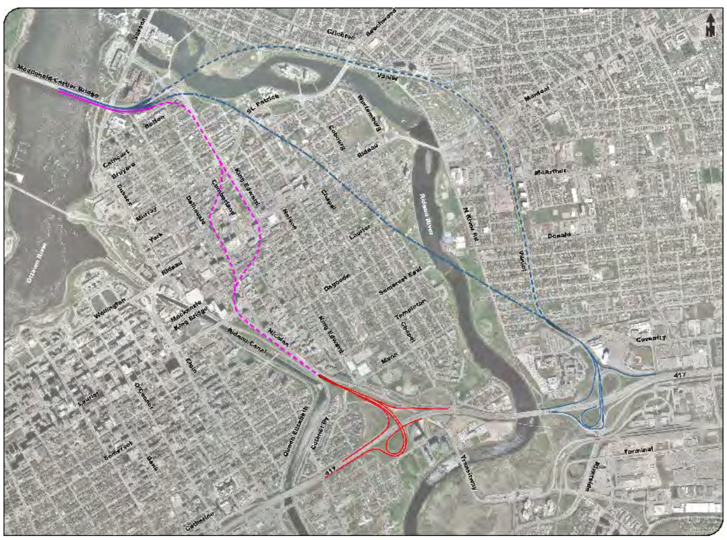
These alternatives were then carried forward for a complete analysis and evaluation. **Figure 14** shows the chronology of the various alternatives and when they were carried forward.

The feasibility decision process was also carefully executed. **Figure 15** graphically represents the feasibility decision process.

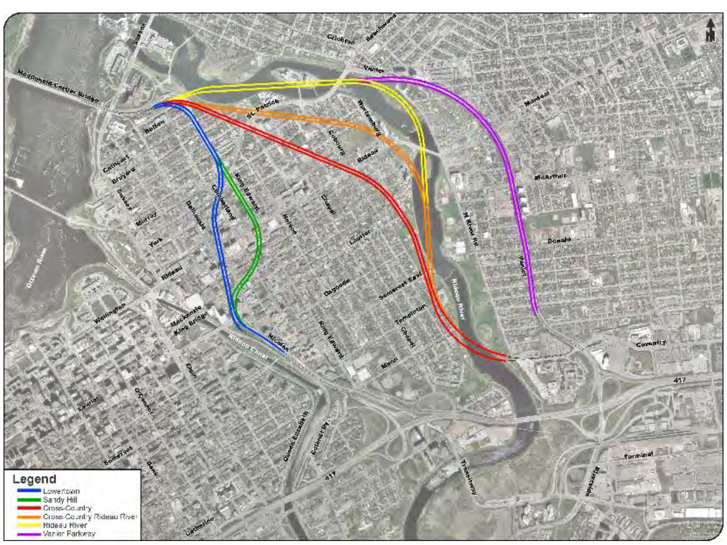
Figure 16: Chronology of Alternatives at Stages during the Screening Process



First Round of Alternatives (Pre-Workshop) (Enlarged version see **Figure 18**)

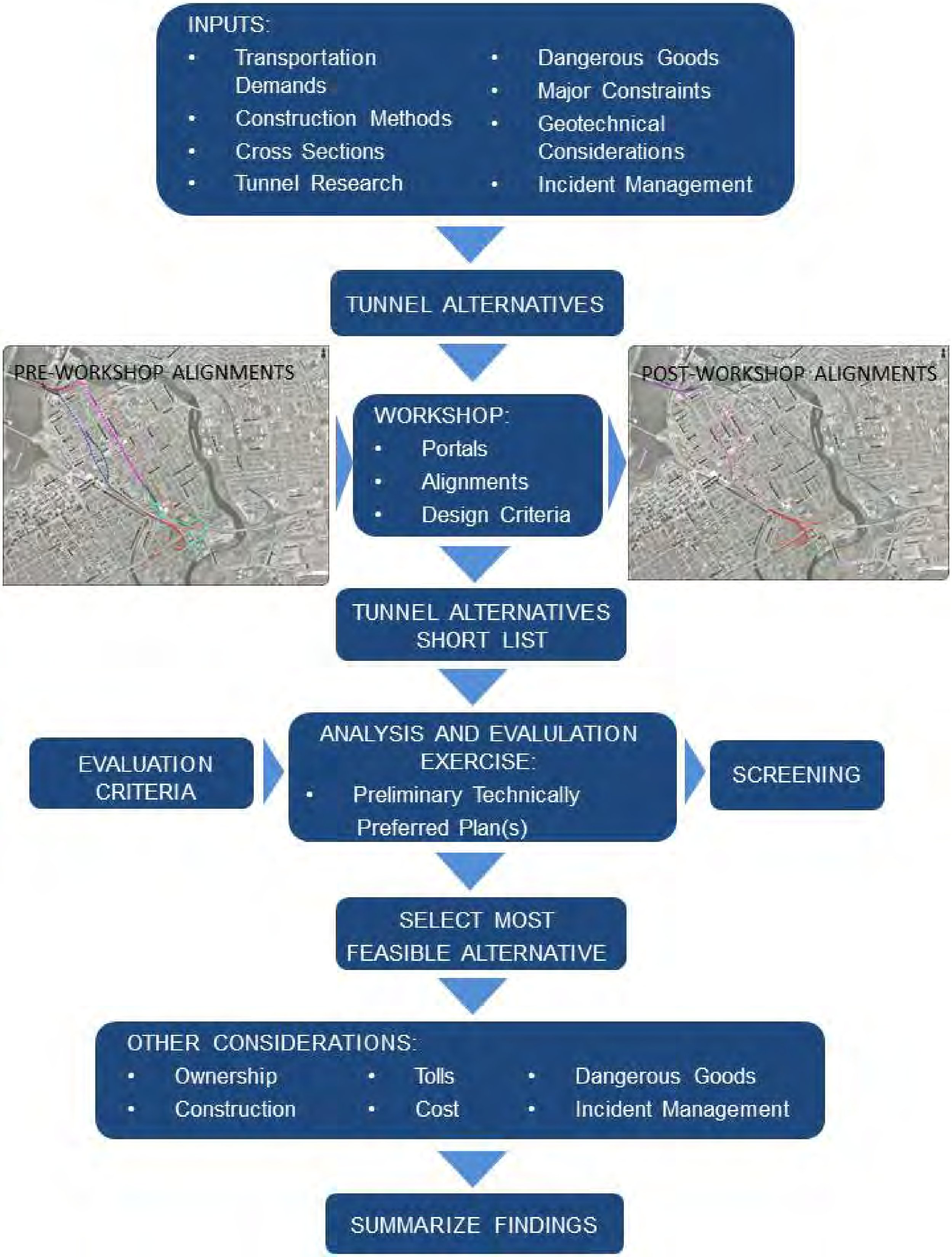


Second Round of Alternatives (Post-Workshop) (Enlarged version see **Figure 19**)



Third Round / Carry-Forward Alternative (Enlarged version see **Figure 20**)

Figure 17: Tunnel Feasibility Decision Process



3.1 Alternative Development

3.1.1 Design Criteria

Based on the work presented in previous sections, a set of design criteria were assembled (Table 1) that, at a functional level, provide a reasonable base for these designs.

Table 1: Design Criteria

Design Element	Proposed Standard	TAC Reference
Classification	Arterial	Study Team Assumption
No. Lanes	Two tunnels of 2 lanes each	Study Team Assumption
Design Speed	80 km/h	Study Team Assumption
Posted Speed	60 km/h	Study Team Assumption
Driving Lane Width	3.75 m	Study Team Assumption
Minimum Horizontal Radius	250 m	Table 2.1.2.3
Maximum Superelevation	6%	Page 2.1.2.3 (Rural Areas)
Minimum Vertical Curve – Crest "K" (stopping sight distance)	24 – 36	Table 2.1.3.2
Minimum Vertical Curve – Sag "K" (stopping sight distance)	12 - 16 (comfort control)	Table 2.1.3.4
Minimum Gradient	-5%	Study Team Assumption
Maximum Gradient	5%	Study Team Assumption

3.1.2 Pre-Workshop Alternatives

In preparation for the TCG Workshop a set of conceptual alignments were developed to look at the feasible range of connections. The development of the alignments was split into three segments to allow for localized consideration of issues. The three segments are the North Portal area, the South Portal area and the Central Connecting Zone. The first round of alternatives (Pre-Workshop) are shown in **Figure 18**.

The North Portal area focuses on connections to the south end of the Macdonald Cartier Bridge. There appear to be five potential options to connect:

- Dalhousie Street – the connection geometry would very tight between the end of the bridge to Dalhousie Street creating a short tunnel portal. King Edward, particularly the southbound lanes from the bridge, would be significantly impacted during construction.
- Cumberland Street – this alternative would have a more generous connection geometry than the Dalhousie route and not require major disruption of King Edward during construction. There are utility challenges, including the proposed CSST which will run under a significant portion of Cumberland.
- King Edward Avenue – assumed to be the preferred corridor in prior work, this option would provide reasonable curve geometry at the portal and keep the majority of the works under the public road allowance. The wide right-of-way in the northern section would allow for insertion of the portal and provide for through lanes on King Edward to be maintained.
- Rose Street / Nelson Street – would provide a generous curve at the portal entry and potentially allow for a staging area to be established in Bordeleau Park to connect the tunneled section (to the south) with the cut and cover portal (to the west). Road discontinuity near St. Patrick will require private easement.
- Vanier Parkway Corridor – following the old rail corridor, most of its length being currently occupied by the Vanier Parkway. This route provides very generous road geometry and would provide a generous curve at the portal entry and potentially allow for a staging area to be established in Bordeleau Park to connect the tunneled section (to the south) with the cut and cover portal (to the west).

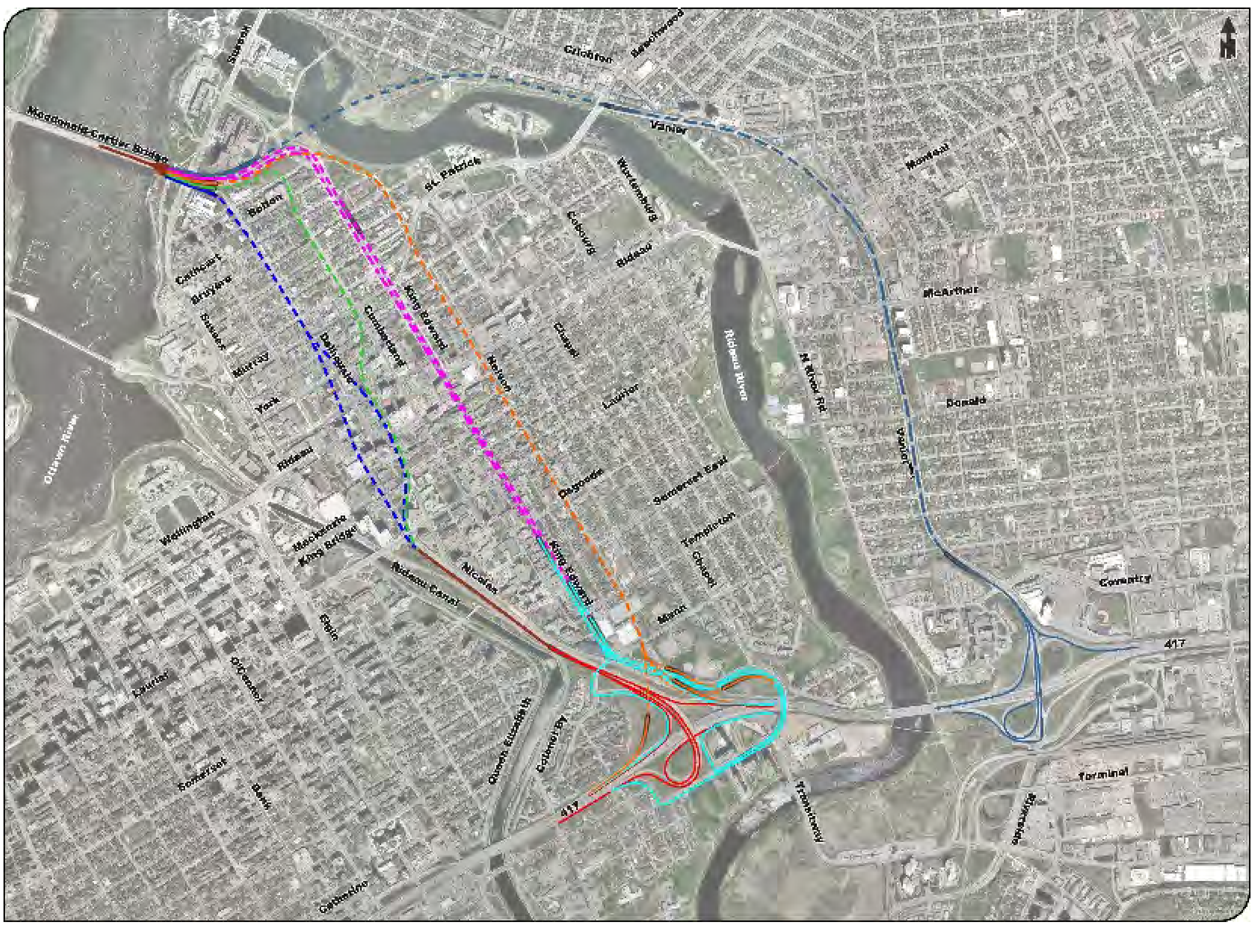


Figure 18: First Round of Alternatives (Pre-Worksop)

The South Portal area focuses on how the southern end of the tunnel will interface with access to Highway 417, including the existing local streets and highway ramps. Three potential configurations were developed at the Nicholas interchange:

- Nicholas Street – a portal in the Nicholas right-of-way would allow the existing freeway interchange to provide the connections to the highway. The portal will need to be south of the Laurier signal to allow for the free flow of traffic out of the tunnel. Preliminary review indicates that separate portals may be required for the northbound and southbound traffic to integrate into the local environment.
- King Edward Avenue – a portal in the King Edward right-of-way would require vehicles accessing and egressing the tunnel to use the local street network to connect with the freeway ramps. Lees, Mann, Greenfield and King Edward would see increased traffic volumes.
- New Interchange Connections – a set of underground connections would be created to provide a direct link between the freeway ramps and the tunnel. This option would be the most expensive option by far and will be geometrically challenging.

There does not appear to be a feasible portal along the Nicholas Street / Waller Street segment north of Laurier that works from a flow or a geometric perspective. One option only was shown for a Vanier south portal as follows:

- Vanier Parkway Corridor – the tunnel would approach the Vanier/Coventry intersection under the Vanier Parkway. To integrate into the existing intersection and provide drivers with opportunities to position themselves in the correct lane would likely require a traffic circle.

3.1.3 Workshop Results

There were fundamental discoveries and decisions made at the TCG Workshop. The design criteria were confirmed including some required physical constraints such as a minimum five metre restricted separation between the tunnel and other major infrastructure such as the LRT and CSST. This need screened out several alternatives including Dalhousie, Cumberland, and Rose / Nelson. To provide these connections, the profiles of the tunnel portal would extend northerly onto the Macdonald-Cartier Bridge where the reconfiguration of bridge abutment was deemed too onerous a task.

As part of the discussion, the required separation between existing and proposed infrastructure was discussed. Ideally there is a separation between new tunneled infrastructure and existing tunnels equivalent to two diameters of the new tunnel. For smaller diameter sewers this separation is relatively easy to achieve, however larger tunnels such as the proposed CSST and the truck tunnel cannot reasonably achieve this separation. There are several factors that would influence the minimum separation that can be achieved without modifications or protection to an existing tunnel. The construction method of the tunnels (drill and blast requires a greater separation as the blasting may have fractured rock beyond the intended zone), the age of the tunnels, the type and form of tunnel lining, whether the new tunnel is perpendicular or parallel to the older tunnel (parallel requiring greater separation), all affect the desired separation. For planning purposes the team discussed a range of values and agreed that a 5-meter separation criteria represents a reasonable separation that can be achieved with minimal additional intervention.

At the south portal, any alternative that proposed new interchange connections was deemed to have non-mitigatable impact to the surrounding land uses (such as the University of Ottawa and surrounding neighbourhoods).

A summary of the rationale for screening out various routes is provided below:

- Dalhousie – this route is too close to the end of the Macdonald-Cartier Bridge to allow for the development of a portal and connection. It may be suitable for a southbound tunnel, but no northbound connection can be made using this alignment. The route is also discontinuous at the south end, creating challenges to connect to Nicholas/Waller.
- Cumberland – this route has more generous geometry than the Dalhousie route and does not require major disruption of King Edward during construction. There are utility challenges, including the proposed CSST which will run under a significant portion of Cumberland Street, requiring the alignment to be lower to achieve appropriate separation. The alignment would also pass under Cathcart Park, which is a major interconnection point for the major storm and sanitary sewers in the area. The south end is discontinuous, making a connection to Waller/Nicholas challenging.
- Rose/Nelson – option would significantly impact a large number of homes creating a lengthy and costly construction timeframe. In addition, the rock cover is much lower which presents a greater degree of risk for this solution. As the route under Rose/Nelson approaches Templeton and Mann Avenue it would require a complicated series of directional ramps at Highway 417, which are not feasible.
- Of the options for a south portal
    - Nicholas is challenging given the poor ground conditions and proximity of the University and Rideau Canal. No connections north of Laurier are possible given the geometric limitations and the need to maintain connections to development sites in the area.
    - King Edward/Mann ramp connections are circuitous and require routing traffic along part of Lees Avenue to make some connections work. The tight road geometry make these connections infeasible.
    - New underground ramps could be used to connect a King Edward or Nelson route to the interchange, but would be prohibitively expensive to build. Given the likely cost and construction complexity the geometric issues were only reviewed at a very high level.
    - Vanier Parkway portal would be challenging to tie into the existing intersection and provide adequate traffic capacity without backing traffic up into the tunnel. Space in the road alignment, and utilities in the corridor would make connections challenging. Connecting the southbound leg to Vanier south of Coventry, to permit freer flow, is impractical given the short distance and the need for weaving for traffic to access the westbound and eastbound ramps.
    - Vanier/Coventry connection through the creation of “a fourth leg” for the intersection provides a better traffic solution that other connections, but bisects the RCMP site. With appropriate mitigation this option is feasible. A roundabout would be created to maintain traffic flows to prevent traffic backup into the tunnel.

As such, a short list of alternatives was carried forward (**Figure 19**).

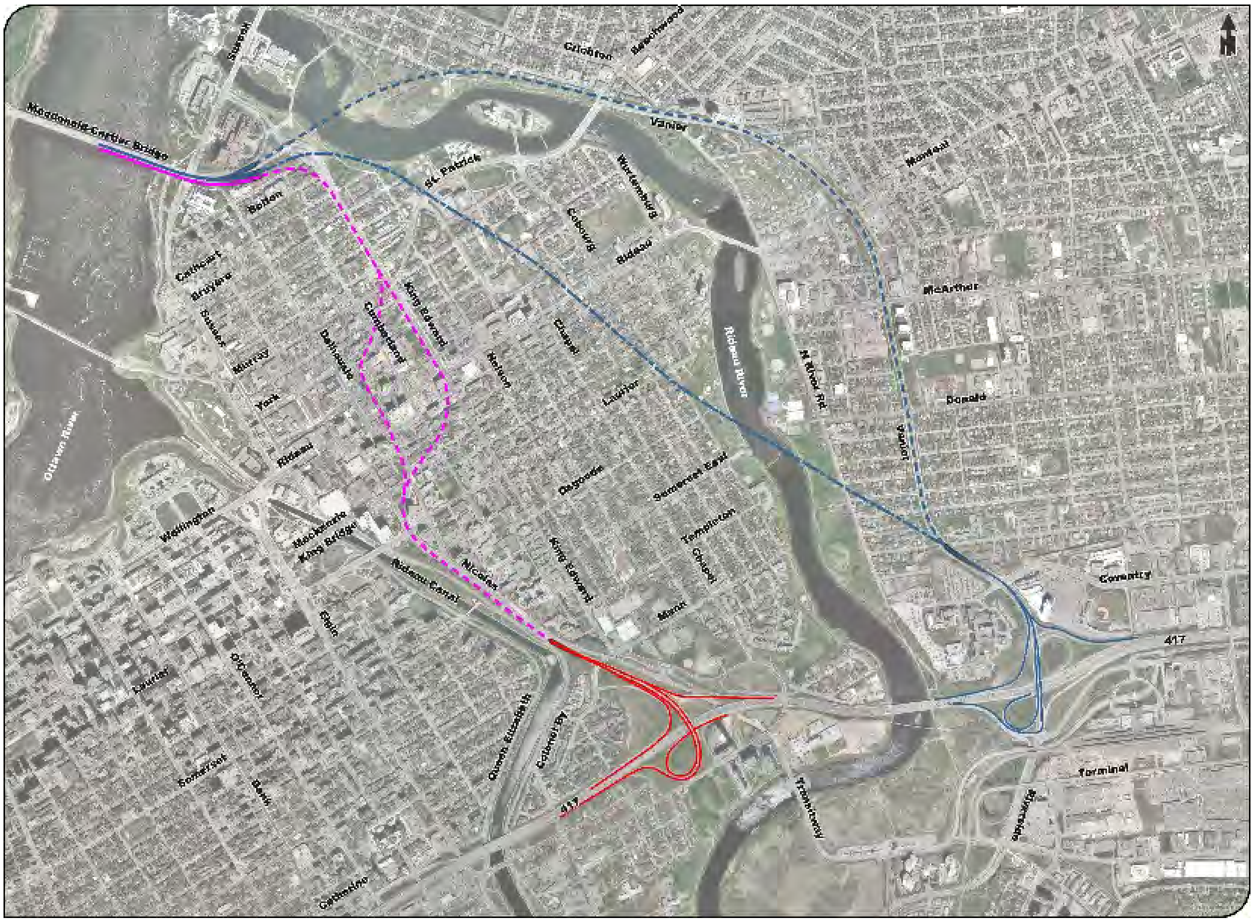


Figure 19: Second Round of Alternatives (Post-Workshop)

3.1.4 Post-Workshop Alternatives and Refinements

Based on the TCG's direction, a Second Round of Alternatives (Post-Workshop) was developed, which refined the alignments discussed at the Workshop. The four alignments investigated further by the consulting team include:

- King Edward – Lowertown – Waller – Nicholas
- King Edward – Sandy Hill – Nicholas
- Vanier Parkway
- Cross-country to the Vanier Interchange

This focused set of alignments included the Vanier Parkway alignment, and a cross-country alignment traveling in a more direct path from the Macdonald-Cartier Bridge to the Vanier Parkway interchange (minimizing tunnel length).

During the refinement of the Second Round of Alignments (Post-Workshop), other logical combinations emerged, primarily in the eastern section of the study area. The Third Round/Carry Forward Alternatives (**Figure 20**) includes the four alignments coming out of the Second Round and introduces two variations of the Cross-country alignment, which reduce some of the community impacts.

