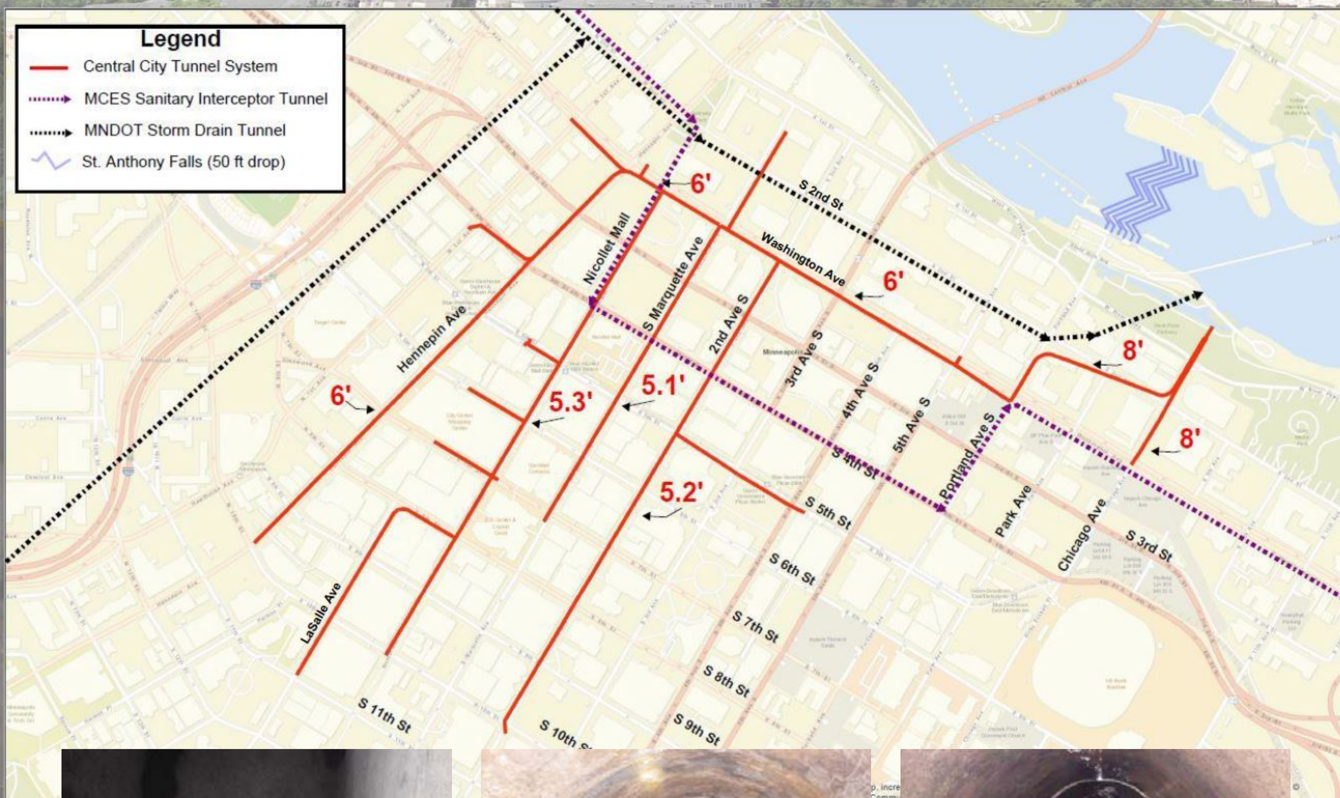
Attachment F

PRELIMINARY DESIGN REPORT



CENTRAL CITY TUNNEL SYSTEM

FEBRUARY 2018

Minneapolis
City of Lakes

CDM Smith

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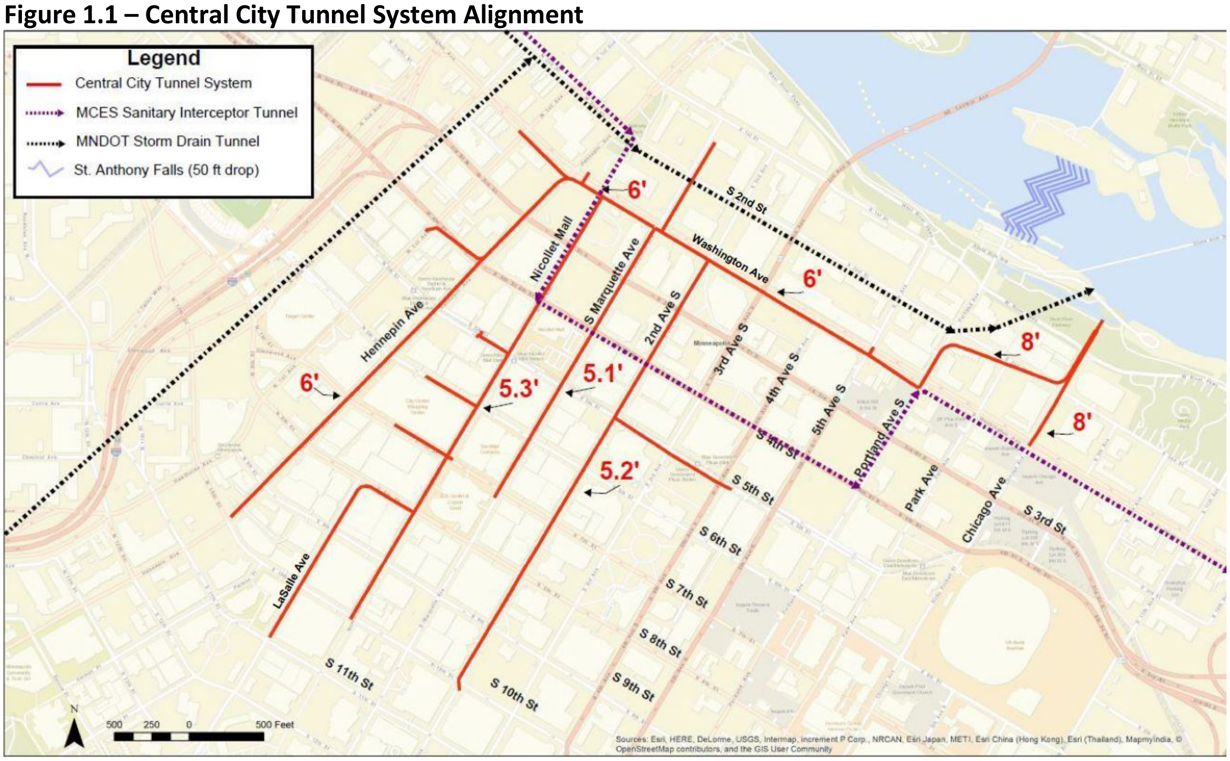
Section 1

Executive Summary

The City of Minneapolis (City) contracted with CDM Smith to update the existing XPSWMM model of the Central City Tunnel System and provide a conceptual design for improvements to mitigate stormwater surcharge within the Central City Tunnel System. As a part of the project, a field survey and condition assessment of the existing tunnel system was conducted. Information from the survey was used to update the existing Central City Tunnel System XPSWMM model provided by the City, and develop systemwide alternatives. The systemwide alternatives were focused on improvements to the tunnel system.

The Central City Tunnel System provides stormwater runoff drainage for nearly the entire area of the City's downtown commercial district. The system consists of deep stormwater tunnels constructed in the St. Peter Sandstone approximately 70 feet below the street surface. The primary tunnels comprising the Central City Tunnel System are located below Chicago Avenue, 2nd Street South, Portland Avenue South, 2nd Avenue South, Washington Avenue, Marquette Avenue South, Nicollet Mall, LaSalle Avenue, and Hennepin Avenue, as shown in **Figure 1.1**.

Figure 1.1 – Central City Tunnel System Alignment



Pressurization of the Central City Tunnel System has been an ongoing issue for the City, leading to repeated and expensive maintenance repairs during storm events. The current deep tunnel stormwater system, primarily built in the 1930s did not anticipate the increase in runoff volumes and shortened time-of-concentration associated with increased impervious surfaces in the downtown commercial district. Repeated pressurization of the tunnel during large, intensive rainfall events has caused the existing concrete liner to crack, contributing to areas of liner failure and erosion of the sandstone immediately behind the tunnel liner at multiple locations. Repairs are expensive, requiring the identification of void locations behind the liner caused by erosion, filling of the voids with grout, and repairing the cracks that led to the creation of these voids. This report identifies more permanent solutions that will alleviate surcharge in the existing tunnel system, thereby reducing the amount of future maintenance required.

Purpose and Approach

The purpose of this analysis was to determine the limits of improvements needed for the Washington Avenue segment of the Central City Tunnel System to reduce pressurization of the existing tunnel system in preparation for a capital improvement project, which will address the identified capacity constraints the City has scheduled for construction in 2020.

After collection of background data and completion of the field survey, the information was incorporated into the existing XPSWMM model and a hydraulic analysis was conducted of the Central City Tunnel System. The goal of this hydraulic analysis was to determine the cross-sectional area of each tunnel segment that is necessary to lower the hydraulic grade line (HGL) to acceptable conditions that will not compromise the structural integrity of the unreinforced tunnel liner.

A geo-structural evaluation of the existing tunnel system was completed with the goal of identifying and evaluating risks associated with enlarging tunnel cross-sections to increase the hydraulic capacity of the system.

Analysis Results

In summary, the hydraulic capacity and geo-structural analyses for the Central City Tunnel System improvements have concluded:

- Increased capacity is required on the Washington Avenue and 2nd Avenue South tunnel segments to bring the system to a 10-year level of service.
- Increased hydraulic capacity is required on the Washington Avenue, 2nd Avenue South, and Nicollet Mall tunnel segments to bring the system to a 100-year level of service. Improved hydraulic performance of the Nicollet Mall leg could be accomplished by constructing an 8th Street South relief tunnel between Nicollet Mall and 2nd Avenue South. This 8th Street South cross-connect tunnel would also increase the capacity of the 2nd Avenue South tunnel.
- The outfall structure has sufficient hydraulic capacity to discharge runoff to the Mississippi River for a 100-year level of service without additional improvements, other than minor repairs.
- Green infrastructure (GI) and in-line storage are not viable hydraulic solutions to the ongoing pressurization of the Central City Tunnel System.
- Construction of a parallel tunnel is the most cost-effective approach to expand hydraulic capacity.

- Ongoing crack repair and modifications of the existing tunnel segments that remain in operation after hydraulic capacity improvements should continue to be implemented.

- Roadheader excavation is the most viable method of construction for the Central City Tunnel System improvements. This is preferable to construction via tunnel boring machine, hydraulic lance, or microtunneling.

Recommended Alternative

Phased Approach

At the request of the City, CDM Smith developed a phased approach to implement these improvements. Two phases were identified:

1. Phase I: Washington Avenue Improvements.

2. Phase II: 2nd Avenue South and 8th Street South Cross-Connect Improvements.

Each of these phases were evaluated at the 10-year and 100-year levels of service. Because the exact timing of the second phase is unscheduled, this section of the report also assesses the hydraulics of the system during the interim period between the two phases.

Phase I: Washington Avenue Improvements

The first phase of improvements increases the hydraulic capacity of the Washington Avenue tunnel between Hennepin Avenue and the Mississippi River. Construction of the first phase is scheduled to begin in 2020. A parallel tunnel will be constructed from Hennepin Avenue to Portland Avenue South, within the Washington Avenue right-of-way. The proposed parallel tunnel will be offset 12 feet to the north of the existing stormwater tunnel on Washington Avenue. At Portland Avenue South, the tunnel will become an expanded tunnel and turn to the north within the Portland Avenue South right-of-way. At 2nd Street South, the tunnel will continue to the east where an extension to the Chicago Avenue tunnel will provide additional available capacity. The Central City Tunnel System will then turn north down Chicago Avenue and connect to the existing convergence structure. The existing storm tunnel, from Portland Avenue South to Chicago Avenue is under private property and can be abandoned so that the entire tunnel is within public rights-of-way. This layout was evaluated at both the 10-year and 100-year levels of service. Associated recommendations are described below.

10-Year Level of Service Improvements

The XPSWMM model was used to refine the hydraulics for the 10-year level of service improvements. The refinements, include:

- Washington Avenue
  - At Hennepin Avenue: Structure to split the flow into parallel tunnels.
  - Cross-connect structures between the existing tunnel and the new parallel tunnel at Nicollet Mall, Marquette Avenue South, and 2nd Avenue South help to equalize flow and allow maintenance access.

- Specific Washington Avenue tunnel sizing requirements for the 10-year level of service.

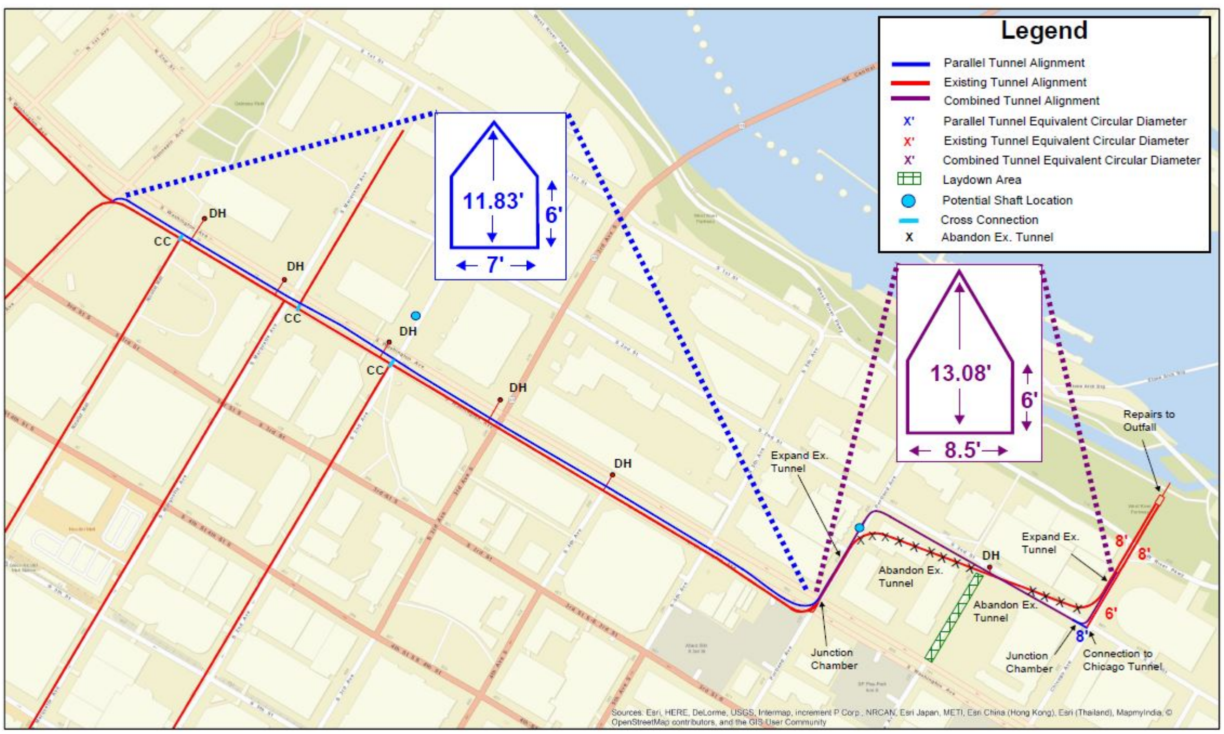
- Junction Chamber at Washington Avenue and Portland Avenue South
  - Convergence structure and construction of new expanded tunnel designed to convey flow from both tunnels.
  - Existing parallel tunnel located below private property will be abandoned, and the resultant expanded storm tunnel will be located entirely within street right-of-way.

- 2nd Street South, at approximately Chicago Avenue
  - Structure to split flow back into the existing tunnel system, with one leg directing flow to the Central City Tunnel System segment on Chicago Avenue, and the second leg directing the flow to the Chicago Avenue tunnel segment also located below Chicago Avenue.

- Minor repairs to outfall structure.

Figure 1.2 shows the specific configuration of this 10-year level of service project, including the Washington Avenue tunnel configuration from Hennepin Avenue to the Mississippi River, location of convergence and flow splitting structures and access shafts.

Figure 1.2 – Central City Tunnel System Phase I Tunnel and Structures Alignment – 10-Year Level of Service



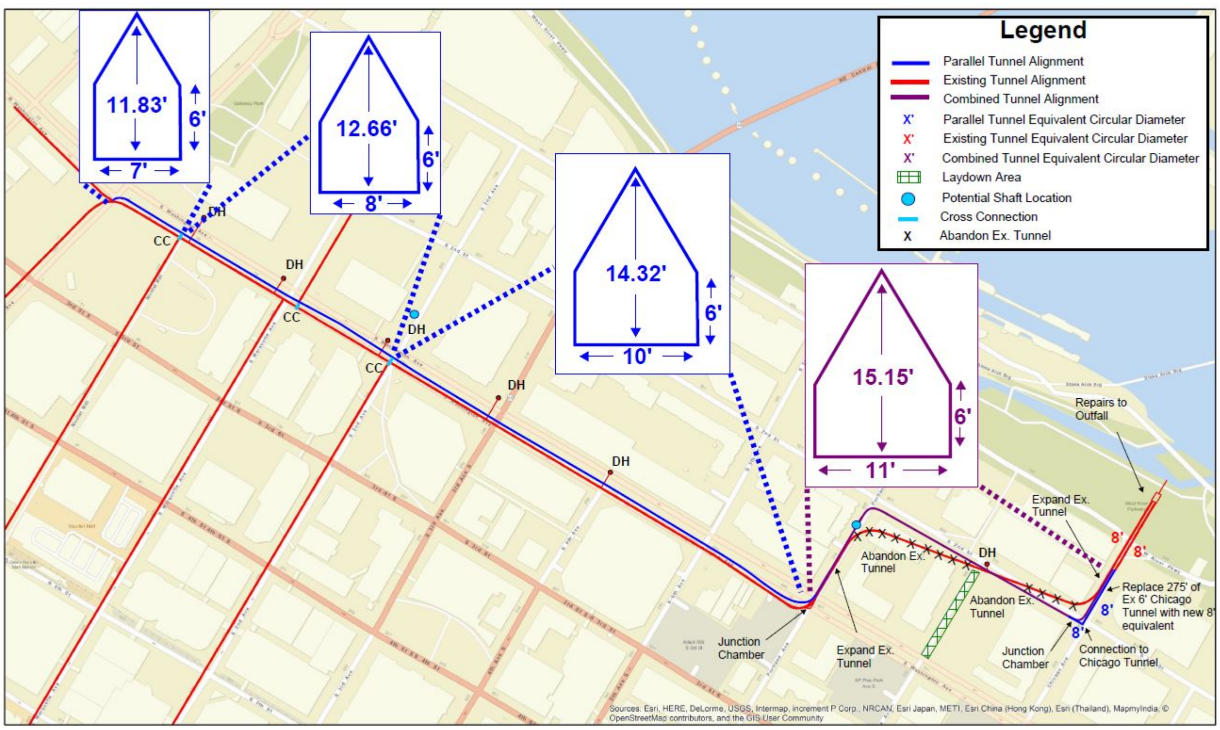
100-Year Level of Service Improvements

The 100-year level of service improvements contain the same components as the 10-year level of service described above, with the following additions:

- Larger sized Washington Avenue tunnel to accommodate the additional 100-year storm flow.
- Replace 275 feet of the existing 6-foot diameter Chicago Avenue tunnel with a new 8-foot diameter equivalent tunnel, between 2nd Street South and the tunnel convergence chamber to address hydraulic constrictions in this area.

Figure 1.3 shows the specific configuration and sizing of the 100-year level of service project area of Washington Avenue from Hennepin Avenue to the Mississippi River. As with the 10-year alignment, the proposed parallel tunnel, convergence/flow splitting structures, and access shafts can be located fully within the City's street rights-of-way. Note that the convergence chamber does not need to be reconstructed for this improvement; however, repairs to the outfall have been included in the project.

Figure 1.3 – Central City Tunnel System Phase I Tunnel and Structures Alignment – 100-Year Level of Service



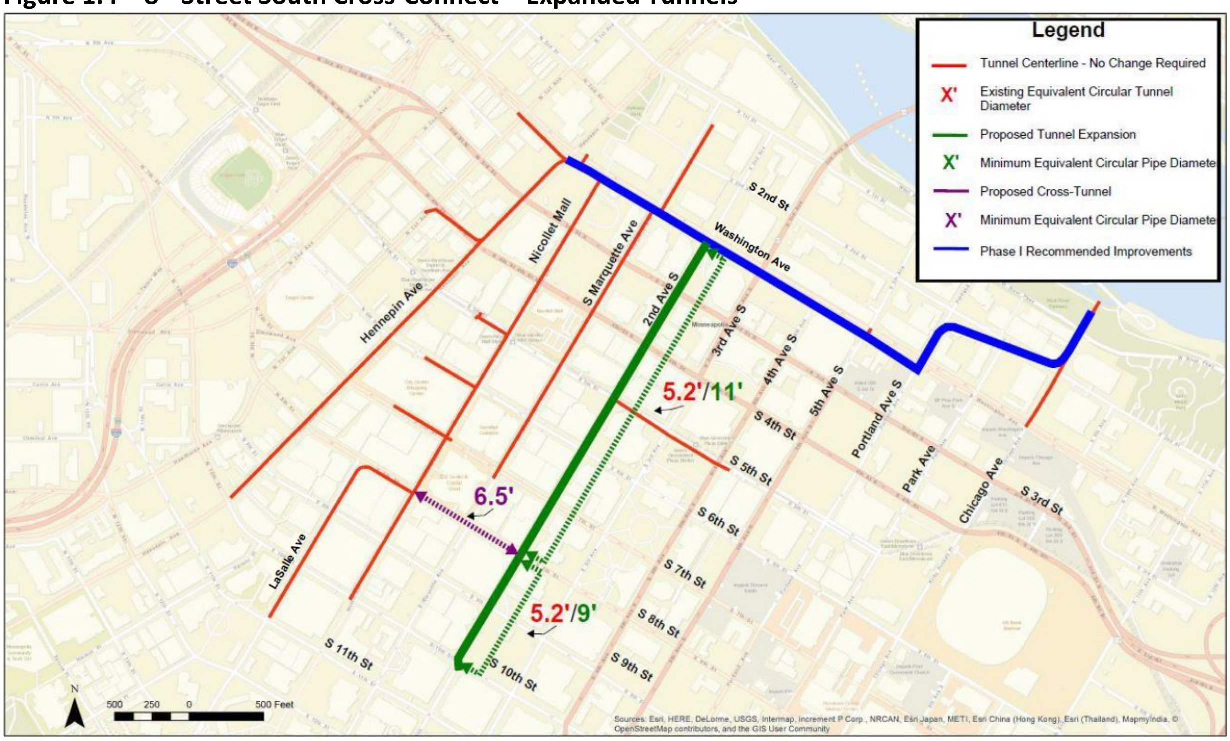
Access Shaft Locations

For the purpose of cost estimation and preliminary design, two proposed access shafts are recommended in the same locations for both the 10-year and 100-year levels of service (as shown on Figures 1.2 and 1.3). Locations were chosen based on field visits and on information received from Gopher State One Call mapping requests. These two locations were selected to minimize utility relocation, minimize local traffic access, and keep all construction activities entirely within the existing City rights-of-way. The 2nd Avenue South shaft location will facilitate construction of the Washington Avenue segment of the tunnel, such that the Washington Avenue tunnel could be constructed predominately in dry conditions year-round. The Portland Avenue South shaft location is intended to facilitate construction of the tunnel segment from Washington Avenue to the outfall chamber, which assumes that this segment will need to be constructed during winter months while active flow must be bypassed. Each shaft is proposed to be approximately 70 feet deep and 20 feet in diameter for roadheader access. It is assumed that as the project enters the detailed design phase, the location of these access shafts may be adjusted as more detailed site information is developed.

Phase II: 2nd Avenue South & 8th Street South Cross-Connect Improvements

The second phase of improvements increases the capacity of the 2nd Avenue South tunnel segment and provides relief to the Nicollet Mall stormwater tunnel through an 8th Street South cross-connection from 2nd Avenue South to Nicollet Mall. The 8th Street South cross-connect is recommended to eliminate the need for construction of additional tunnel capacity on Nicollet Mall. The 2nd Street South tunnel capacity would be increased to accommodate additional flow from the Nicollet Mall tunnel via 8th Street South, as well as the additional capacity needed to convey the runoff that is directly tributary to 2nd Avenue South. This 8th Street South relief tunnel is only necessary for the 100-year rainfall event, based on the conclusion that the Nicollet Mall tunnel segment has sufficient capacity for the 10-year rainfall event. The recommended alignment and tunnel diameters for Phase II are shown in **Figure 1.4**.

Figure 1.4 – 8th Street South Cross-Connect – Expanded Tunnels



Surge and Pressurization

Surge flow is not predicted to be an issue because the gravity outlet and numerous individual drill holes distributed throughout the tunnel network provide sufficient pressure relief to prevent surge conditions.

The proposed improvements will significantly reduce the surcharge presently predicted for the 10-year and 100-year level of service storms. The new Washington Avenue parallel tunnel is predicted to not pressurize in either design storm because the hydraulic grade line is entirely within the new tunnel. However, some pressurization of the existing Washington Avenue tunnel will continue to occur after all recommended improvements are complete. The worst condition during a 100-year level of service rain event will create a maximum pressure head of 7.9 feet that is predicted to exist for a 44.6-minute duration. This condition will exist because the top of the parallel, new Washington Avenue tunnel will be at a higher elevation than the top of the existing Washington Avenue tunnel. The only method to avoid this pressurization would be to lower the new Washington Avenue tunnel such that the top of both parallel tunnels are the same elevation and the invert of the new parallel tunnel would be 6 feet to 8 feet lower than the existing tunnel. This configuration was determined to be infeasible since it would require full reconstruction of the outfall structure and Chicago Avenue tunnel, and would fully submerge the outfall to an elevation that is lower than the invert of the Mississippi River.

The hydraulic grade line of the proposed tunnel will be within the tunnel and future improvements along 2nd Avenue South will continue to reduce the surcharge presently observed along 2nd Avenue South. A similar condition of pressurization of the existing 2nd Avenue South tunnel, such that the maximum pressurization during the 100-year level of service rain event will equal 8.1 feet that is predicted to exist for a 44.6-minute duration. This condition in unavoidable for a parallel tunnel option for 2nd Avenue South for similar reasons for the Washington Avenue tunnel. Additionally, a lowered invert for a parallel 2nd Avenue South tunnel would conflict with the Metropolitan Council Interceptor 1-MN-310, which crosses under the 2nd Avenue South tunnel at 4th Street South.

Opinion of Probable Construction Cost – Phase I: Washington Avenue Tunnel Improvements

An opinion of probable construction cost (OPCC) was developed for refinement of the recommended Phase I project, as described above. Costs for 10-year and 100-year levels of service are summarized in **Table 1.1**.