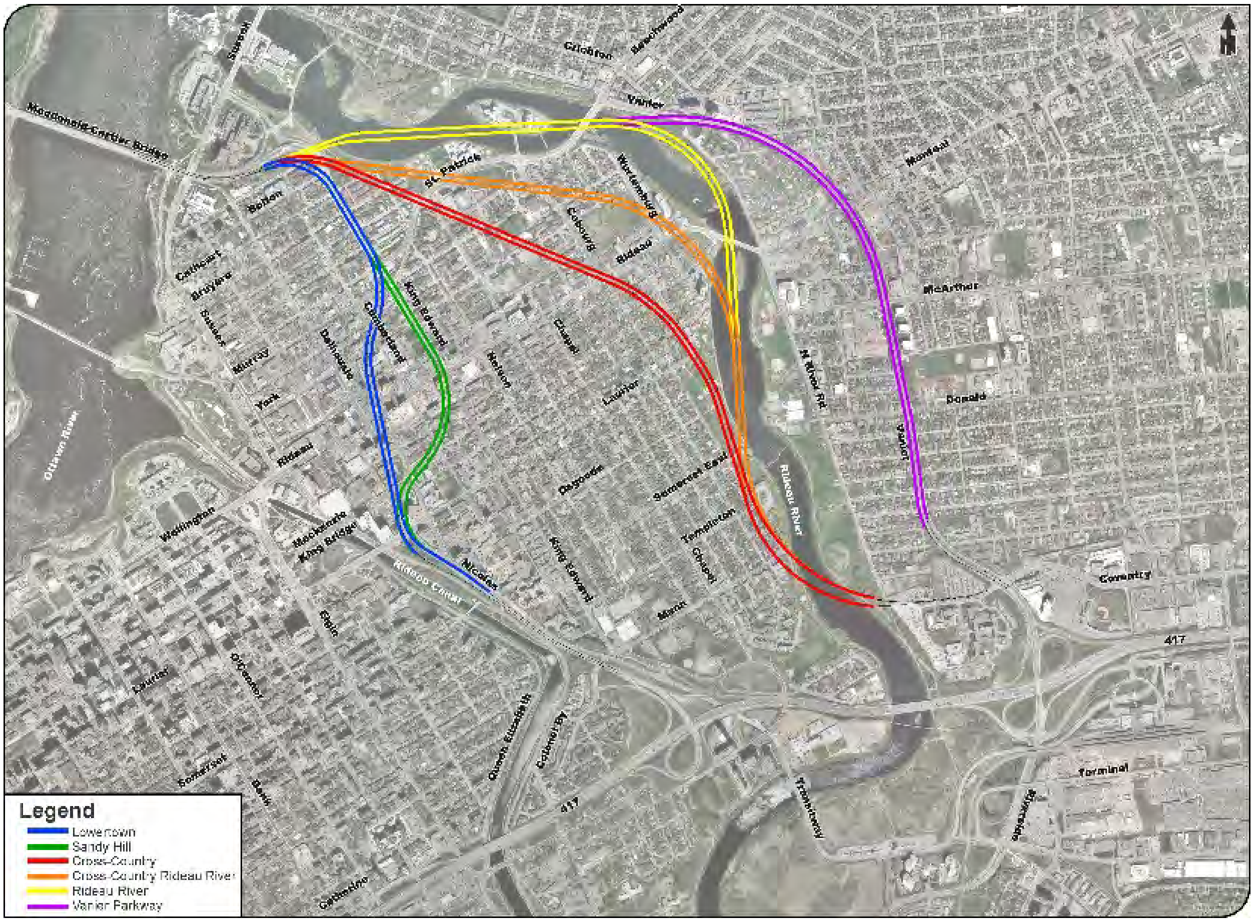


Figure 20: Third Round / Carry-Forward Alternatives (Post-Workshop)

The Central Connecting Zone includes all possible routes between the North Portal and South Portal locations. The connections can be broadly broken down into two groups; those following the municipal road allowances, and cross country routes that pass under private lands. The alignments that follow the road right-of-way will need to consider the overall right-of-way width, which in many cases is insufficient for the required width of a tunnel. The cross country routes will need to consider the interaction with existing and future building foundations.

The Third Round/Carry Forward Alignments include the following:

- Lowertown (North Portal Length:100m; South Portal Length:110m; Actual Tunnel Length: 1,940m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Turns south under King Edward
    - Turns west to pass under Lowertown to Waller
    - Runs under Waller

    - Emerges at two south portals on Nicholas south of Laurier (separate Northbound and Southbound portals)

- Sandy Hill (North Portal Length: 100; South Portal Length: 110m; Actual Tunnel Length: 2,040m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Turns south under King Edward
    - Turns west to pass under Sandy Hill to Nicholas/Laurier
    - Emerges at two south portals on Nicholas south of Laurier (separate Northbound and Southbound portals)

- Cross-country (North Portal Length: 100m; South Portal Length: 140m; Actual Tunnel Length: 3,130m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Turns south and heads to the north end of Strathcona Park at the east end of Laurier
    - Turns south to parallel the Rideau River under Strathcona Park
    - Sweeps east to the north edge of the RCMP site
    - Emerges at a south portal just west of the Vanier/Coventry intersection

- Cross-country Rideau River (North Portal Length: 100m; South Portal Length: 140m; Actual Tunnel Length: 3,400m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Turns south and heads to the west end of Cummings Bridge
    - Sweeps south to follow the Rideau River before sweeping east to the north edge of the RCMP site
    - Emerges at a south portal just west of the Vanier/Coventry intersection

- Rideau River (North Portal Length: 100m, South Portal Length: 140m; Actual Tunnel Length: 3,780m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Heads east to the Rideau River
    - Follows the Rideau River to the south end of Strathcona Park
    - Sweeps east to the north edge of the RCMP site
    - Emerges at a south portal just west of the Vanier/Coventry intersection

- Vanier Parkway (North Portal Length: 100m; South Portal Length: 140m; Actual Tunnel Length: 3,640m)
    - North portal in the median of King Edward south of Sussex Bridge
    - Heads east to the Rideau River
    - Follows the former rail corridor to Vanier Parkway
    - Runs under Vanier Parkway
    - Emerges at a south portal just north of the Vanier/Coventry intersection

3.2 Tunnel Analysis and Evaluation

3.2.1 Criteria

The consulting team undertook an analysis and evaluation process to determine which alternatives would result in the most-preferred option(s). With input from the Technical Consultation Group (TCG), draft evaluation criteria were created to reflect the planning principles and complexity of the study. These criteria were selected because they demonstrate meaningful differences between alternatives. As such, some potential criteria are not included. For example, vehicle traffic operations of the north portal are not included as the north portal for each alternative is the same. The following criteria were those used to evaluate the six alternative alignments:

1. Accommodation of surface vehicles
2. Vehicle traffic operation of south portals
3. LRT and CSST impacts
4. Major underground utility conflicts
5. Surface effects of vent shafts / emergency access on surrounding land uses / sensitive receivers
6. Surface effects on surrounding urban landscape of south portals
7. Subsurface risks (geotechnical considerations, groundwater effects)
8. Impact on properties (surface and subsurface)
9. Deep foundations / bridge foundations potentially affected
10. Development precluded to tunnel
11. Availability of construction staging areas
12. Comparative costs – based on length
13. Comparative costs – utility relocation
14. Comparative costs – operation and maintenance
15. Safety and emergency management (complexity / emergency access points)

3.2.2 Ranking Definitions

The criteria were applied to each of the alternative alignments to assess the degree of feasibility of each alternative. Each alternative was given one of three colour rankings to determine a level of feasibility. **Table 2** below describes each ranking and its corresponding level of feasibility.

Table 2: Evaluation Process

Terms Describing		Feasibility Constraints	Definition
Negative Effects	Positive Effects		
None / No / Negligible / Low	Good / Best High	Minimal	The impact is judged to be either completely non-existent, has the least impact, or is of a magnitude small enough that it has little effect, or is of limited benefit compared to all the alternatives. Few mitigation measures are required.
Some Medium / Moderate	Reasonable Medium / Moderate	Minor	The impact exists and is of relatively low magnitude, but enough to have a measurable effect or contribution. Some mitigation measures may be required.
Significant High	Limited / None / No or Least Low	Major	The impact exists and has a moderate to relatively large effect, or has the most impact when compared to all other alternatives. A high degree of mitigation measures are required.

3.2.3 Criteria Evaluation

The following section describes the key considerations, importance and evaluation rationale for each criterion.

1. Accommodation of Surface Vehicles

The impetus for this feasibility study came out of a consensus that the current KERWN corridor should no longer accommodate surface vehicles (particularly the volume of truck traffic) through Ottawa's downtown core. Accommodation of surface vehicles, however, was still deemed appropriate to include as an evaluation criteria.

All tunnel alternatives must be able to accommodate a sufficient number of vehicles that would otherwise use the existing surface streets. Potential usage of a tunnel based on *existing* traffic data, is as follows:

- 1,700 trucks per day (which as noted above could vary depending on local truck patterns and dangerous goods vehicles)
- 25,000 autos per day (with the majority of traffic to / from east of Nicholas Street on Highway 417 as the Macdonald Carter Bridge is the easternmost bridge connecting Ottawa and Gatineau)

Potential usage of a tunnel based on a *2031 planning horizon* is as follows:

- Up to approximately 2,400 vehicles per hour in the peak hour (includes an estimated 1,500 vehicles per hour) diverted from competing inter-Provincial bridges.

Importance: A tunnel would alleviate traffic on existing surface streets. Re-routing a substantial portion of the truck traffic out of the downtown would also allow for the opportunity to reconstruct surface streets to a more pedestrian- / cyclist-friendly alternative.

Alternative	Assessment	Ranking
Lowertown	***No differentiation.***	
Sandy Hill		
Cross-Country		
Cross-Country / Rideau River		
Rideau River		
Vanier Parkway		

2. Vehicle Traffic Operation of South Portals

The existing configuration of on-ramps and off-ramps at both the Nicholas Street and Vanier Parkway interchanges will greatly influence future traffic flow. The number of signalized intersections leading to/from each highway interchange will influence traffic moving east / west on Highway 417. New road alignments and road configurations around these south portals will also greatly affect traffic flow at each location.

For all alternatives, there are two portal designs to compare:

- Ramps to / from Nicholas Street at the Nicholas Street interchange, and

- Coventry Road / Vanier Parkway roundabout (proposed) and Vanier Parkway Interchange.

Vehicle traffic operations at the south portals must consider the following:

- Number of traffic-controlled intersections to access / egress the Highway 417 Corridor;
- The long term potential for the Alta Vista Transportation Corridor link south of the existing Highway 417 / Nicholas Street interchange;
- Distance between the selected portal location and the location where a driver must make a decision to safely maneuver to the correct land; and,
- Availability of approach capacity.

Importance: The south portal connection (**Figure 21**) must be able to accommodate vehicle traffic traveling to / from a tunnel, as well as surface traffic traveling to above-ground destinations.

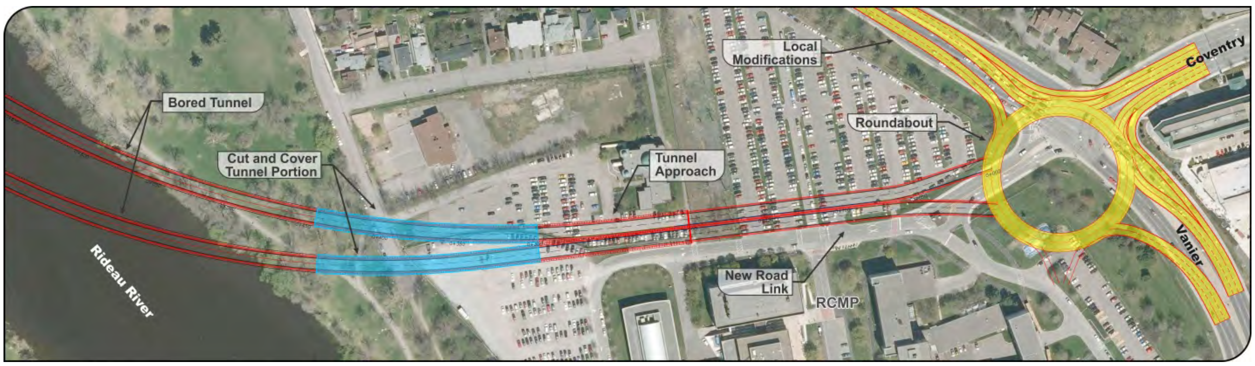


Figure 21: Vanier Parkway South Portal

Alternative	Assessment	Ranking
Lowertown	Compatible with Nicholas Street interchange – minimal conflict.	
Sandy Hill	Compatible with Nicholas Street interchange – minimal conflict.	
Cross-Country	Proposed roundabout provides required connectivity, but may be congested during peak hours.	
Cross-Country / Rideau River	Proposed roundabout provides required connectivity, but may be congested during peak hours.	
Rideau River	Proposed roundabout provides required connectivity, but may be congested during peak hours.	
Vanier Parkway	Only three 'legs' to the proposed roundabout will be provided considering the proximity to the interchange, this configuration is expected to have poor operation.	

3. Potential Impacts to LRT and CSST

LRT: The Confederation Line enters the study area along Rideau Street, with a relatively deep station under the street in front of the Rideau Centre. East of the station the LRT tunnel heads east and turns to the south-east under Waller, rising until just south of Laurier when it breaks the ground surface and runs in the former Transitway corridor parallel to Nicholas Street. The LRT is shown in **Figure 22**. A five metre horizontal buffer from the LRT infrastructure is desired.

Figure 22: Future LRT Alignment

CSST: From west to east, the planned Combined Sewage Storage Tunnel (CSST) would move through the downtown area along Laurier Avenue, where it would connect to a midpoint launch shaft at the Laurier / Nicholas intersection. It would continue to travel east along Laurier Avenue, turning sharply under the Tabaret Lawn to then travel north under Cumberland Street. The CSST would then head north-east and cross both King Edward Avenue and the Rideau River to head to an outlet chamber in the New Edinburgh Park area. The grade of the CSST would be very shallow and could not be altered; a five metre horizontal buffer is desired from the pipe. The CSST is shown in **Figure 23**.

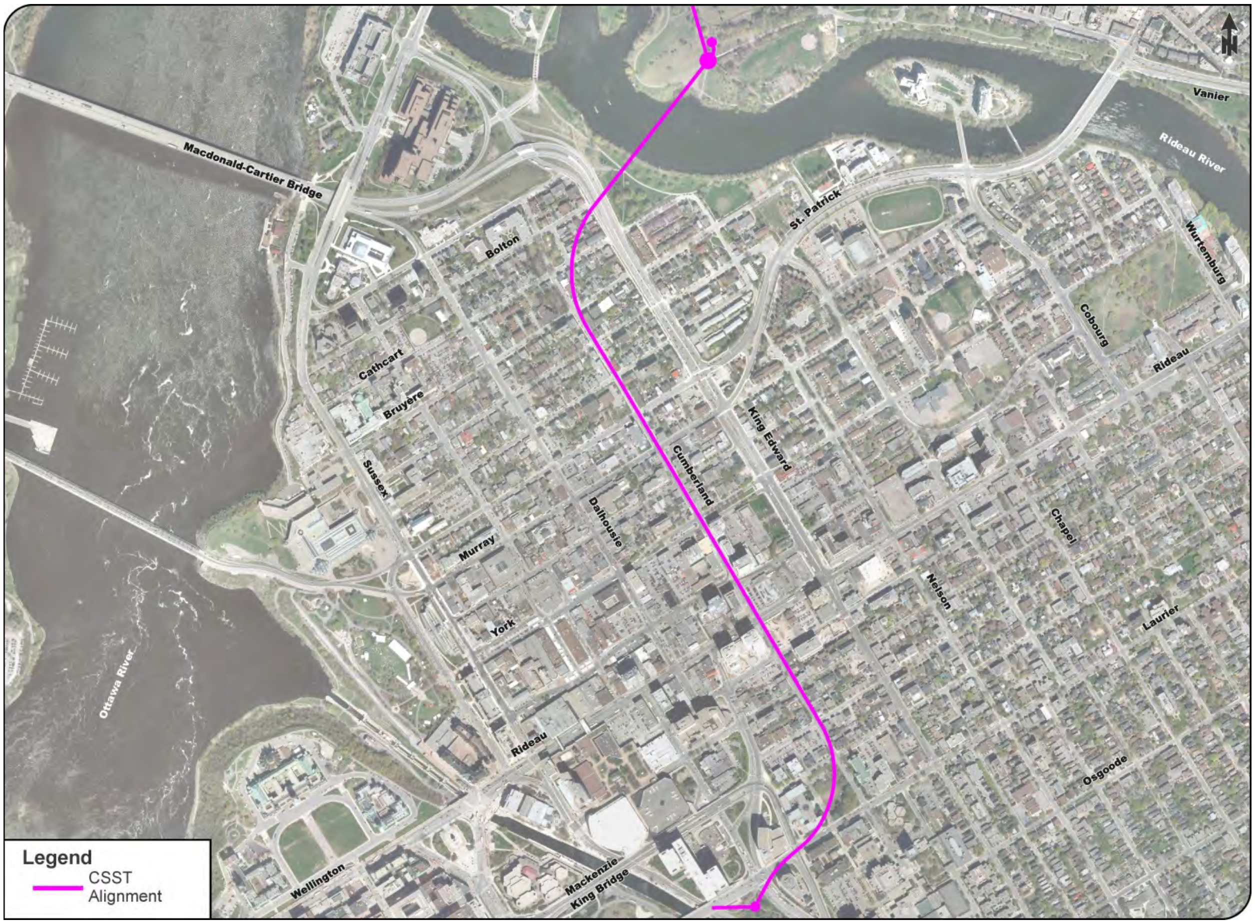


Figure 23: CSST Alignment

Importance: Finding a balance between the design criteria for the tunnel and avoiding the LRT and CSST alignments is a key challenge in the development the various alternatives. These tunnels are considered to be hard constraints and based on TCG recommendations a 5-metre minimum buffer between tunnels is desirable. However possible mitigation measures such as construction techniques are also considered in this criterion.

Alternative	Assessment	Ranking
Lowertown	This alignment crosses the LRT tunnel once in the vicinity of Besserer Street. The buffer between the two is approximately, 1.4 metres, which is less than the 5 metre desirable buffer. This alignment crosses the CSST three times. First, in the vicinity of Bolton Street/King Edward Avenue intersection, second between Clarence Street and York Street on Cumberland Street, and third by Laurier Avenue East/Nicholas Street intersection. In each location, the buffer is approximately 3.4, 7.8, and 2.7 metres respectively, two crossings provide less than the 5 metre desirable buffer.	
Sandy Hill	This alignment crosses the LRT tunnel once in the vicinity of Waller Street. The buffer between the two is approximately, 1.5 metres, which is less than the 5 metre desirable buffer. This alignment crosses the CSST three times. First, in the vicinity of Bolton	

Alternative	Assessment	Ranking
	Street/King Edward Avenue intersection, second between Daly Avenue and Stewart Street on Cumberland Street, and third by Laurier Avenue East/Nicholas Street intersection. In each location, the buffer is approximately 3.3, 3.3, and 2.6 metres respectively, all less than the 5 metre desirable buffer.	
Cross-Country	This alignment avoids crossing the LRT tunnel. This alignment crosses the CSST once in the vicinity of Bolton Street/King Edward Avenue intersection. In each location, the buffer is approximately 2.7 metres, less than the 5 metre desirable buffer.	
Cross-Country / Rideau River	This alignment avoids crossing the LRT tunnel. This alignment crosses the CSST once in the vicinity of Bolton Street/King Edward Avenue intersection. In this location, the buffer is approximately 2.6 metres, less than the 5 metre desirable buffer	
Rideau River	This alignment avoids crossing the LRT tunnel. This alignment crosses the CSST once in the vicinity of Bolton Street/King Edward Avenue intersection. In this location, the buffer is approximately 3.3 metres, less than the 5 metre desirable buffer.	
Vanier Parkway	This alignment avoids crossing the LRT tunnel. This alignment crosses the CSST once in the vicinity of Bolton Street/King Edward Avenue intersection. In this location, the buffer is approximately 3.1 metres, less than the 5 metre desirable buffer.	

4. Major Underground Utilities

Sanitary Trunk Sewers: Three major sanitary trunk sewers exist within the downtown core: Interceptor Outfall Sewer, Rideau River Collector Twin, and King Edward Ave Trunk. None of these trunks can be altered without major downstream impact. Additionally, the 375mm King Edward Pullback crosses the Macdonald-Cartier Bridge Approach, to connect to a combined sewer overflow outlet at the Ottawa River, shown in **Figure 24**. All sanitary trunk sewers have a desirable crossing buffer of five metres.

The Interceptor Outfall Sewer crosses the downtown area in a more “cross country” alignment. From west to east, the sewer moves through the downtown under Wellington and Rideau Streets, heading north along Mackenzie Avenue and begins to head in a northeast direction after passing the York Street intersection. The sewer continues a north-eastern direction until the Bolton Street, Cathcart Square intersection where it crosses both King Edward Avenue and the Rideau River.

Figure 24: Interceptor Outfall Sewer, King Edward Sanitary Trunk and Pull Back

The King Edward Avenue Trunk travels down King Edward Avenue from the Rideau Street intersection until turning onto Cathcart Street and then northwest where the sanitary sewer network connects to the Interceptor Outfall Sewer.

The Rideau River Collector Twin, shown in **Figure 25**, follows along the Rideau River. From west to east, the trunk crosses the St. Patrick Street, Beechwood Avenue, and the Vanier Parkway intersection following the Vanier Parkway alignment until it turns south onto North River Road. The sewer continues along North River Road until it separates after the Montreal Road intersection into twin sewers. One sewer still following the North River Road centerline alignment and the other following closer to the Rideau River bank. The twinning merges together close to the Wright Street / North River Road intersection and continues following a southwestern direction, parallel to Rideau River, as it crosses Highway 417.

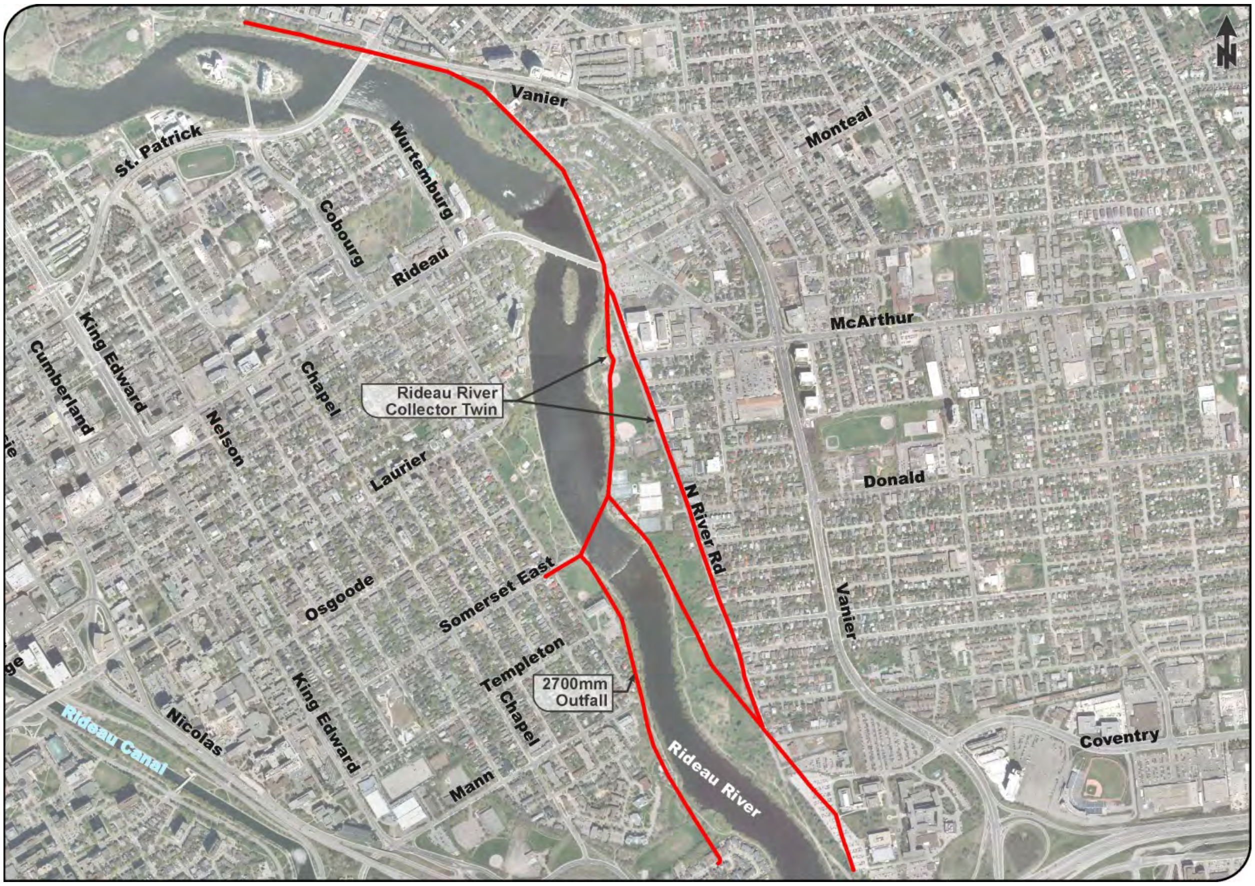


Figure 25: Major Storm Sewers along the Rideau River

Major Storm and Combined Sewers: Various major sewer networks exist in the downtown area: King Edward parallel system, the storm outfall sewer, the storm collector pipe along Bolton Street, the Macdonald-Cartier Bridge Approach storm network, the Rideau Canal 1800mm crossing combined sewer, Charlevoix Street's 2700mm storm sewer tunnel, northern Vanier Parkway storm network, the Drouin Avenue storm outfall, and the 2700mm Outfall from the Royal Canadian Mounted Police lands from Vanier Parkway and Coventry Road. Major utilities have a desirable crossing buffer of five metres.