Table 1.1 – Central City Tunnel System Phase I Opinion of Probable Construction Cost

Items	Parallel Tunnel (10 year)	Parallel Tunnel (100 year)
Shafts (2)	$1,780,000	$1,780,000
Access Tunnel (8' Equivalent Circular Diameter)	$280,000	$280,000
Tunnel (8' Equivalent Circular Diameter)	$5,120,000	--
Tunnel (10' Equivalent Circular Diameter)	$3,910,000	$3,290,000
Tunnel (12' Equivalent Circular Diameter)	--	$11,350,000
Drifts (6 Connections to New Tunnel)	$300,000	$300,000

Items	Parallel Tunnel (10 year)	Parallel Tunnel (100 year)
Cross Connects (3-8' Equivalent Circular Diameter)	$110,000	$110,000
Abandonment of Existing Central City Tunnel Sections	$820,000	$820,000
Chicago to Tail Race (12' Equivalent Circular Diameter)	$470,000	$470,000
Chicago Connection (8' Equivalent Circular Diameter)	$60,000	$90,000
Site Improvements/Utilities/Restoration	$2,000,000	$2,000,000
Junction Chambers (3)	$1,500,000	$1,500,000
Chicago Tunnel Expansion from 6' to 8'	--	$870,000
Outfall Repair	$742,000	$742,000
Subtotal	**$17,092,000**	**$23,602,000**
Undeveloped Design Details	$1,710,000	$2,361,000
Subtotal	**$18,802,000**	**$25,963,000**
Engineering, Legal, Fiscal	$3,761,000	$5,193,000
Total	**$22,563,000**	**$31,156,000**

Construction

Construction of the parallel tunnels along Washington Avenue can be completed year-round by maintaining existing flows in the existing Central City Tunnel System while work on the parallel tunnel proceeds. Construction of the area downstream of Washington Avenue and Portland Avenue South would need to be completed during winter months to deal with existing drainage and avoid larger summer rainfall events. Final connections to the existing tunnel at Hennepin Avenue and cross-connections, as well as drill holes, would be completed after all downstream improvements are completed.

To accomplish this work, two potential access shafts are needed. A shaft located on 2nd Avenue South north of Washington Avenue would facilitate construction along Washington Avenue, and a shaft located near Portland Avenue South and 2nd Street South to facilitate construction between the outfall and Washington Avenue.

Downstream construction between Washington Avenue and the outfall will need to be completed during winter months with temporary conveyance/bypass segments. Final connections along Washington Avenue can then also be constructed in winter months. Existing tunnel segments that are no longer needed could then be abandoned and outfall repairs could be completed with the installation of a coffer dam and continued bypass pumping.

Construction along Washington Avenue would be completed in the dry with temporary connections to existing drill holes maintained to the existing tunnel only and new cross-connections not installed until downstream work is completed.

Section 2

Background and Approach

The City of Minneapolis (City) contracted with CDM Smith to update the existing XPSWMM model of the Central City Tunnel System and provide a conceptual design for improvements to mitigate stormwater surcharge within the Central City Tunnel System. As a part of the project, a field survey and condition assessment of the existing tunnel system was conducted. Information from the survey was used to update the existing Central City Tunnel System XPSWMM model provided by the City, and develop systemwide alternatives. The systemwide alternatives were focused on improvements to the tunnel system, as described below.

The Central City Tunnel System provides stormwater runoff drainage for nearly the entire area of the City's downtown commercial district. The system consists of deep stormwater tunnels constructed in the St. Peter Sandstone approximately 70 feet below the street surface. The primary tunnels comprising the Central City Tunnel System are located below Chicago Avenue, 2nd Street South, Portland Avenue South, 2nd Avenue South, Washington Avenue, Marquette Avenue South, Nicollet Mall, LaSalle Avenue, and Hennepin Avenue, as shown in **Figure 2.1**. Figure 2.1 also displays the equivalent circular diameter of the existing tunnel segments. This network of tunnels conveys the runoff from a 305-acre tributary area that is generally bound by Hennepin Avenue and 1st Avenue North to the east, 12th Street South to the south, 4th Avenue South and 7th Avenue South to the west, and 2nd Street South to the north. The tunnel aligns with and converges with the Chicago Avenue stormwater tunnel approximately 50 feet upstream of the outfall to the Mississippi River. The drainage area is also generally bounded by the Mississippi River on the north and by depressed highways served by deep tunnels along the perimeter, limiting the potential for future runoff entering the system from outside of the existing drainage area.

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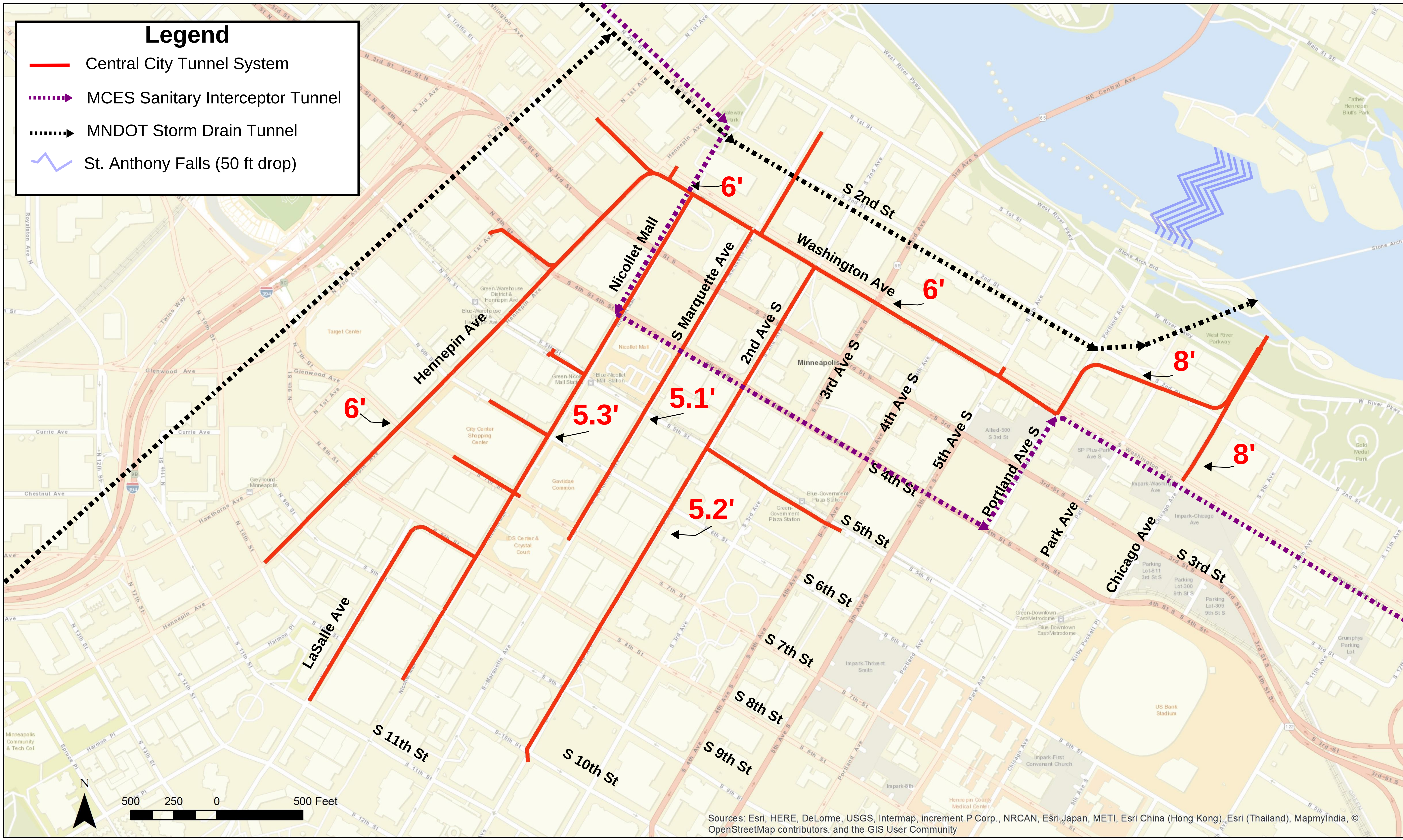

Minneapolis City of Lakes

CDM Smith

Existing Tunnel Alignment

Figure 2.1

Pressurization of the Central City Tunnel System during storm events has been an ongoing issue for the City, leading to repeated and expensive maintenance repairs. The current deep tunnel stormwater system, primarily built in the 1930s did not anticipate the increase in runoff volumes and shortened time-of-concentration associated with increased impervious surfaces in the downtown commercial district. Repeated pressurization of the tunnel during large, intensive rainfall events has caused the existing concrete liner to crack, contributing to areas of liner failure and erosion of the sandstone immediately behind the tunnel liner at multiple locations. Repairs are expensive, requiring the identification of void locations behind the liner caused by erosion, filling of the voids with grout, and repairing the cracks that led to the creation of these voids. This report identifies more permanent solutions that will alleviate surcharge in the existing tunnel system, thereby reducing the amount of future maintenance required on the system.

Existing Stormwater System Alignment and Hydraulics

The existing stormwater system operates as a gravity flow system, with the tunnels ranging in depth from approximately 30 feet to 70 feet below ground surface. These tunnels were constructed within the St. Peter Sandstone layer of bedrock and emerge from the bedrock at the Mississippi River. The Central City Tunnel System and Chicago Avenue tunnel system converge into a single outfall at the Mississippi River. The runoff discharges from the converged outfall to a side channel of the Mississippi River, called a tailrace, located near the Guthrie Theater. The outfall at the Mississippi River is located on Minneapolis Park and Recreation Board (MPRB) property within an existing easement that represents an extension of the Chicago Avenue right-of-way. The last segment of the outfall may not be covered by an easement.

The City of Minneapolis Division of Surface Water and Sewers provided 32 historic plats detailing the plan and profile of the tunnel system. The tunnel plats indicate that most of these tunnels were constructed between 1936 and 1940, except for Marquette Avenue South, which was constructed in 1963 and 1964. The tunnel plats for the segment of the Central City Tunnel System and Chicago Avenue tunnel system between Washington Avenue and the Mississippi River were constructed earlier, but do not show a date of construction. There is a stamp on each sheet regarding the elevation datum used: 0.0 Minneapolis City Datum =710.3 Sea Level (1929 Adj.).

Tunnel Characteristics

The tunnel plats show nine different cross-section configurations. Eight configurations within the overall system generally show the same geometric "cathedral" shape with the dimensions varying from 4 feet to 6 feet in width and 6 feet to 8 feet in height. Most of the tunnel is lined with unreinforced concrete against the underlying sandstone. Three types of tunnel support were used to construct the tunnel: 1) no support required; 2) light timber support; and, 3) heavy timber support. Additional definition of these tunnel supports is contained in Section 5.

The stormwater tunnels on Hennepin Avenue, LaSalle Avenue, and Marquette Avenue South between 4th Street South and 7th Street South, and Nicollet Mall between 9th Street South and 10th Street South all have sanitary sewers that cross immediately below or are located in-line with the storm tunnel, below the invert of the Central City Tunnel System. These sanitary sewers are clay pipes encased in concrete and range from 12 inches to 24 inches in diameter. The Central City Tunnel System crosses immediately over sanitary sewer tunnels at Washington Avenue, Nicollet

Mall, Marquette Avenue South, 2nd Avenue South, and the sanitary sewer tunnel is approximately at the same invert as the Central City Tunnel System at Washington Avenue and Portland Avenue South. The location of the sanitary sewers limits relocation opportunities and changes in proposed tunnel grades.

The Central City Tunnel System, as it approaches the convergence structure, is a 7.5-foot wide by 7.9-foot tall cathedral shape tunnel constructed of limestone block below the springline and concrete liner above the springline. The Chicago Avenue tunnel system, as it approaches the convergence structure, transitions from a 6-foot to an 8-foot diameter circular brick structure. The outfall structure, below the convergence of the Central City Tunnel System and Chicago Avenue tunnel system, has a unique cross-section configuration with a mushroom shape at the convergence that transitions to a cathedral shape for approximately 50 feet immediately upstream of the outfall structure at the Mississippi River. Additional details of these segments are described in Section 4.

Purpose and Approach of Hydraulic and Geo-Structural Analyses

The purpose of this analysis was to determine the limits of improvements needed for the Washington Avenue segment of the Central City Tunnel System to reduce pressurization of the existing tunnel system in preparation for a capital improvement project, which will address the identified capacity constraints the City has scheduled for construction beginning in 2020.

Preliminary hydraulic modeling by Barr Engineering[1] concluded that increasing the hydraulic capacity along Washington Avenue and 2nd Avenue South could relieve the excessive pressure during a 10-year or 100-year rainfall event, which is the primary cause of liner failure and the corresponding erosion of sandstone around the exterior of the tunnel liner. CDM Smith was tasked to conduct a survey of the Central City Tunnel System, update the existing hydrologic and hydraulic (H&H) model, assess the structural properties of the St. Peter Sandstone, document the existing stormwater tunnel condition, and create a preliminary layout for future Washington Avenue tunnel improvements. This design report updated the existing XPSWMM model with additional detail and used the updated model results to develop a preliminary design for an improved tunnel along Washington Avenue.

CDM Smith used the following approach to create a final recommendation for the Washington Avenue segment improvements:

1. Conduct a field survey of the Central City Tunnel System.
2. Update the existing conditions calibrated model with additional dimensional information collected as part of the field survey, and update the model based on other hydrologic and hydraulic modifications as described in Section 4.

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[1] *Central City Tunnel System Hydrologic and Hydraulic Analysis Modeling Using XPSWMM, Central City, Eleventh Ave, and Chicago Ave Tunnel Systems*, June 2015, and *Central City Tunnel System Feasibility Study, Central City Tunnel System Pressure-Mitigation Options*, June 2015

3. Use the updated XPSWMM model to identify all tunnel segments with insufficient hydraulic capacity in existing conditions.

4. Create an ultimate conditions XPSWMM model to determine an equivalent circular diameter tunnel that would convey the predicted stormwater volumes for all tunnel segments identified as having insufficient hydraulic capacity. Assess two scenarios: 1) enlargement of existing tunnel(s); and, 2) construction of parallel tunnel(s). Assess each scenario for two levels of service: the 10-year design rainfall event and the 100-year design rainfall event. Also assess whether installation of green infrastructure or in-line storage could effectively reduce the length or cross-sectional area of a tunnel expansion project.

5. Assess the subsurface conditions of the St. Peter Sandstone and the ability of the existing liner to withstand internal pressurization. Investigate the tunnel liner improvement approaches and techniques for maintenance of tunnel segments that were not upgraded for additional hydraulic capacity.

6. Identify viable construction methods for two scenarios: 1) enlargement of the existing tunnel(s); and, 2) construction of parallel tunnel(s). Use these scenarios to identify construction methods to develop screening level cost estimates and identify the most viable approach for Washington Avenue segment improvements.

7. Fine-tune the ultimate conditions XPSWMM model based on specific information obtained from the survey by adjusting the pipe diameters and lengths, and test the hydraulic performance with 10-year and 100-year rainfall event levels of service.

8. Develop several alternatives for analysis, including parallel and enlarged tunnels based on the 10-year and 100-year events, and assess the feasibility of surface and subsurface storage and green infrastructure.

9. Create a plan and profile of the identified Washington Avenue segment improvements that include location of tunnel improvements, transition and cross-over structures, drill holes, and new access shafts.

10. Develop a revised opinion of probable construction cost for the Washington Avenue segment improvements, incorporating specific information from the plan and profile, and refine the XPSWMM model.

11. Develop an interim conditions XPSWMM model that predicts the hydraulic performance of the Central City Tunnel System after the Washington Avenue segment improvements are complete and before any other ultimate capacity recommendations are implemented.

12. Conduct a preliminary assessment of construction considerations, including risk analysis procedures.

13. Review implementation issues, including permitting and historic considerations.

This Preliminary Design Report documents the results of these hydraulic and geo-structural analyses.

Section 3

Tunnel Survey

An internal survey of the Central City Tunnel System was completed that recorded the tunnel inverts and coordinates, and measured the tunnel shape. Before the survey began, a Health and Safety Plan was developed establishing the protocols for safe access, monitoring, communications, and emergency response. All personnel assigned to tunnel work were required to have current Confined Space Entry training, and were required to certify that they would comply with the procedures set forth in the Health and Safety Plan.

The survey and inspection reveal that, in general, the Central City Tunnel System was found to be in relatively good condition. Vertical and transverse crack spacing was on average 57 feet apart, and 90 percent of existing cracks were large enough to allow grains of sandstone to migrate into the tunnel. Voids behind the liner were noted at several crack locations.

Results of the condition assessment are discussed in Section 5 of this document.

Figure 3.1 – 2nd Street South Tunnel Above Convergence with Chicago Avenue Tunnel

Photo Credit: CDM Smith

The survey information was used to create an AutoCAD file of the alignment of the tunnels. Liner defects were recorded and photographed. **Appendix A** contains a *pdf of the tunnel survey. **Appendix B** contains the tunnel inspection notes.

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Section 4

Existing Conditions Hydraulic Analysis

After collecting background data and completing the field survey, the information was incorporated into the existing XPSWMM model and a hydraulic analysis was conducted of the Central City Tunnel System. The goal of this hydraulic analysis was to determine the cross-sectional area of each tunnel segment that is necessary to lower the hydraulic grade line (HGL) to acceptable conditions that will not compromise the structural integrity of the unreinforced tunnel liner. The base XPSWMM model utilized in this analysis was developed by Barr Engineering and is summarized in two reports:

- *Central City Tunnel System Hydrologic and Hydraulic Analysis Modeling Using XPSWMM, Central City, Eleventh Ave, and Chicago Ave Tunnel Systems*, June 2015.
- *Central City Tunnel System Feasibility Study, Central City Tunnel System Pressure-Mitigation Options*, June 2015.

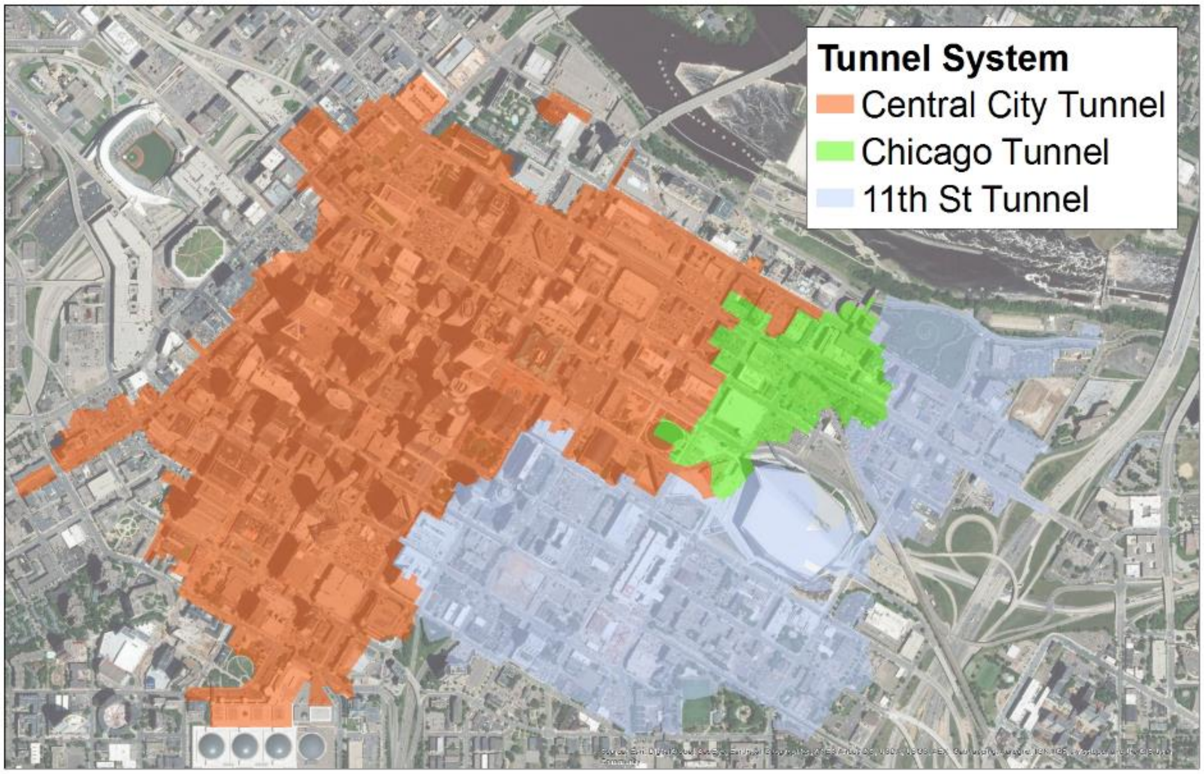
The June 2015 Feasibility Study reviewed nine options that would mitigate, but not eliminate, pressurization of the tunnel during a design rainfall event. These options assessed construction of parallel tunnels in combination with oversized tunnels utilizing the existing void space for additional hydraulic capacity.

The hydraulic analysis, as described in the following sections, assumed the ultimate capacity of the upgraded tunnel system objective should be based on a cross-sectional area that causes minimal pressurization during a design rainfall event. This was based on an analysis of tunnel liner conditions concluding that tunnel segments with voids behind the liner cannot support any pressurization, as described in additional detail in Section 5. Cross-sectional areas developed in this hydraulic analysis are identified as circular equivalent areas required to improve hydraulic performance and subsequently lessen the ongoing maintenance activities of the City.

Existing XPSWMM Model

The existing hydraulic and hydrologic model provided by the City included all areas tributary to the Central City Tunnel System, Chicago Avenue tunnel system, and Eleventh Street tunnel system, as shown in **Figure 4.1**. All subsurface storm sewers and tunnels were explicitly modeled with a simplified representation of overland street flow during extreme rainfall which could induce street flooding and surface ponding.

Figure 4.1 – Central City Tunnel System XPSWMM Model Project Area



As part of the previous calibration efforts, watershed parameters such as delineations, surface slope, and impervious coverage were calculated using data from the best available sources and City-developed standards. Parameters such as roughness coefficients, overland flow lengths, and depression storage depths were calibrated to match observed pressure data within the tunnel network.

Model Revisions

Data Review

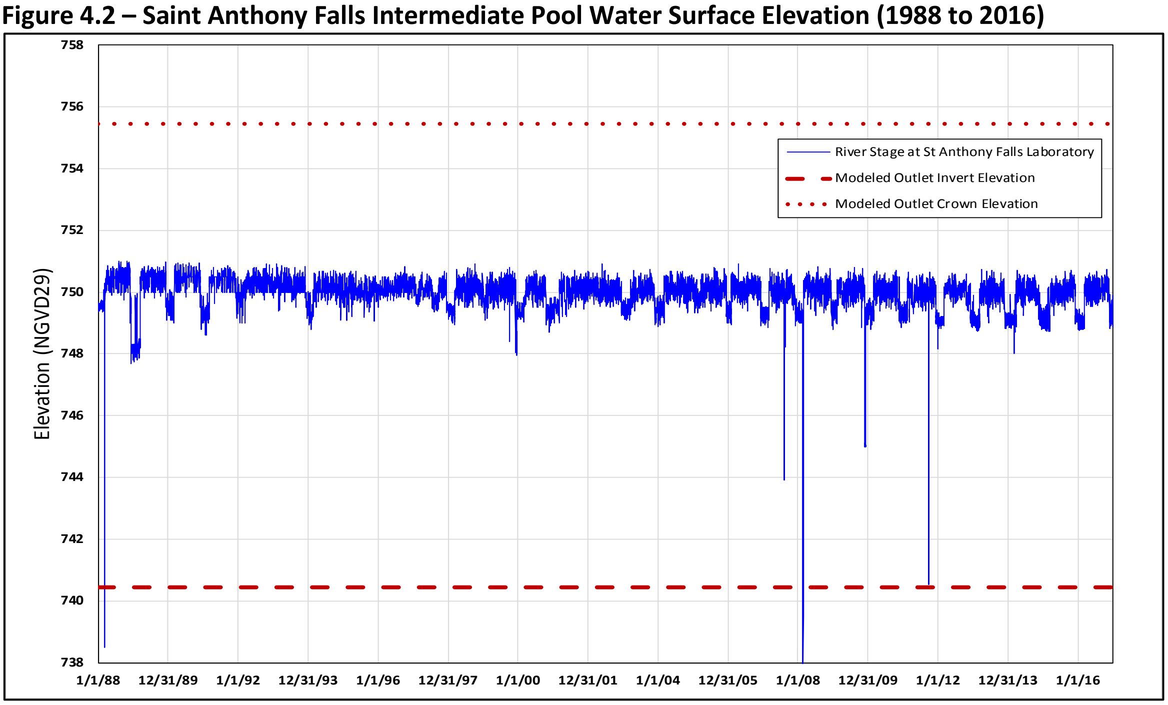
Data was collected from the six sources listed below and this data was used to supplement or update the existing calibrated model.

- **Tunnel Survey**: The tunnel dimensions, alignment, inverts, and stationing information for each branch of the tunnel system were provided from the field survey. This data was incorporated into the XPSWMM model. Chamber dimensions and the alignment of the sweep at Portland Avenue South and Washington Avenue were incorporated into the model. In addition to the CAD survey file, site photos and a record of each liner defect were recorded by CDM Smith during the tunnel survey.

- **Pressure Data**: Pressure meter data throughout the tunnel system were obtained from the City of Minneapolis Department of Public Works. The data included the station range, date and time, pressure (psi), and temperature at the time of reading for the period between March 2012 and November 2016. The data was used in the geo-structural analysis to assess the ability of the existing concrete liner, with and without voids in the geo-structural analysis to assess the ability of the existing concrete liner, with and without voids in the sandstone supporting the concrete liner, to withstand the existing pressures recorded in the tunnel system.

- **Maintenance Data**: A summary of the repair work performed on each tunnel reach was provided by the City of Minneapolis Department of Public Works in January 2017. The maintenance data included descriptions of tunnel reaches requiring maintenance such as invert repair, invert cleaning, crack sealing, and void grouting. An excel file noting the tunnel defects and inspection notes was included, along with photos of major maintenance events. The information was assessed to determine whether there were any major areas of liner or sandstone debris during the calibration events that could have affected the hydraulic performance. As a result, it was determined that there were no tunnel collapses or significant sections of debris present during the rain events used to calibrate the model.
- **Rainfall Data**: Rainfall data was obtained from a rain gauge located at 503 3rd Street South. The rainfall was recorded at this location at an interval of five minutes from 2011 to 2016. A second dataset was obtained from the University of Minnesota Saint Anthony Falls Hydraulic Laboratory and used to verify the accuracy of the downtown rain gauges. No discrepancies were identified.
- **River Elevations**: The water level for the Mississippi River for the period between January 1, 1988 and February 27, 2017 was obtained from the United States Army Corps of Engineers (USACE). Data obtained from the USACE is shown in **Figure 4.2.**

Figure 4.2 – Saint Anthony Falls Intermediate Pool Water Surface Elevation (1988 to 2016)

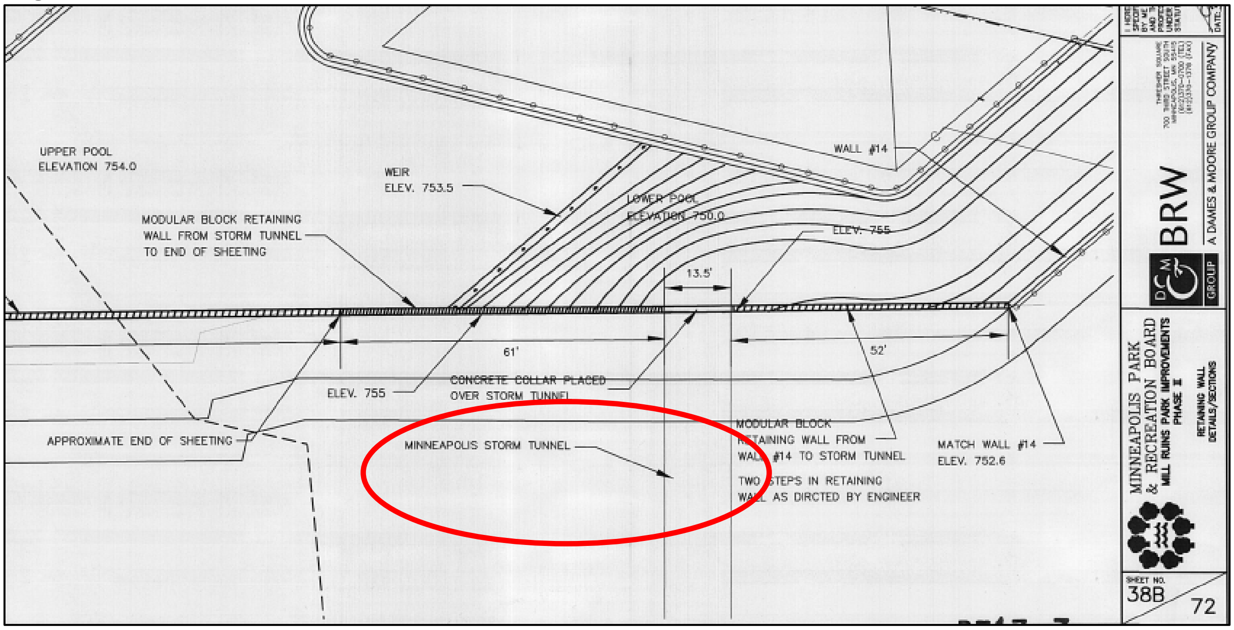


Source of Data: USACE[2]

[2] Data provided by Daniel Fasching, USACE, February 2017

- **MPRB Tailrace Plans**: The record drawings for the MPRB tailrace were provided by the MPRB in March 2017. The information was reviewed to determine the configuration of the Mississippi River tailrace channel that receives the discharge from the Central City Tunnel System. The location of where the Central City Tunnel System discharges into the tailrace channel is identified on **Figure 4.3**.

Figure 4.3 – Mississippi River Tailrace Plans Noting the Location of the Central City Tunnel System Alignment and Outfall



Source: As-Built Plan for Pedestrian and Bicycle Trails, Bridges No. 27A55 and No. 27A56, prepared by BRW for Minnesota Department of Transportation (MnDOT), MPRB, and Hennepin County, dated February 8, 2002, Sheet #38B

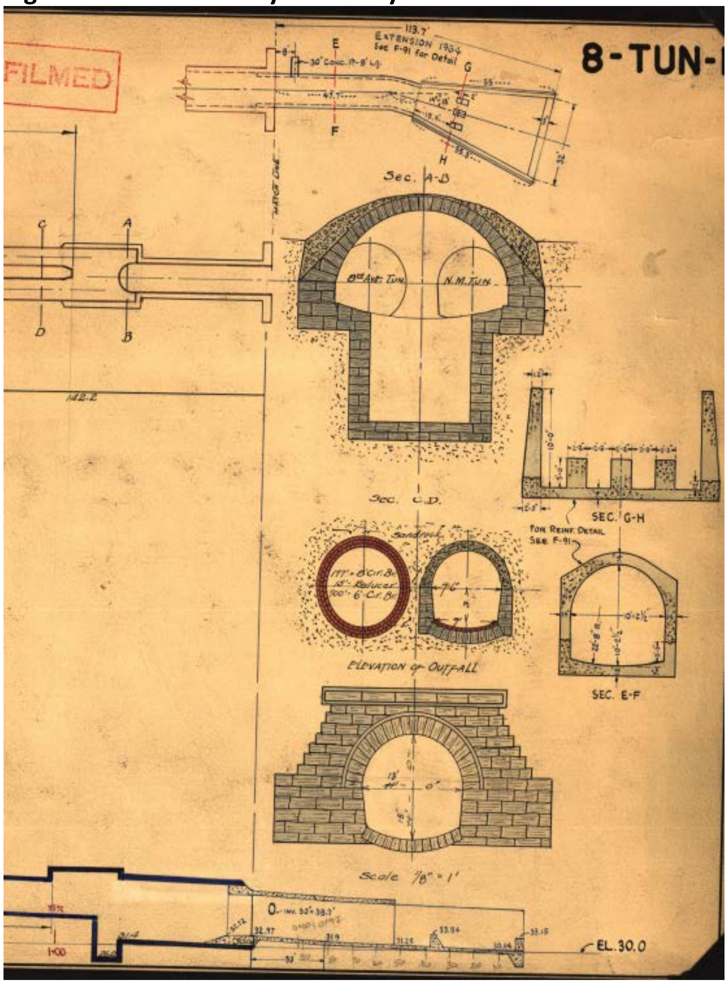
Hydraulic Updates and Impacts

The following describes the modifications incorporated into the XPSWMM Central City Tunnel System model.

- **River Stage Boundary**: The calibrated model the City provided assumed a free discharge to the Mississippi River at the outfall of the Central City Tunnel System. In reality, the Mississippi River water surface elevation between the Saint Anthony Falls Upper and Lower Dams is held at a long-term average elevation of 750 feet (as determined by the water surface elevation provided by the USACE), while the invert of the outfall pipe is approximately 9 feet below the target water surface elevation. This lack of appropriate tailwater has the potential to overpredict the discharge capacity of the tunnel segments immediately upstream of the outfall. The model was modified to include a fixed boundary elevation of 750 feet to account for this tailwater. Additionally, minor hydraulic losses at the outfall were added to account for the changes in flow direction that occurs within the Mississippi River tailrace.

- **Outfall Shape and Length**: The calibrated XPSWMM model the City provided simplified the geometry of the outfall pipe as a circular pipe and incorporated the pipe length as recorded on historic record drawings. The modified model adjusted the outfall length based on the results of the field survey and the shape of the outfall to account for the horseshoe shape of the brick/block pipe, as shown in **Figure 4.4**.

Figure 4.4 – Central City Tunnel System Outfall Cross-Section



Source: Minneapolis Sewer Plan #8-TUN-1

- **Sweeps**: The dimensions, elevations, and alignments of all sweeps (i.e., the long curves along the Central City Tunnel System between Washington Avenue and the outfall) were updated based on survey data.

- **Portland Avenue South/Washington Avenue Chamber**: The sweep and enlarged chamber at Portland Avenue South and Washington Avenue were updated to reflect the geometry, invert elevations, dimensions, and connections based on survey data.

- **Chicago Avenue/Portland Avenue South Convergence Chamber**: Similar to the outfall structure, the physical dimensions of the chamber at the convergence of the Central City Tunnel System and Chicago Tunnel were incorporated into the XPSWMM model to reflect the atypical geometry, as shown in the upper cross-section in Figure 4.4. The length of this segment was also updated based on survey data.

- **Inverts – Main Tunnel and Drifts**: Tunnel and drift inverts were updated for all major tunnel legs within the Central City Tunnel System (Washington Avenue, Hennepin Avenue, Nicollet Mall, LaSalle Avenue South, Marquette Avenue South, and 2nd Avenue South) based on survey data.

- **6th Street South Tunnel**: The 6th Street South tunnel does not have any stormwater inputs via any drop shafts, drill holes, or private connections, and was not included in the calibrated model provided by the City. The 2016 tunnel survey did measure the length and inverts for this tunnel, therefore the tunnel was added using information from the survey.

- **Drift Tunnels**: The calibrated model the City provided separated every drill hole into individual inputs into the Central City Tunnel System, but did not contain a unique link for every drift tunnel. Long drift tunnels were included in the model, but the short tunnels, typically less than 10 feet in length, were completely omitted. This approach was reviewed and tested as to how the hydraulic results would change if each of the drift tunnels were added to the model. The test section selected was along Hennepin Avenue. The result was a less stable model with little to no change in the peak flows predicted for large rain events. The reduced stability stems from submerged pipes that are short in length with significant tailwater and ebbing flows that make computational convergence less likely. Because these drift tunnels are very short and are already submerged in the design storms of interest, the transport time from the drill hole to the tunnel proper is negligible and provides no appreciable volumetric storage to reduce peak flow rates. It was also noted that XPSWMM has a non-adjustable function that lengthens all short links to a minimum length of 32.81 feet (exactly 10 meters), which produced excessive warnings when running a simulation. This function creates extraneous storage volume within the drift tunnels as XPSWMM automatically creates pipes that are longer than the input parameters. It was concluded that the additional effort to add the small portion of omitted drift tunnels would not significantly impact the hydraulic results and would not provide meaningful benefit to overall alternatives analysis.

An interim model run was conducted after the hydraulic changes were made to verify whether these changes affected the calibration of the model. Although there were several updates made to the calibrated conditions model, none were observed to have a significant impact on model results. The hydraulic configuration changes made at the sweeps, convergence chambers, and outfall structure had minimal impacts. However, the Mississippi River stage and updated tunnel inverts did show observable changes in peak flow rates predicted for a range of synthetic storms[3], as shown in **Table 4.1**. Because the predicted flows of the updated hydraulic XPSWMM model were at or below the predicted flows of the previously calibrated model, it was concluded that it was appropriate to proceed with revisions to the hydrologic updates to the XPSWMM model without changes to the calibration parameters.

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[3] National Oceanic and Atmospheric Agency (NOAA) Atlas 14, Volume 8, Version 2 for Minneapolis. Point Precipitation Frequency Estimates for 24-hour duration: 2-year event =2.85 inches; 10-year event =4.27 inches; 100-year event =7.47 inches; 500-year event =10.50 inches.

Table 4.1 – Comparison of Peak Flows Between Hydraulic Updated Model and Initial Calibrated Model

	Updated Model Peak Flow (cfs)				Change from Calibrated Model			
	2-Yr	10-Yr	100-Yr	500-Yr	2-Yr	10-Yr	100-Yr	500-Yr
Hennepin Avenue at Washington Avenue	93	106	206	210	-6%	-16%	-5%	-7%
Nicollet Mall to Washington Avenue	128	174	212	208	15%	-18%	-25%	-21%
Marquette Avenue at Washington Avenue	105	129	112	154	7%	20%	-10%	-5%
2nd Avenue at Washington Avenue	304	391	357	320	-9%	-3%	-11%	-10%
Washington Avenue at Portland Avenue	413	673	750	758	-11%	-9%	-15%	-15%
Chicago Tunnel at Convergence Structure	116	163	290	396	0%	0%	1%	-1%
Central City Tunnel System Discharge	476	819	1011	1023	-8%	-7%	-12%	-12%

Hydrologic Updates – Sub-Catchment Update

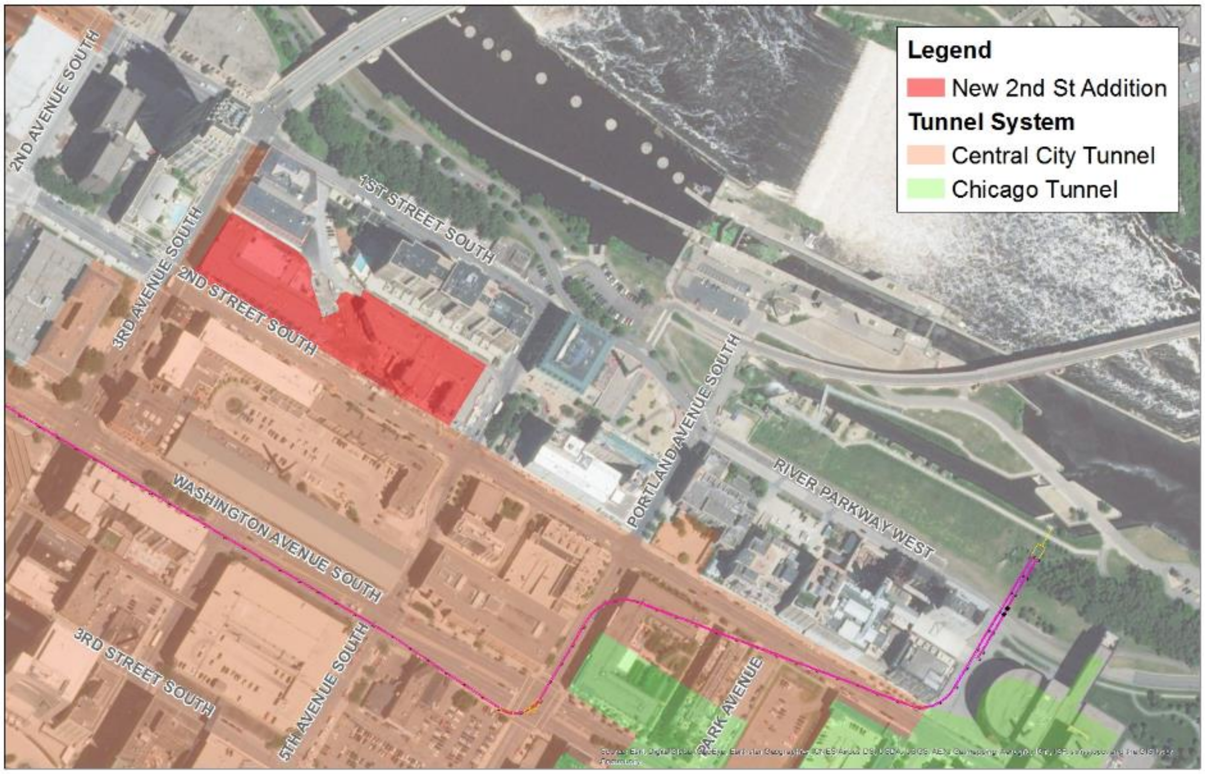
Two sub-catchments were updated to reflect redevelopment that occurred within the study area in the period after the XPSWMM model was developed and calibrated. The following describes these changes:

- **US Bank Stadium**: The Metrodome existed within the Chicago Avenue catchment of the XPSWMM model during the rain events that were used for the initial calibration and verification. Since that time, the Metrodome was demolished and the new US Bank Stadium was completed. The site plan for the US Bank Stadium was obtained from the City and used to compare the contributing area and percent impervious as input into the calibrated model. It found that the total catchment area contributed to the Chicago Avenue tunnel system had increased, and that the percent impervious had decreased. Although this change had no effect on the Central City segment of the tunnel system, the new information was input into the model to ensure that the model reflects current conditions. The updated model now includes delineations that reflect the new construction and watershed boundaries between the Central City Tunnel System, Chicago Avenue tunnel system, and 11th Street tunnel system after construction of US Bank Stadium. **Figure 4.5** shows the contributing areas before and after construction of the new stadium. Because US Bank Stadium discharges to the Chicago Avenue tunnel system, the re-delineation has no impact on tunnel HGLs in the Central City Tunnel System.

Figure 4.5 – Pre- and Post-US Bank Stadium Sub-Catchment Delineations

- **2nd Street South Redevelopment**: A significant redevelopment project along 2nd Street South shifted 2.33 acres of area from the 1st Street South storm drains into the Central City Tunnel System drainage area. That area was not contributing to the Central City Tunnel System prior to calibration, but is now re-graded such that runoff flows to a drill hole tributary to the Washington Avenue stormwater tunnel system. **Figure 4.6** shows the additional area that was added to the sub-catchments along 2nd Street South. The site plan included the installation of underground rate control structures designed to reduce the peak flow contributions to the 2nd Street South storm drains. However, the peak flows were not adjusted to account for a worst-case scenario. Because there are more than 300 acres contributing to the Central City Tunnel System, the additional 2.3 acres of runoff area to 2nd Street South had no noticeable impact on tunnel HGL.

Figure 4.6 – Pre- and Post-2nd Street South Redevelopment Sub-Catchment Delineations



Hydrologic Updates – Additional Division of Sub-Catchment Delineations

At the request of the City, the model was assessed as to whether it would be improved if the sub-catchments of the calibrated model were divided into smaller areas. The Orchestra Hall block (node 417333) was selected for this analysis because it is a larger sub-catchment with multiple types of surfaces including roadway, building (the Orchestra Hall itself), and a plaza. After splitting this 4.21-acre sub-catchment into three similarly sized sub-catchments, those runoff volume and rates were compared to the original sub-catchment runoff volumes and rates. **Figure 4.7** depicts the original and re-delineated catchment delineations. **Figure 4.8** illustrates the comparative runoff for each scenario.

Figure 4.7 – Orchestra Hall Node 417333 Original and Re-Delineated Catchment Areas

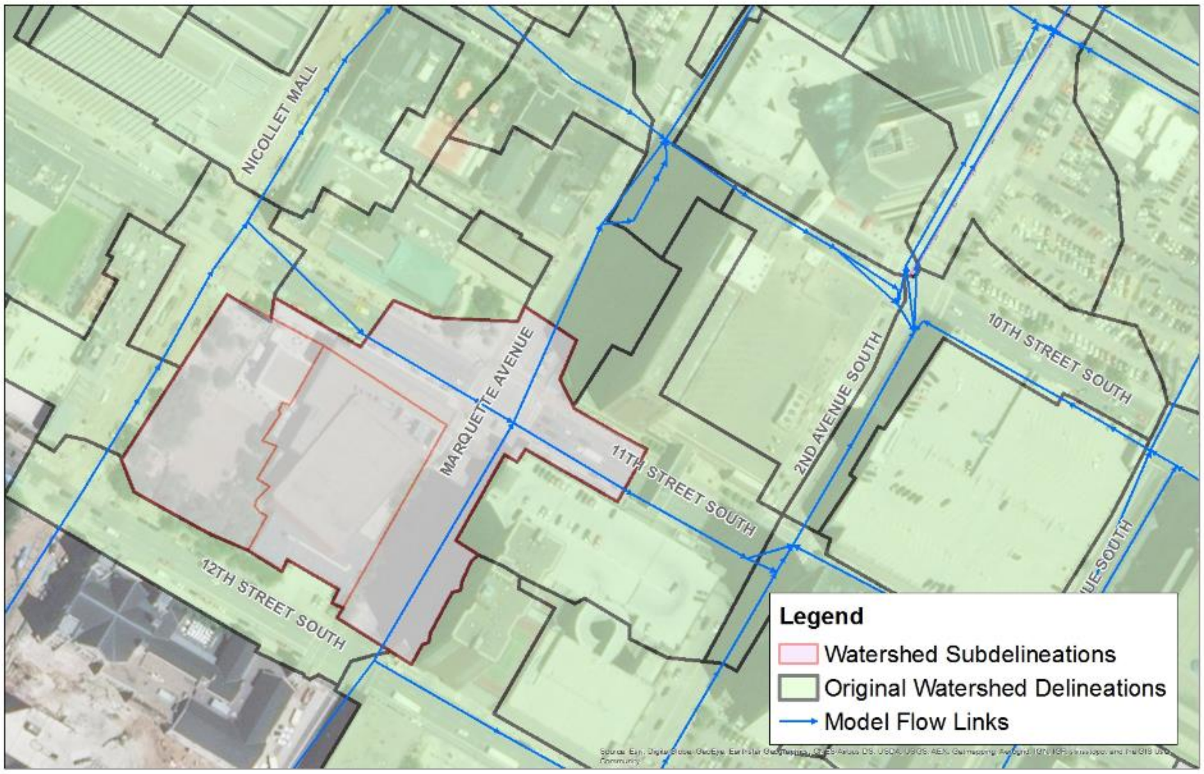
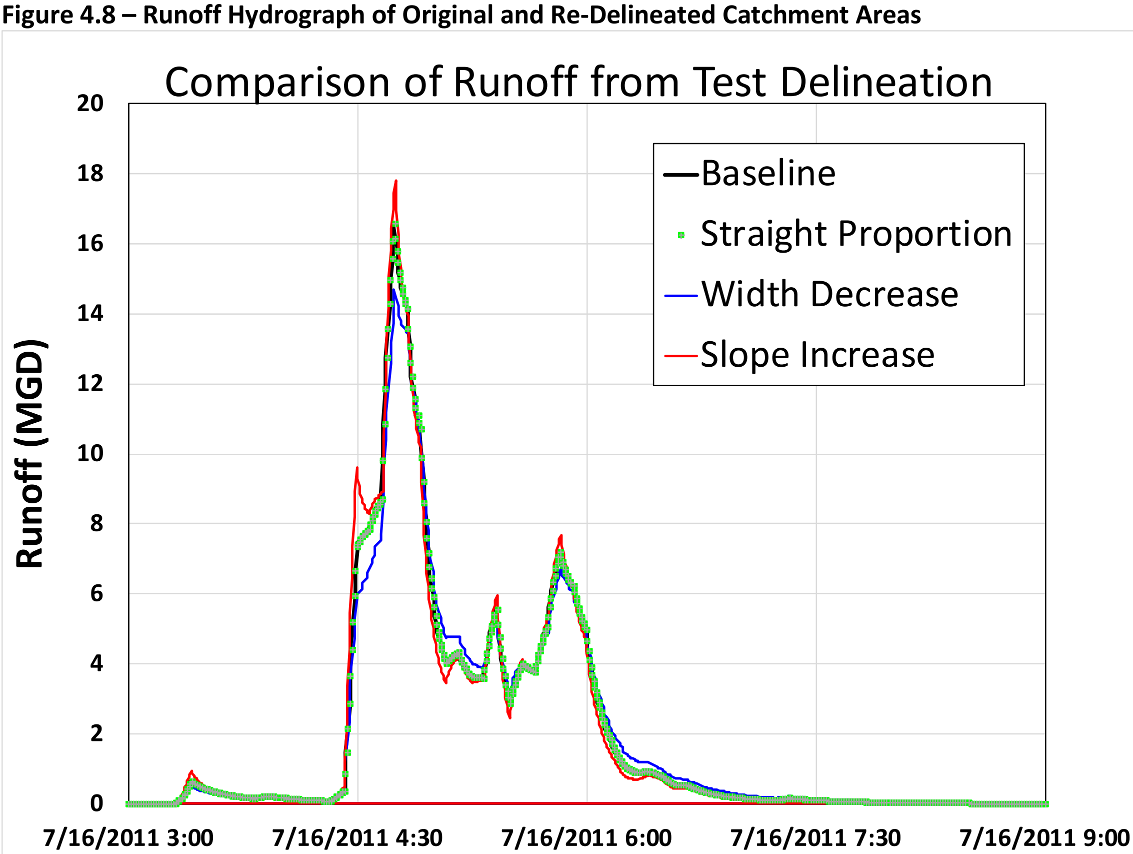


Figure 4.8 – Runoff Hydrograph of Original and Re-Delineated Catchment Areas



The four scenarios shown in Figure 4.8 represent four approaches of how the sub-catchment could be re-delineated, including:

- **Baseline**: Single sub-catchment results from calibrated existing conditions model.
- **Straight Proportion**: Division into three sub-sub-catchments, without change to sub-catchment slope and with proportional change to sub-catchment width.
- **Width Decrease**: Division into three sub-sub-catchments with measured change to widths.
- **Slope Increase**: Division into three sub-sub-catchments with proportional change to sub-catchment widths and increase in sub-catchment slopes.

As shown in Figure 4.8, the results of this analysis are as follows:

- Runoff volume remained identical.
- Negligible differences in peak runoff rate.
- Indiscernible differences in tunnel peak HGL's.
- It is noted that sub-catchment slope and sub-catchment width are typically adjusted as part of model calibration to best match the model hydrograph with the measured hydrograph. Therefore, any irregularities within sub-catchments that could be adjusted by smaller sub-catchment areas had already been accommodated by the model calibration.

Because there were no obvious benefits of increasing the resolution of hydrologic sub-catchments and the calibrated conditions matched extremely well with observed data, the sub-catchment delineations and parameters of the calibrated model were maintained.

Summary of Model Changes

A summary of the hydraulic and hydrologic changes is described in **Table 4.2**.

Table 4.2 – Hydraulic and Hydrologic Model Change Summary

Location	Hydraulic or Hydrologic?	Description of Change	Details
All	Hydraulic	▪ Revise inverts, alignment, and pipe dimensions	▪ Per survey information
Outfall	Hydraulic	▪ Add permanent Mississippi River tailwater ▪ Add loss coefficient	▪ Tailwater set at elevation 750 based on long-term United States Geological Survey (USGS) river stage data ▪ Loss coefficient to account for 90˚ bend in flow direction within tailrace channel
Tunnel Segment Between Junction and Outfall	Hydraulic	▪ Revise cross-section of pipe between junction chamber and outfall	▪ Change from rectangular to user-defined shape based on historic plat information
Junction Chamber for Central City and Chicago Tunnels	Hydraulic	▪ Define cross-sectional area of chamber ▪ Add minor loss coefficients	▪ Create user-defined shape based on historic plat information ▪ Loss coefficient to adjust for abrupt change in shape of junction chamber
Portland and Washington	Hydraulic	▪ Add sweep from survey ▪ Add expansion and contraction loss ▪ Edit volume of chamber	▪ Per survey information ▪ Loss coefficients to adjust for abrupt expansion and contraction through the sweep ▪ Revise volume of chamber based on survey information
Drift Tunnels	Hydraulic Hydrologic	▪ No changes to number or length of drift tunnels	▪ Add drift tunnels to Hennepin Avenue segment to test effects on model ▪ Hydraulics – minor reduction in peak flow (-0.5-foot) caused by input of additional storage volume, but actual volume is artificial because XPSWMM lengthens all pipe segments to 10 meters ▪ Hydrology – no change in peak flows at nodes
Catchments not Divided into Sub-Catchments	Hydrologic	▪ No change to the catchment subdivisions of model	▪ Conducted test of 4-acre catchment that showed a very minor change in peak flow, dependent on which parameter was adjusted (catchment length vs. catchment area) ▪ Determined that changes are too small to justify additional catchment subdivisions
6th Street Tunnel	Hydraulic	▪ Add tunnel segment	▪ Missing from model ▪ No change in hydrologic inputs
US Bank Stadium	Hydrologic	▪ Update US Bank Stadium hydrologic data	▪ Total acreage increased by 0.3 acres per site plan information provided by the City
Mill City Quarter (2nd Street South)	Hydrologic	▪ Update 2nd Street South hydrologic data	▪ Total 2nd Street South catchment acreage increased from 0.02 to 2.33 acres per site plan information provided by the City
Calibration	Hydraulic Hydrologic	▪ No changes	▪ Calibration was checked after each hydraulic and hydrologic revision and conclusion is that calibration remains valid

Quality Review

A thorough review was performed of the input parameters in the calibrated model. This review included checks of all hydraulic parameters for erroneous inputs. The results include:

- All Manning's roughness coefficients are reasonable, including 3 with a high roughness representative of unpaved ditches.
- All pipes have reasonable slopes, although 38 have no slope at all. These 38 pipes all generate a warning upon simulation start, but this does not impact model results.
- Of the 1,191 conduits in the model, 23 percent have actual conduit lengths that are smaller than the minimum conduit length required by the XPSWMM engine. These links all generate a warning upon simulation start, but were not found to have significant impact on model results.
- Many conduits have minor loss coefficients representative of access shafts/manholes and converging pipes. None are noteworthy.
- Orifices representative of drill holes are represented with dimensions as shown on as-builts and typical discharge coefficients.

A separate review was performed to check hydrologic parameters for valid inputs, such as:

- Model sub-catchment area was compared with GIS-delineated area, and all sub-catchments matched within the tolerance of expected rounding errors.
- Most sub-catchment contributing areas were found to have sufficient resolution to account for the numerous connections to the tunnel system, as shown in **Table 4.3** below.