The King Edward parallel system travels primarily down King Edward Avenue along with the King Edward Ave. Sanitary Trunk until turning south-west onto Cathcart Street. The system either continues to outlet through the storm outfall sewer, which crosses the Macdonald-Cartier Bridge approach before heading and outletting to Ottawa River, or connects to the storm collector pipe on Bolton Street. The collector sewer pipe turns again to a southwest direction and travels along Bolton Street until it crosses Sussex Drive and Lady Grey Drive before heading and outletting to the Ottawa River, as shown in **Figure 26**.

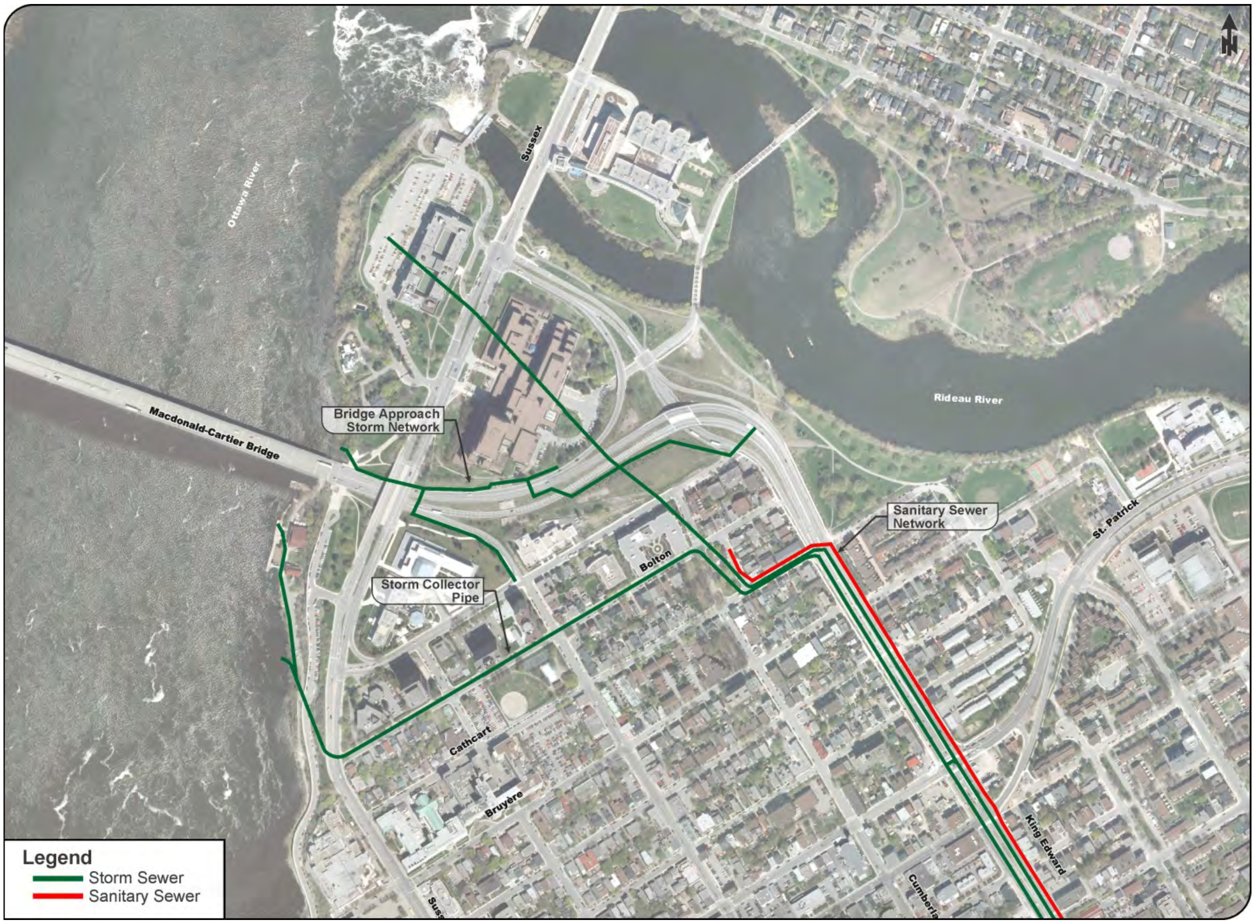


Figure 26: Major Storm and Sanitary Alignments – North End

Separate from the outfall, the Macdonald-Cartier Bridge Approach network is the storm system responsible for the Bridge approach drainage and follows along its corridor. To accommodate the tunnel, the storm network may require alterations.

The 1800mm combined sewer, shown in **Figure 7** (Page 21), crosses Queen Elizabeth Drive, Rideau Canal, Colonel By Drive, Nicholas Street, and King Edward Avenue eventually travelling under Templeton Street heading east. This sewer cannot be altered without substantial downstream impacts.

Charlevoix Street's 2700mm storm sewer tunnel is a deep sewer that connects to the northern Vanier Parkway system and conveys flows north to Mackay Street. The northern Vanier Parkway storm network travels through the Vanier corridor from the Glynn Avenue intersection northward. This sewer system cannot be altered. Both storm networks are shown in **Figure 27**.

Figure 27: Northern Vanier Parkway Major Storm Sewers

The Drouin Avenue storm outfall crosses Vanier Parkway by the Prince Albert Street intersection. Travelling west to outlet to the Rideau River. Minor alternations to the sewers will not cause major challenges to the outfall.

The last major sewer is a 2700mm with parallel 900mm sanitary pipe outfall that travels through the Royal Canadian Mounted Police lands and crosses Vanier Parkway. **Figure 28** shows the alignment. The sewer draining flow from the Presland Road and Coventry Road systems to outlet to the Rideau River. There is the potential to realign the outfall through Wright Street if required.

Figure 28: Southern Vanier Parkway Major Storm Sewers

Importance: Finding a balance between the design criteria for the tunnel and avoid the existing major utilities is a key challenge in the development the various alternatives. If utilities are likely to be impacted, possible mitigation measures such as their relocation or construction techniques are also considered in these criteria.

Alternative	Assessment	Ranking
Lowertown	Multiple utility crossings. Crosses Interceptor Outfall Sewer and combined 1800mm pipe twice – with less than the desired buffer.	
Sandy Hill	Multiple utility crossings. Crosses Interceptor Outfall Sewer and combined 1800mm pipe twice – with less than the desired buffer.	
Cross-Country	Multiple utility crossings. Crosses Interceptor Outfall Sewer, combined 2700mm pipe, Rideau River Collector Trunk twice – with less than the desired buffer.	
Cross-Country / Rideau River	Multiple utility crossings. Crosses Interceptor Outfall Sewer, combined 2700mm pipe, Rideau River Collector Trunk twice – with less than the desired buffer.	
Rideau River	Multiple utility crossings. Crosses Interceptor Outfall Sewer, combined 2700mm pipe, Rideau River Collector Trunk twice – with less than the desired buffer.	

Alternative	Assessment	Ranking
Vanier Parkway	Multiple utility crossings. Crosses Interceptor Outfall Sewer twice – with less than the desired buffer.	

5. Surface Effects of Vent Shafts / Emergency Access on Surrounding Land Uses

Surface effects on existing land uses include elements such as the location and number of vent shafts and emergency access points. Vent shafts may impact surrounding land uses, depending on the size and noise levels they project. Emergency access points may also impact surrounding land uses, depending on their sizing. These elements may interfere with existing and future development of lands.

While the feasible option likely does not require any intermediate vent shafts or emergency access points the following analysis is included for completeness and to inform future design stages.

Importance: Surface effects of vent shafts and emergency access points could potentially impact people from both a social and health perspective, given the noise and nuisance that these elements may bring.

Alternative	Assessment	Ranking
Lowertown	This alternative is 1,940m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 5 and 13 emergency cross passages and semi-transverse ventilation with jet fans that will be used with one ventilation system. While locations for vent shafts and emergency access points would be challenging to integrate there are ample opportunities in the corridor.	
Sandy Hill	This alternative is 2,040m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 5 and 13 emergency cross passages and semi-transverse ventilation with jet fans that will be used with one ventilation system. While locations for vent shafts and emergency access points would be challenging to integrate there are ample opportunities in the corridor.	
Cross-Country	This alternative is 3,130m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 9 and 22 emergency cross passages and semi-transverse ventilation with jet fans that will be used with two ventilation systems. Locations for vent shafts and emergency access points would be very challenging to integrate as there are few opportunities in the corridor, many of which would impact residential development.	
Cross-Country / Rideau River	This alternative is 3,400m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 9 and 22 emergency cross passages and semi-transverse ventilation with jet fans that will be used with two ventilation systems. Locations for vent shafts and emergency access points would be very challenging to integrate as there are few opportunities in the corridor, many of which would impact residential development.	
Rideau River	This alternative is 3,780m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 10 and 24 emergency cross passages and semi-transverse ventilation with jet	

Alternative	Assessment	Ranking
	fans that will be used with two ventilation systems. As the alignment is located under the river, vent shafts and emergency access points would need to be significantly offset from the tunnel, increasing costs and making their development more challenging.	
Vanier Parkway	This alternative is 3,6040m long (actual tunnel length). According to PIARC 2011 and NFPA, there should be between 9 and 22 emergency cross passages and semi-transverse ventilation with jet fans that will be used with two ventilation systems. Locations for vent shafts and emergency access points would be very challenging to integrate as there are few opportunities in the corridor, many of which would impact residential development.	

6. Surface Effects on the Urban Landscape near South Portals

This criterion considers surface effects on the urban landscape at Nicholas Street and at the Vanier Parkway. All tunnel alternatives use the same north portal at the Macdonald-Cartier Bridge and therefore do not require assessment because their surface effects are all the same. Elements of the urban landscape include institutions, transit corridors, waterways like the Rideau Canal and even significant view corridors.

Nicholas Street: A portal (or pair of portals) along Nicholas Street will need to consider large institutions like the University of Ottawa and right-of-ways like the LRT. There are also culturally significant areas like the Rideau Canal (a UNESCO World Heritage Site) and its multi-use pathways and bridges that provide connections and views.

Vanier Parkway: A portal at the Vanier Parkway will need to consider the RCMP grounds located at the junction of Highway 417 and the Vanier Parkway. There is also a church site (Sts. Peter and Paul Church) located near the south portal as well as the Rideau River eastern multi-use pathway.

Both south portals must also consider the following:

- Land displacement, potentially located near adjacent residential development;
- Existing road alignments would require alterations for both portals; and
- Social concerns, including noise and nuisance levels.

Importance: Portal alternatives will create conflicts with various elements of the urban landscape that include noise, land displacement, and road alignment adjustments.

Alternative	Assessment	Ranking
Lowertown	Land uses impacted by greater noise and traffic include University of Ottawa, future LRT line, NCC / Rideau Canal lands, Nicholas Street / Highway 417 interchange.	
Sandy Hill	Land uses impacted by greater noise and traffic include University of Ottawa, future LRT line, NCC / Rideau Canal lands, Nicholas Street / Highway 417 interchange.	
Cross-Country	Land uses impacted by greater noise and traffic include RCMP campus, existing street configurations.	
Cross-	Land uses impacted by greater noise and traffic include RCMP	

Alternative	Assessment	Ranking
Country / Rideau River	campus, existing street configurations.	
Rideau River	Land uses impacted by greater noise and traffic include RCMP campus, existing street configurations.	
Vanier Parkway	Land uses impacted by greater noise and traffic include existing adjacent residential development, existing street configurations.	

7. Subsurface Risks

Subsurface risks include geotechnical risk and effects on groundwater (drawdown and inflows).

Geotechnical Risks: Proposed tunnel alternatives will be predominantly within limestone or shale bedrock, which is generally favourable for tunnelling. The primary geotechnical risks associated with tunnelling in bedrock in Ottawa include: low rock crown cover, including variability of the rock surface and the potential for mixed-face (soil and bedrock) conditions; areas of poor rock quality (such as resulting from faults, or near the soil/rock interface); and, the potential that widespread lowering of the piezometric pressure in clay which could lead to consolidation settlement of heavy buildings on raft slabs. Other considerations include the potential for the higher groundwater inflows in the upper bedrock, the time dependent deformation behaviour, swelling and slaking of the shale bedrock, and the potential for claims resulting from ground movement when tunneling below or in close proximity to existing buildings and other infrastructure.

Groundwater Effects (Drawdown and Inflows): The groundwater table is typically about 3 to 5 metres below the ground surface in much of the study area, and is at or just above the river level near the Rideau River. The hydraulic conductivity of the bedrock rock is generally quite low (ranging from 10^{-6} to 10^{-8} m/s) generally decreasing with depth. Flow primarily occurs along horizontal bedding planes and vertical joints. Higher inflows (up to 10^{-3} m/s) are generally associated with areas of low rock crown cover (the rock tends to be more fractured near the soil/rock interface), but can also be associated with areas of bedrock faulting. Conventional rock tunnelling using a tunnel boring machine (without immediate lining or the use of pre-cast segments), cut and cover construction and/or segmental excavation with a roadheader will create a drain in the bedrock which, over time and without mitigation, will result in widespread lowering of the piezometric pressure in both the rock and the overlying soils. Changes in piezometric pressure (i.e. drawdown) in the marine clay deposits can result in consolidation settlement, particularly beneath heavily loaded buildings. Underdrainage can also result in mobilization of contaminants from landfills or other areas of concern.

Importance: The geotechnical conditions will directly impact the ease with which a tunnel can be excavated and the need for the mitigation measures (i.e., added cost) to minimize the risks to worker and public safety and to limit impacts (e.g., property damage) resulting from tunnelling. The groundwater conditions will directly impact stability of the excavation and the need for the mitigation measures (i.e., added cost) to address: 1) high inflows to minimize the risks to worker and public safety and/or 2) groundwater drawdown and clay consolidation settlement, to minimize property damage resulting from tunnelling.

Alternative	Assessment	Ranking
Lowertown	Poor rock quality and mixed face conditions at south end of alignment. High groundwater inflows in buried valley / faulted bedrock. Need to limit groundwater drawdown, heavy buildings on clay nearby. Mobilization of contaminants (former service stations and dry cleaners).	
Sandy Hill	Poor rock quality and mixed face conditions at south end of alignment. Higher groundwater inflows in buried valley/faulted bedrock. Need to limit groundwater drawdown, heavy buildings on clay nearby. Mobilization of contaminants (former coal gasification plant).	
Cross-Country	Limited rock profile/rock quality information in Sandy Hill / Lowertown. Short river crossing - risk of significantly higher groundwater inflows. Need to limit groundwater drawdown, area overlain by clay.	
Cross-Country / Rideau River	Possible local low rock cover near Rideau Street. River crossing - risk of significantly higher inflows. Need to limit groundwater drawdown, north half of alignment overlain by clay.	
Rideau River	Under Rideau River, significantly increased risk of higher inflows. Lower potential for clay settlement, most clay is located away from alignment. Mobilization of contaminants (landfills along Rideau River).	
Vanier Parkway	Shale bedrock may require additional ground support. Long river crossing - risk of significantly higher inflows. Lower potential for clay settlement, most clay is located far from the alignment. Mobilization of contaminants (landfills along Rideau River).	

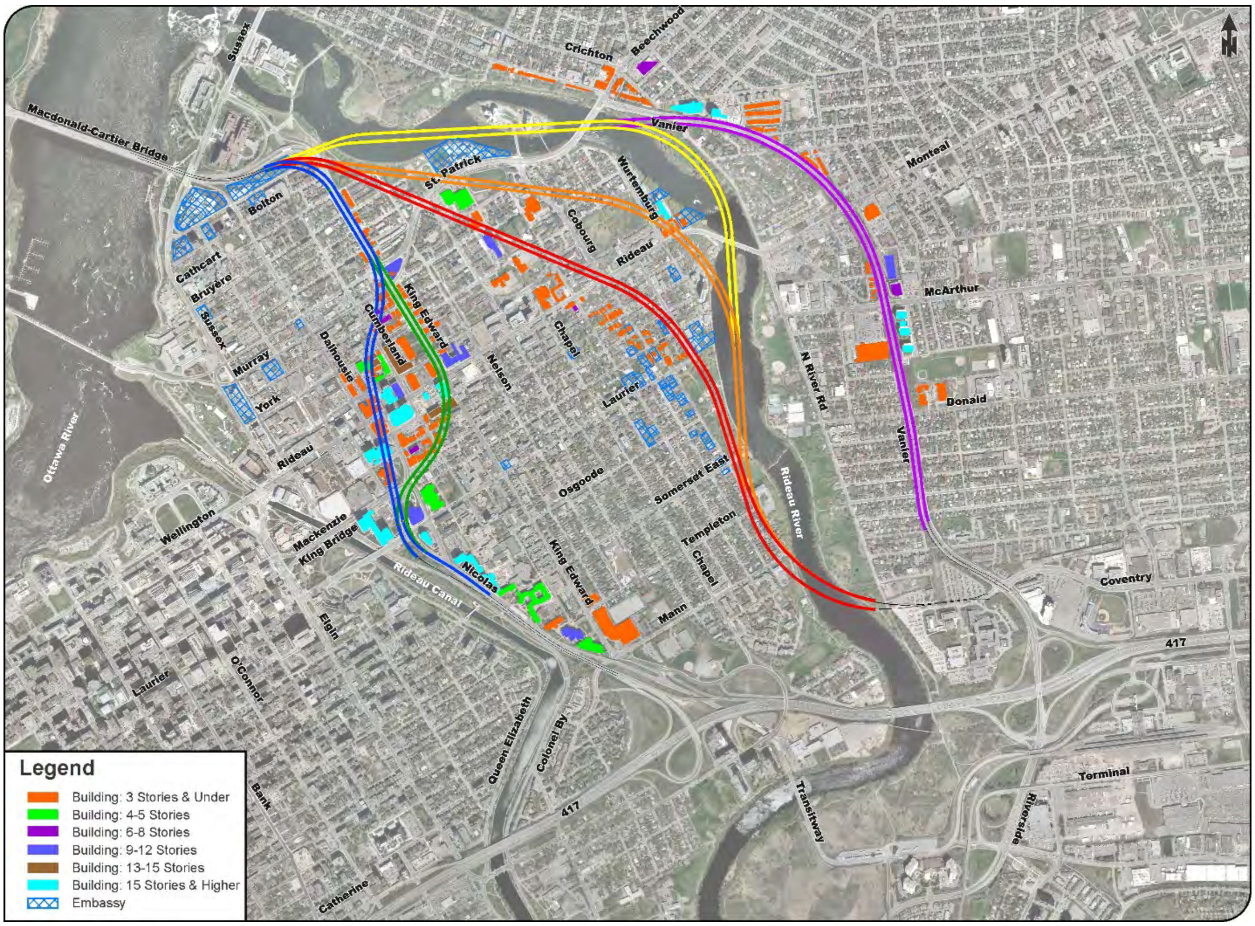
8. Impact on Properties (Surface and Subsurface)

Downtown Ottawa, particularly west of the Rideau River and east of the Rideau Canal, includes many large private buildings associated with the University of Ottawa, private corporations / businesses, embassies, and condominiums, among others. There are also several federal and provincial government buildings located in this area. These building locations become especially significant if they include elements like laboratories, high security facilities, and/or multi-level underground parking garages (**Figure 29**).

Importance: Private surface and subsurface properties and structures will directly impact underground rights, particularly if there are building sensitivities in the foundations. As such, parks and open space lands are more favourable for tunnel alignments.

Alternative	Assessment	Ranking
Lowertown	This alternative potentially impacts commercial development, institutional and high density residential buildings, and University of Ottawa campus lands.	
Sandy Hill	This alternative potentially impacts some commercial development, institutional and high density residential buildings, and University of Ottawa campus lands.	
Cross-Country	This alternative potentially impacts some commercial development and low density residential buildings.	

Alternative	Assessment	Ranking
Cross-Country / Rideau River	This alternative potentially impacts some commercial development, low density residential buildings.	
Rideau River	This alternative generally follows the Rideau River and has negligible impact on private properties.	
Vanier Parkway	This alternative generally follows the Vanier Parkway right-of-way. While it is adjacent to some high density buildings, its impact is expected to be negligible.	



**Data current as of 2012*

Figure 29: Properties Affected

9. Deep Foundations / Bridge Foundations Potentially Affected

Downtown Ottawa, particularly west of the Rideau River and east of the Rideau Canal, includes many large private buildings associated with the University of Ottawa, corporations, embassies, and condominiums, among others. There are also several federal and provincial government buildings located in this area. These buildings become especially significant if they include elements like laboratories, high security facilities, and/or multi-level underground parking garages. Existing bridge foundations also warrant consideration; disturbing foundations can compromise the structural integrity of bridges in the area.

Importance: Deep basements or foundations of buildings or bridge structures will directly impact how deep underground a tunnel alignment will need to be (i.e. to avoid conflicts with existing basements, tie-backs, or deep foundation systems such as piles or caissons).

Alternative	Assessment	Ranking
Lowertown	There is significant impact on commercial development, institutional and high density residential buildings and University of Ottawa campus lands.	
Sandy Hill	There is significant impact on commercial development, institutional and high density residential buildings and University of Ottawa campus lands.	
Cross-Country	There is minimal impact on commercial development and low density residential buildings.	
Cross-Country / Rideau River	There is minimal impact on some commercial development and low density residential buildings.	
Rideau River	The alignment in part follows the Rideau River. There is minimal impact with buildings. Impact on bridge foundations includes St. Patrick Street and Montreal Road.	
Vanier Parkway	The alignment follows the Vanier Parkway right-of-way. The alignment is adjacent to some high density residential buildings. Impact on bridge foundations includes St. Patrick Street and Montreal Road.	