Table 4.3 – Percentage of Sub-Catchments by Acreage

Acreage	Count	Percentage
< 0.5	94	25%
0.5 – 1	93	25%
1 – 2	94	25%
2 – 3	60	16%
3 – 5	30	8%
5 – 10	6	2%
10 – 15	1	0%
TOTAL	**378**	**-**

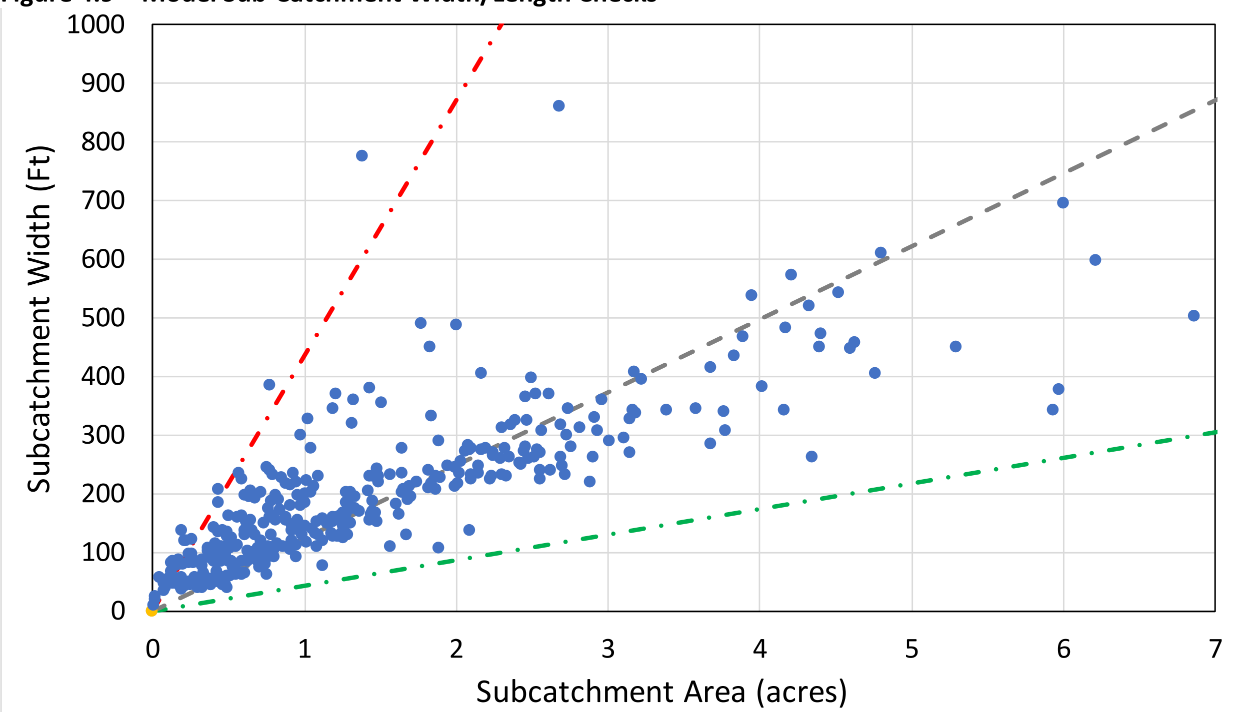
- Most sub-catchments are 100 percent impervious, as shown in **Table 4.4**. A visual review of the project area confirms the high level of impervious coverage.

Table 4.4 – Number of Sub-Catchments by Percentage Impervious

Impervious Percentage	Count
0 – 25%	5
25 – 50%	1
50 – 75%	10
75 – 99%	29
100%	333
TOTAL	**378**

- Sub-catchment lengths all fall within the range expected for urban development, as shown in **Figure 4.9**.

Figure 4.9 – Model Sub-Catchment Width/Length Checks



- Pervious infiltration parameters are all set to the standard City soil type.
- One extremely small sub-catchment of less than 1,000 square feet was found to have a slope of 155 percent. It was determined that this steep slope in a very small sub-catchment does not influence the model results and, therefore, it was not adjusted. All others fall within the expected range.

Existing Condition Analysis

Unrestricted Tunnel Flow Analysis – Individual Tunnel Segments

Free discharge conditions were created at the points where Hennepin Avenue, Nicollet Mall, Marquette Avenue South, and 2nd Avenue South tunnels discharge into the Washington Avenue tunnel to determine if the observed pressure surcharge within each tunnel leg was a product of the individual tunnel segment or downstream hydraulic constraints. Each tunnel leg was analyzed using the 2-year, 10-year, 100-year, and 500-year design storms to determine the level of service of each tunnel leg. The following describes the hydraulic capacity of each of these tunnel segments when not influenced by the HGL of the Washington Avenue stormwater tunnel, as summarized in **Table 4.5**.

- **Hennepin Avenue**: Hennepin Avenue operated without surcharge for a 10-year design rainfall, had negligible surcharge during a 100-year design rainfall, and had 5 feet to 10 feet of surcharge for a 500-year design rainfall.
- **Nicollet Mall**: Nicollet Mall, including contributing flows from the LaSalle Avenue tunnel, had negligible surcharge during a 10-year design rainfall, and 20 feet to 50 feet of surcharge during a 100-year design rainfall.
- **Marquette Avenue South**: The Marquette Avenue South tunnel was able to convey the runoff from all rain events within the crown of the pipe, up to a 500-year design rainfall.
- **2nd Avenue South**: The 2nd Avenue South tunnel surcharged as much as 30 feet during a 2-year design rainfall and had significantly greater surcharge during the larger design rainfall events.

Table 4.5 – Free Discharge for Each Individual Tunnel Segment

Level of Service	Tunnel Segment						
	Hennepin	Nicollet	Marquette	2nd Ave	Washington	Chicago	Outfall
2-Year	OK	OK	OK	Surcharge	Surcharge	OK	OK
10-Year	Negligible Surcharge	Negligible Surcharge	OK	Surcharge	Surcharge	OK	OK
100-Year	Negligible Surcharge	Surcharge	Negligible Surcharge	Surcharge	Surcharge	OK	OK
500-Year	Surcharge	Surcharge	Negligible Surcharge	Surcharge	Surcharge	OK	OK

System Flow Analysis

The tunnel segments were then recombined to assess how the hydraulic conditions of Washington Avenue, in combination with the known deficiencies in hydraulic capacity of each tunnel leg, influenced the total flow. The results are shown in **Table 4.6**. The most significant changes occurred in the Hennepin Avenue and Marquette Avenue South legs of the Central City Tunnel System, changing from no surcharge or negligible surcharge to surcharge in all design rainfall events. However, the

Chicago Avenue tunnel and the converged Central City/Chicago Avenue outfalls have sufficient capacity for all modeled rainfall events.

Table 4.6 – Existing Conditions Hydraulic Analysis

Level of Service	Tunnel Segment						
	Hennepin	Nicollet	Marquette	2nd Ave	Washington	Chicago	Outfall
2-Year	Surcharge	Surcharge	Surcharge	Surcharge	Surcharge	OK	OK
10-Year	Surcharge	Surcharge	Surcharge	Surcharge	Surcharge	OK	OK
100-Year	Surcharge	Surcharge	Surcharge	Surcharge	Surcharge	OK	OK
500-Year	Surcharge	Surcharge	Surcharge	Surcharge	Surcharge	OK	OK

Results and Recommendations

The hydraulic and hydrologic model revisions and the preliminary modeling results were presented at a workshop with staff from the City of Minneapolis Division of Surface Water and Sewers. The following conclusions and recommendations were discussed and resolved:

- The hydraulic changes to the model did not result in significant changes to the peak flows predicted by the calibrated XPSWMM model; therefore, re-calibration was not required.
- The addition of all drift tunnels to the XPSWMM model would not improve the model, and would have a risk of adding instability to the model. It was agreed that the representation of the drift tunnels in the calibrated model should not be changed.
- Additional sub-delineations into smaller sub-catchment areas would not affect the peak flows predicted from the individual sub-catchments. It was agreed that no additional sub-delineation of the sub-catchments should be made to the model.
- The future conditions models should include recommended hydraulic improvements to the three tunnel legs that do not have sufficient hydraulic capacity for the 100-year design rainfall event: Washington Avenue, 2nd Avenue South, and Nicollet Mall. The Marquette Avenue South and Hennepin Avenue tunnel legs will have improved hydraulic performance after improvement of the Washington Avenue tunnel segment and, therefore, do not need further analysis.
- Hydraulic capacity needs.
- CDM Smith should continue to assess improvements needed for both the 10-year and 100-year design rainfall events.

Section 5

Existing Tunnel Conditions

A geo-structural evaluation of the existing tunnel system was completed with the goal of identifying and evaluating risks associated with enlarging tunnel cross-sections to increase the hydraulic capacity of the system.

Subsurface Conditions

The general subsurface profile in the drainage system area is very consistent as shown on the tunnel plats provided by the City. This general profile consists of:

- **Overburden**: Sand, gravel, boulders, and in some locations, a thin layer of clay below the granular material.
- **Weathered Rock**: Described differently on profiles ranging from hardpan and boulders to broken limestone.
- **Rock**: Predominantly limestone, in some locations a thin shale stratum overlying a 15-foot to 40-foot thick stratum of limestone that serves as a cap rock to a very thin soapstone and below the soapstone is the St. Peter Sandstone.
- **Groundwater**: Not identified on any of the tunnel plats. Recent analysis of the Nicollet Mall sanitary sewer, which is in the project area, had not discovered any groundwater at a drilled boring depth of 40 feet. This corresponds to elevation 90 for the vertical datum used on the sewer plats provided by the City.

Table 5.1 presents a summary of the various strata thickness, in feet, along the various tunnel segments. The initial support system is identified at the drill hole locations. The initial support system used during the construction is identified along the tunnel profiles. The table was developed from the existing storm tunnel plats provided by the City.

Table 5.1 – Sub-Surface Profiles Along the Drainage Tunnel Alignments

Tunnel	Sta (ft)	Initial Support	Cross St Location	Strata Thickness above Tunnel Crown (ft)					
				Soil	Weathered Rock	Lime-stone	Soap-stone	Sand-stone	Total Cover
2nd Avenue	0+00	None	Wash	30	7	20	3	1	61
	3+90		3rd St S	30	13	20	3	5	70
	8+00	None	4th St S	20	3	15	1	8	46
	11+91	None	5th St S	33	12	31	2	0	78
	16+52	Light Timber	6th St S	28	18	29	2	1	78

Tunnel	Sta (ft)	Initial Support	Cross St Location	Strata Thickness above Tunnel Crown (ft)					
				Soil	Weathered Rock	Lime-stone	Soap-stone	Sand-stone	Total Cover
	19+78	Light Timber	7th St S	47	1	30	2	0	80
	24+23		8th St S	47	3	29	2	0	82
	28+80		9th St S	34	13	30	0	6	83
	32+64		10th St S (shaft)	48	4	27	0	5	83
Crossing 2nd Street South		Concrete & Brick	At drift	24	4	31	0	2	61
5th Street South	0+00	None	Nicollet	22	18	19	4	15	77
6th Street South	0-36	Light Timber	Hennepin	24	24	17	2	15	82
	3+92	None	Nicollet	21	22	10	3	21	77
7th Street South	2+73	Light Timber (above tunnel)	DH #158-A	19	27	17	0	15	77
8th Avenue South (Chicago Avenue)	2+50	None	2nd St S.	12	7	29	0	5	52
8th Street South	3+82	None	LaSalle	30	10	19	3	15	77
Portland Avenue South	3+23	Concrete & Brick	Wash	29	4	26	3	4	66
	7+42		3rd St S	30	5	27	3	4	69
Hennepin Avenue	0+46	Heavy Timber	Wash	15	11	8	3	36	72
	4+18	Light Timber	3rd St S	29	13	20	3	5	70
	8+35	None	4th St S	23	15	35	3	1	76
	13+64	Light	5th St S	30	0	14	3	28	75
	17+22	None	6th St S	32	0	11	2	30	75
	21+45	Light Timber	7th St S	20	16	12	4	24	75
	26+12	None	8th St S	34	2	14	3	21	73
	30+36	Light Timber	9th St S	29	6	15	4	17	71
	32+90	Light Timber	10th St S	24	10	13	2	24	71
LaSalle Avenue	3+83	None	8th St S	30	13	16	3	16	78
	7+31	None	9th St S	34	0	25	5	12	75
	11+46	None	10th St S	23	10	32	4	8	75

Tunnel	Sta (ft)	Initial Support	Cross St Location	Strata Thickness above Tunnel Crown (ft)					
				Soil	Weathered Rock	Lime-stone	Soap-stone	Sand-stone	Total Cover
	15+82	None	11th St S	16	17	30	3	5	72
Marquette Avenue South	0+00	None	150 ft west of 1st St S	15	12	13	4	25	68
	2+20	None	2nd St S	16	9	15	4	22	65
	6+54= 0+00	None	Wash	30	6	13	4	20	73
	4+00	None	3rd St S	32	4	12	6	16	70
	8+03	None	4th St S	36	4	22	3	11	76
	12+00	None	5th St S	38	12	18	4	7	80
	16+24	None	6th St S	50	8	16	6	3	83
	20+30	None	7th St S	34	6	14	22	4	80
	21+04	None	End of tunnel	39	13	23	5	0	79
Nicollet Mall	0+00	None	2nd St S	20	10	8	5	28	71
	4+20	None	3rd St S	25	6	9	2	28	70
	7+80	Light Timber	4th St S	31	3	13	5	22	74
	12+12	None	5th St S	23	17	18	4	15	78
	16+49	None	6th St S	19	31	14	0	16	80
	20+22	Light Timber	7th St S	17	35	16	0	11	80
	24+61	None	8th St S	17	25	29	0	8	79
	28+73	Light Timber	9th St S	23	20	30	0	2	75
	32+70	Light Timber	10th St S	27	14	33	0	1	75
Washington Avenue	0-46	Heavy Timber	Hennepin Ave	17	11	10	4	31	72
	0+00	Heavy Timber	Shaft @ Hennepin	17	11	10	4	31	72
	1+56	Heavy Timber	Initial Support Change	20	11	7	5	29	71
	1+67	Light Timber	Nicollet Mall	20	11	7	5	29	71
	2+95	Light Timber	Marquette Ave S	29	0	18	5	20	72
	9+68	Light	2nd Ave S	28	10	18	0	13	68
	13+77	Light	3rd Ave S	30	0	30	0	6	65
	17+88	Light	4th Ave S	31	0	28	3	2	64
	22+29	Light	5th Ave S	30	0	29	2	2	63
	26+41	Light	6th Ave S	30	0	30	3	1	64

Preliminary Engineering Rock Parameter Values

The preliminary engineering rock parameter analyses focused on the interaction between the tunnel lining and the St. Peter Sandstone. This sandstone is unique in that it is composed of a very uniform sand size grains that is 99 percent quartz. The rock strength is from the compressive strength of the sandstone, yet it exhibits almost no cohesion and readily erodes when the compressive load is eliminated. The sandstone becomes harder and denser with depth, yet it is very friable. Turbulent water in contact with a fresh surface of sandstone will cause a rapid erosion, which leads to voids in the areas exposed to the water.

In 1967, Charles Payne published a thesis[4] analyzing the rock parameters of the St. Peter Sandstone in Minneapolis and St. Paul. Rock samples presented in this thesis were from an area that is within a few blocks of the Central City Tunnel System project area. Therefore, the rock parameters are assumed appropriate for use in this preliminary analysis. The parameters, as described in the thesis are noted below:

- **Total unit weight** of the rock as measured in the laboratory and reported in the thesis was measured as 135±4 pcf[5].
- **Gradation and sieve analyses** of the sandstone indicate that approximately 90 percent of the sand grains were between the 140 and 60 sieve sizes. This is indicative of a fine sand.
- **Porosity** of the rock averaged 0.28.
- **Unconfined compressive strength** testing of 11 samples presented in the thesis reported compressive strength values ranging from 683 to 2816 psi with an average strength of 1566±400 psi.
- **Friction angle,** ϕ, was determined by triaxial tests performed on the rock. A total of eight tests were conducted with the friction angles ranging from 58.8° to 69.4°. This correlated with published friction angles of the St. Peter Sandstone reported as ranging between 54° to 65°. Two of the Payne's test results were above this upper limit and appear as outliers. These two outlier tests were not used in the analysis. Using the remaining test results an average ϕ of 61.4°±1.5° was calculated.

CDM Smith's assessment of the test results presented in Payne's thesis is that the values are representative of intact rock strength and are applicable for this preliminary analysis. With minimal to no cohesive strength in the sandstone, it would be difficult to collect a test sample in an area of sandstone that contains a joint (break in the sandstone) since the rock could not re-heal once that joint had developed. The primary reason that the samples used in Payne's thesis were intact rock is that rock will fail on the weak plane via a joint or foliation plane in the core

[4] Engineering Aspect of the St. Peter Sandstone in the Minneapolis-St Paul Area of Minnesota, Charles M Payne, University of Arizona, 1967

[5] ϕ = friction angle, gm = grams, cm^3 = cubic meters, pcf = pounds per cubic foot, psi = pounds per square inch, cm^2 = square meters, MPa = megapascal (a unit of pressure)

being tested. To account for the rock mass strength, which will consider joints in the rock mass, CDM Smith adjusted the intact strength using the GSI Tool[6] developed by P. Marinos and E. Hoek.

A statistical evaluation of the data presented in the Payne thesis was performed to calculate the average ϕ range, based on a 95 percent confidence interval and standard deviation values. The Central City Tunnel System (no support, light support, heavy support as described in the Step 2 Results section below) was used as a guide in evaluating the rock condition along the tunnel. The guide used was based on the average unconfined compressive strength (UCS) for the sandstone of 1566 psi. The correlations provided in the GSI Tool used the metric system. To be consistent with that system, CDM Smith converted all unit weight, elastic properties, and strength parameter values to metric prior to analysis by the Phase[2] program.

The values used for the rock are presented in **Table 5.2**. It is assumed that the tunnel support was added at locations where rock quality was lower than the average UCS value. Arbitrary adjustments were made to account for reduced strength values from the intact rock strength values. Geotechnical investigations will be required to confirm these assumptions during final design.

Table 5.2 – Tunnel Initial Support System and Unconfirmed Compressive Strength Values Used for Modeling

Existing Tunnel Support System	Adjustment to Average Parameter Values	Resulting UCS of Intact Sandstone
No initial support and final lining consisting of unreinforced concrete	No adjustment to computed average value	1566 psi (10.8 MPa)
Initial lining consisting of light timber support	Used average value minus calculated confidence interval value	1160 psi (8.0 MPa)
Initial support consisting of heavy timber	Used average value minus one standard deviation	870 psi (6.0 MPa)

Analysis Procedures

The geo-structural analysis required assessment of both the liner strength of the existing tunnel system and the ability for adjacent or parallel expansion of the tunnel during construction.

Existing Tunnel System

In the November 16, 2016 inspection, voids were noted in the tunnels on Marquette Avenue South, Nicollet Mall, and LaSalle Avenue. These voids were from 3 inches to 48 inches deep behind the outside of the tunnel lining. Water inflows were also noted on these same tunnels. In addition, drips were noted in the tunnels under both 2nd Avenue South and Hennepin Avenue. Probing of the cracks indicated a void exists behind the liner requiring that the void be filled with a cement grout to provide support to the lining.

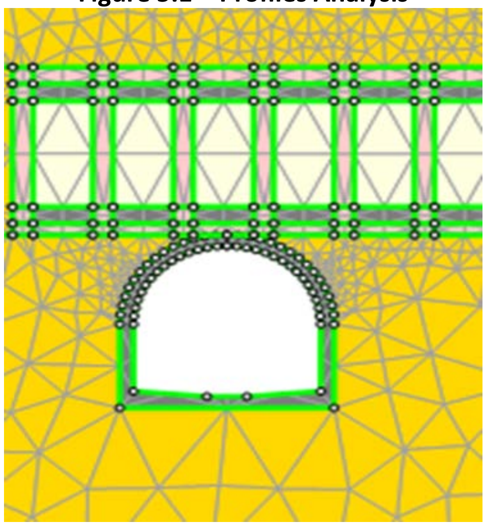
To analyze the existing tunnel system, the Phase[2] Rocscience software program for 2D evaluations of the tunnel was utilized. After review of the existing tunnel plats, five possible configurations were identified and evaluated. The existing tunnel materials were modeled using

[6] GSI: A Geologically Friendly Tool for Rock Mass Strength Estimation, P. Marinos and E Hoek. 2000

Mohr-Coulomb failure criteria to account for the lack of reinforcing steel and an inability to resist tensile stress. Failure of the existing tunnel liner was conservatively assumed to occur when the liner is in tension. The analysis configurations consisted of the following:

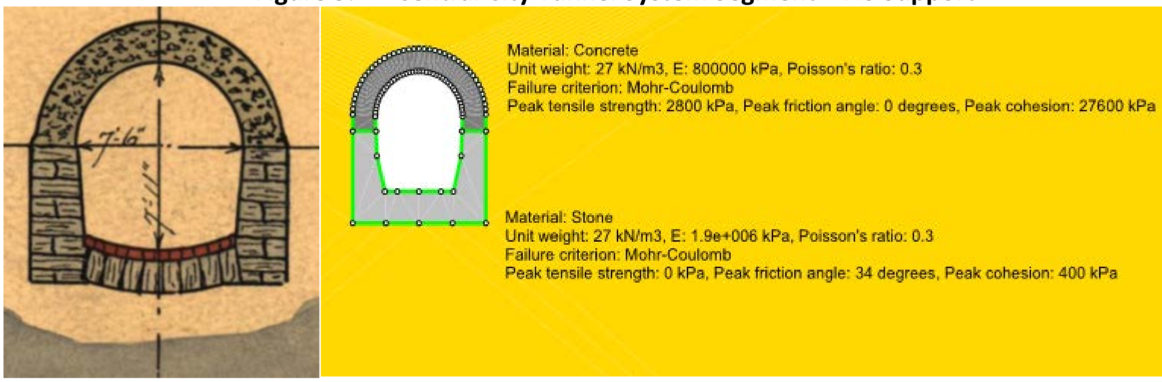
- **Profile Analysis** of the excavation of the storm drainage tunnel at locations where it crosses directly above an existing sanitary sewer tunnel was conducted. This analysis (as illustrated in **Figure 5.1**) was performed to evaluate the magnitude of change in stress in the existing underlying sewer tunnel due to excavation above it.

Figure 5.1 – Profiles Analysis



- **Cross-Sectional Analysis**: An analysis of different support types was performed using adjusted rock strength values depending on the existing liner support system, including no timber, light timber, and heavy timber support behind the liner. The analysis consisted of applying a cyclical internal pressure to the tunnel representing loads experienced during a the 100-year rainfall event, as predicted by the XPSWMM existing conditions model, as updated by CDM Smith. The frequency of the cyclical loading was based on a review of 5 years of historic pressure data provided by the City. During this 5-year period, there were six events that surcharged the tunnel at the pressure meters. These surcharges ranged from 4 feet to 38 feet above the tunnel crown. For the modeling, we extrapolated this to 20 surcharge loadings, representing the occurrence of one surcharge event every 5 years for a period of 100 years. The applied internal pressure represented by the 100-year rainfall event is predicted to be 35 psi, or 80.7 feet of water. This represents a factor of slightly greater than 2 times the measured event. Each of the three different liner conditions and locations, were modeled as follows:
  - **No Lining Support**: There are several locations on the City's tunnel plats where the tunnel liner is shown as concrete placed against the sandstone without initial support. **Figure 5.2** represents a typical No Support segment. The average rock strength parameters were used, without strength reduction, since there is no initial liner support. This is based on an assumption that the St. Peter Sandstone at these locations was in good condition, with few joints or loose materials.

Figure 5.2 – Central City Tunnel System Segment – No Support

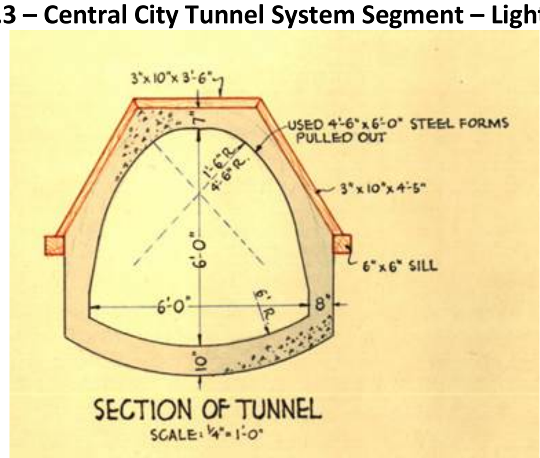


Source: Minneapolis Tunnel Plat No. 2-TUN-7, 2nd Street South, Portland Avenue South to 8th Avenue South

- **Light Timber Support**: At locations where light timber support was identified, the drainage tunnel is approximately 6 feet high by 6 feet wide, as represented in **Figure 5.3**. A light wood support encompasses the upper portion of the tunnel from springline to crown and back to the springline in a trapezoidal configuration. The support consists of three sets of 3-inch by 10-inch timbers that sit on sills excavated into the sandstone at an elevation that is close to the tunnel springline elevation. These ribs were installed approximately 4 feet on-center. At completion of a tunnel reach the annular void between the form and exposed rock and ribs was filled with concrete.

  It was assumed that the ribs were used in locations where the rock quality exhibited some joints or fractures, requiring some additional initial support. To account for this condition, the model used the reduced rock strength of the intact rock as presented in Table 5.1. As previously discussed, the timber supports provide a seepage path for groundwater outside the tunnel and leakage through the tunnel to cause erosion of the sandstone. This results in a source of sand to migrate through cracks in the lining and creates an ongoing process of lining support deterioration by creating greater areas of unsupported lining.

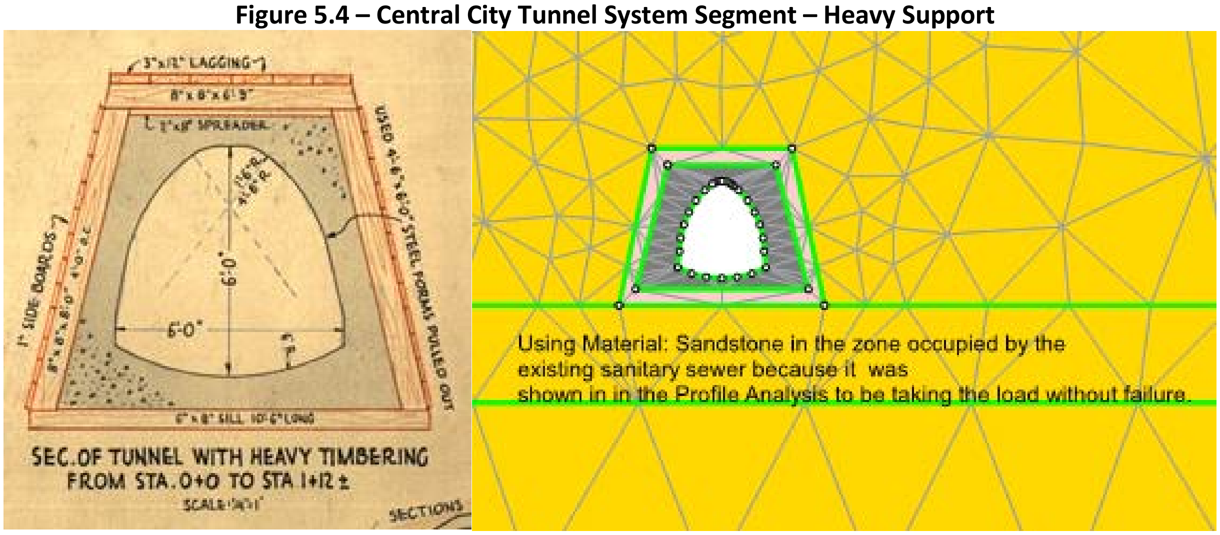
Figure 5.3 – Central City Tunnel System Segment – Light Support



Source: Minneapolis Tunnel Plat No. H-TUN-1, Hennepin Avenue, 4th Street South to Washington Avenue

- **Heavy Timber Support**: Heavy timber support locations consist of wood ribs that fully surround the tunnel perimeter with wood lagging, as represented on **Figure 5.4**. Heavy timber supports were used where the rock quality was significantly poorer than at other segments of the tunnel, requiring this stronger initial support. To account for this condition, the model used the reduced rock strength of the intact rock as presented in Table 5.2. The tunnel plats show that this heavy timber system consists of four sections of 8-inch by 8-inch timber ribs installed 4 feet on-center in a trapezoidal configuration with 1-inch thick lagging place against the sandstone and kept in place by the ribs. After completion of the tunnel, a concrete liner was cast in place. The same process of loss of strength of the initial support system was used to model the behavior of the tunnel as a function of time and cyclical loads.

Figure 5.4 – Central City Tunnel System Segment – Heavy Support



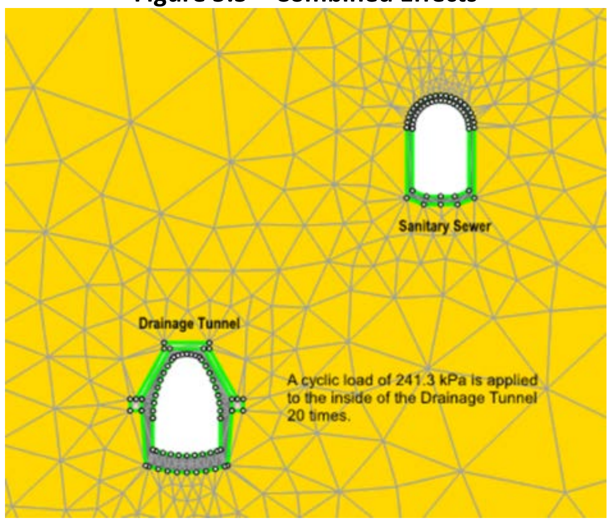
Source: Minneapolis Tunnel Plat No. W-TUN-2, Washington Avenue South, 2nd Avenue South to 4th Avenue South

- **Reduction in Liner Strength**: The purpose of a reduction in strength is to account for degradation of the underlying timber supporting the tunnel liner related to the environmental cycles of wet and dry conditions. As the wood both shrinks in volume and decreases in strength, deformation of the sandstone would follow with each cyclical loading due to a storm event. This loss of external support, originally provided by the sandstone, causes a tensile loading on the unreinforced segments of the concrete liner. The tensile loading results in liner cracks, which creates a pathway for seepage of groundwater from outside the tunnel liner during non-storm events, and leakage into the sandstone during a pressurized storm event to cause erosion of the sandstone. The resulting sand migration through liner cracks results in an ongoing process of deterioration of liner support by creating increasing areas of unsupported lining over time. To account for this long-term reduction in liner strength, it was assumed that the timber strength reduced by 5 percent between each cyclical loading event.

- **Concrete Liner Loading**: An assessment of the liner after each loading event was conducted. Providing there was continuous rock support against the liner, deformations were found to be minimal. However, where joints were formed due to shrinkage of the unreinforced concrete, the measured cracks were of sufficient size to allow passage of sand grains into the tunnel. This loss of ground was modeled by assuming a void behind the tunnel lining at each tunnel crack.

- **Combined Effects**: To evaluate locations where several factors may increase the loads, an analysis was performed taking into account the combined effect of nearby sanitary sewers, weakened condition of the tunnel lining, and disturbance to the rock.

Figure 5.5 – Combined Effects



Expansion of the Tunnel System

A review of the relationship between the existing tunnel and the caprock above the tunnel, as drawn on the tunnel plats, showed that several tunnel segments are close to the caprock and have limited space available for vertical tunnel expansion without penetrating the caprock. According to the Payne thesis, tunnels constructed at elevations above the limestone caprock are significantly more difficult to support and double to triple the cost. Therefore, only tunnel expansion in a horizontal direction with limited vertical expansion was evaluated. Segments of the overall tunnel drainage system, where there is very limited sandstone height above the tunnel crown are shown in Table 5.1. For example, along Washington Avenue between 3rd Avenue South and 6th Avenue South there is only 2 feet to 6 feet of sandstone above the crown of the drainage tunnel. To evaluate adjacent tunnel expansion conditions, CDM Smith assumed a sequential excavation adjacent to the existing tunnel on either side of it would be required to a width of 8 feet. The resulting flat roof is not by itself stable as a function of the rock structure. Assuming limestone with horizontal layering this excavation can be made stable with rock bolts anchored into the limestone zone of reinforced rock to support the overlying soils.

There are also several adjacent sanitary and storm drain tunnels that either share a lining wall or are very close to one another. Because of these adjacent tunnels, it was concluded that the storm tunnel cannot be lowered, or substantially re-aligned due to the conflicts created by these nearby, and crossing, sanitary tunnels. Therefore, the adjacent tunnel expansion analysis only evaluated the potential to increase the cross-sectional size of selected tunnels along its existing alignment to create the additional cross-sectional area needed to increase the hydraulic capacity of the stormwater tunnel system.

Limitations or restrictions used for the proposed new tunnel cross-section needed to increase the tunnel capacity were:

- Maintaining a gravity flow.
- Avoiding conflict with existing sanitary tunnels that cross below the storm tunnels.
- Inability to excavate into the limestone caprock.
- Increasing the tunnel capacity so that future hydraulic surcharges are mitigated to a level that does not cause additional deformation and cracking of the tunnel lining.
- Miner safety during excavation with regards to rain events that can flood the tunnel during active construction.

For expansion of the existing tunnel two possible configurations were identified and evaluated:

- **Excavation within the existing tunnel**: Increase in the tunnel cross-section using a step by step removal of the tunnel lining support in a sequential excavation method to reduce excessive stresses on the lining left in place.
- **Excavation Adjacent to the Existing Tunnel**: Sequential excavation of tunnel adjacent to the existing tunnel on either side of it and to a length of 8 feet was assumed. The resulting flat roof is only stable as a function of the structure, joint spacing in the overlying limestone. Additionally, with a moderate spacing of 6 feet for vertical joints in the limestone with horizontal layering, this excavation can be made stable with rock bolts anchored into the limestone.

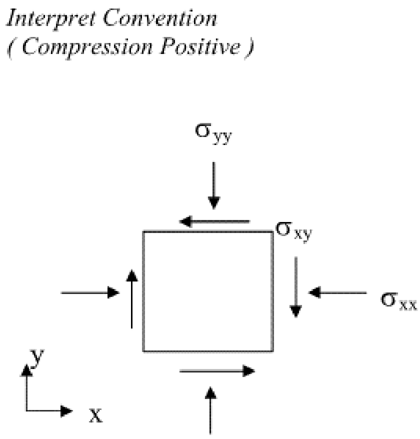
Results of Existing Tunnel System Liner Analyses

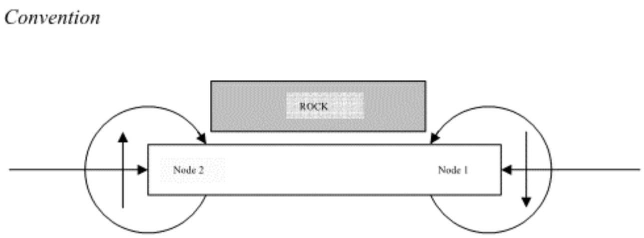
Profile Analysis

The profile analysis evaluated tunnel excavation at the locations where sanitary tunnels cross under the Central City Tunnel System. The results of this analysis represent an unloading on the existing underlying sanitary sewer liner. The most significant result of this 2D analysis is that the existing sanitary sewer liner remains in compressive loading. There is a relatively minor decrease in the load on the sanitary sewer tunnel liner, resulting in a reduction in the compressive stresses in the sanitary sewer liner from top to bottom. The reduction in the stress load from top to bottom of the tunnel lining is only slightly more than 1 psi. Therefore, the overall conclusion is that the construction of the Central City Tunnel System segments had negligible effect on the underlying sanitary sewer tunnel.

Cross-Sectional Analysis

The results from each of the three-different liner support conditions are discussed below and illustrated in **Figure 5.6** through **Figure 5.15**. The figures show the stress, strain, and displacement for the tunnel liner versus the clockwise distance from the tunnel crown. Positive stress indicates compression as shown in the diagram below for the Phase^2 interpret convention. Conservatively, failure was assumed to occur when the liner reached a state of tension.





No Lining Support

Results of cyclical loading in the model show that no cracking is developing in the concrete where the liner is in direct contact with the sandstone. The changes in stresses, strains, and deformation of the tunnel show negligible effect on the liner due to the application of an internal pressure on the liner. The results of this analysis are shown in **Figure 5.6**, **Figure 5.7**, and **Figure 5.8**.

Figure 5.6 – Total Normal Stress from the Phase² Model of the Cross-Section with No Timber Reinforcement

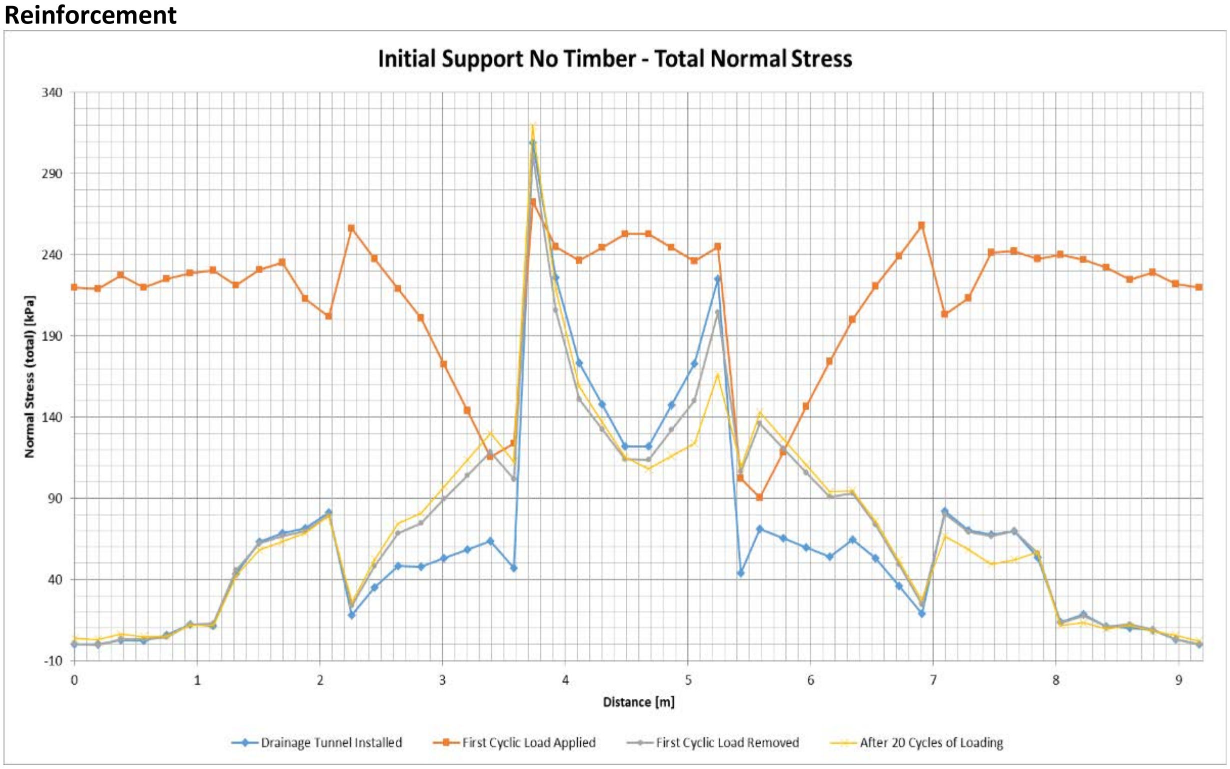


Figure 5.7 – Volumetric Strain from the Phase^2 Model of the Cross-Section with No Timber Reinforcement

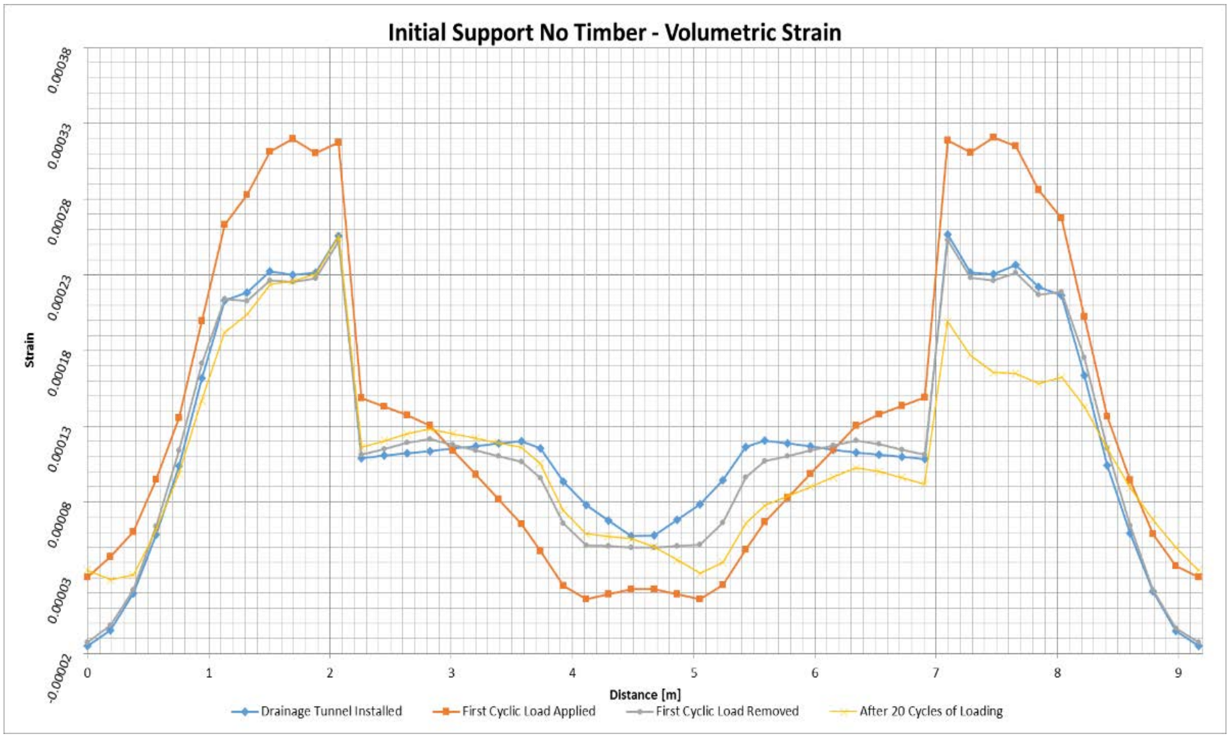
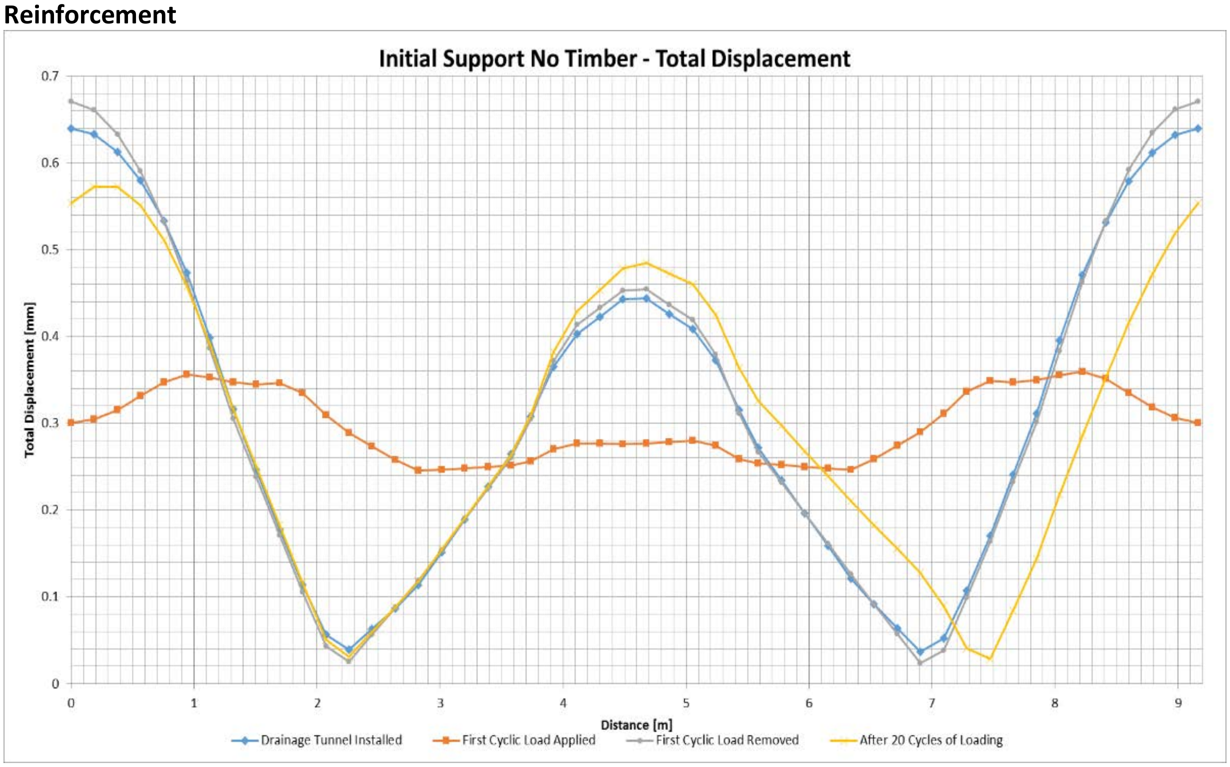


Figure 5.8 – Total Displacement from the Phase^2 Model of the Cross-Section with No Timber Reinforcement



Light Timber Support

The results of cyclical loading show that no cracking is developing in the concrete where there is direct contact between the liner and the sandstone. The results of this analysis are shown in **Figure 5.9**, **Figure 5.10**, and **Figure 5.11**. The changes in stresses, strains, and deformation of the tunnel show negligible effect on the lining when an internal pressure is applied on the liner. However, there is a change to the liner stress where there is a void behind the lining, which may have developed as a result of erosion of sandstone by seepage along the timber supports. These conditions exist and were noted during the inspection as either a sand deposit in the tunnel or by inserting probes through existing cracks which indicated voids of several inches in depth.

Figure 5.9 – Total Normal Stress from the Phase^2 Model of the Cross-Section with Light Timber Reinforcement

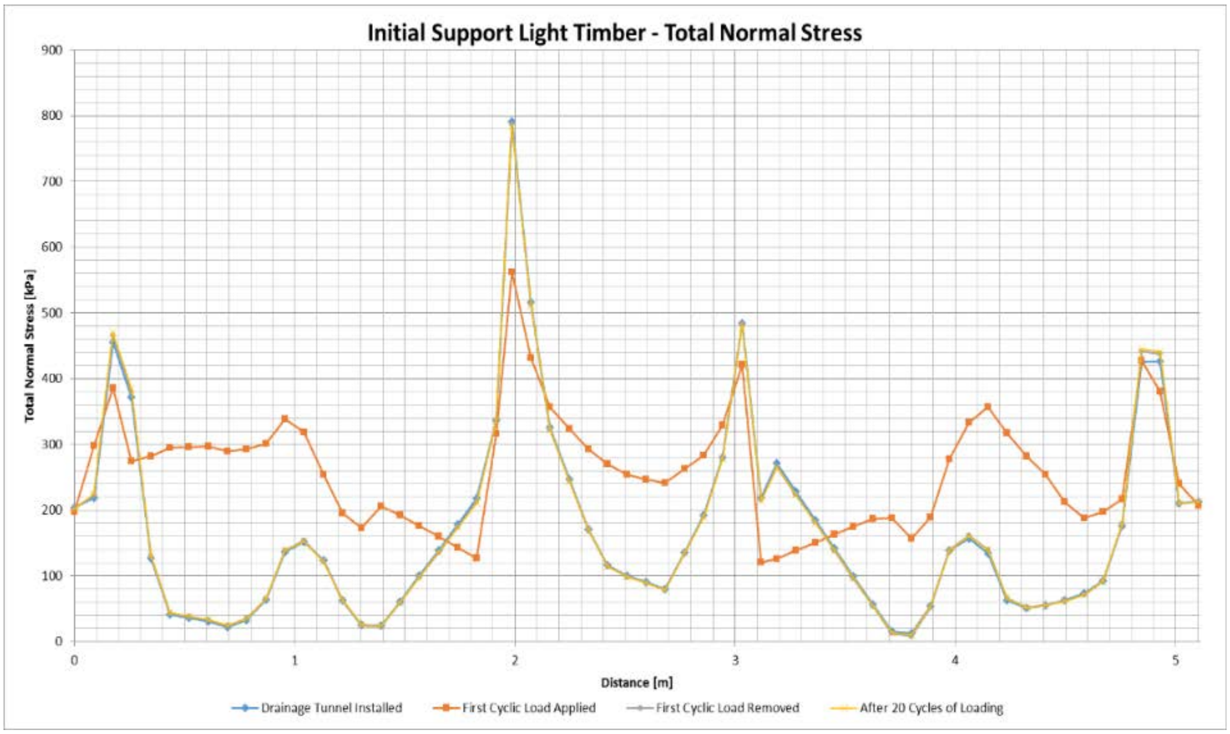


Figure 5.10 – Volumetric Strain from the Phase[2] Model of the Cross-Section with Light Timber Reinforcement

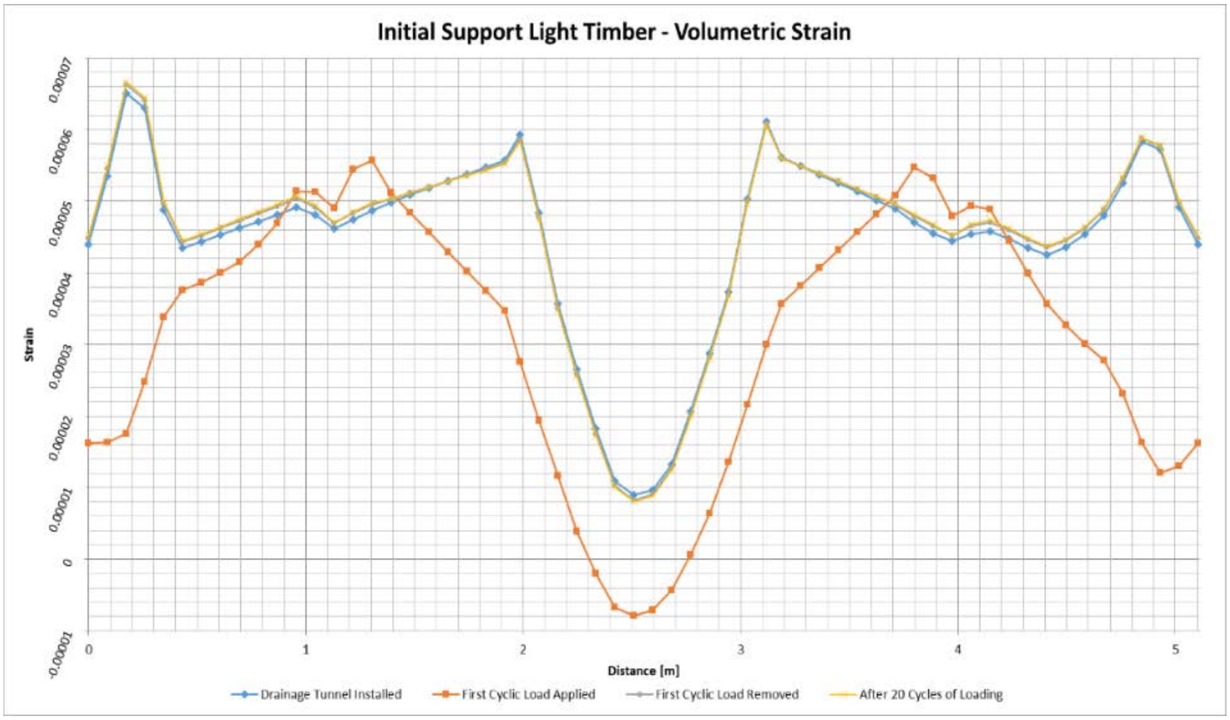
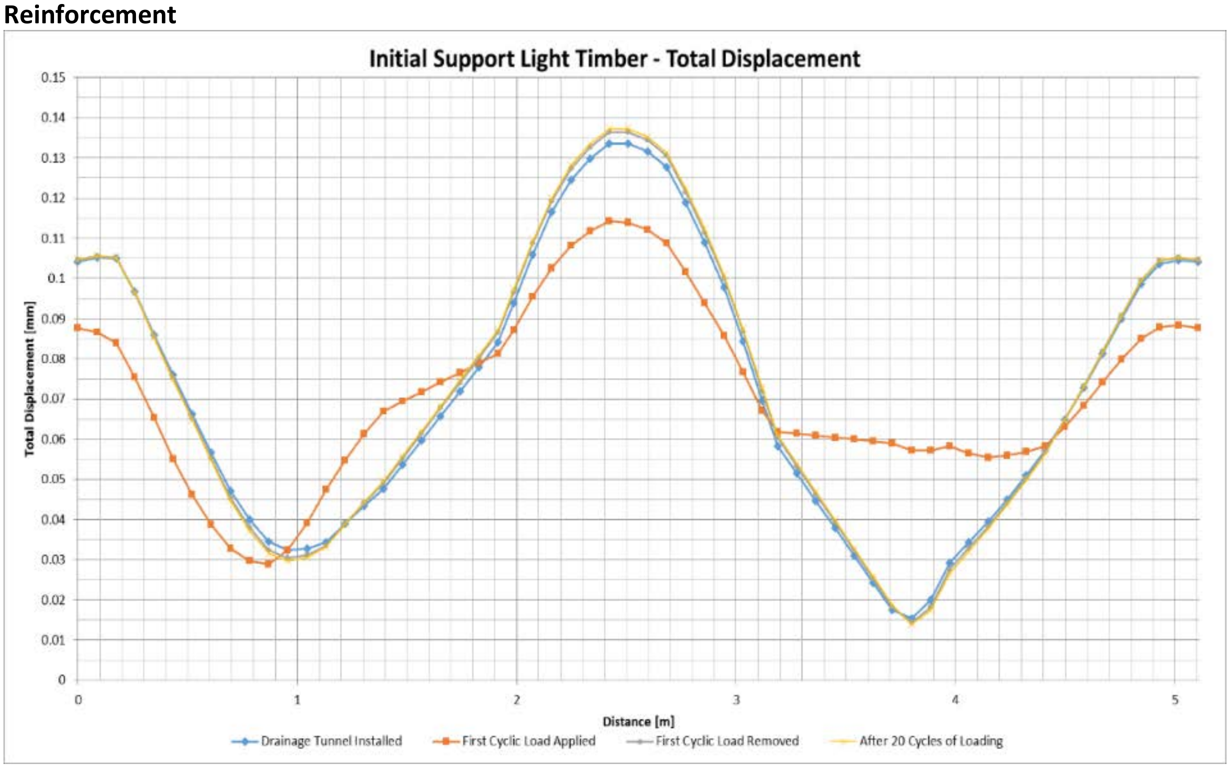


Figure 5.11 – Total Displacement from the Phase[2] Model of the Cross-Section with Light Timber Reinforcement



Heavy Timber Support

Results of this cyclical loading show that no cracking is developing in the concrete when the liner is in direct contact with the sandstone. The results of this analysis are shown in **Figure 5.12**, **Figure 5.13**, and **Figure 5.14**. The changes in stresses, strains, and deformation of the tunnel show negligible effect on the lining due to the application of an internal pressure on the liner.