10. Development Precluded due to Tunnel

A future tunnel will require the establishment of underground rights, as well as acquiring land for elements such as vent shafts and emergency access. As such, some of this land may preclude other future development, especially on prime redevelopment land. Infill development land closer to the downtown may be weighted more heavily due to the locational nature of development opportunity and its real estate potential.

Importance: If a tunnel alignment passes under a property, it will require the establishment of underground rights, thereby precluding any future development / intensification of a property. Hence, alternatives passing under areas experiencing redevelopment (i.e., central Ottawa) will preclude future development.

Alternative	Assessment	Ranking
Lowertown	There is significant impact on downtown infill redevelopment opportunities.	
Sandy Hill	There is significant impact on downtown infill redevelopment opportunities	
Cross-	There is minimal impact on commercial, low density residential	

Alternative	Assessment	Ranking
Country	buildings.	
Cross-Country / Rideau River	There is some impact on commercial, low density residential buildings, embassies.	
Rideau River	This alignment in part follows the Rideau River. There is some impact on low density buildings and embassies.	
Vanier Parkway	This alignment follows the Rideau River. There is some impact on low density buildings and embassies.	

11. Availability of Staging Areas

As with any major infrastructure project, staging areas will be required to construct any tunnel alignment. Availability of staging areas including locations for storage of equipment, supplies, stockpiles and vehicles is needed to ensure a safe, timely and manageable construction process. Staging areas should ideally be flat areas and able to accommodate the movement of equipment and material required for an optimal construction process. Staging area locations must also consider proximity to other land uses, especially those that may pose potential conflict, including environmentally sensitive areas, residential areas, and existing heavily-trafficked areas. Typically, staging areas are located near each portal.

Importance: Knowing which alternatives are able to accommodate staging areas is important so that vehicles, supplies and construction equipment are positioned for access and use to a tunnel construction site.

Alternative	Assessment	Ranking
Lowertown	There is little room to construct Tunnel Boring Machine (TBM) Launchpad at the north *and* south portals.	
Sandy Hill	There is little room to construct TBM launch pad at the north *and* south portals.	
Cross-Country	There is little room to construct TBM launch pad at the north portal. Room to construct TBM launch pad at south portal.	
Cross-Country / Rideau River	There is little room to construct TBM launch pad at the north portal. Room to construct TBM launch pad at south portal.	
Rideau River	Challenge / little room to construct TBM launch pad at north portal. Room to construct TBM launch pad at south portal.	
Vanier Parkway	Challenge / little room to construct TBM launch pad at north portal. Room to construct TBM launch pad at south portal.	

12. Comparative Costs – Based on Length

Costs of a future tunnel are based on the length of the tunnel, itself. We assume that the longer the tunnel (linear length) the costlier it will be to construct.

Importance: Associated cost of a tunnel is a critical component when assessing alternatives. It can determine a project's feasibility based on the overall affordability of the project and the cost per diverted driver or vehicle.

Alternative	Assessment	Ranking
Lowertown	1,940m long (actual tunnel length). Lowest likely capital cost.	
Sandy Hill	2,040m long (actual tunnel length). Lowest likely capital cost.	
Cross-Country	3,130m long (actual tunnel length). Moderate likely capital cost.	
Cross-Country / Rideau River	3,400m long (actual tunnel length). Moderate likely capital cost.	
Rideau River	3,780m long (actual tunnel length). Highest likely capital cost.	
Vanier Parkway	3,640m long (actual tunnel length). Moderate likely capital cost.	

13. Comparative Costs – Utility Relocation

Costs of a future tunnel are based on the amount effort of relocation of utilities required for the various alignments.

Importance: Associated cost of a tunnel is a critical component when assessing evaluation criteria. It can determine a project's go-ahead based on how much the city / provincial government / federal government is willing to spend.

Alternative	Assessment	Ranking
Lowertown	Least utility relocation. Lowest cost.	
Sandy Hill	Least utility relocation. Lowest cost.	
Cross-Country	Moderate utility relocation. Moderate cost.	
Cross-Country / Rideau River	Moderate utility relocation. Moderate cost.	
Rideau River	Moderate utility relocation. Moderate cost.	
Vanier Parkway	Moderate utility relocation. Moderate cost.	

14. Comparative Costs – Operation and Maintenance

Costs of a future tunnel are based on manageability of operations and maintenance. We assume that the shorter the tunnel length, the more manageable and cost-effective it is to operate and maintain.

Importance: Associated cost of a tunnel is a critical component when assessing evaluation criteria. It can determine a project's go-ahead based on how much the city / provincial government / federal government is willing to spend.

Alternative	Assessment	Ranking
Lowertown	1,940m long (actual tunnel length). Greater ease of operations and maintenance.	
Sandy Hill	2,040m long (actual tunnel length). Greater ease of operations and maintenance.	
Cross-Country	3,130m long (actual tunnel length). Poses some challenge to operations and maintenance.	
Cross-Country / Rideau River	3,400m long (actual tunnel length). Poses some challenge to operations and maintenance.	
Rideau River	3,780m long (actual tunnel length). Poses some challenge to operations and maintenance.	
Vanier Parkway	3,640m long (actual tunnel length). Poses some challenge to operations and maintenance.	

15. Safety and Emergency Management

This section refers to emergency exits and service facilities as well as emergency tunnel closures. Emergency exits for tunnel users are established with the purpose of having a safe route / escape in the event of an emergency. The exits will mainly be used in the event of a fire in the tunnel. While safety elements such as ventilation systems and emergency escape routes will be used for any tunnel alternative, they may vary in their performance due to the various alternative alignments.

Importance: Safety and emergency management is of priority when considering tunnel alignment alternatives. Identifying which tunnel alignment alternative is best able to mitigate risk is important. The safety of a tunnel in an area like downtown Ottawa has significant local, social and economic impacts.

Alternative	Assessment	Ranking
Lowertown	Lower traffic incident probability due to shorter tunnel length, but more interference with development. Fewer number of required egress shafts and cross passages. Steeper slope entering / exiting tunnel may increase traffic incidents. High tunnel traffic incident probability. Potential problems could occur on Nicholas Street in the event of a tunnel closure.	
Sandy Hill	Lower traffic incident probability due to shorter tunnel length, but more interference with development. Fewer number of required egress shafts and cross passages. Steeper slope entering / exiting tunnel may increase traffic incidents. High tunnel traffic incident probability. Potential problems could occur on Nicholas Street in the event of a tunnel closure.	

Alternative	Assessment	Ranking
Cross-Country	Less interference with development – less of an impact in the event of a tunnel closure. Moderate tunnel traffic incident probability. Slope is not as steep entering / exiting tunnel.	
Cross-Country / Rideau River	Less interference with development – less of an impact in the event of a tunnel closure. Moderate tunnel traffic incident probability. Slope is not as steep entering / exiting tunnel.	
Rideau River	Less interference with development – less of an impact in the event of a tunnel closure. Moderate tunnel traffic incident probability. Slope is not as steep entering / exiting tunnel.	
Vanier Parkway	Less interference with development – less of an impact in the event of a tunnel closure. Moderate tunnel traffic incident probability. Slope is not as steep entering / exiting tunnel.	

3.2 Summary of Evaluation

A consolidated table evaluating each alternative with the various criteria is shown below. From here, we are able to recognize patterns when examining how these alternatives compare with one another.

EVALUATION CRITERIA	TUNNEL ALTERNATIVES					
	Lowertown	Sandy Hill	Cross-Country	Cross-Country / Rideau River	Rideau River	Vanier Parkway
1. Accommodation of Surface Vehicles	No differentiation					
2. Vehicle Traffic Operation of South Portals						
3. LRT and CSST						
4. Major Underground Utilities Conflicts	No differentiation					
5. Surface Effects on Route						
6. Surface Effects, Urban Landscape – South Portals						
7. Subsurface Risks						
8. Impact on Properties (Surface / Subsurface)						
9. Deep Foundations / Bridge Foundations						

EVALUATION CRITERIA	TUNNEL ALTERNATIVES					
10. Development Precluded to Tunnel						
11. Availability of Construction Staging Areas						
12. Comparative Construction Costs – Length						
13. Comparative Costs – Utility Relocation						
14. Comparative Costs – Operation / Maintenance						
15. Safety and Emergency Management						

The two cross-country alternatives ('Cross-Country' and 'Cross-Country / Rideau River') were deemed the most feasible / most preferred alternatives out of the six alternatives evaluated.

Alternative	Assessment	Analysis
Lowertown		**LEAST FEASIBLE** **Due to:** • *Conflict with LRT/CSST which potentially compromises those facilities* • *Conflict with surrounding urban landscape which limits or precludes future development* • *Conflict with deep foundations which places some existing buildings at risk* • *Conflict with the Rideau Canal UNESCO World Heritage Site designation* • *Significant geotechnical risks due to poor ground conditions near the Nicholas Street / Laurier Avenue portal* • *Little availability for staging areas* These options present high risk, high cost, substantial impacts, and poor geometric design standards impacting safety, which would be extremely challenging to mitigate and are therefore not recommended.
Sandy Hill		
Cross-Country		**MOST FEASIBLE** **Despite the fact that these options are longer, they are still recommended due to:** • *No 'show stopping' elements* • *Minimal conflict / interference with existing built form* Results in a high geometric standard, has little to no impact on adjacent development, anticipated impacts at portals can be
Cross-Country / Rideau River		

Alternative	Assessment	Analysis
		mitigated, and there appears to be opportunities to modify / fine tune the design to improve the performance of the solution. Therefore a cross-country route is recommended as the most feasible alternative.
Rideau River		**MODERATELY FEASIBLE** **Due to:** • *Manageable conflict with surface effects on land uses* • *Manageable impact on surface water / groundwater* • *Manageable impact on vehicle traffic operations* These options present moderate to high risk, moderate to high cost, moderate impacts, which would be challenging to mitigate and are therefore not recommended unless the most feasible alternatives are determined to be unacceptable.
Vanier Parkway		

4. Description of Most Feasible Alternative

After further evaluation, the consulting team then selected a 'most feasible alternative': the ***Cross Country*** alignment (shown in **Figure 30**).

4.1 Alignment

From the Macdonald-Cartier Bridge at the north, the alignment from the north portal curves slightly beneath the Rideau River, then toward a straight south-easterly direction beneath elementary schools and detached and multi-unit residential housing in the Lowertown neighbourhood. The alignment then curves south running parallel to the Rideau River beneath Strathcona Park until Mann Avenue where it passes beneath the river. The south portal opens up at North River Road (east of the River) where the alignment runs across the north portion of the RCMP campus lands to the Vanier Parkway / Coventry Road intersection. A roundabout is proposed at this intersection to alleviate traffic build up and improve traffic flow.

This alignment is the shortest alternative (3,130m long – actual tunnel length; 3,370m – including the north and south portals) using the Vanier Parkway interchange.

In terms of profile the alignment was selected to:

- Define a suitable position to start the underground sections in order to have a reasonable rock cover of approximately 5-8 metres.
- Limit as much as possible any utility relocations.
- Go as deep as possible as quickly as possible to enter into the bedrock and maintain a minimum cover of 10m between the top of the tunnel and the interface between rock and superficial soil deposits.

The total average cover obtained is varying from 13m to 26m.

4.1.1 Traffic and Dangerous Goods

At the onset of the project, the consulting team, together with the Technical Consultation Group, decided that no dangerous goods would pass through a future tunnel alignment. Analysis in Section 2.6 indicates that a formal risk approach should be used to make the final determination.

Dangerous goods events are more easily managed on the road network where Emergency Services have the training to deal with any event, the equipment to manage the event and open space around the event to undertake control and clean up. While this will mean that some through trucks are not able to be diverted from the KERWN Corridor it will provide a safer environment for all road users.

4.1.2 Portals – General

The portals are the transition zones between the surface road network and the underground infrastructure. These areas are the two main points where the construction works will impact the everyday surface activity of the city.

The selected locations of these portals will have a minimal level of disturbance to their surroundings. The selected locations must still consider the following required construction operations:

- Temporary and multiple traffic re-directions/deviations;
- Utility relocations;
- Long trench excavation to allow the road transition from surface to underground;

- Consolidation work to launch the proper underground construction.

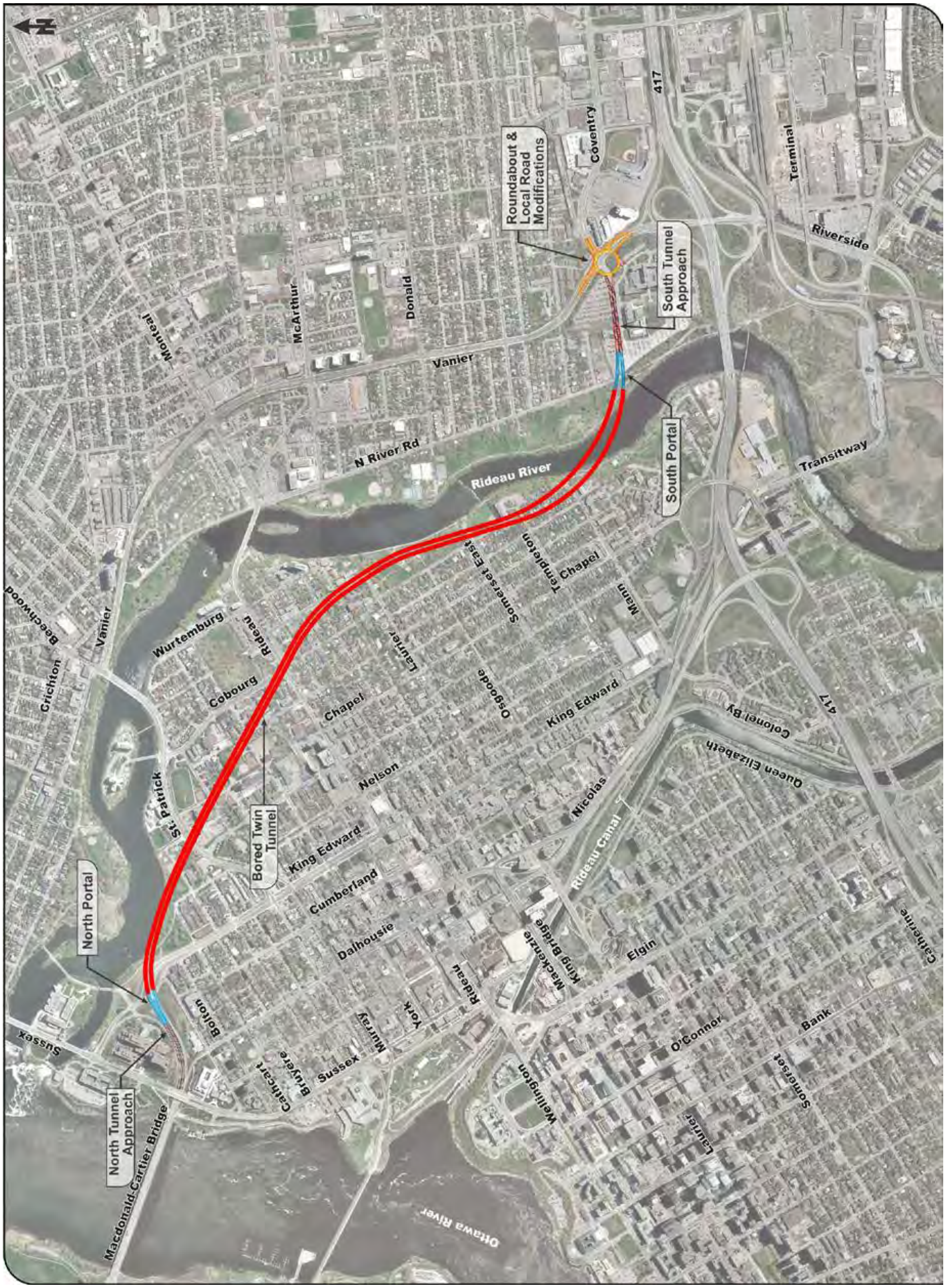


Figure 30: Most Feasible Alternative

In the same area, a cut & cover structure will be realized for the transition between the trench zone and the underground section.

A building to accommodate the ventilation system will be also required. Space should also be available in close proximity of the portals, for all the compound facilities needed during construction.

4.1.3 North Portal Impacts

In the initial concept design, the opportunity for the north portal exists because the State of Qatar embassy property is undeveloped. The study team's perspective was that impacts on property, or in particular undeveloped property, was not considered a constraint when deciding if an option was feasible or not. Traveling from the Macdonald-Cartier Bridge, the northbound and southbound portals occupy the majority of the embassy property. This provides for good tunnel and approach geometry and will allow the facility to be constructed with minimal impacts on other infrastructure. **Figure 31** illustrates the initial north portal concept.

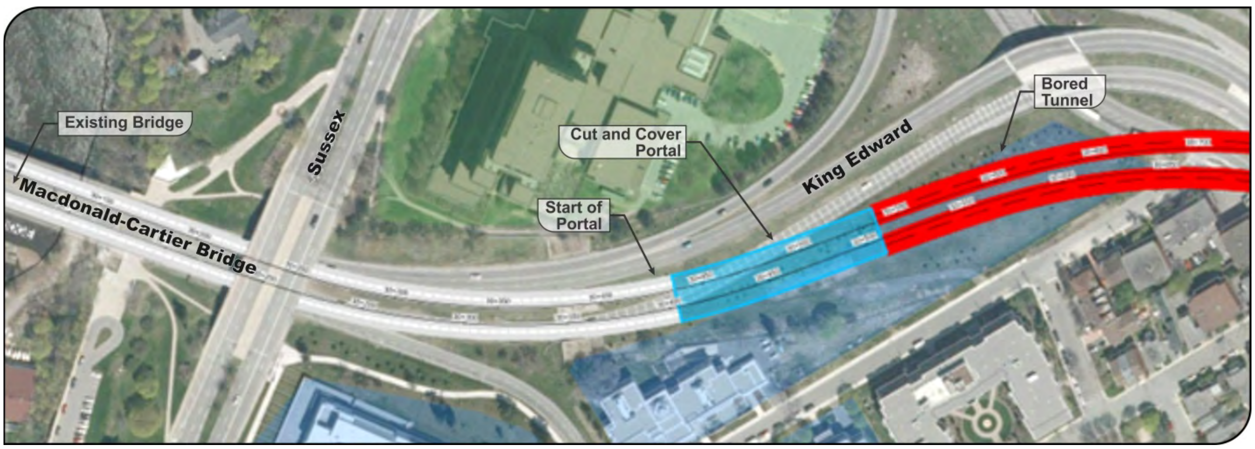


Figure 31: New Traffic Arrangement – North Portal

However, it is recognized that the most feasible options would significantly impact the State of Qatar future embassy property, immediately south of the King Edward Avenue, as it transitions from the Macdonald-Cartier Bridge. The study team revisited this alignment in order to refine both the horizontal and vertical geometry of the north and southbound portals and tunnels. The portal arrangement is similar, but introduces a tighter curve at the start of the tunnel and will require additional works at the surface to maintain all of the existing road and access connections. **Figure 32** illustrates the revised portal arrangement and **Figure 34** illustrates the tunnel profile of the north portal.

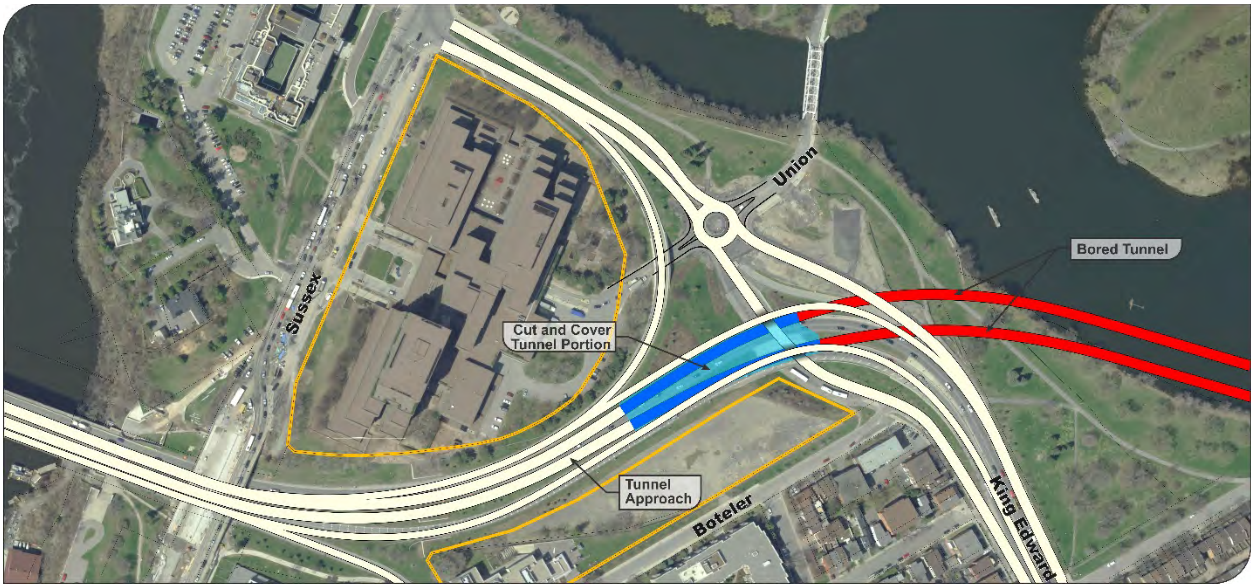


Figure 32: REVISED New Traffic Arrangement - North

The location of the north portal also conflicts with various large utilities (**Figure 33**). These include the local storm network along the Macdonald Bridge Approach and a 1980mm x 1310mm storm outfall pipe which internally includes the Sanitary King Edward Avenue Pullback. The local network follows along the bridge approach straight to the Macdonald Bridge and outlets at Ottawa River. The outfall pipe crosses the bridge approach and continues to the Ottawa River in a more northern direction, going underneath the Lester B Pearson Building. Based on the tunnel's alignment and effect on the bridge approach's geometry, both of these conflicts would require that the services be relocated to continue servicing the surrounding area. It is possible for the local network to be moved, avoiding the portal layer. The outfall sewer would be moved closer to the King Edward Underpass to avoid the tunnel.