Figure 5.12 – Total Normal Stress from the Phase^2 Model of the Cross-Section with Heavy Timber Reinforcement

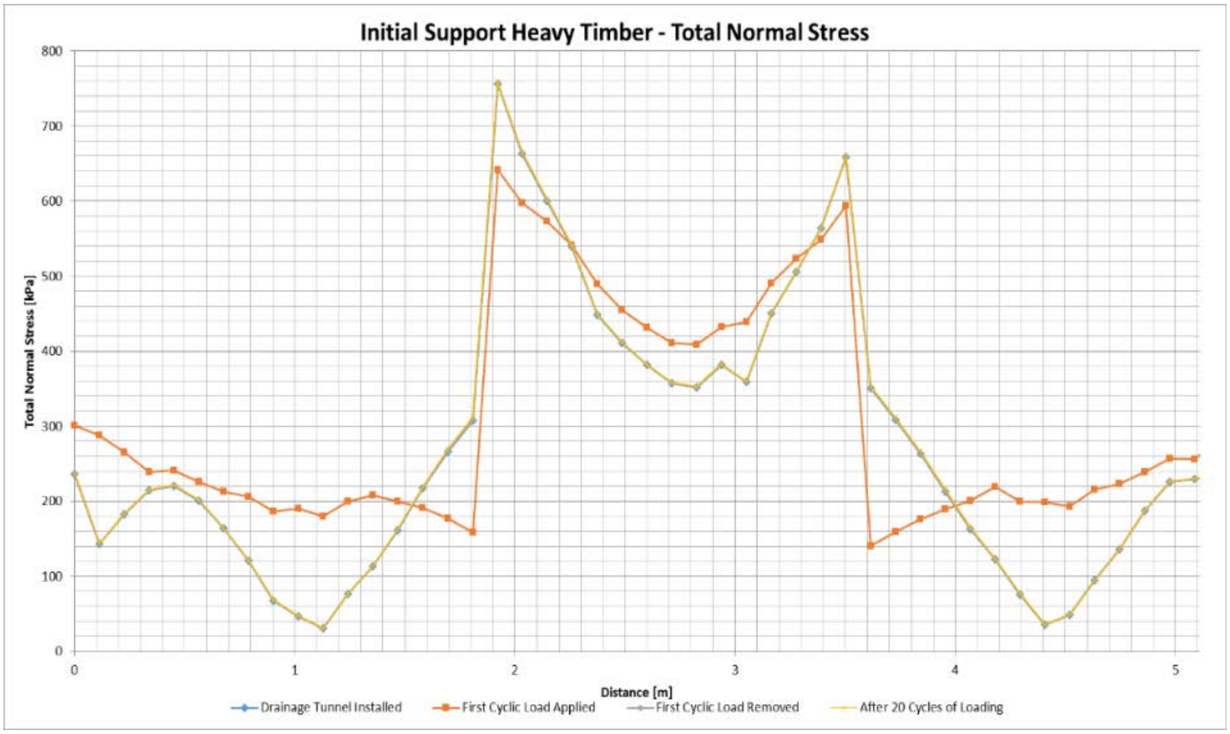


Figure 5.13 – Volumetric Strain from the Phase[2] Model of the Cross-Section with Heavy Timber Reinforcement

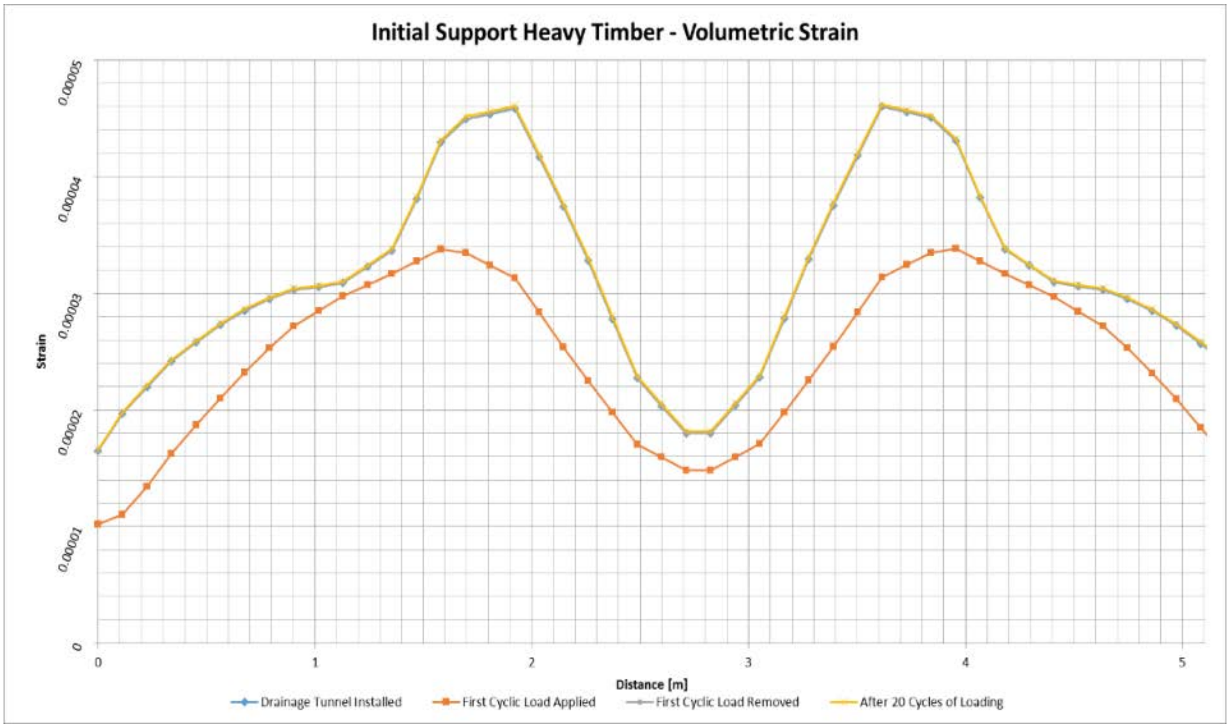
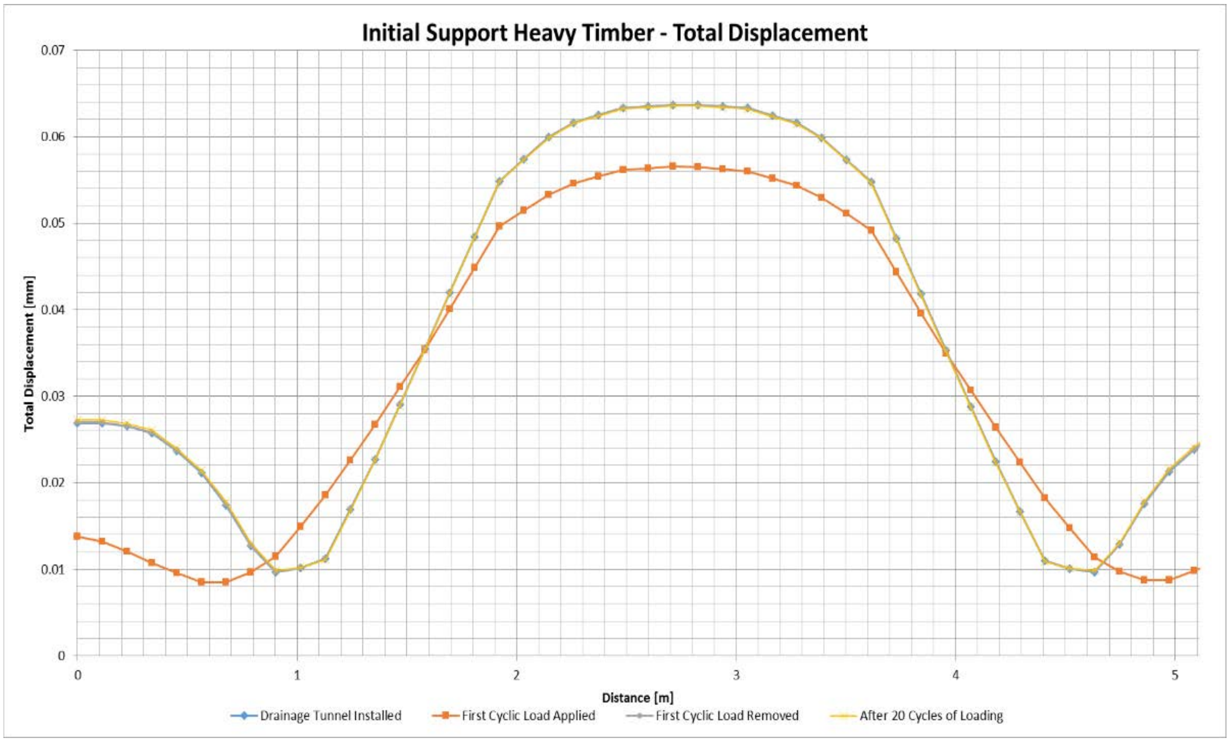


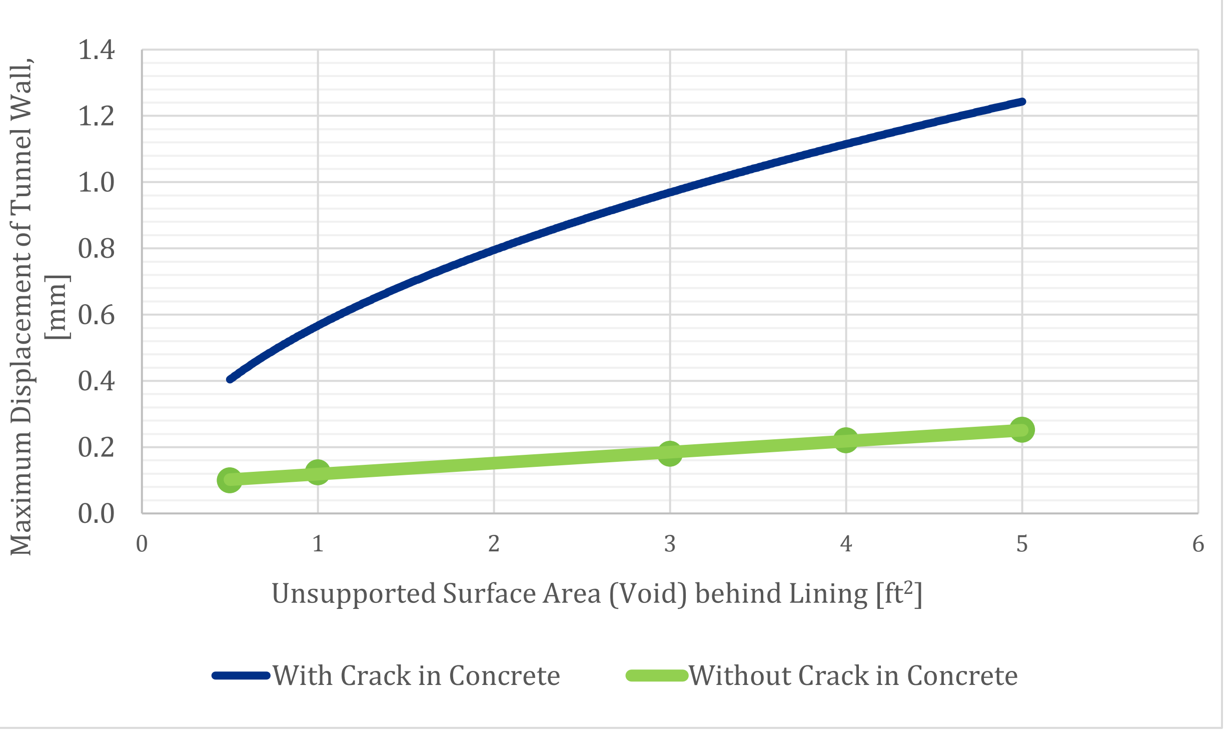
Figure 5.14 – Total Displacement from the Phase[2] Model of the Cross-Section with Heavy Timber Reinforcement



Reduction in Liner Strength and Concrete Liner Loading

Results of reduction in liner strength and concrete liner loading analyses both showed that as voids form behind the concrete liner they allow increased displacement of the concrete liner until failure of the liner results. The concrete liner loading analysis showed that the rate of lining deformation is significantly greater where there is a crack in the lining. **Figure 5.15** shows the relationship between displacement of the liner and void surface area for both cracked and un-cracked concrete liners.

Figure 5.15 – Tunnel Lining Displacement as Function of Void Surface Area



Existing Tunnel System Analysis Conclusion

Phase² model results all indicate that the existing tunnel structures are stable where the tunnel liner is in contact with the St. Peter Sandstone. However, accumulations of sand can be an indication of eroded sandstone behind the liner, causing additional stress on the liner. It is assumed that the reason for these deposits is the combination of shrinkage cracking of the liner, and the natural behavior of the friable sandstone that causes the fine sand to erode as water moves along the outside of the tunnel liner. It should be noted that groundwater flowing through the liner was not observed during the tunnel inspection.

Figure 5.16 – Photographs of Sand in Tunnel

The basis for this conclusion is that the tunnel liner consists of unreinforced concrete that ranges in thickness from 7 inches to 12 inches, based on the details shown on the tunnel plats provided by the City. There is no indication of expansion joints being installed in any of the tunnels. The inspections, contained in Appendix B, indicated that spacing of vertical cracks and transverse cracks averaged about 57 feet apart, as shown in **Table 5.3**, when measured along the tunnel axis. Vertical cracks were of lengths less than half the perimeter length of the tunnel section, whereas, transverse cracks extended around the entire tunnel perimeter. Over the entire length of tunnels inspected, 235 vertical and transverse cracks were noted. Crack widths are shown in **Table 5.4**. Considering that 90 percent of the sandstone grain size is fine sand and can pass through about 90 percent of the observed cracks, it is possible for sand grains to migrate and, thus, create void spaces that as shown in the analyses will self-perpetuate the deterioration of the tunnel lining as a function of surcharge loading. The crack size observed during the inspection is shown in Table 5.3. Based on the Phase^2 analysis results, an increase in cracking should be anticipated in locations were poor rock conditions are present. This is supported by the inspection data. Table 5.4 shows a comparison of the average crack spacing ratio to areas with light timber support and no timber support.

Table 5.3 – Typical Transverse Crack Opening Sizes

Transverse Crack Size	Percent of Cracks
No Opening	11%
1 mm	36%
1-2 mm	51%
>3 mm	2%

Table 5.4 – Crack Space Comparison

Support Type	Crack Spacing (ft. apart)
No Support	88
Light Timber	50
Average	57

Repair and Modification Methods

Some repairs in the form of preventing the movement of sand into the tunnel and filling the voids behind the lining are recommended to stop long-term deterioration of the liner. Determination of the locations and approximate volume of voids behind the liner could be conducted by an extensive geophysical survey from inside the tunnels. The results of such a survey could then be used to quantify a program of repairs to the tunnel.

The repair would consist of filling of the voids behind the lining and removing a short segment of the concrete lining to install a water stop/expansion joint. This operation would mitigate future cracking of the tunnel. However, it would not provide any increase in the hydraulic capacity of the tunnel. Therefore, the tunnel would still be subject to surcharge.

This report focuses on hydraulic improvements that would mitigate the ongoing severe pressurization experienced in the Central City Tunnel System. As noted in Section 4, there are segments of the system that have adequate hydraulic capacity and are therefore, not in need of reconstruction. The following modification techniques described in this section are recommended for those tunnel segments that show signs of liner stresses, but are not recommended for reconstruction.

Several methods can be considered for repairs to the existing tunnel without enlarging the hydraulic capacity of the tunnel. Once the repair options are considered, it should be assumed that additional cracks will form unless the cause of the cracking is identified and resolved. Therefore, it is recommended that a future inspection and record of vertical and transverse cracking be conducted to detect new cracks that may occur. A review of inspection reports provided by the City that occurred prior to the November 2016 inspection performed by CDM Smith did not make note of vertical and transverse/circumferential crack locations in the tunnels. Therefore, no comparison to these cracks identified by CDM Smith in the most recent inspection could be made.

Option 1 – Chemical Grout

Option 1 consists of performing repairs at existing joints and cracks in the unreinforced tunnel liner by chemical grout injection. The grout is a polyurethane and considered to be permanent once injected. The grout would provide a flexible yet watertight seal to the existing joints and cracks. No new joints would be installed in this scenario. Details of the chemical grout include:

- **Material**: The compound is a single component, expanding, moisture reactive polyurethane grout designed to seal cracks and open joints in concrete. The cured chemical grout will form a compressed closed cell urethane foam that completely fills the crack or joint. An accelerator can be used if recommended by the manufacturer of the polyurethane chemical grout depending on the conditions and actual grout used.
- Products/Manufacturers:
  - SikaFix HH Hydrophilic by Sika Corporation, Lyndhurst, NJ.
  - MasterInject 1210 IUG by BASF, Shakopee, MN.

- AV-330 Safeguard by Avantigrout, Webster, TX.

In general, installation and curing of chemical grout should be in accordance with the manufacturer's requirements.

Option 2 – Chemical Grout with Grout Expansion Joints

Option 2 is the same procedure as Option 1 with the additional installation of new expansion joints. The installation of expansion joints may not be needed, based on our review of crack development due to shrinkage. The expansion joint work would consist of providing a full-depth sawcut (assume 8-inch depth) at 15m (50-foot) increments in the tunnel liner and injecting the sawcut with chemical grout. This option should only be considered where the existing cracks are more than 30.5 meters (100 feet) apart. At this time, this option is considered to be a less essential repair.

Option 3 – Chemical Grout with Steel Plate Expansion Joints

Option 3 includes performing repairs at existing joints and/or cracks in the unreinforced tunnel liner (same as Option 1), with additional full-depth circumferential expansion joints at a spacing of 15 meters (50-foot) along the length of the tunnel. The lower portion of the expansion joints, the invert and lower 460 millimeters (18-inch) of the sidewalls, should be "armored" with stainless steel plates to protect the expansion joint material from the debris that enters the tunnel with a storm event.

This option could be considered in sections of the tunnel where there are several cracks in a short distance such as in the 2nd Avenue South tunnel between 7+80 and 8+45, where five cracks were observed. This would involve replacing the existing concrete lining with a new shotcrete sprayed-on lining and installing only one expansion joint rather than repair of all the joints using the process described in Option 1. Economics of the repair cost should be the deciding factor.

At locations where voids exist behind the tunnel lining these voids need to also be filled. Filling these voids can be done using the existing lining as the form to inject a low-strength flowable grout behind the lining. This operation needs to be performed with a minimum of two grout ports pumping the grout from the lower port until it flows out of the top port. The difficulty and risk with this procedure is that the volume of grout is unknown. If the lining is removed first, so a more accurate estimate of the void volume can be calculated, then a form must be used to place the grout.

In these areas, as noted on the inspection reports, the Option 3 repair will likely also be required.

Section 6

Alternative Development and Evaluation

This section develops options to improve the hydraulic capacity of the Central City Tunnel System. The primary alternatives that were evaluated involve increased hydraulic conveyance capacity through construction of parallel tunnels as compared to expansion of the cross-sectional area in the same alignment of the existing tunnels. The effects of Green Infrastructure and in-line storage were assessed, but found to not have a beneficial effect on the hydraulics of the 10-year and 100-year level of service flow rates, or were otherwise found to not be cost-effective. These alternatives are described at the end of the section.

Hydraulic Capacity Discussion

As described in Section 4, three segments of the Central City Tunnel System were found to have insufficient hydraulic capacity: Washington Avenue, 2nd Avenue South, and Nicollet Mall (100-year level of service rainfall, only). Preliminary analysis concluded that sufficient hydraulic capacity exists in the outfall segment of the tunnel system between the convergence with the Chicago Avenue stormwater tunnel and the outfall at the Mississippi River, and therefore, is not included in the analysis.

The goal of increased conveyance capacity is to provide sufficient total tunnel cross-sectional area such that the hydraulic grade line for the peak flow is at or below the crown of all segments of the expanded tunnel system. For expanding the Central City Tunnel System, this analysis focuses on two levels of service, 10-year and 100-year rainfall events, as described in **Table 6.1**.

Table 6.1 – Peak Flow for Each Tunnel Segment

	Peak Flow (cfs)	
	10-Year	100-Year
Nicollet Mall	174	212
2nd Avenue South	391	357
Washington Avenue (at Portland Avenue South)	673	750
Chicago Tunnel (at Convergence Structure)	163	290
Central City Tunnel System Discharge	819	1,011

Increased tunnel hydraulic capacity is limited to alternatives that match the existing tunnel invert elevation due to the need to maintain gravity flow, avoid conflicts where the Central City Tunnel System crosses above the existing sanitary sewer tunnel, and match the invert at the outfall discharge to the Mississippi River. Increasing the height of the tunnel is also limited by a minimal separation of 2 feet between the tunnel crown and bottom of the soapstone, or limestone where the soapstone is absent. Additionally, it will be necessary to select a construction method that allows the existing Central City Tunnel System to remain operational while the tunnel is being enlarged, or while a new parallel tunnel is under construction.

Given these limitations, there are two viable options to increase the capacity of the drainage system:

- Parallel tunnel.
- Increased cross-sectional area of the existing tunnel.

Increased Conveyance Capacity Alternatives

The Existing Conditions XPSWMM model was used to compute the equivalent circular cross-sectional area for each hydraulic alternative such that the tunnels will not pressurize during the 10-year design rainfall event and the 100-year design rainfall event. Results are tabulated in **Table 6.2**. The alternatives are described in the following text.

Table 6.2 - Central City Tunnel System, Existing and Upgraded Equivalent Pipe Diameter for 10-Year and 100-Year Level of Service

<table>
<tr><th colspan="3"></th><th colspan="2">Existing Tunnel</th><th colspan="4">Alternative Description and New Tunnel Equivalent</th></tr>
<tr><th rowspan="2">Tunnel Leg</th><th rowspan="2">Cross Street</th><th rowspan="2">Station (from Survey)</th><th rowspan="2">Geometry</th><th rowspan="2">Equivalent Circular Pipe Diameter, ft</th><th colspan="2">Alternative 1</th><th colspan="2">Alternative 2</th></tr>
<tr><th>10-Yr, Expanded Tunnel, ft</th><th>100-Yr, Expanded Tunnel, ft</th><th>10-Yr, Parallel Tunnels, ft</th><th>100-Yr, Parallel Tunnels, ft</th></tr>
<tr><td rowspan="7">Washington</td><td>Hennepin</td><td>4265</td><td rowspan="4">6' x 6' Catenary</td><td rowspan="4">6.0</td><td>7</td><td>10</td><td>4</td><td>8</td></tr>
<tr><td>Nicollet</td><td>4005</td><td rowspan="2">8.5</td><td rowspan="2">11</td><td rowspan="2">6</td><td rowspan="2">9.5</td></tr>
<tr><td>Marquette</td><td>3600</td></tr>
<tr><td>2nd</td><td>3190</td><td rowspan="4">10</td><td rowspan="4">12</td><td rowspan="4">8</td><td rowspan="4">10</td></tr>
<tr><td>Wash/Portland</td><td>1550</td><td rowspan="3">8' x 7.5' Horseshoe</td><td rowspan="3">7.9</td></tr>
<tr><td>2nd/Chicago</td><td>450</td></tr>
<tr><td>Convergence</td><td>0</td></tr>
<tr><td rowspan="4">2nd Ave</td><td>10th St</td><td>3261</td><td rowspan="4">6' x 4' Horseshoe</td><td rowspan="4">5.2</td><td rowspan="2">7.5</td><td>9</td><td rowspan="2">5.5</td><td>7.5</td></tr>
<tr><td>8th St</td><td>2400</td><td rowspan="3">9.5</td><td>8</td></tr>
<tr><td>5th St</td><td>1200</td><td rowspan="2">8</td><td rowspan="2">6.5</td><td rowspan="2">8.25</td></tr>
<tr><td>Washington</td><td>0</td></tr>
<tr><td rowspan="3">Nicollet</td><td>8th St</td><td>2450</td><td rowspan="3">6' x 4' Horseshoe</td><td rowspan="3">5.3</td><td rowspan="3">No Modification</td><td rowspan="3">8</td><td rowspan="3">No Modification</td><td rowspan="3">6</td></tr>
<tr><td>5th St</td><td>1200</td></tr>
<tr><td>Washington</td><td>0</td></tr>
<tr><td rowspan="2">8th St</td><td>Nicollet</td><td>825*</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td></tr>
<tr><td>2nd Ave</td><td>0*</td></tr>
<tr><td colspan="4">*New Tunnel Segment, distance estimated</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Parallel Tunnel Alternative (Alternative #1)

One alternative to increase conveyance capacity of the system involves construction of a new parallel tunnel adjacent to the existing tunnel. The minimum cross-sectional area of a circular parallel tunnel was computed for both the 10-year design rain event and the 100-year design rain event. A parallel tunnel could either be circular or it could be another shape, given the variables of the St. Peter Sandstone, available headspace between top of tunnel and top of St. Peter Sandstone, and conflicts with the Metropolitan Council interceptor. An in-depth description of tunnel shapes is contained in Section 5.