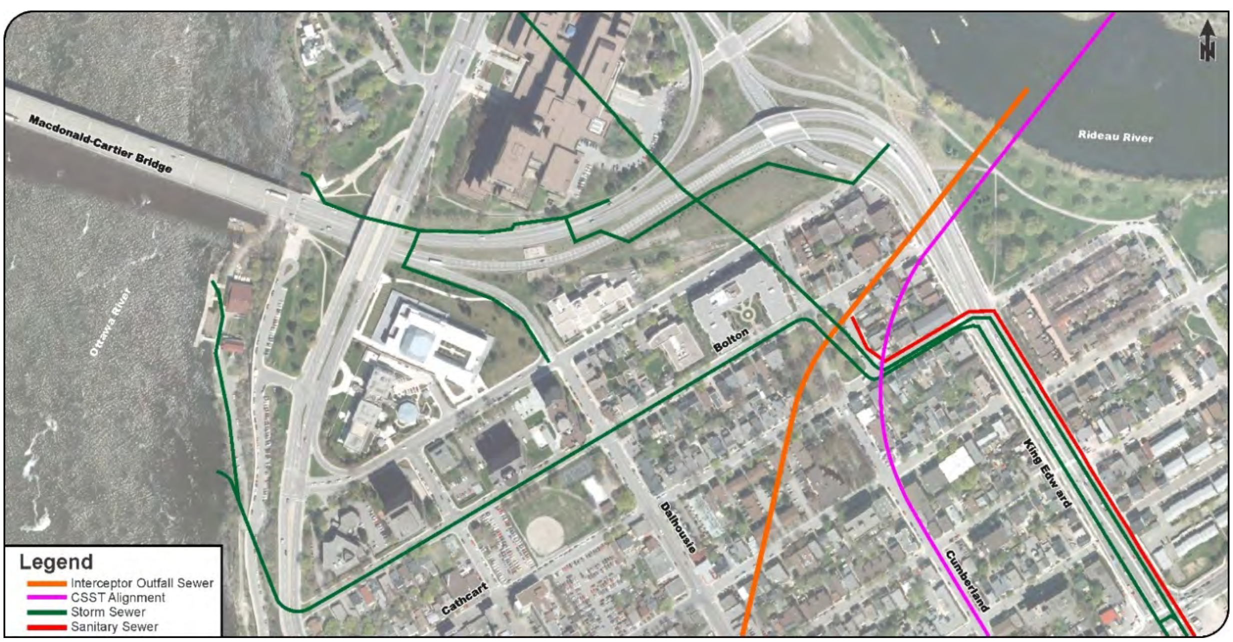


Figure 33: Major Underground Utilities – North Portal

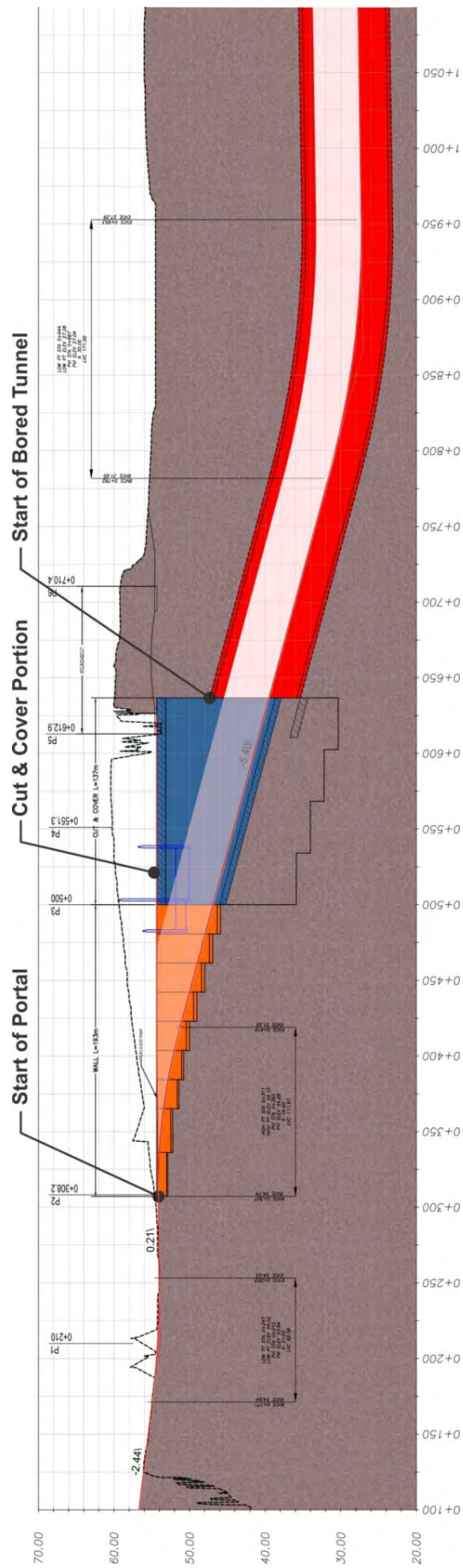


Figure 34: Tunnel Profile – North Portal

Two notable utilities cross the tunnel alignment just south of the north portal, the CSST and Sanitary Interceptor Outfall Sewer. These large sanitary sewers pose concern as their proximity to the tunnel is less than the desired buffer of five meters. Mitigation measured would be required in field to ensure that both sewers remain undisturbed during construction. This interface area will need to be constructed in a trench to provide adequate risk mitigation.

The cut and cover portal would extend to the north side of Bordeleau Park where the TBM or conventional tunnelling would begin (or end). The park also provides a site for staging of the works.

4.1.4 South Portal Impacts

There are important elements that impact the proposed alignment at the south portal (**Figure 35**). The RCMP campus lands will be impacted by the proposed alignment, particularly at the intersection of Vanier Parkway and Coventry Road where a roundabout is proposed to improve traffic flow.

The proposed tunnel alignment impacts various existing infrastructure at the southern portal. The alignment has been proposed to follow the existing circulation route within the RCMP campus lands to link to the Coventry Road and Vanier Parkway intersection with a proposed roundabout to improve traffic flow (shown in **Figure 36**). This route impacts to the Rideau River Eastern pathway, North River Road, and access to the RCMP parking lots and position of the existing gate. **Figure 37** illustrates the tunnel profile of the south portal.

Security for the RCMP site, particularly if the parking lot to the north is still used to service the site, will need to be considered. Some form of pedestrian crossing will be needed, and could be either elevated or underground depending on how it connects to the main building. Access to the parking lot and main facility will also need to be reviewed.

Multiple utilities exist at this location, including the sanitary Rideau River Collector sewer and connecting 900mm pipe, a 600mm watermain, and two storm outfalls, sizes 600mm and 2700mm. **Figure 35** illustrates the utilities at the southern portal. Both the Rideau River Collector and 600mm watermain cross the tunnel with less than the desirable 5 metre buffer and mitigation measures would be required to keep both undisturbed during construction. The 900mm sanitary sewer, 600mm storm outfall, and 2700mm storm outfall would need to be relocated out of the tunnel alignment. Both the 900mm sanitary sewer and 2700mm storm outfall could be replaced along Wright Street, requiring an easement to contain the sewers. The 600mm storm outfall current services the RCMP buildings and would require to be relocated south of the tunnel.

The additional traffic on the new leg of the Coventry/Vanier Parkway intersection through the RCMP site will need to be reviewed in terms of noise and vibration impacts on the adjacent developments, particularly the townhouse complex in the northeast quadrant of the intersection and residents along Wright Street.

Options to allow drivers to exit the tunnel entrance after leaving the roundabout, and before they commit to travelling to the Macdonald-Cartier Bridge and crossing the river, will need to be reviewed as there are no opportunities to provide an off-ramp at the north portal. The option of a U-turn between the inbound and outbound lanes of traffic, or a ramp connection to North River Road would both need to be reviewed.

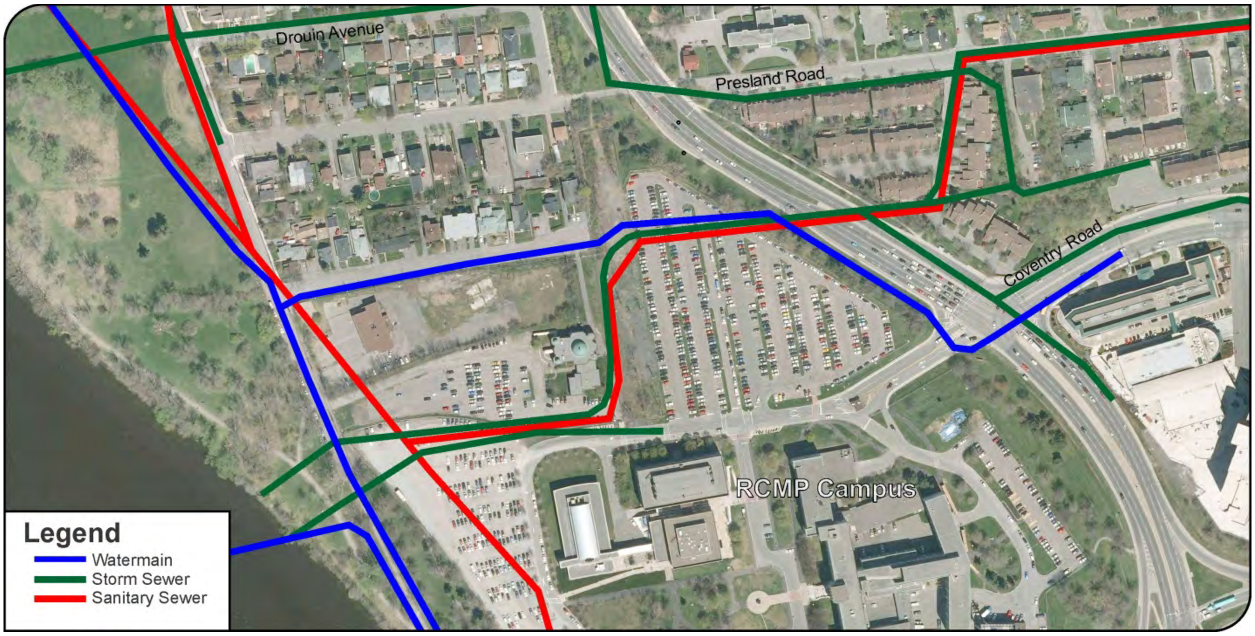


Figure 35: Impacted Major Underground Utilities – South Portal

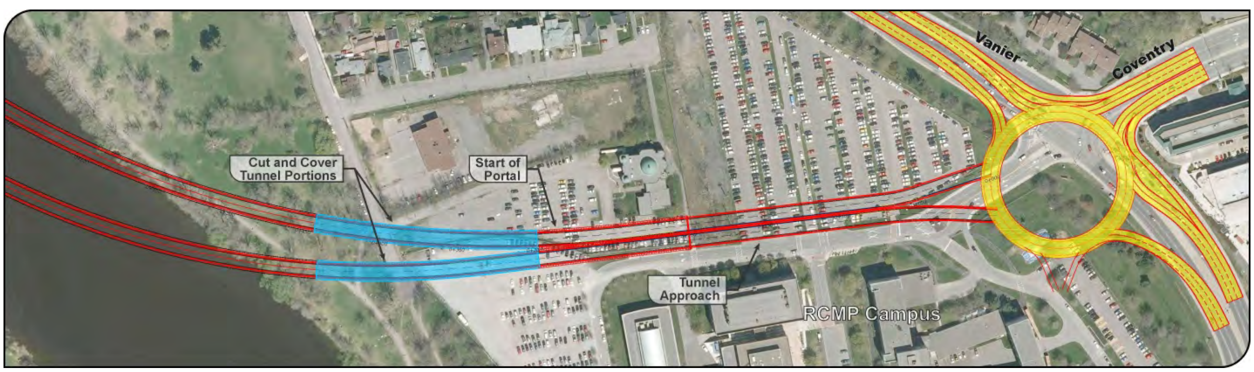


Figure 36: New Traffic Arrangement – South Portal

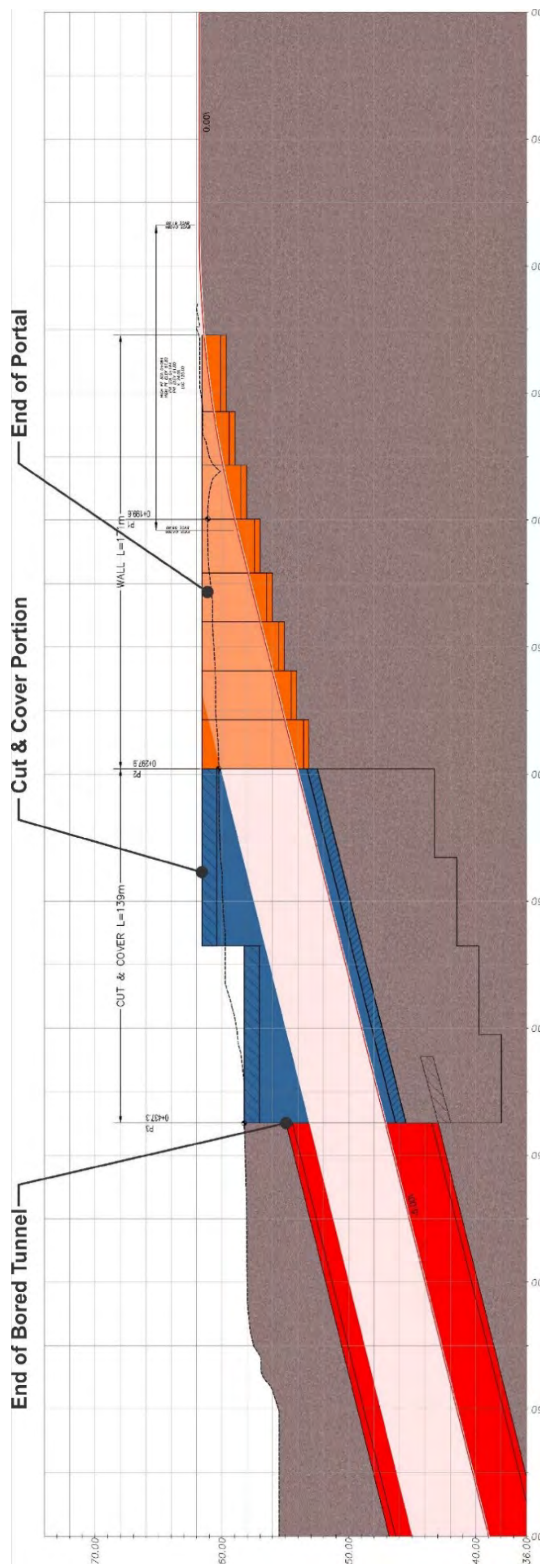


Figure 37: Tunnel Profile – South Portal

4.1.5 Cross-Section

The tunnel cross section should be structured to accommodate all construction and maintenance equipment foreseen for the tunnel. Using the applicable international standards and the safety rules for such a road tunnel connection the basic geometrical elements for each tube include:

- Two lanes 3.75m width considering the tight curves and slope;
- Maximum transversal slope of the carriageway due to the curve effect equal to 5.52% according to AASHTO;
- Two walkways 1.12m width with free height of 2.3m according to NFPA 502;
- The space for the jet fans 1.2m in diameter;
- The cross section needed to evacuate the exhausted air confined on top by a concrete deck 25cm thick;
- Space for cables ducts and drainage system along the sidewalks.

In addition, it is likely that a series of pedestrian and vehicular cross passages will be needed to connect the two tubes.

No vehicle laybys will be constructed, which means that stopping within the tunnel will not be permitted. If a vehicle must stop, it should stop in the right lane so that the tunnel can continue operating with a single lane (the left lane) for the distance needed to overpass the obstacle or arrange for the needed interventions.

Figure 38 to **Figure 41** show the construction results of the equipped cross sections for both conventional and mechanized excavation processes.

Figure 38: Cross Section – Conventional Excavation along a Straight Alignment (excavation area = 110 square metres)

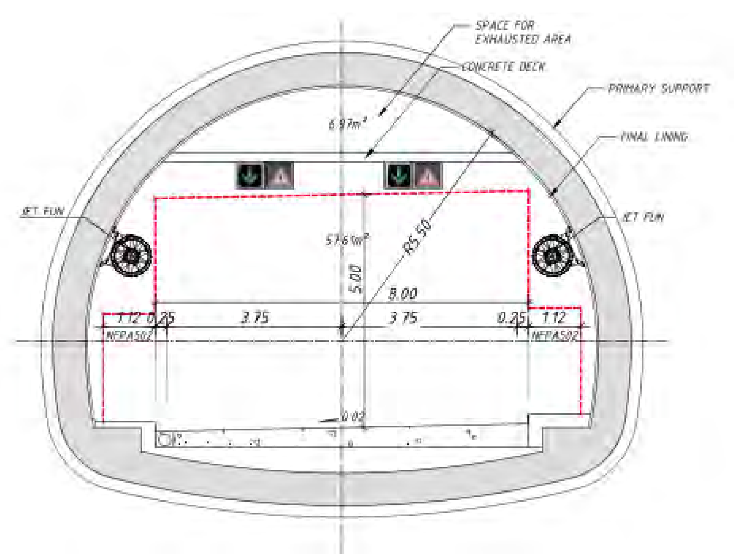


Figure 39: Cross Section – Conventional Excavation along a Curved Alignment (excavation area = 110 square metres)

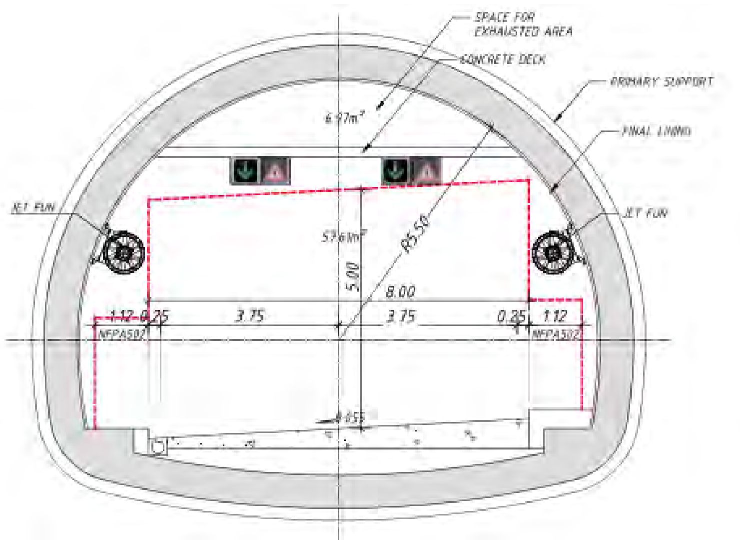


Figure 40: Cross Section – Mechanized Excavation along a Straight Alignment (excavation area = 120 square metres)

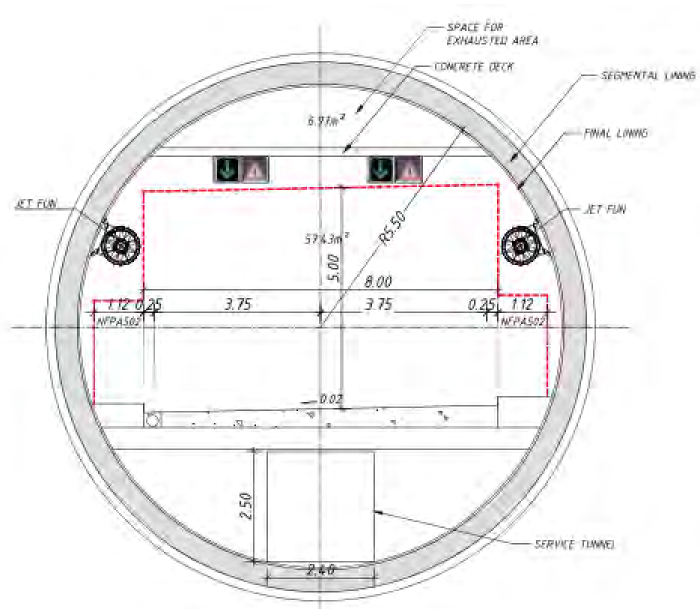
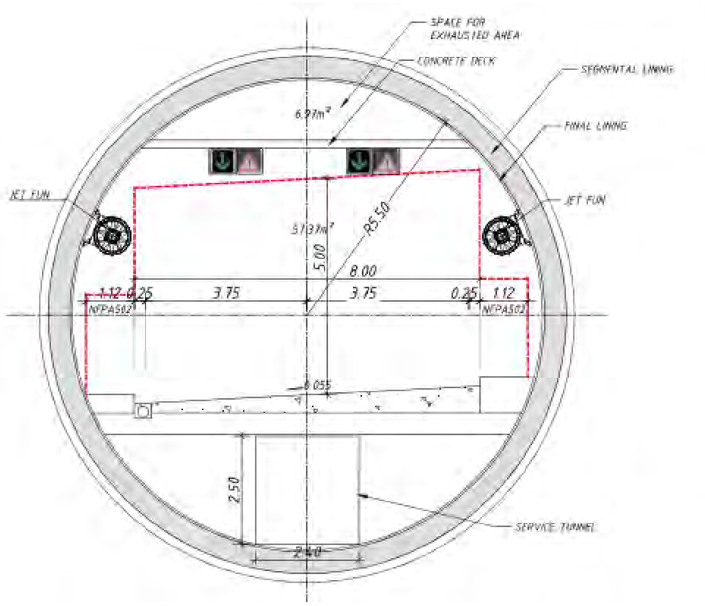


Figure 41: Cross Section – Mechanized Excavation along a Curved Alignment (excavation area = 120 square metres)



The main difference between the two sections is that one has free space underneath the carriageways as a result of a full round section.

The urban location of this tunnel can benefit from this space availability: the “below-the-road” space can be used in different ways such as:

- Additional entrance of rescue crew (the normal / principal one will be the other tube with appropriate equipment);
- Space to locate some additional utilities not in conflict with the road uses (i.e. telecommunications cables and low to mid voltage electrical power).

The tight horizontal geometry at the north portal may mean that the cut and cover portal structure may need to be longer than absolutely necessary to navigate the tight turn and to construct the passage under the CSST and IOS. This may have a marginal cost impact but significantly reduce construction risk.

4.2 Geotechnical Conditions and Hydrogeology

The tunnel alignment is located in an urban setting, and near-surface fills should be anticipated throughout the project area. The fill should be expected to be highly variable in composition, ranging from reworked silty clay to silty sand, to imported crushed stone. In the area of the portals, it is expected that the fill at the north portal is 2 to 3 metres thick and consists of silty sand fill with metal and concrete debris and cobbles. At the south portal, fills are expected to consist of sand with varying amounts of silt, clay, and gravel, and are expected to be 1 to 3 metres thick. Thin alluvial deposits may be present at both portal locations and should also be anticipated along the Rideau River. A relatively thin alluvial sand cap is also indicated to be present along the central portion of the study area, in the neighbourhood known as Sandy Hill. The fill and alluvial sand cap, where present, are underlain within much of the study area by Champlain Sea clay. The upper 3 to 5 metres of the clay have often been weathered and form a stiffer crust. Along the central part of the alignment between Laurier Avenue and Beausoleil Drive in the area known as Sandy Hill, the silty clay deposits are about 10 to 15 metres thick and, below the depth of weathering, are of firm to stiff consistency. North of Beausoleil Drive, the deposits are about 2 to 11 metres in thickness, are stiff to very stiff. Loading of the clay close to or beyond its apparent preconsolidation pressure (e.g., through lowering of the groundwater table and/or additional building loading) can result in significant consolidation settlement (i.e., compression) of the deposit. Clay deposits are not anticipated at either of the portal locations. The underlying glacial till deposits typically consist of a heterogeneous mixture of gravel, cobbles and boulders in a matrix of silt and sand. The glacial till along the tunnel alignment is anticipated to vary from about 1 to 5 metres in thickness. At the north portal and approach, a thin layer of till (less than 1 metre) is expected. At the south portal and approach, the glacial till is expected to be 4 to 5 metres thick.

The bedrock in the study area consists of series of conformable sedimentary rocks, consisting of Ordovician shales, limestones, dolostones and sandstones that are, in turn, underlain unconformably by igneous and metamorphic rock of the Precambrian Shield. The main geological formations found within the study area within the anticipated depth of construction are, from oldest to youngest, Verulam, Lindsay, Billings and Carlsbad Formations. The Verulam Formation is characterized by limestone, with thin interbeds and seams of shale. The overlying Lindsay Formation is characterized as nodular limestone, with varying thickness of shale interbeds, with shale content increasing upwards in the sequence. Conformably overlying the Lindsay Formation is the Billings Formation, which consists of a weak, slake susceptible shale. Gradationally superseding the Billings Formation is the Carlsbad Formation which consists of interbedded shale, fossiliferous calcareous siltstone, and silty limestone. Shales of the Carlsbad and Billings Formation are anticipated south of about Somerset Street, with limestones of the Verulam and Lindsay formation anticipated along the remainder of the tunnel alignment. Based on available information, the bedrock surface along the tunnel alignment is anticipated to be at an elevation of between about 48 and 55 metres elevation. Because of the sedimentary nature of the bedrock, the bedrock surface is expected to be relatively flat-lying, however, some steps in the bedrock surface should be expected.

Major water features within the study area include the Ottawa River to the north of the project area and the Rideau River to the east. The Rideau Canal is located just west of the study area; however, it is a man-made seasonal watercourse and is understood to have minimal connectivity to the bedrock groundwater flow system. Regional groundwater flow in downtown Ottawa is generally north towards the Ottawa River and east towards the Rideau River. Groundwater levels in the study area are typically between about 2 and 5 metres below ground surface, and higher near the river.

4.3 Construction Methods and Impacts

This section examines the possible excavation techniques to be used for the main part of the alignment, thus the underground portion of the two running tunnels.

The portal area will be excavated using other techniques such as:

- Open trench excavation;
- Cut and Cover using a top-down or bottom-up sequence; and
- Short stretch of conventional tunneling to enter underground section in a protected area.

Initial investigation reviewed two types of tunneling techniques: conventional tunneling or mechanized tunneling.

4.3.1 Conventional Tunnelling (NATM)

Construction sequence for conventional tunneling are listed here below with reference to longitudinal sections of a typical tunnel:

1. Excavation at the face with mechanical equipment (road-header or back-hoe excavator)
2. Scaling and mucking
3. Temporary support installation
4. Water-proofing membrane installation at invert
5. Steel cage installation at invert
6. Concreting of the invert
7. Water-proofing membrane installation at sidewalls and crown
8. Steel cage installation at sidewalls and crown
9. Concreting of the sidewalls and crown
10. Installation of drainage system for the water from platform
11. Filling and road structure
12. Deck construction
13. Installation of all Equipment
14. Road surface finishing

Steps 1 to 4 can be split in two to accommodate two excavation phases such as top-heading and bench.

Steps 5 to 11 can be done at the end of the process when all excavation is complete.

Steps 11 to 14 are the last tasks in the process when all civil works into the tunnel are completed.

In advance of the excavation, a pre-consolidation of the face or a pre-support of the face/roof might be required depending on the anticipated geotechnical conditions (fractured zone, buried valley filled with soft soil, etc.). Depending of the characteristics of these more difficult conditions, there may be longer lead times to achieve the appropriate interventions ahead of the face.

The installation of the permanent concrete liner (Steps 5 to 9) can either be done at a certain pre-determined distance from the face (say 150 metres to allow for efficient tunneling) or at the end of the excavation. The choice is based on the following two main elements:

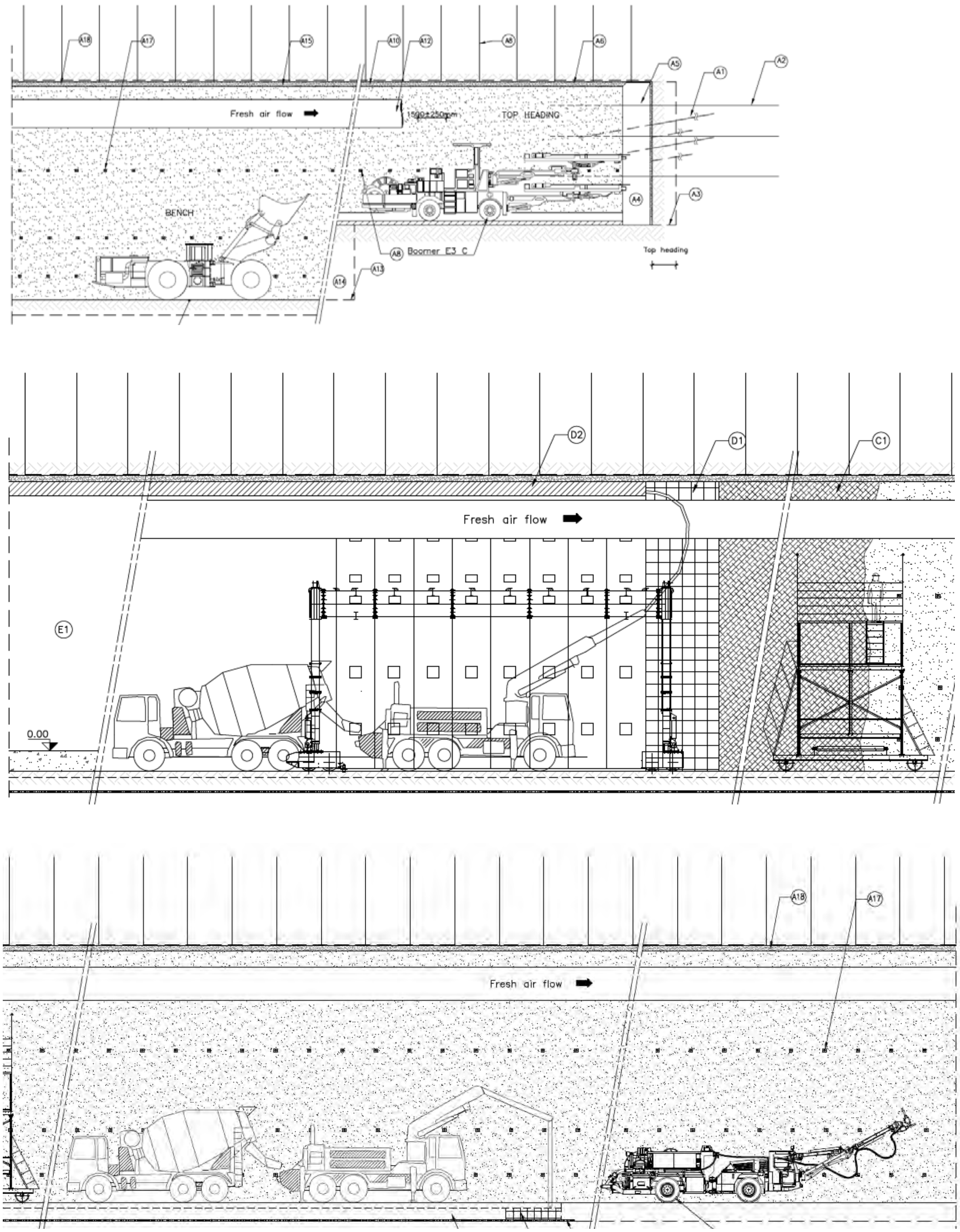
- Install the final lining (for stability reasons); and
- Close the section to stop the drainage effects.

This technique which has a quite slow average speed of advance has the advantages that it can be organized to excavate from all the four available faces (two for each the two portals) and that the construction can start using quite ordinary and available machine from immediately after the portals construction.

The disadvantages in this specific case is that the drainage effect on the surface can be quite extensive (see section 4.2) and that to stop that effect a full set of equipment from the installation of waterproofing system to concreting must be available for any advancing face. Impacts to the organization of work and the slowly-advancing long-drained section are key considerations in this case.

Figure 42 shows a typical sequence as described above. The machine at the face in the first sketch is applying reinforcement at the face while the excavation machinery (backhoe excavator or road-header is waiting).

Figure 42: Scheme of a Typical Conventional Method Sequence for Tunnelling



The typical equipment used for this type of tunneling are listed here below for reference:

- Tunneling excavator or road-header
- Backhoe excavator
- Compact excavator
- Excavator equipped with bucket
- Dump Truck
- Flatbed truck
- Sprayemec or similar shotcrete pumping system
- Load Haul Dumper
- Boomer or Jumbo for rock bolts installation or face consolidation

4.3.2 Mechanized Tunnelling (TBM)

The other possible excavation technique is mechanized tunnelling using a shield Tunnel Boring Machine with the ability to pressurize the face in order to control stability of the ground contour (i.e., prevent ground settlements) and prevent drainage of the ground water.
There are two types of systems are available on the market:

1. Earth Pressure Balance (EPB) system;
2. Slurry Shield (SS) system.

The schemes of the two machines are explained in **Figure 43** and **Figure 44**.

Figure 43: Slurry Shield Operating Principle

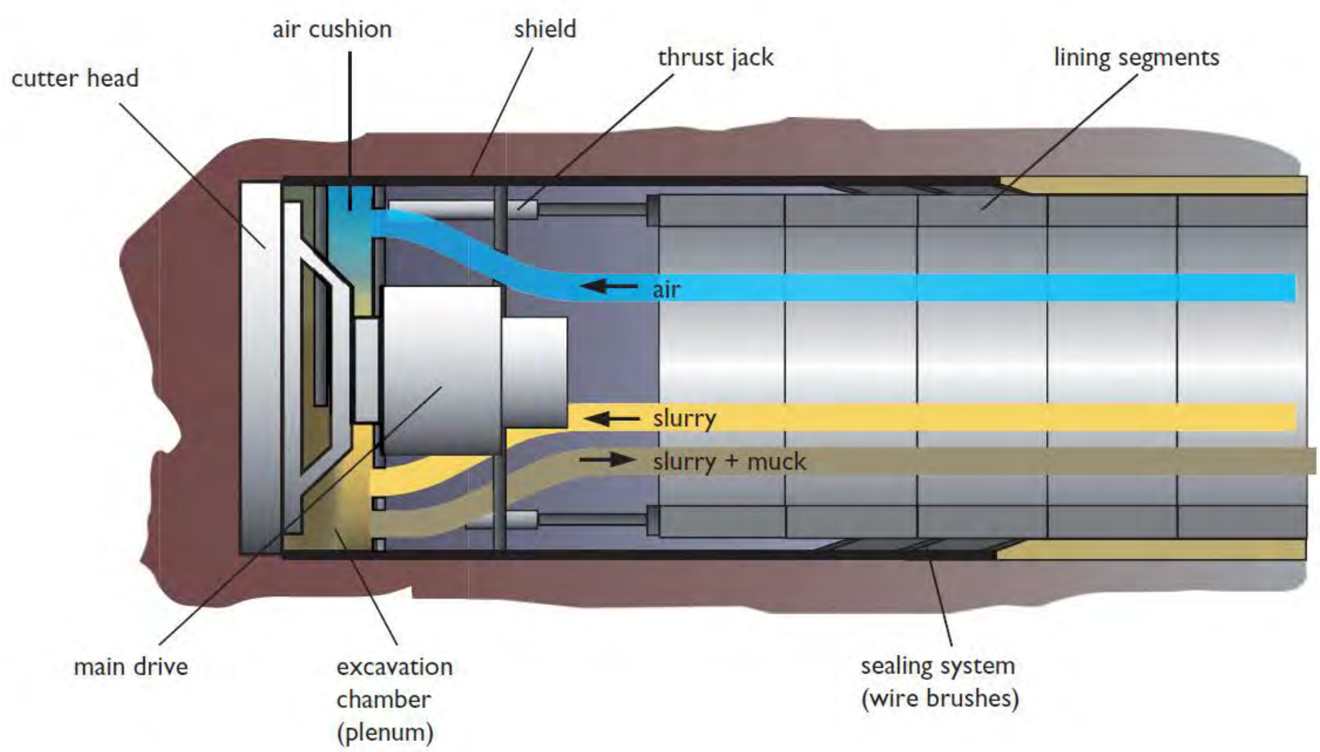
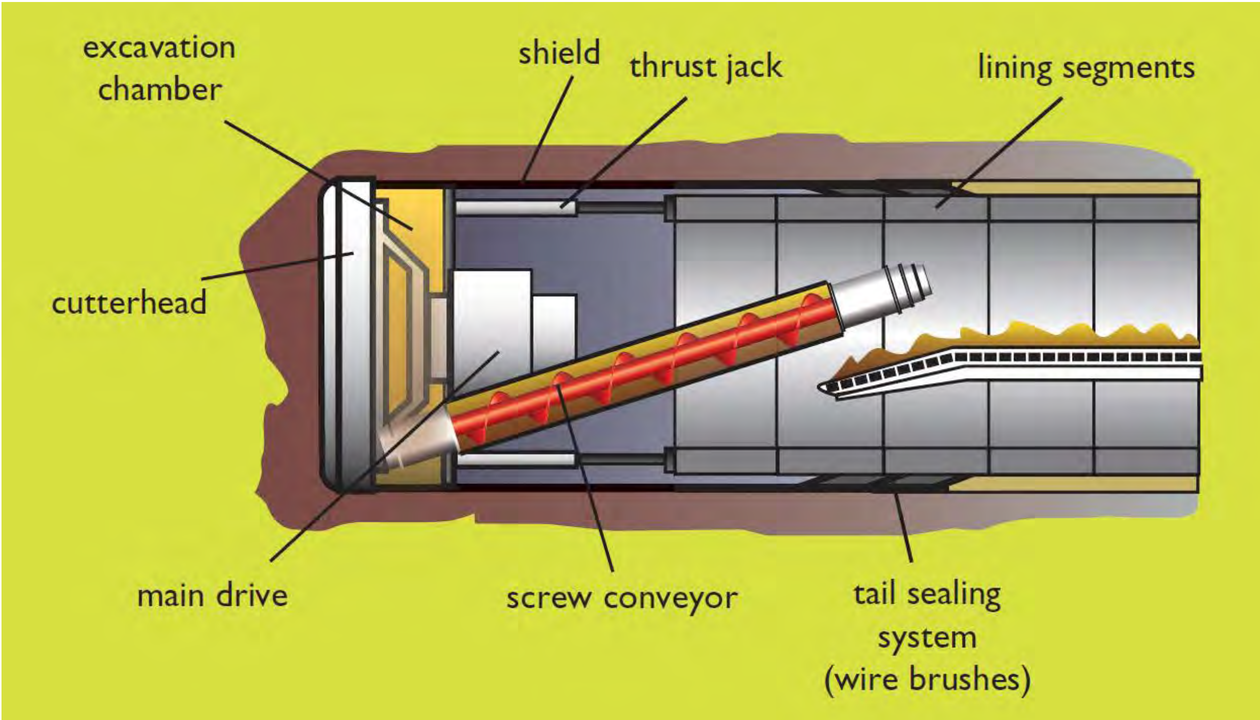


Figure 44: EBS Shield Operating Principle



Despite the differences between the two specific techniques' capabilities to keep the face pressure, based on the geotechnical characteristics of the ground and related equipment required, the basic sequence is as follows.

1. Advancement of the TBM for one single round (1.5-2.0m for this dimension)
2. Installation of one ring inside the shield (same length of the round)
3. Installation of drainage system for the water from platform
4. Filling and road structure
5. Deck construction
6. Installation of all Equipment
7. Road surface finishing

During normal advancement of the TBM (Steps 1 and 2), the muck removal is continuous using a conveyor belt or special trucks.

The tunnel is excavated by repeating steps 1 and 2 for the entire tunnel length. Simultaneously the tunnel is lined with a water-proofed segmental lining made of precast elements. The face stability and the water pressure (to control drainage) are assured by applying the correct face pressure through one of the two available techniques.

Installation of the road-related elements (Steps 3 to 7) can proceed only at the end of the excavation of any single tube. The two tubes can be excavated using a single TBM that makes the two runs, one after the other, or two identical TBMs can be run simultaneously (offset by 100-150 metres) for the excavation depending on the schedule constraints. The advantage of this technique is that it guarantees the minimum of disturbance to the surroundings both in terms of existing structures or utilities and water table equilibrium.

The advancement speed of the face is higher when compared to conventional tunneling. The time to construct the tunnel using conventional tunnelling with four advancing faces would be similar to using a single TBM machine making two passes (one for each tunnel).

Tunnel boring cannot begin until portal construction is complete and the TBM is assembled on site prior to launching.

It must be noted that no significant difference is anticipated in the TBM operation or speed of advance in case of passing through fractured zone or buried valley filled with soft soil.

4.3.3 Construction of Cross Passages

The Cross Passages should be constructed with an inter-distance of about 250m as part of the emergency management strategy. For every three pedestrian cross passages, one vehicular cross passage must be installed (1 per km). The construction of the cross passages in terms of transversal section can be considered as the same for the two techniques, as shown in **Figure 45** and **Figure 46** (one for the pedestrian and one for the vehicular).

Figure 45: Pedestrian Cross Passages Geometry

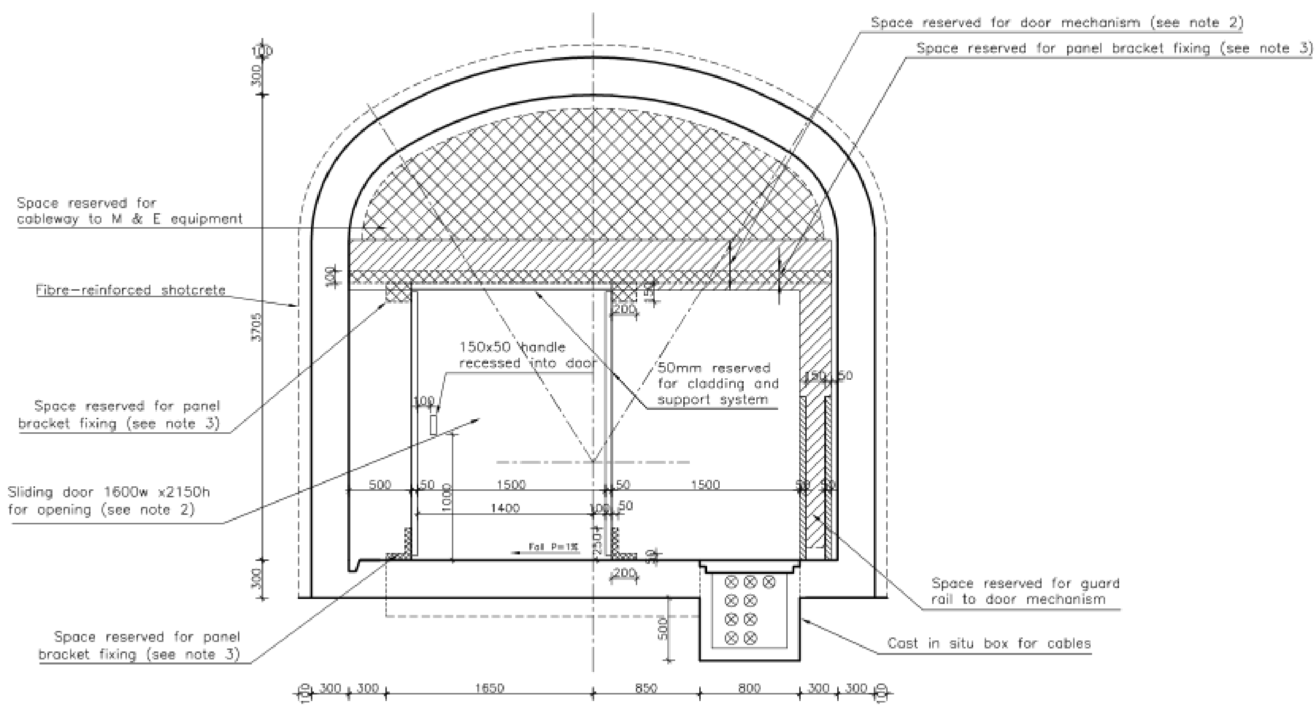
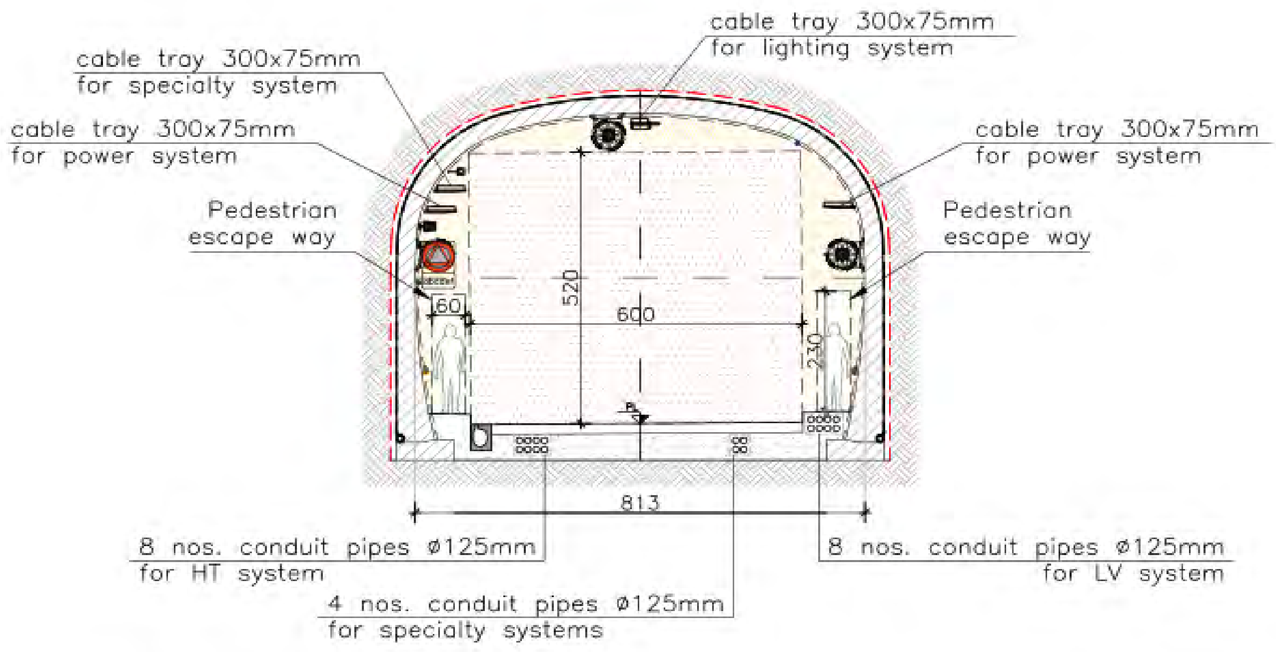


Figure 46: Vehicular Cross Passages Geometry



Differences exist between the two excavation techniques. They include:

For the Conventional tunneling

- The excavation can proceed using the same available equipment used for the main excavation.
- The excavation must be completed after excavation of the main tunnel and before the completion of the waterproofing membrane installation for sidewalls and crown. This can extend the length of open or unlined tunnel for the leading excavation.

For the Mechanized tunneling

- Specific equipment must be introduced for this work.
- The construction is less dependent on the progress of the main tunnel, and can be delayed up to the end of the complete tunnel excavation in order to minimize the time along which the cross passage will remain open and thus with a drained section.

4.3.4 Preferred Construction Method

Based on the available geotechnical and hydrogeological assessment and the description of the possible construction method, the preferred alternative at this stage is a mechanized tunnelling solution implementing a system to control face stability and drainage effects, as well overall settlement impacts. The rationale for this choice is as follows:

1. The densely urbanized area requires the implementation of a construction technique that minimizes impacts on surroundings reducing to the degree possible any potential settlements that could occur during excavation process;

2. The drainage effects of the excavation deeply impacts this specific environment because of the soft Leda Clay (normal consolidated soft material), which can undergo substantial consolidation if a change in water level is introduced;
3. The underground of Ottawa has many utilities that will be crossed by the truck tunnel; although a careful alignment study has been already carried out and further refinement are possible, it is anticipated that the twin tunnels will pass very close to some of these utilities and thus a further even more controlled excavation will be needed to avoid unacceptable movements; and
4. The anticipated geological environment indicates the possibility of an hydraulic connection between river and tunnel section when the tunnel is under or in the close vicinity to the river; deep fractured areas or buried valleys might occur along alignment; these two circumstances also suggest that an excavation technique able to deal with unanticipated mixed face condition and permeable soil/rock should be used.