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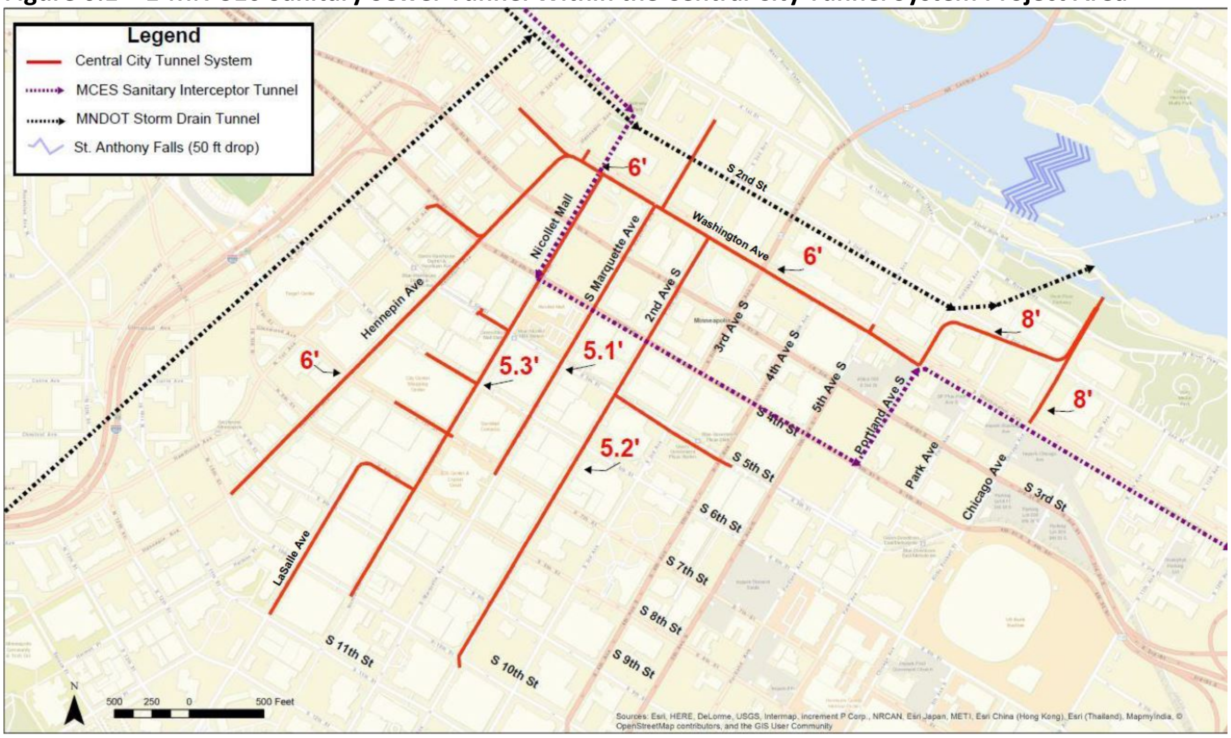
Conceptually, the parallel tunnel alternative could allow construction of a parallel tunnel along any alignment within one block of an existing tunnel segment. However, major conflicts between the tunnel elevations of the Central City Tunnel System and Metropolitan Council Interceptor 1-MN-310 prevented shifting of the parallel tunnels to an alternative street right-of-way. As shown in **Figure 6.1**, the 4th Street South segment of the Interceptor sewer crosses immediately beneath the Central City Tunnel System at Nicollet Mall, Marquette Avenue South, and 2nd Avenue South. The two tunnels have nearly similar invert elevations at the intersection of Portland Avenue South and Washington Avenue, making any crossing infeasible.

Figure 6.1 – 1-MN-310 Sanitary Sewer Tunnel Within the Central City Tunnel System Project Area



The parallel tunnel size required for Alternative #1 for the 10-year rainfall event is shown in **Figure 6.2**, and Alternative #1 100-year rainfall event is shown in **Figure 6.3**. For this hydraulic analysis, sufficient width was assumed within the existing right-of-way to construct a parallel tunnel that has a parallel separation from the existing tunnel of 10 feet. However, this minimum cross-sectional area could apply to multiple alignments of parallel tunnels if a construction or alignment constraint were encountered.

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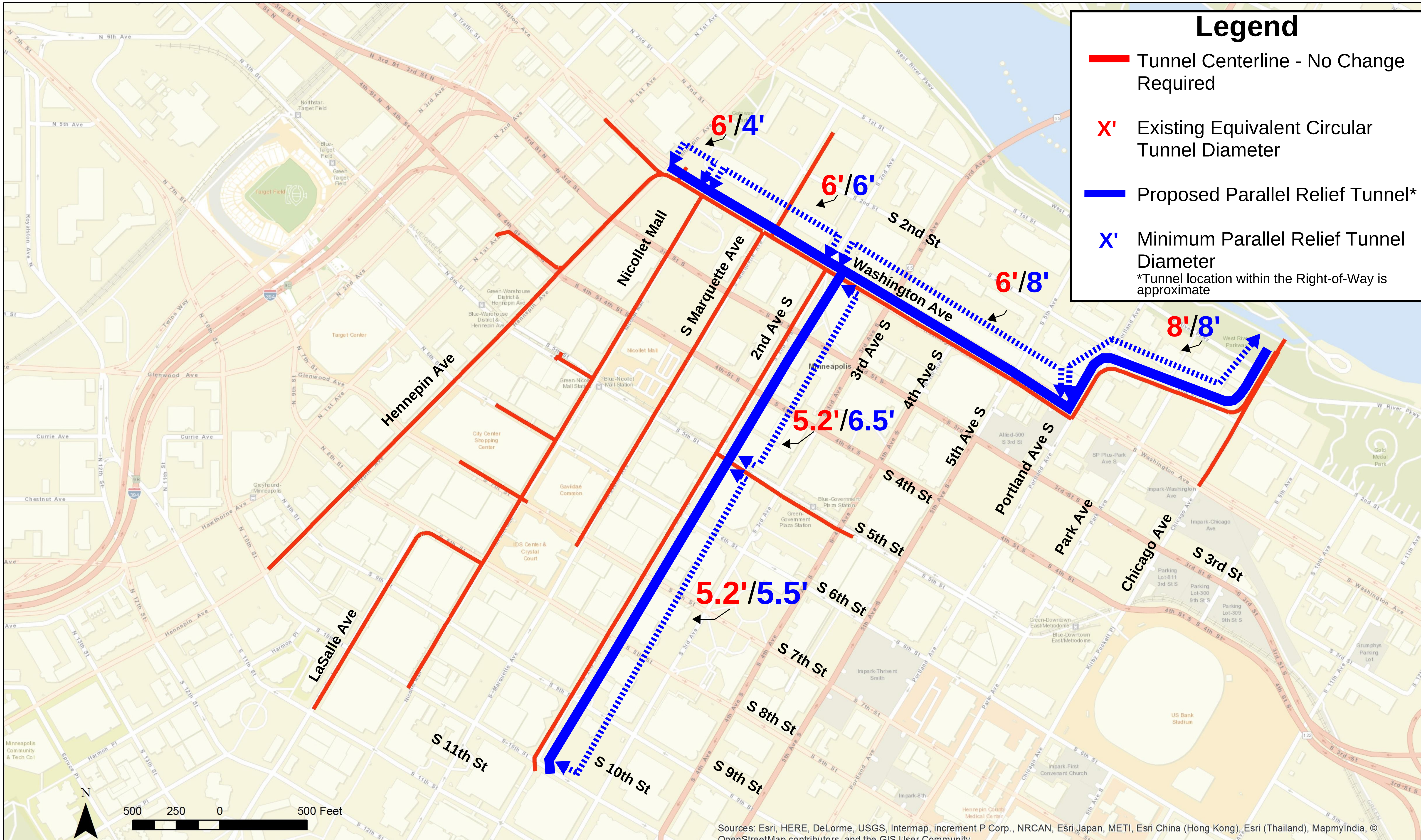

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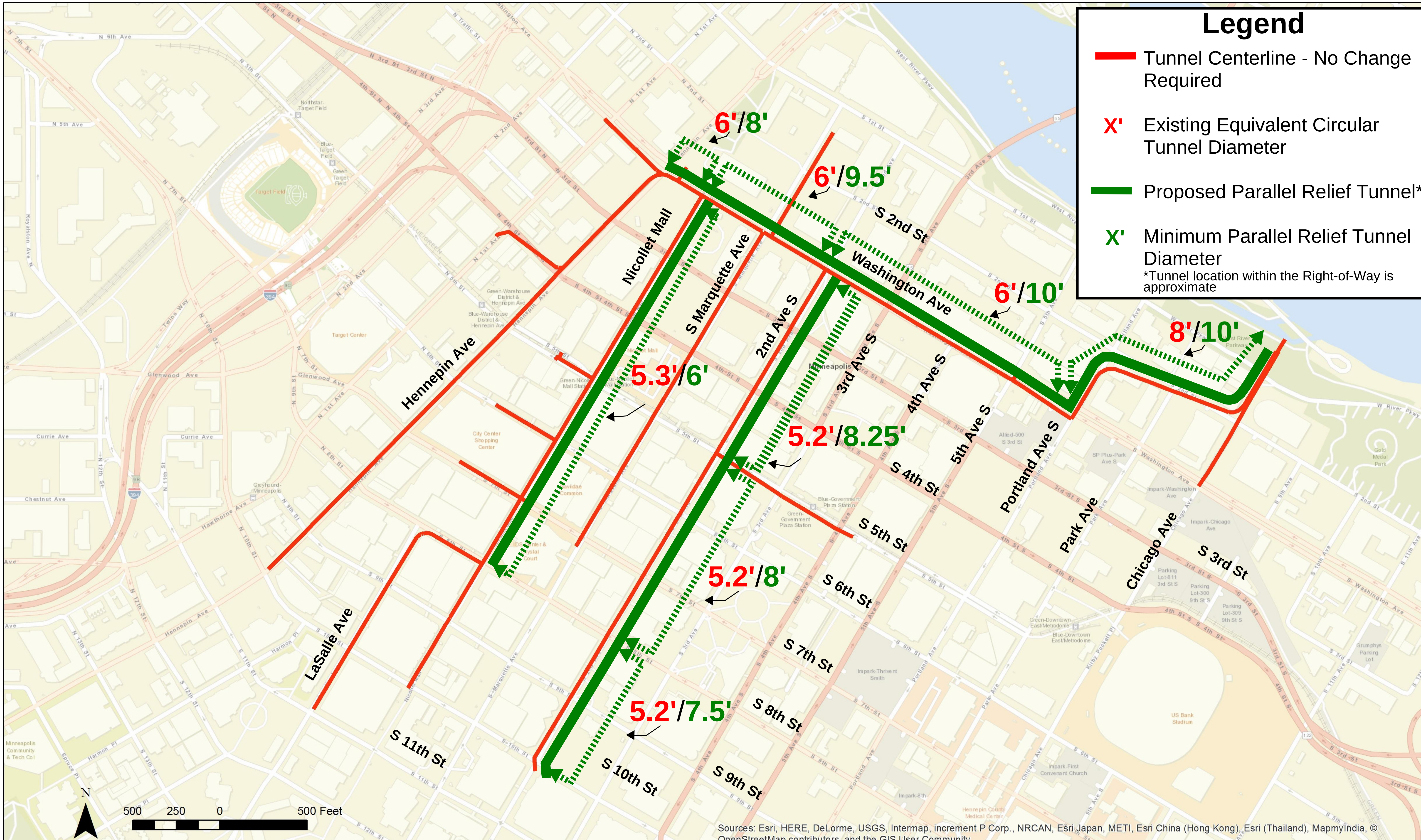
Alternative 1 (Parallel Tunnel)

10-Year Design Rain Event

Figure 6.2



Alternative 1 (Parallel Tunnel)

100-Year Design Rain Event

Figure 6.3

Parallel Tunnel Construction Methods

Hydraulic capacity of parallel tunnels would range in size from the equivalent of a 6.5-foot to 12-foot (2000-mm to 3600-mm) internal diameter circular tunnel. The economics of tunnel construction of this wide a range of sizes becomes a function of tunnel length as well as diameter. The following tunneling methods are available for construction of a parallel tunnel:

- **Hydraulic Lance**: Miners use hand-held lances that emit highly pressurized streams of water that cut through the sandstone. Benefits of this method include the ability to excavate in small spaces and create non-circular shapes. Disadvantages include slower pace of excavation and limited number of contractors having experience with the hydraulic lance. Hydraulic lances are advantageous as a secondary method for areas such as transition structures, that will have a unique shape that cannot be created by a boring machine.

- **Microtunnel Boring Machine (MTBM)**: The MTBM is a remote-controlled, closed-face boring machine that drills a fixed circular-diameter tunnel. A pipe, such as Hobas or reinforced concrete pipe, is jacked into the excavated area behind the MTBM. The advantages of a MTBM is speed of excavation. Disadvantages are an inability to change the diameter of the excavated cross-section and the need for a significant surface area to stage the liner pipe.

- **Tunnel Boring Machine (TBM)**: The TBM is large boring machine that is well suited for larger-diameter tunnels. A liner is installed behind the machine as the TBM progresses through the rock. Advantages include large boring face and efficient boring speed. Disadvantages include need for large diameter access shaft, more time to set-up, and inability to maneuver machine through short-radius curves.

- **Roadheader Machine**: As shown in **Figure 6.4**, the roadheader is a wheeled construction machine that has a mounted articulating arm on the front. The arm maneuvers a small drill head that uses a combination of hydraulic jets and drill bits to create the desired shape of tunnel. It can create a non-circular tunnel and is easily maneuvered through changes in tunnel alignment. Advantages include smaller area needed for equipment installation, and ability to maneuver into non-circular shapes and non-straight alignments. Disadvantages include slow rate of advancement and the need for more personnel in the tunnel.

Figure 6.4 – Roadheader Machine

The hydraulic lance method has not been used for several years in the Minneapolis area, and finding labor and equipment using this method can be a limitation.

In today's market, the hydraulic cutter, such as the Antraquip axial (lengthways), is commonly used for narrow trenches, remediation, profiling, scaling, controlled demolition applications and other specialized applications. Models are available for carriers ranging in size from 3-ton to 50-ton. This type of hydraulic rock cutter is applicable for rock with compressive strengths of less than170 MPa (25,000 psi). We expect the sandstone to be about 70 MPa, (10,000 psi) or less.

The construction procedure for the lance method consists of the following:

1. Placement of the equipment in a shaft that extends to the tunnel excavated invert elevation.
2. Excavate the rock on the outside of the lining.
3. Install rock bolts as the tunnel advances.
4. Place brace supports between the existing tunnel lining and rock to support the rock as the tunnel is subjected to internal surcharge loading.
5. Apply shotcrete liner.

Generally, microtunneling is a more economical method of tunnel excavation than conventional TBM tunneling for smaller-diameter tunnels. Microtunneling diameters, however, are limited to the diameter of the available jacked pipe. The cost of transporting a concrete or HOBAS pipe with a diameter of more than 10 feet (3.05 meters) adds costs, which typically has been the economic cut-off between MBTM and TBM approaches. The economical limitations on TBM relate to the tunnel length and cost of the TBM. Unit costs are very high for TBM tunneling when the tunnel footage is less than about 3,000 feet (915 meters). Both these methods have two additional limitations: the diameter of the segment is set by the machine; a change in diameter would require a second machine. Both methods would also require two shafts – one to launch the machine and a smaller shaft to retrieve the machine at the end of the tunnel.

The use of a roadheader also has limitations. These limitations are based on the size of the machine versus the excavation size. Roadheader power and ability to cut rock is a function of the machine size. A small machine will be sufficient to excavate a tunnel that is only about 8 feet in height and of the rock strength presented in the modeling report.

The hydraulic roadheader can excavate the rock into any cross-sectional shape that has been determined to be the most stable, creating tunnels that are able to obtain the required equivalent hydraulic capacity as it changes along the alignment. The other advantages are: that it can make very short radius turns eliminating the need for a shaft at a street intersection; and, only one shaft is required because the machine can be backed out of the tunnel once the excavation is completed. Use of the roadheader also allows for construction of a non-circular tunnel and is particularly apt for constructing a tunnel with a non-circular (Cathedral or other) shape that takes advantage of the properties of the St. Peter Sandstone. Disadvantages to the roadheader are that the shape is not circular, tool wear can be expected to lead to higher tool wear/replacement because of the high quartz content, and the advancement rate is less than that of a TBM or microtunnel approach.

Expanded Tunnel Alternative (Alternative #2)

A second alternative, Alternative #2, to increase conveyance capacity of the system involves increasing the size of the existing tunnel cross-sectional area. The minimum cross-sectional area of an equivalent circular tunnel to maintain the corresponding HGL generally below the crown of the tunnel was computed for both the 10-year rainfall event and the 100-year rainfall event, as estimated by National Oceanic and Atmospheric Administration Atlas 14, Volume 8. The actual cross-sectional shape of an expanded tunnel will likely not be circular, given variables described in the parallel tunnel alternative. Equivalent tunnel diameters for the 10-year rainfall event are shown in **Figure 6.5**, and the 100-year rainfall event is shown in **Figure 6.6**.

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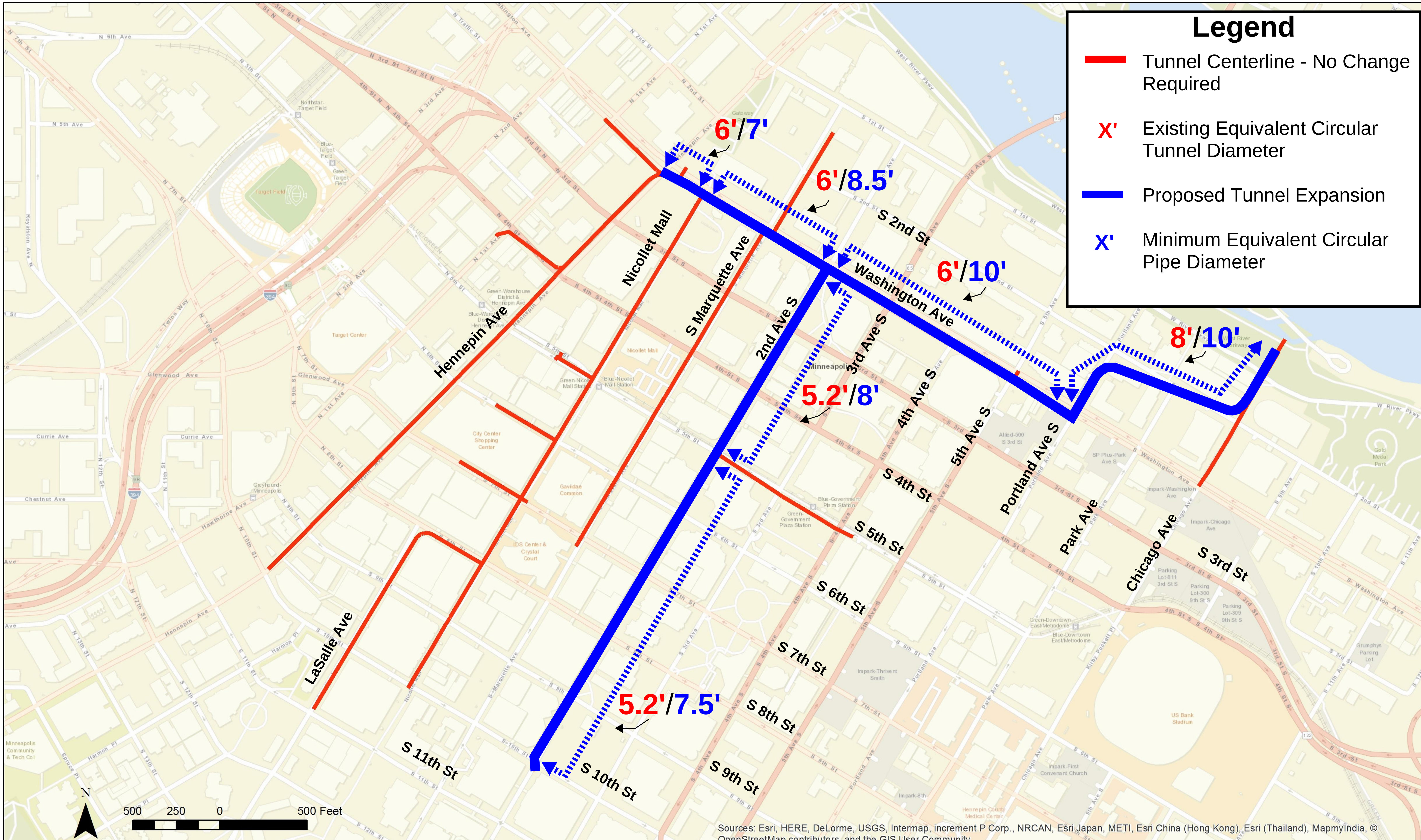

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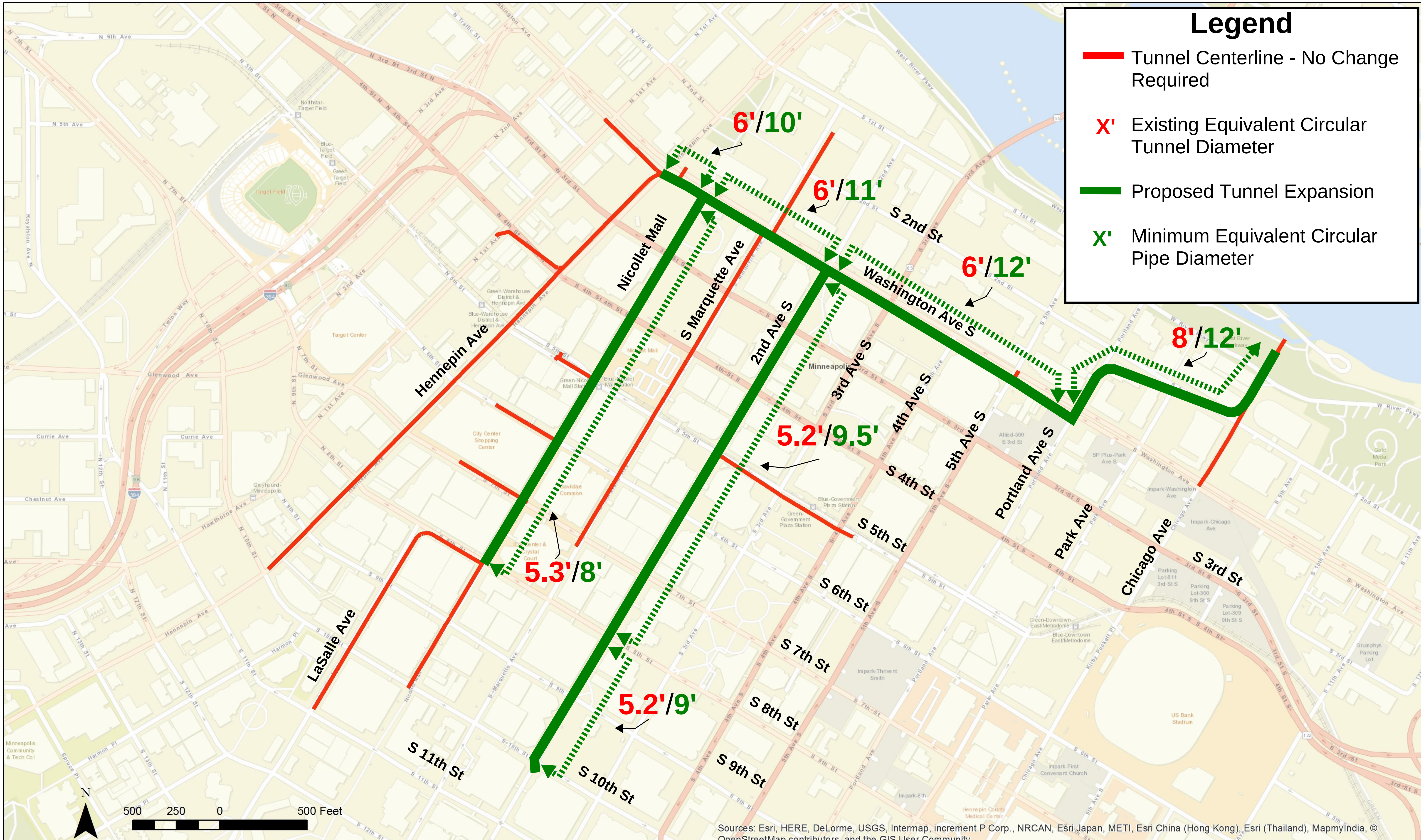
Alternative 2 (Tunnel Expansion)

10-Year Design Rain Event

Figure 6.5



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Alternative 2 (Tunnel Expansion)

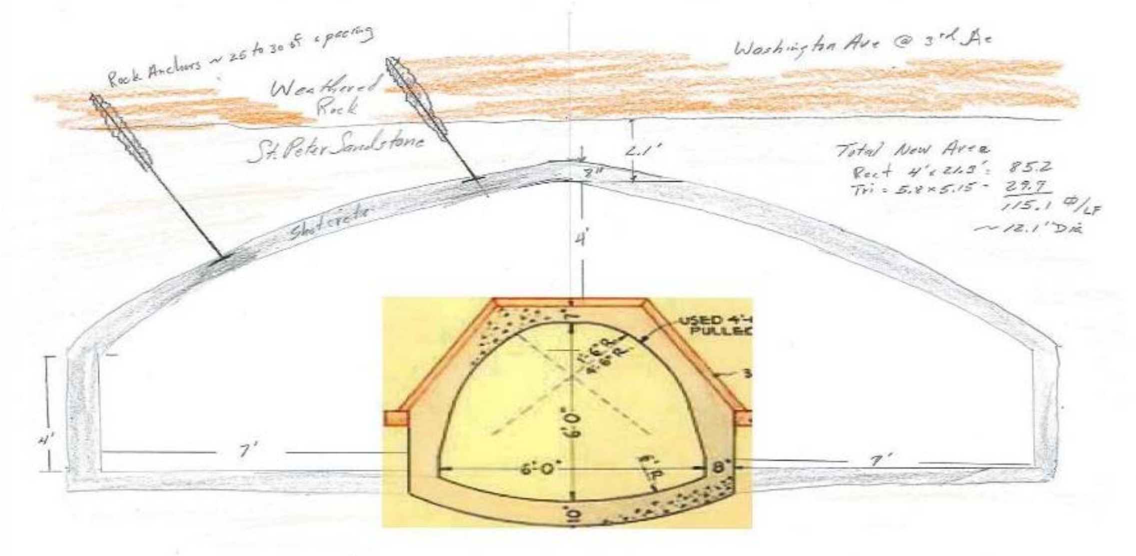
100-Year Design Rain Event

Figure 6.6

Expanded Tunnel Construction Methods – Horizontal Expansion

The modeling performed indicates that there is adequate sandstone cover over the tunnel so that the tunnel can be enlarged laterally with a minor amount of vertical expansion needed to create a stable shape. The enlargement can be performed by excavating the sandstone on the outside of the permanent liner to the dimensions required, applying a reinforced shotcrete liner to support the rock. This work could be done while the tunnel is still operational, allowing the existing liner to be a temporary barrier between the operating tunnel and the adjacent enlargement area. These tunnels would be subject to internal pressures if a sufficiently large storm event did occur. As stated before, this condition has an occurrence history of 6 events with a surcharge of at least 4 feet above the crown over a 5-year cycle. To maintain stability during construction, external braces that support the tunnel liner would be required. Rock anchors will be needed to secure the new shotcrete liner into the bedrock. These anchors are estimated to be about 3 meters long and 25 millimeters diameter (10 feet by 1-inch diameter). Anchor spacing of about 3-meter^2 (32 square feet) would be required to provide roof stability, as shown in **Figure 6.7**.

Figure 6.7 – Tunnel Liner Anchor Spacing (Typical)



As shown in Table 6.1, there are several sections of tunnel under each street that have the existing tunnel with less than adequate depth to expand the cross-sectional area to the required hydraulic capacity. Limited horizontal capacity is defined here as making an excavation that is stable without the need for rock bolts. This limited height means that increasing the cross-sectional area will require excavation on either side of the existing tunnel. The roof of the tunnel will require support because there is not sufficient space above the tunnel for a conventionally stable cathedral shape cross-section in the sandstone. Rock anchors into the limestone will be required. Depending on the increased size of the tunnel, excavation can be performed either by hydraulic lance or using a roadheader. The quantity of rock anchors will also be a function of the roof span. At this time, a reasonable and stable spacing would assume rock anchors extending 10 feet into the limestone spaced so that each anchor supports approximately 3.0 m^2 (32 square feet) of roof is a reasonable and stable spacing.