4.4 Buildings / Properties Impacted

The alternative passes near several significant buildings and properties. The alignment aims to avoid passing under buildings such as embassies and educational institutions like schools. **Figure 47** highlights the path of the alternative in relation to significant buildings nearby. Embassies are indicated with blue and educational facilities and other buildings of interest are indicated with green.

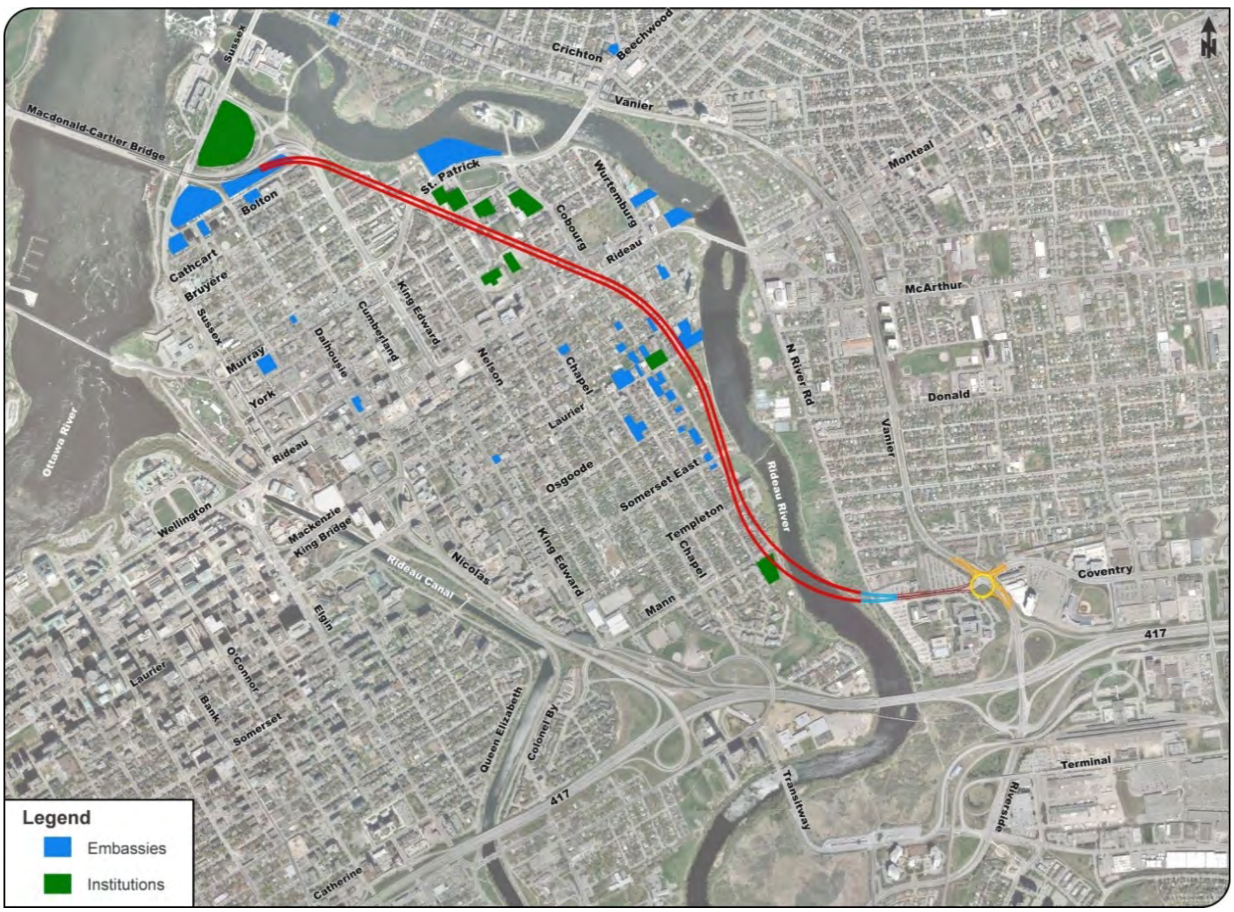


Figure 47: Important Buildings Surrounding the Most Feasible Alternative

4.5 Major Underground Utilities Impacted

This alternative has minimal interference with major underground utilities. The tunnel passes under the CSST and IOS near the north portal. There are several sewer conflicts with the alternative near the south portal, but all appear to be manageable.

4.6 Systems (Ventilation / Emergency Management)

4.6.1 Design Guidelines

The following design standards and guidelines were reviewed as best practices and used as input to the current study;

- World Road Association (PAIRC) 2012R05EN, Road Tunnels: Vehicle Emissions and Air Demand for Ventilation
- National Fire Protection Association (NFPA) 502 (2014)
- European DIRECTIVE 2004/54/EC, which outlines the minimum safety requirements for tunnels in the Trans-European Road Network.

These standards and guidelines inform the functional requirements for the normal and emergency air handling. The following sections outline the development of a conceptual design solution. The analysis also assumes that given the urban context of the project and the depth of the tunnel, particularly at the midpoint under Sandy Hill, that intermediate vent shafts will not be part of the design and that ventilation plant will be located at the north and south portals only.

4.6.2 Projected Traffic

According to the current traffic flow and TRANS regional model at year 2031 planning horizon, the daily peak hour traffic through the tunnel would be 2,400 vehicles per hour with 6.8% of trucks. According to PIARC 2012, congested traffic can be defined as traffic speed in a tunnel that is lower than 20km/h.

4.6.3 Tunnel and Design Assumption

The proposed length of tunnel alignment for the cross country solution is 3,370m (including the north and south portals).

In order to estimate the ventilation requirements in the current feasibility study, the following assumptions have been made:

- Tunnel type — Twin-bore tunnel with unidirectional traffic
- Tunnel cross section area — ~ 60m^2
- Maximum tunnel gradient — 5.4% (ramp at North portal with 400m in length)
- Tunnel height — 5.7m from pavement to ceiling
- Surface roughness of tunnel lining — 3.0mm
- The fleet composition
  - Heavy goods vehicles — 6.8%
  - Passenger cars — 93.2%
- Design fire size — 100MW (no dangerous good in tunnel)
- Maximum air/smoke velocity in exhaust duct — 12.5m/s

4.6.4 Fresh Air Requirement in Normal Operation

In normal operation conditions, the tunnel ventilation system should control the pollution level to satisfy the following criteria from World Road Association (PIARC) 2012 recommendation (Table 3).

Table 3: Set points and thresholds for tunnel air quality

Traffic situation	CO (ppm)	Visibility (OP) m^{-1}	NO_2 (ppm)
Free flowing peak traffic 50 - 100 km/h	70	0.005	1
Daily congested traffic, stopped on all lanes	70	0.007	1
Exceptional congested traffic, stopped on all lanes	100	0.009	1
Planned maintenance work in a tunnel under traffic	20	0.003	1
Threshold values for closing the tunnel	200	0.012	1

The NO_2 level is the average value and the rest are peak values in tunnel.

Planned maintenance work should be scheduled when the tunnel traffic is light (e.g. night time). Otherwise, traffic control should be in place to keep the pollution levels under control.

Based on the above criteria and the design conditions in the last section, the fresh air requirements for different traffic speeds and for different pollutants are shown in the following table (Table 4).

Table 4: Fresh air requirements

Traffic speed (km/h)	Fresh air requirement (m3/s)		
	CO	OP	Nitric Oxide / Nitrogen Dioxide
70	9	113	42
50	11	114	45
40	13	83	52
30	15	83	62
20	19	85	80
10	18	44	81
0	16	11	84

In estimating the fresh air requirement, a 30% margin has been added to that for CO (carbon monoxide) and NOx (nitrogen oxides) and 10% for OP to account for the 400m 5.4% gradient tunnel section at each portal. The small margin for OP is due to the importance of non-emission opacity that is not affected by tunnel gradient.

As indicated in the table above, the maximum fresh air amount required to achieve the desired air visibility within the tunnel, and required to meet the design criteria is 114m^3/s.

4.6.5 Ventilation Requirement in Fire Emergency

For tunnels longer than 1000m, emergency ventilation is required by the NFPA 502 and DIRECTIVE 2004/54/EC. As an urban tunnel, traffic congestion has to be considered in case of fire emergency, as vehicles downstream of a tunnel fire may not be able to drive out of the tunnel freely because of congestion further ahead. This leads to the choice of semi transversal ventilation system as required by the following design guidelines (Table 5):

Table 5: Selection of emergency ventilation mode

CONDITION	PIARC 2011		NFPA 502		2004 / 54 / EC	
NOT CONGESTED TRAFFIC (1)	LONGITUDINAL VENTILATION	√	LONGITUDINAL VENTILATION	√	LONGITUDINAL VENTILATION Allowed for tunnel length <3000m	✖ √
	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM	√	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM	√	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM For tunnel with length >3000m	√
CONGESTED TRAFFIC (2)	LONGITUDINAL VENTILATION[A]	✖ √	LONGITUDINAL VENTILATION	✖	LONGITUDINAL VENTILATION For tunnel up to length of 3000m (specific measures to be taken)[B]	✖ √
	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM	√	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM	√	TRANSVERSE OR REVERSIBLE SEMI TRANSVERSE SYSTEM For tunnel with length >3000m	√

(1) Drivers downstream of the fire are free to escape by their own cars (traffic downstream of the fire site can leave the tunnel and the stopped traffic upstream is in the fresh airstream of the longitudinal ventilation.

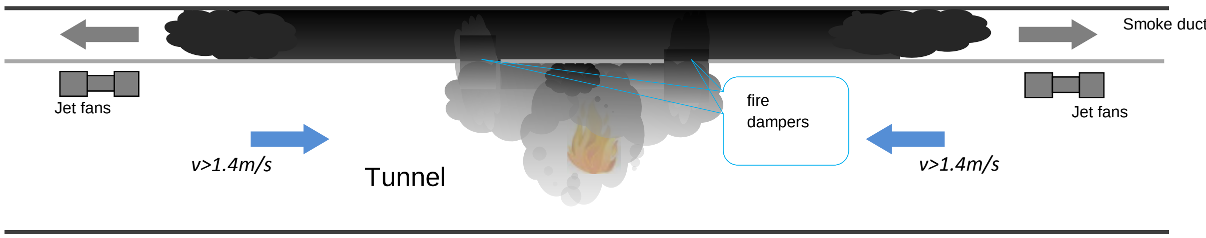
(A) Smoke exhaust duct is required, when traffic exceeds a threshold that has to be estimated through risk analysis (eg. 3000 vehicles/day).

(B) Appropriate traffic management, shorter emergency exit distances, smoke exhaust at intervals (intermediate shaft shall be required).

(2) People can be on both sides of the fire; this case needs the same kind of analysis, in the design phase, as a bi-directional tunnel.

With the semi-transversal ventilation system, smoke is extracted into the ceiling duct of tunnel through locally open fire dampers. Jet fans are provided to control the air flow in the tunnel so that the longitudinal velocity at the fire site is near zero. This limits the spread of smoke layer and provides a safe egress path underneath it. **Figure 48** illustrates the proposed emergency ventilation system.

Figure 48: Semi-transverse Fire Ventilation Scheme



In the above system, the total mass of smoke extracted with the tunnel ventilation fans is the same as that of the fresh air provided in the tunnel by the jet fans. In order to contain the spread of fire smoke and also prevent the breakup of smoke layer, the World Road Association 2011 has recommended that the tunnel air velocity from each side of the fire be less than 1.4m/s. The total air flow extracted by the ventilation system is 168m^3/s.

Subject to environmental restrictions at the portal locations ventilation plants may be provided at each tunnel portal or at one portal only. With the maximum design air velocity of 12.5m3/s, a required smoke duct cross sectional area of 6.72m^2 is required, assuming that smoke is extracted by fans at both portals.

4.6.6 Tunnel Ventilation Fans

In semi-transverse ventilation systems, there are a series of dampers along the roof of the tunnel. While only those immediately above the fire emergency are fully opened, the ventilation system must account for some duct leakage around the other dampers. Accounting of duct leakage, the initial estimation of tunnel ventilation fan capacity is 200m^3 @2500Pa. In addition, 20 jet fans with thrust of 800N each are also required in each tunnel tube to manage the air flow in the tunnel.

4.6.7 Emergency Management

In case of a fire alarm in the tunnel, all tunnel users should be advised to evacuate through the cross passages or one of the portals. The ventilation system (including the fans for cross passage pressurisation) will be switched to, and started in, emergency mode. The cross passage pressurisation fans will start. All fire dampers on the ceiling of tunnel will be partially open and the smoke extraction fans start running. After the fire has been located, all fire dampers away from the fire site will be closed leaving only two to four dampers right above the fire site open for smoke extraction. Tunnel jet fans will start and the longitudinal air flow in the tunnel will be monitored to ensure that the air velocity at the fire site is close to zero and the smoke layer has been controlled for emergency egress.

After the evacuation has finished, the ventilation system control would be handed over to the emergency services to facilitate firefighting.

4.7 Environmental Impacts

4.7.1 Natural Environment

Phase 1 Environmental Site Assessment:
Nineteen (19) potentially contaminating activities (PCAs), mainly associated with former retail fuel outlets, auto garages with underground storage tanks (USTs), and/or dry cleaning facilities, were identified along the tunnel alignment. In addition, fill of poor quality containing metal and polycyclic aromatic hydrocarbons (PAHs) exceeding the MOE Table 3 Standards is present at the area where the south portal of the tunnel will be constructed (based on the results of previous subsurface investigations completed by Golder for the City of Ottawa). Eight (8) of the 19 PCAs were identified to represent medium and high risks of subsurface impacts (4 medium and 4 high risks PCAs) due to the close proximity of these PCAs to the tunnel alignment and/or portals, the nature of the PCAs and/or the physical and chemical properties of the chemicals associated with these PCAs (in terms of their mobility in the subsurface) and their potential for downward migration into fractured bedrock. Eleven (11) PCAs of the 19 PCAs were identified as having a low risk of potential subsurface impacts on the project as these PCAs were either located cross to down gradient of the alignment, were located at a greater distance, or the chemicals associated with these PCAs are characterized with low mobility in the subsurface.

The presence of PCAs with high or medium risk of subsurface impacts may result in subsurface contamination along the tunnel alignment which may have implications on the management of potentially contaminated excavated materials during the construction. Considerations should be given during the groundwater pumping or underdrainage, as significant changes in groundwater levels during tunnel construction may result in drawing-down the overburden groundwater along with potential contaminants into the bedrock (if the overburden and bedrock groundwater are hydraulically connected) or mobilization of contaminants from one property to another.

In addition to the identified PCAs, naturally occurring compounds such as, metals and/or organic compounds may be present in concentrations exceeding MOE Table 3 Standards within the excavated tunnel rock spoils and there is acid generation potential of the shale bedrock which would need to be considered with respect to potential off-site reuse options.

A full desktop Environmental Site Assessment is found in Appendix F.

4.7.2 Archaeological and Heritage Impacts

Archaeology:
A Stage 1 assessment of the complete truck tunnel study area is required by provincial legislation. This assessment will identify specific areas of archaeological potential in areas which will be altered by the truck tunnel construction. A cursory review of the tunnel access points reveals that they are both near large water bodies (the Ottawa and Rideau River) and they are both in areas of early historic settlement therefore they have immediate archaeological potential. As archaeological potential is recognized, Stage 2 archaeological assessment will be necessary in areas which have not been previously disturbed by development.

Cultural Heritage:
The truck tunnel study area from the Ottawa River to the Rideau River contains cultural heritage resources identified and protected by federal, provincial and municipal governments. The area is also full of potential cultural heritage resources in buildings and streetscapes that may have cultural heritage value but have not yet been formally identified or protected.

A heritage impact assessment should be done for the north-west tunnel portal area to determine potential impacts on the nearby federal heritage building at 125 Sussex Drive and the nearby Lowertown West Heritage Conservation District.

A cultural heritage evaluation report is recommended for all properties west of the Rideau River that are adjacent to and directly affected by surface ground disturbance to determine if any potential cultural heritage resources will be affected or if the streetscape/potential heritage landscape will be affected. Parks Canada should be consulted regarding the proposed construction and operation beneath the Rideau River (a Canadian Heritage River) and potential impacts to the Earnscliffe National Historic Site of Canada.

Along the general tunnel alignment, if surface ground disturbance is required within properties or immediately adjacent to properties identified as cultural heritage resources including designated heritage properties and heritage conservation districts, a heritage impact assessment is recommended to determine the effect of this disturbance on these properties.

A complete Archaeological and Cultural Heritage Overview is found in Appendix G.

4.7.3 Air Quality, Noise and Ground Vibrations

Potential impacts relating to air quality, noise and ground vibrations have been qualitatively summarized and compared to standard criteria as a precursor to more detailed subsequent studies.

Air Quality:
Vehicle emission from gasoline and diesel combustion engines would be the primary sources of emissions related to the project. Typical products of combustion include Carbon Monoxide, Oxides of Nitrogen, gaseous hydrocarbons, and particulate matter. The recommended ventilation scheme for the truck tunnel is a semi transverse system, where fresh air is drawn in through the entrance portal (and possibly intermediate vent shafts). Emissions inside the tunnel would be exhausted though the exit portal into the atmosphere. Given concentration levels of vehicle emission inside need to be maintained to safe levels for vehicle occupants inside the tunnel, the impact to surroundings at the exit portals is expected to be minimal. The ventilations fans will need to be sized appropriately to provide sufficient fresh air inside the tunnel to dilute emissions to concentrations levels below health and safety limits.

Roadway Traffic Noise:
Airborne noise associated with the tunnel would be limited to the portal and vent shaft areas. The north portal is located just south of the Macdonald-Cartier Bridge at the virtual intersection of Boteler Street and King Edward Avenue. Currently a large volume of traffic passes through the area and existing noise levels at nearby residences are expected to be above the City of Ottawa's Environmental Noise Control Guidelines' objective level of 55 dBA, primarily due to King Edward Avenue. The introduction of the tunnel is not expected to produce significant changes in noise levels compared to existing conditions, as traffic patterns are expected to be similar. The south portal is located in an employment / institutional area with the nearest residence more than 100 m from the portal alignment, therefore minimal noise impacts are expected from the south portal. Locations for vent shafts should be selected away from noise sensitive buildings, or incorporate industrial silencers into the design to maintain acceptable noise levels at nearby sensitive locations.

The additional traffic on the new leg of the Coventry/Vanier Parkway intersection through the RCMP site will need to be reviewed in terms of noise and vibration impacts on the adjacent developments, particularly the townhouse complex in the northeast quadrant of the intersection and residents along Wright Street.

Ground Vibrations:

The estimated ground vibration levels are generally low, and fall below the human perception level of 0.1 mm/s (72 dBV), in areas located at least 50 meters away from Highway 417 and 6 meters away from the proposed tunnel. Within these distance limits, the impacts of ground vibrations gradually increase to perceptible levels with increasing proximity to roadways. Ground-borne noise levels produced by ground vibrations have similar impacts.

5. Consultation

This feasibility study did not have a public consultation component. No public open houses or other public consultation activities were undertaken. The focus was on developing the technical feasibility of an alignment as a “proof of concept” to feed into the definition of potential future work, which may include a comprehensive Environmental Assessment Study and a more involved planning and design effort. Formal consultation with First Nations also did not occur as part of this study. Such consultation would be part of any subsequent Environment Assessment Study.

The study process began with the establishment of a Technical Consultation Group (TCG), aimed at providing feedback to the consulting team at various stages of the study. Members of the TCG included City staff, particularly those with expertise in construction and asset management, as well as members of both Quebec and Ontario Provincial Transport Ministries and the National Capital Commission. City staff included members from the following departments:

- Transportation Planning;
- Rail Implementation;
- Policy Development and Urban Design;
- Realty Services;
- Development Review – Urban Services;
- Transit Services;
- Traffic Services;
- Traffic Operations;
- Infrastructure Services;
- Asset Management;
- Design and Construction;
- Paramedic Services;
- Fire Services;
- Police Services.

The TCG convened five (5) times throughout the process: four (4) times through a meeting format and once through a workshop format. The following is a summary of each TCG meeting, highlighting the issues and outcomes needed to move the project forward:

5.1 TCG Meeting No. 1

The first meeting introduced the study, clarified the feasibility nature of the study, and provided background for the upcoming workshop. The consulting team presented an overview of the work plan as well as background information and issue identification pertaining to the following topics:

- Existing traffic patterns;
- Review of similar tunnels;
- Tunnel sizing issues;
- Utilities information; and
- Geotechnical considerations.

The consulting team also presented potential routing options (First Round of Alternatives – Pre-Workshop) aimed at linking the Macdonald-Cartier Bridge to the Nicholas Street interchange. There was also a discussion about introducing a routing option that would link the Macdonald-Cartier Bridge to the Vanier Parkway. Although this alternative was beyond the scope of the original Study Area, both the consulting team and TCG members believed that a Vanier Parkway routing option warranted further consideration for the duration of the study. TCG members asked questions and provided meaningful feedback to the issues presented.

5.2 TCG Meeting Workshop

The second TCG event was a workshop, intended to solicit more detailed feedback from TCG members on the various topics presented at Meeting No. 1. Members offered advice and expertise in breakout discussion topic areas related to the following topics:

- Traffic;
- Tunnel cross-sections options;
- Utilities information;
- Tunnel profiles;
- Routing options (tunnel alternatives);

Tunnel alternatives presented at the workshop were screened out and some additional routes were added at the end of the workshop for further consideration, generating the Second Round of Alternatives – Post-Workshop. A cross-country route connecting the Macdonald-Cartier Bridge to Vanier Parkway was also added to the set of alternatives.

5.3 TCG Meeting No. 2

TCG Meeting No. 2 summarized and discussed the background research conducted and input gathered from the workshop for the various tunnel alternatives. Consulting team members provided a revised set of tunnel alternatives while TCG members provided feedback on proposed locations and construction techniques, including design details of each of the south portals (Nicholas Street interchange and Vanier Parkway interchange). The consulting team also presented a preliminary set of criteria that would be used to evaluate the tunnel alternatives.

TCG members offered feedback and additional evaluation criteria to the ones presented by the consulting team. The consulting team then took this information and incorporated it into the revised list.

5.4 TCG Meeting No. 3

This meeting summarized and discussed the refined set of six (6) tunnel alternatives to be carried forward for analysis and evaluation (Third Round/Carry Forward Alternatives). The consulting team presented the preliminary analysis and evaluation results of each tunnel alternative while TCG members provided feedback on the preliminary methodology and analysis of each alternative. After providing explanation and justification for each criteria assessment, the consulting team identified preliminary technically preferred plan(s). These preferred alternatives were carried forward for further refinement. The presentation also highlighted some of the ongoing major factors that may be challenging to tunnel construction, safety and operation as well as other considerations that may influence tunnel operations such as tolls, ownership and overall costs.

5.5 TCG Meeting No. 4

This final meeting was used to review a draft of the final report and the planned presentations for MTO Regional Staff and the City's Transportation Committee. TCG members offered any outstanding feedback that they believed should be considered in the final report. Members were also encouraged to provide written comment on the report following the meeting. The consulting team then referred to this feedback for consideration for the final report.

6. Other Considerations

There are other important considerations that need to be addressed for tunnel implementation. Construction, ownership and tolls are all interconnected in the implementation process.

6.1 Delivery Strategy

KPMG International's report, *Project Delivery Strategy: Getting it Right* discusses project delivery options available and describes the factors that influence selection of one method over another. Developing an effective project delivery strategy can influence project cost, quality of design, construction, long-term maintenance, and project completion date. Various project delivery strategies and methodologies are defined in the table below (Table 6).

Table 6: Project Delivery Strategies and Methodologies

Strategy	Methodology
Traditional	• Design-bid-build • Multiple prime contracting
Collaborative	• Agency construction management • Construction management at risk • Design-build • Engineering-procurement-construction • Turn key
Integrative	• Alliancing • Partnering • Integrated project delivery
Partnership	• Build-operate-transfer • Build-own-operate • Build-own-operate-transfer • Concession • Design-build-finance-operate • Private finance initiative • Public private partnership

A tunnel delivery strategy will depend on decision makers' choice and objectives for the future. KPMG International's complete report detailing project delivery strategy is found in Appendix H.

6.2 Ownership

Determining ownership of a future tunnel will be an important consideration. It will determine how the tunnel will function and operate based on who owns it.

As noted earlier (Section 2.2), the review of other urban tunnels indicates that the majority are publically owned, either by the city they are in (to serve local needs) or the provincial or state authority (part of a regional network). With the move towards alternative project delivery for large municipal infrastructure projects, the option of creating a concession to construct the tunnel and operate it for a defined period is a prime candidate for this project. Ultimately the tunnel would be owned by one level of government or another.

There are unique arrangements in Ottawa whereby there are three levels of government who own and operate portions of the road network. In addition, the 1961 agreement in place relating to the Macdonald-

Cartier Bridge will need to be carefully reviewed to determine if it impacts the potential arrangements to construct and operate a tunnel.

There are several tunnel ownership options worth considering:

Crown Agency

As a state-owned enterprise, a crown agency could manage the commercial activities of the tunnel. This model is appropriate if the link is considered part of the provincial highway network and is developed to connect Highway 417 with the provincial highway network in Gatineau.

Private Ownership

If the tunnel assumed private ownership, a private company would own, operate and maintain it. Similar to other private infrastructure investments like Highway 407 in the Greater Toronto Area, a private company would manage the day-to-day activities of the tunnel. The Ambassador Bridge connecting Windsor and Detroit is also privately owned. Agreements would need to be reached with the provincially-owned highways of Quebec and Ontario to ensure operations run smoothly and efficiently with highway connections.

Public Ownership

If the tunnel was owned by a public entity, the same or a different public entity would assume responsibility for its operation and maintenance. It would connect with the provincially-owned highway networks in both Ontario and Quebec.

Tunnel Authority

The creation of a tunnel authority is another possible option to assume responsibility of the tunnel's management, operation and maintenance. It would need to work directly with provincially-owned connecting highways.

6.3 Considering Toll

The National Cooperative Highway Research Program (NCHRP) has prepared an excellent two-volume report entitled "Assessing Highway Tolling and Pricing Options and Impacts". The Forward of the report states:

> *"NCHRP Report 722: Assessing Highway Tolling and Pricing Options and Impacts provides state departments of transportation (DOTs) and other transportation agencies that are considering instituting or modifying user-based fees or tolling on segments of their system with a decision-making framework and analytical tools that better describe likely impacts on revenue generation and system performance. This report is presented in two volumes. Volume 1: Decision-Making Framework should be of immediate use to staff responsible for structuring the policy-level evaluation of potential tolling and pricing solutions to examine their policy implications, performance expectations, and financial impacts. Volume 2: Travel Demand Forecasting Tools will provide staff who develop the forecasts of potential revenue, transportation demand, and congestion and system performance with an in-depth examination of the various analytical tools available for direct or adapted use."*

As this report provides an overview of the tolling issues relevant to the feasibility of a truck tunnel in Ottawa, this report has been used to develop the following section of the report. The following précis attempts to condense the key elements of the decision-making framework into a concise overview of the process. While some elements of the language have been slightly modified to make them relevant to the Ottawa and Ontario context in this précis, the essence of the original is intact. The high level overview is presented here with a more detailed overview in Appendix I. The complete report is available from the NCHRP website or through the Transportation Research Board.

Before embarking upon an exploration of the issues associated with tolling and pricing, it is helpful to establish definitions for these terms.

- ***Tolling strategies*** involve the imposition of fees for the use of a roadway facility. Classic examples include fixed fees that motorists pay—usually based on the number of axles or vehicle weight—to cross a bridge or tunnel or drive on a tolled highway facility. Tolling strategies are used primarily as a revenue source to finance and expedite the implementation of needed transportation improvements.
- ***Pricing*** specifically refers to strategies that vary toll rates by time of day or traffic volume level to manage congestion or use of that facility. Pricing is used as a tool to influence travel behavior, reduce congestion, maximize vehicle throughput and provide new transportation options.

The distinction between the two concepts underlies their primary goals:

- Creating a new income stream that can be used to pay for transportation improvements; and
- Using roadway pricing as a means to manage congestion.

Tolling provides decision makers the advantage of a new source of revenue that can be leveraged up front to implement costly improvement projects. At the same time, advances in toll collection technology provide the opportunity to use pricing to encourage drivers to consider travel options that can reduce congestion.

Other goals often associated with tolling and pricing include expediting the delivery of new transportation improvement and, in certain cases, engaging the private sector as an investment partner. The goals underlying tolling and pricing projects drive the evaluation and decision-making processes, which must be tailored to assess and compare the ability of different pricing options in meeting regional needs.

6.3.1 Process

Despite a great variety of approaches and significant influence from regional conditions, the National Cooperative Highway Research Program has created a decision-making framework based on their research and various case studies. They divide the work into four major phases of analysis when assessing tolling and pricing projects:

- ***Exploratory.*** The purpose of this initial phase is to determine if further study of tolling and pricing is warranted. This type of conceptual analysis may be used to investigate and compare a range of toll facility configurations, though selection of a specific pricing alternative is premature at this stage.
- ***Preliminary.*** The purpose of this phase is to identify promising projects and create a shortlist of candidates, including each candidate's most promising alternatives. These studies evaluate the feasibility of tolling and pricing projects in an individual travel corridor, a region, or an entire province or state.

- ***Feasibility.*** The purpose of this phase is to identify a preferred physical layout and tolling/pricing scheme for each project. Additionally, project documentation required for environmental approvals is prepared together with a financial feasibility study incorporating refined traffic and revenue estimates. This phase is essential before advancing individual projects into implementation.
- ***Investment Grade.*** The purpose of this phase is to prepare project rating documentation that assesses the potential financial investment using private sector bonds and serves as a basis for subsequent contract negotiations with the private-sector partners. It is an integral part of project implementation if toll-backed financing is involved. Investment Grade Study provides the necessary data to finalize funding arrangements in the Financial Plan, the formal document that details a project's cost estimate and revenue structure and identifies financial resources to be utilized in meeting those costs. This phase is not required for tolling and pricing projects that are not financed by debt backed by future toll proceeds.

Several different factors need to be considered at each phase of the analysis, including:

- ***Transportation Planning (P).*** Considers the pricing project within its regional transportation system and established goals, and requires a comprehensive analysis of the transportation and environmental impacts of candidate pricing projects.
- ***Project Definition (R).*** Relates to the physical layout, access, and cross-section design of the facility as well as analysis of various possible pricing forms, toll rates, and associated toll-collection technologies.
- ***Cost Estimates (C).*** Relates to the comprehensive estimation of all project cost components, including construction, operations and maintenance, and toll-collection equipment. Estimates of capital and operating costs are prepared for most tolling and pricing alternatives.
- ***Traffic and Revenue Forecasts (T).*** Involves preparing traffic and revenue forecasts. Similar to project costs, at the earlier stages of analysis, traffic and revenue forecasts are prepared at the preliminary sketch level. Later, as the physical parameters and pricing forms become more detailed, traffic and revenue forecasts can be more rigorously refined using advanced modeling tools. Traffic and revenue forecasts play a crucial role in the final choice of the preferred pricing alternative and the optimal toll rate that meets the established regional goals, such as congestion relief, revenue maximization, or social welfare maximization.
- ***Financial Feasibility (F).*** Brings together cost and revenue estimates and results in evaluation of the project's financial feasibility. The goal of this assessment is to create a viable financial plan that substantiates full coverage of the project cost from a combination of the expected revenues and additional available funds. This aspect is closely intertwined with traffic and revenue forecasts and also includes the development of important assumptions on the use of generated revenues and availability of other funding sources to support the project.
- ***Institutional Assessment (I).*** Relates to the institutional and organizational framework used to implement and operate tolling and pricing projects. It comprises such issues as the type and structure of the public authority sponsoring the project, the entity responsible for collecting tolls, the entity responsible for enforcement, the entity responsible for the maintenance of the physical infrastructure (both roadways and toll collection equipment) and the possible involvement of a private sector partner. The institutional assessment identifies an appropriate ownership structure for the project and the distribution of roles, responsibilities, and contractual agreements between the various entities involved. This aspect is closely intertwined with financial issues, as well as legal issues that establish the rights and responsibilities of the various entities involved in developing and maintaining the project.

- ***Legal Review (L).*** Involves the assessment of the legislative and regulatory issues associated with pricing and the possible need to provide the sponsoring agency with the authority to collect tolls. Even if general tolling authorities are in place, the use of advanced pricing forms (such as fixed or dynamic variable pricing, pricing differentiation, and associated discounts/exemptions) and issues associated with the use of project revenues may require specific approvals.
- ***Public Outreach (O).*** Includes numerous issues associated with the acceptance of pricing by the general public. The public outreach process involves two aspects: 1) testing different pricing concepts with key stakeholders and the public at large to understand what aspects and policies are generally acceptable and which are not; and 2) educating the public on the need for pricing and the mobility benefits it affords. Feedback from the outreach process is essential to the formulation of alternative pricing concepts. The findings of the outreach process also have a significant impact on decision-making for tolling and pricing projects, as they identify real-world constraint on possible pricing projects, forms, and toll rates.

The phases of analysis and the factors to be combined to form a matrix:

		Technical Aspect							
Phase		Transportation Planning (P)	Project Definition (R)	Cost Estimates (C)	Traffic and Revenue Forecasts (T)	Financial Feasibility (F)	Institutional Assessment (I)	Legal Review (L)	Public Outreach (O)
Exploratory	1	P1	R1	C1	T1	F1	I1	L1	O1
Preliminary	2	P2	R2	C2	T2	F2	I1	L2	O2
Feasibility	3	P3	R3	C3	T3	F3	I3	L3	O3
Investment Grade	4	P4	R4	C4	T4	F4	I4	L4	O4

6.3.2 Exploratory Phase

Exploratory studies typically are done to test the overall feasibility of tolling and pricing concepts within a corridor, region or potentially an entire state or province. They generally rely on limited existing data and involve simple analysis with basic assumptions about the potential market for a new facility, toll levels, and levels of capture. The purpose of these studies is to gain a sense of the market and potential for congestion relief with the application of tolling and pricing.

Exploratory tolling and pricing feasibility studies generally require coordination with existing planning processes, and involve baseline assessments of local travel, economic, financial, and political conditions, as well as public opinion. This information is used to define a variety of tolling or pricing options for further review in subsequent phases. Ultimately, if the decision to move forward with further study is made, plans for doing so would need to be incorporated in the planning process.

Outcomes of Exploratory Feasibility Assessments:
Given the different contexts—both in terms of demographics and geographic characteristics, as well as relationships between planning agencies—a number of different outcomes can be expected at the end of an Exploratory Phase of tolling and pricing. One outcome could be the identification of a shortlist of corridors where the use of tolling and pricing may be effective in achieving regional goals and the recommendation that more detailed investigations take place. Similarly a recommendation could be made against further consideration of the topic. Alternatively, the use of tolling and pricing could be adopted as part of regional transportation policy, or a decision could be made to test the use of tolling and pricing on a pilot basis.

6.3.3 Preliminary Phase (2)

Preliminary studies are typically done to test the feasibility of tolling and pricing projects in an individual travel corridor or region. As described in further detail below, the information flowing from preliminary feasibility studies is often used as inputs to the planning process:

- ***Coordination with the Regional Planning Process (P2),*** including incorporation into the transportation master planning process. Decision makers should be aware of the following procedures and issues as they consider the addition of tolling and pricing projects to regional transportation plans.
- ***Defining Preliminary Tolling and Pricing Options (R2),*** including the physical layout of the facility (number of lanes, access control, and links to transit facilities and service). Pricing projects should be accurately coded in the model network with precise locations for access points and ramps. Vehicle eligibility should be determined. Trip-based or daily pricing should be considered. At more advanced stages of project development, various bulk discounts and credit-based forms may be considered with a trip-based or daily pricing form. Basic toll rates need to be tested. The simplest forms of tolling considered at early stages of evaluation include fixed (one-direction) tolls, distance-based tolls, and entry-exit tolls. Time-of-day variations and the impacts of inflation on toll revenues should be assessed.
- ***Legislation and Regulations (L2/L3/L4),*** need to be clarified as pricing initiatives progress to more advanced stages and as the nature of pricing applications under consideration becomes clearer. Private sector participation, various procurement and delivery models and financing should be investigated. Other agreements on vehicle registration information sharing, use of video and interoperability agreements should be framed.
- ***Public Outreach (O2),*** must continue through this stage. Input gathered through this process must be used to develop alternatives that can garner the support of the widest possible constituency.

6.3.4 Feasibility Phase (3)

The Feasibility Phase of the decision-making framework normally aligns with the environmental assessment process. As mentioned earlier, the Feasibility Phase may involve the assessment of tolling and pricing concepts emerging from earlier phases of the decision-making framework if a more comprehensive approach is being followed. Alternatively, the consideration of tolling and pricing may begin directly with the Feasibility Phase if a specific pricing project is identified by public decision makers or private investors, or if a decision is made to consider the possible use of tolling or pricing on a highway improvement that is already undergoing environmental review.

6.3.5 Investment Grade Phase (4)

As described in Section 3.1.6 of the NCHRP report, most toll facilities are financed by borrowing debt backed by future toll revenues. A number of coordinated activities must take place to reach financial close. They begin with the completion of investment grade traffic and revenue forecasts and the preparation of a financial plan. Documentation describing these analyses is then given to rating agencies, which review the materials and give the project an investment rating. With a rating in place, the project developer seeks potential investors and secures financing commitments. If adequate financing can be raised within the required timeframe, a closing date is set at which lenders provide the project developer with the proceeds from their various loans and other debt instruments. Also, upon reaching financial close, other official project agreements become valid and binding.

Investment grade studies are often completed in parallel with environmental assessments. Information on preliminary capital and annual operating and maintenance costs from these studies is frequently used to obtain a preliminary indication of the financial feasibility. Refined cost estimates are used for the final financial plan.

7. Cost Estimate

A cost estimate for the project has been prepared. The estimate is in constant 2015$ and contains contingencies in keeping with the conceptual nature of the design work. In addition to the estimate prepared by the project team, an independent peer review was undertaken. The peer review noted that the costs for the bored tunnel appeared low based on current North American experience. The cost estimate includes the recommendations of the peer review team.

The cost estimate for the conceptual design followed the typical WBS structure used for City projects. At the conceptual level of design, parametric costing is undertaken using unit rates and quantities for hard cost items, lump sum estimates are added for typical elements such as geotechnical investigation and control plans, and typical percentages are added for project and construction management, design and engineering. Contingencies have been added on top of these line items to reflect the level of uncertainty in the design. A range of contingencies have been used in this case to highlight the conceptual nature of the design and provide a likely cost envelope for future planning work.

Some elements of the cost estimate are more highly variable than others. While the cost of excavation and asphalt as well as utility works are fairly typical in the Ottawa market, there are elements of the tunnel which are far less typical. In particular the mechanical and electrical systems that will be installed in the tunnel can vary in cost significantly depending on the safety codes adopted and the degree of sophistication in some of the monitoring and communications infrastructure. The cost estimate contingency percentages have been applied uniformly to each project element. Future stages should recognize the unique nature of this project and assess contingencies in a more focussed manner.

The estimated cost for the tunnel, with a contingency range, is $1.7 to $2 Billion, in constant 2015$. A detailed cost estimate has been provided to the City. The summary of the estimate is included below.

The cost estimate is broken into 12 WBS categories:

- 10 – Property:
    - Estimating the costs for real property, easements and temporary easements
    - City staff provided expected costs based on other similar City projects including costs for LRT and CSST easements as well as acquisition for road corridors and widenings
- 15 – General:
    - Includes costs for geotechnical Investigations to augment the desktop exercise undertaken as part of this project, construction management including an Environmental Control Plan and an Erosion and Sediment Control
    - Street Cleaning and Traffic Management costs are also estimated
- 20 – Utilities – Sanitary Sewers:
    - Identified modifications to sanitary sewers required to install the north and south portals are costed using typical City rates for similar work
- 30 – Roadwork – subdivided into four segments:
    - 30 – Roadwork South Portal
        - Includes all asphalt and soil removals (excavation and removal of earth and rock and the supply of backfill materials for the areas behind the retaining walls and over the roofed-over box), permanent roadway (granular base, curbs, asphalt courses), ancillary items (signs & pavement markings, electrical and lighting), site restoration (topsoil and sod), and roadway subdrains for the south portal area
    - 32 – Roadwork North Portal

        - Includes all asphalt and soil removals (excavation and removal of earth and rock and the supply of backfill materials for the areas behind the retaining walls and over the roofed-over box), permanent roadway (granular base, curbs, asphalt courses), ancillary items (signs & pavement markings, electrical and lighting), site restoration (topsoil and sod), and roadway subdrains for the north portal area
    - 35 – Roadwork Vanier/Coventry Roundabout
        - Includes similar items as category 30 for the road improvements beyond the south end of the tunnel access structure
        - Includes modifications to the local roads and accesses including installation of the proposed roundabout to replace the Vanier/Coventry intersection
    - 36 – Roadwork North end of King Edward
        - Includes similar items as category 32 for the road improvements beyond the north end of the tunnel access structure
        - Includes modifications to the local roads and accesses including blending the road changes into the south end of the bridge, the Dalhousie ramp and the modifications to King Edward needed to allow traffic to flow around the portal
- 40 – Structures:
    - Construction of the cantilevered retaining walls on the approach to the tunnel and the roofed-over portal structures, including preparation for the launch or retrieval of the TBM machines are included
    - Costs are based on typical costs per square metre of roof deck, walls and base slab
    - Excavation and site preparation are included categories 30 and 32
- 45 – Tunnel Works:
    - This is the largest single category in the cost estimate and includes all costs related to the tunnel proper, based on the use of a TBM and a concrete segmental liner
    - Indirect costs were estimated using industry-standard measures, and typically includes items such as equipment, mobilization and demobilization, operation and maintenance of the Contractor's facilities, weekend maintenance and field supervision. Bonding and insurance costs were also estimated.
    - Tunneling costs were developed using the proposed tunnel diameter and assumed progress rates. Excavation, tunnel liner installation and spoil removal were included. This is the largest single item in the estimate.
    - Mechanical, Electrical and Safety items, including fit out of the ventilation control building, fans, lighting, incident and fire detection, firefighting, CCTV, communication systems and UPS and emergency units were included.
    - Installation of the ceiling, roadway base and asphalt running surface was estimated.
- 50 – Drainage – Storm Water Management:
    - Identified modifications to storm water sewers required to install the north and south portals are costed using typical City rates for similar work
- 60 – Engineering:
    - Soft costs related to the design and approval of the project are added as a percentage (functional, preliminary and detail design and client/owner design management) or lump sum (environmental assessment, permits and approvals) on top of the hard construction cost estimate
- 70 – Project Management:
    - In addition to the engineering costs, a number of project management items are added as a percentage (construction management, indirect construction costs, general management, and 1% for public art) or lump sums (material testing, traffic management,

a public communications programme and administration office disbursements) on top of the hard construction cost estimate

The majority of the work and materials can be sourced in Canada, including the tunnel boring machine(s). There is local knowledge in the Ontario marketplace to support this project as similar large diameter bored tunnels have been built in the Greater Toronto Area (for the subway system) and in the Niagara Falls (for hydro-electric power facilities), however large diameter road tunnels present unique challenges. International expertise should be sought as part of the implementation to reduce risk and bring industry best practices to the project.

The table below provides a summary of the major categories of the cost estimate. A range is provided for each project grouping, reflecting the conceptual nature of the estimate and the range of contingencies applied.

Table 7: Cost Estimate Summary

Scope	**Likely Low Range**	**Likely High Range**
General Works	$40,000,000	$45,000,000
Road Works	$140,000,000	$160,000,000
Portal Structures	$65,000,000	$80,000,000
Tunnel Costs	$1,150,000,000	$1,350,000,000
Tunnel - Indirect Costs, Bonding, Insurance	*$180,000,000*	*$215,000,000*
Tunnel - Pavement	*$35,000,000*	*$40,000,000*
Tunnel - TBM Construction	*$675,000,000*	*$790,000,000*
Tunnel - Mechanical, Electrical, Safety	*$260,000,000*	*$305,000,000*
Engineering	$195,000,000	$225,000,000
Project Management	$110,000,000	$140,000,000
TOTAL	**$1,700,000,000**	**$2,000,000,000**

Cost Estimate is in constant $2015, contingencies have been applied elementally and globally and a range provided to reflect the conceptual nature of the design input.

8. Findings and Next Steps

Parsons was retained by the City of Ottawa to work with the major stakeholders to determine if a feasible alternative exists to provide a direct tunnel connection between the south end of the Macdonald-Cartier Bridge and Highway 417. The study looked at design parameters, known constraints and potential routes to connect to either the Nicholas or Vanier Parkway interchanges.

Through the study process the team found that:

- There is sufficient potential to divert truck traffic from the current KERWN Corridor to consider a tunnel, however not all trucks using the corridor would choose to use the tunnel as many trucks need to make local deliveries within the study area.
- The volume of trucks is not sufficient to warrant their own tunnel, leading the team to evaluate the potential use by car traffic.
- More than 25,000 vehicles per day are likely to use a tunnel facility to make the connection between the bridge and highway, with the Regional TRANS model indicating an even higher usage, drawing traffic to the improved highway network connection.
- While existing and proposed storm and sanitary sewers, as well as the LRT and CSST tunnels, present constraints to the development of a tunnel, the constraints are manageable and can be cost-effectively mitigated.
- The most feasible alternative is a twin-bore tunnel carrying two traffic lanes each connecting form the south end of the bridge to the Vanier/Coventry intersection via a cross-country route under parts of Lowertown and Sandy Hill.

If a decision is made to advance with future steps in the design process, they would include:

- Additional geotechnical investigations to understand the local geotechnical conditions along the proposed alignment, allowing for the design to be refined.
- Conducting an environmental assessment to understand the impacts of the facility on the community and determine effective mitigation measures to minimize any potential impacts
- Integration of the tunnel option into the broader transportation planning processes being considered for the National Capital Region, including the comparison of the effects and benefits of a tunnel-based solution to other network enhancements including a new inter-provincial bridge

The study was designed to review the potential for a tunnel to alleviate truck traffic issues on the KERWN corridor. The study found that a tunnel solution can effectively address the truck traffic issue and provide additional network capacity to address broader travel demand issues. The solution proposed will form the basis of future work, but demonstrates that a technically-feasible and costed solution exists.