Horizontal expansion construction approaches would be limited to hydraulic lance and roadheader, as described in the previous section.

Expanded Tunnel Construction Methods – Vertical Expansion

For tunnel sections where there is insufficient room to expand the tunnel upwards without excavating into the overlying soapstone and limestone, the tunnel would have to be expanded laterally. Extending the depth of the tunnel is not acceptable because the entire system works by gravity. Excavating into the soapstone and limestone creates significant excavation problems because of the rock structure. Such an excavation would require blasting, which would be cost prohibitive and pose significant safety issues.

As the tunnels advance closer to the River and maintain their gravity slope, the sandstone thickness above the tunnel crown increases and there is generally adequate sandstone cover to expand the tunnel upward and maintain a cathedral shape for stability purposes. This expansion should be limited in height to maintain about 2 feet of sandstone above the crown of the expanded tunnel cross-section. A first estimate of the cathedral shape can be calculated based on the friction angle of the sandstone. The height above the springline (vertical wall) of the tunnel is about the sum of half the existing tunnel width plus the proposed increase in the width divided by tan of friction angle/2 ($\phi/2$). The friction angle is about 60° to 62°. The advantage of a vertical expansion in the sandstone is that it eliminates the need for the rock anchors. A requirement of tunneling in the St. Peter Sandstone is that exposed rock is sprayed with sodium silicate so that it does not dry out and flake.

The same limitation of maintaining the existing tunnel in operation and stable when under a surcharge loading, as described in the Horizontal Expansion section above, must be taken into account during excavation. The same approach of bracing the exterior of the tunnel lining against exposed sandstone as described above is required. If expansion is planned for both sides of the existing tunnel, bracing is required on both sides plus the crown of the tunnel. Depending on the condition of the light timber used for initial support, the bracing can be set against this timber as it is exposed.

There are relatively short segments of tunnels that are shown to have heavy timber support. CDM Smith's interpretation of using this initial support system is that the rock is in poor condition relative to the other sandstone encountered in the Central City Tunnel System. These areas may require some additional ground modification such as grouting or using a welded wire mesh to prevent fall out of rock during the excavation. If a mesh is applied, it would be covered with a thin layer of shotcrete in a short time period. A second layer could be applied once the tunnel excavation is completed.

Horizontal expansion construction approaches would be limited to hydraulic lance and roadheader, as described in the previous section.

Summary of Viable Tunnel Construction Methods

Based on the evaluation criteria and discussion for each trenchless method set forth above, **Table 6.3** summarizes the general applicability of the proposed methods to perform the tunnel enlargement or the construction of a parallel tunnel. The selection of the most appropriate tunneling method is dependent upon numerous factors such as tunnel alignment, cost, construction schedule, availability of skilled personnel and contractor, equipment availability, and aversion to risk. Actual settlement is affected mainly by the construction method, as well as the size of the tunnel, soil conditions, and many other factors.

Table 6.3 – Viable Tunnel Construction Method Comparison

Item	Roadheader	Microtunnel	Tunnel Boring Machine
Shafts required	1 per 2,500-ft.	2 per alignment	2 per alignment
Curve radius	50-ft.	800-ft.	1,200-ft.
Alter shape during tunneling	Yes	No	No
Advancement rate ft/hr	0.5 to 1.0	3 to 5	2 to 4
Machine setup time	2 days	2 weeks	6 to 8 weeks
Miners in tunnel	All the time	Limited	All the time
Viable for enlarging?	Yes	No	No
Practical tunnel area /diameter	100 to 300 sq. ft.	<10-ft.	>8-ft.
Practical tunnel length	< 2,500 l.f.	500 to 3,500 l.f.	2,500 to 25,000 l.f.

Preliminary Cost Analysis of Viable Construction Methods

For the purpose of selecting a viable and constructible hydraulic alternative, CDM Smith computed the relative construction costs for the three viable construction techniques: roadheader, microtunneling, and TBM. This initial cost analysis is strictly for comparison between construction methods, and is not of the necessary level of detail for development of a construction budget.

For the purpose of this baseline comparison of cost, the following was considered:

- Construction assumes the largest diameter required for any tunnel segment. This assumption was based on the inability of the microtunnel and TBM equipment to change tunnel diameter. Although a roadheader does have the ability to change tunnel cross-section area, the larger tunnel diameter was assumed for purposes of comparison.
- All work was assumed to be performed in-the-dry and bypass pumping would not be required.
- All access proposed shaft locations would be available and free of utility conflicts.
- The number of access shafts and construction lengths was based on **Table 6.4**.

- Unit prices were developed by CDM Smith's construction arm CDM Constructors Inc. (CCI) with input from local contractors.
- No additional easements or rights-of-way were required.
- Planning level contingencies were applied (25 percent).
- Trucking cost for excavated soil do not consider additional cost for traffic control.

Table 6.4 – Tunnel Construction Technique

	Roadheader		Microtunnel	TBM
	Expanded Tunnel	Parallel Tunnel	Parallel Tunnel	Parallel Tunnel
Unit Cost per 1000 ft. of Tunnel and Shaft	$6,000,000	$3,300,000	$7,000,000	$5,300,000

Summary

Based on the evaluation summary presented in Table 6.3 and Table 6.4 and provided discussion on each trenchless method above, a roadheader is the most viable technique for both the tunnel enlargement and construction of a parallel tunnel, and is the recommended construction technique for this project. The parallel tunnel option using a roadheader for excavation is the most cost-effective approach to increase the hydraulic conveyance of the Central City Tunnel System. Construction using a roadheader allows for shaft construction that is offset from the alignment of the tunnel, which is critical for construction of a tunnel under Washington Avenue, as the entire street was recently re-paved and a shaft located within Washington Avenue would cause significant traffic impacts. In addition, curve radius of the excavation is much tighter than can be accomplished through microtunneling or TBM. Use of a roadheader will enable construction of the cross-connect structures, maintaining temporary drift connections to the existing tunnel during parallel tunnel construction, and construction of unique convergence structures.

Other Options Considered

Green Infrastructure

Green Infrastructure Definition and Purpose

The goal of Green Infrastructure (GI)is to mimic the natural water cycle such that stormwater runoff from pavement is retained and then soaked up by the soil or vegetation. GI, by definition, differs significantly from conventional gray stormwater infrastructure, which serves to move stormwater runoff away from pavements and structures as rapidly as possible. The problem with gray stormwater infrastructure is that the rapid movement of stormwater results in the rapid movement of stormwater pollutants as these pollutants are picked up from the pavements and discharged to surface waters. Pollutants in stormwater runoff are best managed by the slow movement of runoff, allowing for pollutants to settle, be filtered, or be absorbed by soils or plants.

The following are GI installations most commonly used in urban areas:

- **Bioretention** is a category of GI features that collect and capture runoff in depressed vegetated basins. The stored water can slowly filter through special soils to be used by the vegetation. Excess water from heavy rainstorms can bypass the bioretention area. Bioretention is also known as rain gardens, or bioinfiltration.
- **Bioswales** are similar to bioretention, except that these swales are long and narrow, which allows the runoff to slowly move along the surface of the swale, creating both a vertical infiltration of the runoff, as well as horizontal movement through the vegetation.
- **Green Rooftops** replace the hard surface of a roof with vegetation, capturing and storing the runoff of the roof. Green rooftops can be cost-effective treatment options in high density areas where space is limited for surface stormwater collection and storage.
- **Permeable Pavements** directly capture the runoff as it falls on the pavement, via movement through the pavement's joints or pores, into the subsurface for storage.
- **Tree Trenches** collect the runoff and store in below-surface vaults for uptake by vegetation, typically trees. Tree trenches, also known as planter boxes, are best for sites with limited space.
- **Rainwater Harvesting** is the collection of runoff from a rooftop into a cistern or vault to be stored and reused for landscape irrigation or other non-potable water use, such as vehicle washing.

These types of GI can be installed to infiltrate directly into the soils or be collected in underdrains that redirect the filtered and stored runoff back to the gray stormwater infrastructure. Underdrains are common in areas where the soils have low permeability, such as clay soils, where there are other sub-surface utility lines that should not come into contact with the runoff, or where the groundwater is near the surface.

GI is highly effective in reducing the runoff volume and removing pollutants when measured over the length of a year. This is because GI is generally designed to capture the runoff from small, frequent rain events, typically up to a 1-inch rainfall. In an average year in Minnesota, this rainfall would occur for 90 percent of the rain events during the non-winter season. For the remaining larger rain events, the GI would allow the excess runoff to bypass directly to the gray infrastructure.

The effectiveness of a GI application can be highly variable when measured over a single rain event. This is especially true when assessing the ability of GI to manage the large volumes, peak flows, and rapid velocities of runoff that occur after an extreme stormwater event, such as the 100-year level of service that is targeted in this Central City Tunnel System preliminary design report.

The purpose of this analysis is to study the site conditions of the Central City Tunnel System to determine the extent that GI could mitigate ongoing pressurization within the tunnel system.

Hennepin Avenue GI Analysis

The focus of this GI analysis is to determine whether installation of GI would have a positive impact on the peak flows entering the Central City Tunnel System. One opportunity to install GI within the Central City drainage area would be in coordination with the Hennepin Avenue paving project, scheduled for reconstruction in 2020. The GI analysis considers the characteristics of the Hennepin Avenue corridor as the basis for GI selection and calculations. However, it is expected that similar characteristics would exist throughout the area served by the Central City Tunnel System and that the results of this analysis could be applied throughout the area.

A review of the Hennepin Avenue corridor concluded that there are three types of GI that are most feasible:

1. **Green Rooftops**. It is assumed that up to 95 percent of an existing roof area would be available to be converted to a green rooftop. The remaining space is needed by heating and ventilation equipment and other building specific needs. This alternative assumes that replumbing of the rooftop drainage system is not required to accommodate the green roof. It also assumes that the existing rooftops have sufficient structural strength to support the green rooftop materials.

2. **Permeable Pavement**. It is assumed that the full width of Hennepin Avenue pavement and all sidewalks will be replaced with permeable concrete block pavers of sufficient strength to support the heavy traffic of Hennepin Avenue. Runoff would infiltrate through the joints of the pavers and be temporarily stored within the pores of the pavement subgrade, called the storage layer. A worst-case condition that numerous underground utilities would conflict with infiltration into the native soils below the permeable pavement is assumed. Therefore, the design assumes an underdrain below the permeable pavement storage layer that collects the filtered runoff for discharge to the Central City Tunnel System.

3. **Tree Trenches**. For this alternative, all sidewalk runoff would be directed towards the curb, where it will be intercepted by permeable pavement or tree grates, which then captures and stores the runoff in a trench beneath the sidewalk. Captured runoff is also allowed to infiltrate into the sub-soils. Excess runoff would bypass the tree trenches and flow directly to the Central City Tunnel System. The trenches would be planted with trees, which will uptake the stored water between rainfall events. It is assumed that there are no underground structures or utilities that would conflict with the underground trenches or with infiltration of the stored runoff.

Green Infrastructure Model Development and Results

Typically, the benefits of GI are evaluated as reduction in the volume of stormwater runoff, measured as cubic feet. However, stormwater conveyance systems, such as the Central City Tunnel System, are sized to accommodate the peak rate of runoff generated from each tributary area, measured as cubic feet per second. Therefore, an analysis of the reduction in peak flow rates resulting from installation of GI allows for a direct assessment of the benefits to the Central City Tunnel System.

CDM Smith used EPA SWMM version 5.1 to analyze how the GI will affect the peak runoff flow rate for the following four rain events.

- 2-year rain event (2.9 inches of rainfall over a 24-hour period)
- 10-year rain event (4.2 inches of rainfall over a 24-hour period)
- 100-year rain event (7.5 inches of rainfall over a 24-hour period)
- 500-year rain event (10.5 inches of rainfall over a 24-hour period)

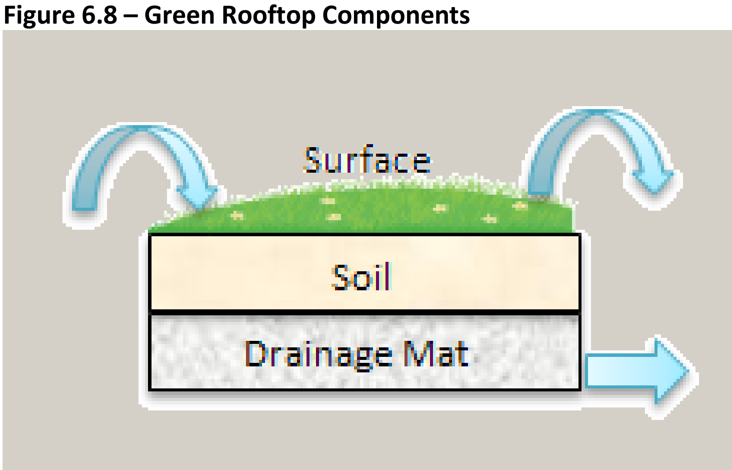
A baseline model was run to determine the peak flow for each rain event with no GI installations. Next, the effects of each type of GI for each of the four rain events were evaluated to determine how each type of GI could reduce the predicted peak runoff flows. Finally, all GI types were combined to predict the maximum potential runoff reduction for Hennepin Avenue.

The "combined GI" scenario was set up such that there is no duplication of GI within any sub-catchment. For example, both the permeable pavement and tree trench GI are assumed to collect runoff from sidewalk areas. SWMM5 does allow for these two GI features to be installed within a single sidewalk sub-catchment. However, the runoff must be split, by percentage, so that the total runoff contributed to both GI features does not exceed 100 percent.

This analysis assumes maximum installation of GI along Hennepin Avenue. It may be infeasible, or impossible, to install GI to this level of intensity throughout the corridor. Furthermore, it may be very expensive to install GI components in this highly-urban setting. However, this maximum installation scenario allows evaluation of the most optimistic condition that could be achieved by using GI within the corridor. Specific assumptions for the maximum GI installation include:

- **Green rooftops** would be installed on 95 percent of the surface area of all rooftops draining to the Hennepin Avenue tunnel. **Figure 6.8** shows the flow of runoff through the typical components of a green rooftop. The EPA SWMM5 model allows users to define the surface vegetation, depth and material of the soil layer, and depth and material of the drainage mat.

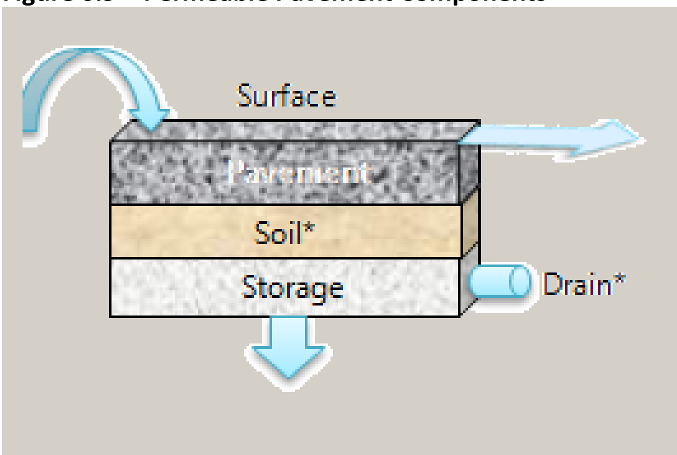
Figure 6.8 – Green Rooftop Components



Source: Environmental Protection Agency SWMM5 Model

- **Permeable pavement** would be installed on 100 percent of the road and sidewalk surfaces. **Figure 6.9** shows the flow of runoff through the typical components of a permeable pavement. The EPA SWMM5 model allows users to define the surface materials, pavement depth, storage layer volume, and underdrain sizing. The soil layer is an optional input that was not utilized in this analysis.

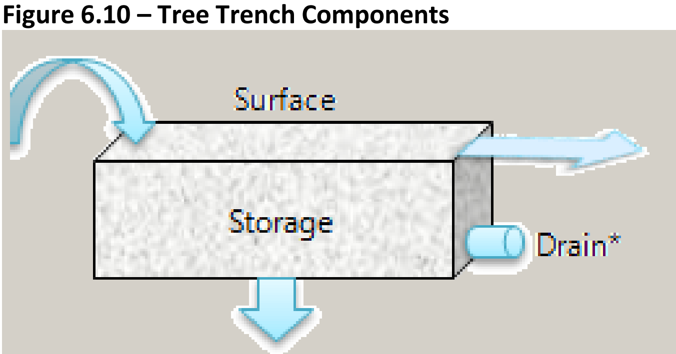
Figure 6.9 – Permeable Pavement Components



Source: Environmental Protection Agency SWMM5 Model

- **Tree trenches** would collect 100 percent of the sidewalk runoff. **Figure 6.10** shows the flow of runoff through the typical components of a tree trench device. The EPA SWMM5 model allows users to define the surface vegetation, surface storage volume, and soil layer material and depth. The optional underdrain feature is not included in the Central City Stormwater Tunnel/Hennepin Avenue tunnel analysis.

Figure 6.10 – Tree Trench Components



Source: Environmental Protection Agency SWMM5 Model

The maximum scenario assumes that all GI features are actively maintained such that performance is not reduced over time due to unhealthy vegetation and/or soil clogging.

The reduction in peak flow rates for each of these individual GI features and combined GI installations are contained in **Table 6.5** (in cubic feet per second per acre of drainage area) and **Table 6.6** (in percent reduction of peak flow). Results under this maximum GI condition show that GI has the potential to reduce the peak flow contributed to the Hennepin Avenue tunnel. However, as rainfall amounts increase, the benefits of the GI decreases considerably.

Table 6.5 – Hennepin Avenue Peak Flow Reduction with Maximum Green Infrastructure Installation (cubic feet per second per acre)

Level of Service	Rainfall	GI Peak Flow Reduction (cubic feet per second per acre)			
		Green Rooftops	Permeable Pavement	Tree Trench	Combined GI
2-year	2.9 inches	2.0	4.8	5.4	3.1
10-year	4.2 inches	1.4	7.3	7.8	4.0
100-year	7.5 inches	0.8	5.6	9.0	3.7
500-year	10.5 inches	0.7	3.9	13.1	4.7

Table 6.6 – Hennepin Avenue Peak Flow Reduction with Maximum Green Infrastructure Installation (percent reduction)

Level of Service	Rainfall	GI Peak Flow Reduction (percentage)			
		Green Rooftops	Permeable Pavement	Tree Trench	Combined GI
2-year	2.9 inches	11%	17%	14%	35%
10-year	4.2 inches	5%	16%	13%	29%
100-year	7.5 inches	2%	7%	9%	16%
500-year	10.5 inches	1%	4%	9%	13%

Although there is a noticeable reduction in the potential peak flow discharged to the tunnel system, it is overly optimistic to assume that all surfaces along Hennepin Avenue could be installed as Green Infrastructure. For this reason, a second set of model runs assumed 50 percent of the runoff cannot drain into or through a GI installation. Specifically:

- **Green rooftops** would be similar to the maximum GI scenario, except that the total surface area of rooftops is reduced by 50 percent. Additionally, reduced infiltration capacity caused by ineffective maintenance was simulated by adjusting the slope and surface roughness of the green rooftops.
- **Permeable pavement** would be installed on 50 percent of the road and sidewalk surfaces. This was accomplished within the model by limiting the depth and capacity of the storage layer. The effects of ineffective maintenance and long-term clogging was replicated by adjusting the surface slope and roughness to a point that the volume of runoff could infiltrate.
- **Tree trench** storage volume was decreased by 50 percent. This was accomplished by reduction in the depth of storage, which effectively reduces the volume of runoff that is stored and available for tree uptake and infiltration.

Additionally, for each GI installation, the infiltration capacity was reduced to replicate the decrease in performance that occurs within GI over time.

The results of this less-optimistic analysis is shown in **Table 6.7**, and **Table 6.8**. Results of this analysis show some reduction in peak flows. However, this reduction has the greatest benefit for the smaller 2-year and 10-year rain events. Because the Central City Tunnel System improvements will be designed to convey the peak runoff flows generated from a 100-year storm, the results show that installation of GI has no benefit to the tunnel improvements.

Table 6.7 – Hennepin Avenue Peak Flow Reduction with 50 Percent Green Infrastructure Installation (cubic feet per second per acre)

Level of Service	Rainfall	GI Peak Flow Reduction (cubic feet per second per acre)			
		Green Rooftops	Permeable Pavement	Tree Trench	Combined GI
2-year	2.9 inches	0.0	4.2	5.3	2.8
10-year	4.2 inches	0.0	0.1	5.7	1.7
100-year	7.5 inches	0.0	0.0	2.3	2.3
500-year	10.5 inches	0.0	0.0	1.8	1.8

Table 6.8 – Hennepin Avenue Peak Flow Reduction with 50 Percent Green Infrastructure Installation (percent reduction)

Level of Service	Rainfall	GI Peak Flow Reduction (percentage)			
		Green Rooftops	Permeable Pavement	Tree Trench	Combined GI
2-year	2.9 inches	0%	14%	14%	24%
10-year	4.2 inches	0%	0%	10%	10%
100-year	7.5 inches	0%	0%	2%	2%
500-year	10.5 inches	0%	0%	1%	1%

Green Infrastructure Recommendations

GI is not recommended as a cost-effective way to decrease peak flows to the Central City Tunnel System. For the 100-year level of service targeted by this study, the GI systems have little or no ability to reduce peak inflows to the tunnel. Given the amount of infrastructure in this highly-urban setting, costs for GI would also be significant. GI concepts may provide water quality and other benefits that are not evaluated as a part of this analysis. However, GI is not recommended for the sole purpose of decreasing peak flows to the Central City Tunnel System.

Stormwater Storage

Near Surface Storage

Near surface storage was considered infeasible for two reasons:

1. The underground area within the full width of the street rights-of-way in the downtown district are utilized by public and private utilities, including sanitary sewer, storm drains, watermains, electrical, telecommunications, gas, and building areaways. Because these storage technologies need to be lower than the existing roadway, these sub-surface utilities would either need to be relocated or would control the overall size/area of any storage structures.

2. The Central City Tunnel System has multiple drill holes or drop shafts per block connecting the surface stormwater drains and the deep tunnel conveyance system. This would require that each drill hole and drop shaft have its own dedicated storage technology, or that all implemented technologies behave as a single system to retain peak runoff.

Sub-Surface Storage

Sub-surface storage was not an effective alternative due to the geographic distribution of drill holes throughout the Central City Tunnel System. Large areas between collections of drill holes made sub-surface storage inefficient. The most cost-effective approach to tunnel construction is to maximize the length of tunnel expansion or construction along a single alignment. The set-up costs, including installation of an access shaft, equipment mobilization, and staging are significant costs that are duplicated for each non-contiguous tunnel segment. Installation of deep tunnel storage for the Central City Tunnel System would necessitate multiple short storage segments, located at critical areas along each leg of the tunnel system. In addition, increased annual maintenance would be required for sub-surface tunnel options. For this reason, deep tunnel storage was eliminated from consideration at the start of the Central City Tunnel System analysis.

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Section 7

Recommended Improvements

The hydraulic capacity and geo-structural analyses for the Central City Tunnel System improvements have concluded:

- Increased capacity is required on the Washington Avenue and 2nd Avenue South tunnel segments to bring the system to a 10-year level of service.
- Increased hydraulic capacity is required on the Washington Avenue, 2nd Avenue South, and Nicollet Mall tunnel segments to bring the system to a 100-year level of service. Improved hydraulic performance of the Nicollet Mall leg could be accomplished by constructing an 8th Street South relief tunnel between Nicollet Mall and 2nd Avenue South. This 8th Street South cross-connect tunnel would also increase the capacity of the 2nd Avenue South tunnel.
- The outfall structure has sufficient hydraulic capacity to discharge runoff to the Mississippi River for a 100-year level of service without additional improvements, other than minor repairs.
- Green infrastructure and in-line storage are not viable hydraulic solutions to the ongoing pressurization of the Central City Tunnel System.
- Construction of a parallel tunnel is the most cost-effective approach to expand hydraulic capacity.
- Roadheader excavation is the most viable method of construction for the Central City Tunnel System improvements.
- Ongoing crack repair and modifications of the existing tunnel segments that remain in operation after hydraulic capacity improvements should continue to be implemented.

The preferred tunnel construction technique is a roadheader. This is preferable to construction via tunnel boring machine, hydraulic lance, or micro-tunneling.

Phased Approach

At the request of the City, CDM Smith developed a phased approach to implement these improvements. Two phases were identified:

1. Phase I: Washington Avenue Improvements.
2. Phase II: 2nd Avenue South & 8th Street South Cross-Connect Improvements.

Each of these phases were evaluated at the 10-year and 100-year level of service. Because the exact timing of the second phase is unscheduled, this section of the report also assesses the hydraulics of the system during the interim period between the two phases.

Phase I: Washington Avenue

The first phase of improvements increases the hydraulic capacity of the Washington Avenue tunnel between Hennepin Avenue and the Mississippi River. Construction of the first phase is scheduled to begin in 2020. A parallel tunnel will be constructed from Hennepin Avenue to Portland Avenue South, within the Washington Avenue right-of-way. The proposed parallel tunnel will be offset 12 feet to the north of the existing stormwater tunnel on Washington Avenue. At Portland Avenue South, the tunnel will become an expanded tunnel and turn to the north within the Portland Avenue South right-of-way. At 2nd Street South, the tunnel will continue to the east where an extension to the Chicago Avenue tunnel will provide additional available capacity. The Central City Tunnel System will then turn north down Chicago Avenue and connect to the existing convergence structure. The existing storm tunnel, from Portland Avenue South to Chicago Avenue is under private property and can be abandoned so that the entire tunnel is within public rights-of-way. This layout was evaluated at both the 10-year and 100-year level of service. The associated recommendations are described below.

10-Year Level of Service Improvements

The XPSWMM model was used to refine the hydraulics for the 10-year level of service improvements. The refinements, include:

- Washington Avenue at Hennepin Avenue: Structure to split the flow into parallel tunnels.
- Washington Avenue: Cross-connect structures between the existing tunnel and the new parallel tunnel at Nicollet Mall, Marquette Avenue South, and 2nd Avenue South help to equalize flow and allow maintenance access. Specific tunnel sizing requirements are also needed for the 10-year level of service.
- Junction Chamber at Washington Avenue and Portland Avenue South: Convergence structure and construction of new expanded tunnel designed to convey flow from both tunnels. The existing parallel tunnel located below private property will be abandoned, and the resultant expanded storm tunnel will be located entirely within street right-of-way.
- 2nd Street South, at approximately Chicago Avenue: Structure to split flow back into the existing tunnel system, with one leg directing flow to the Central City Tunnel System segment on Chicago Avenue, and the second leg directing the flow to the Chicago Avenue tunnel segment also located below Chicago Avenue.
- Minor repairs to outfall structure.

Figure 7.1 shows the specific configuration of this 10-year level of service project, including the Washington Avenue tunnel configuration from Hennepin Avenue to the Mississippi River, location of convergence and flow splitting structures, and locations of access shafts. **Figure 7.2** shows the flow split on 2nd Street South and divergence with the Chicago Avenue tunnel. Two privately owned tunnels have been identified that have the potential to conflict with the proposed tunnel improvements. The first is near the divergence location, just north of the Guthrie Theater and south of the West River Parkway. An east-west aligned mill conveyance tunnel is situated directly above the Chicago Avenue and Central City tunnels. The second is the Twin Cities Rail Tunnel aligned along Portland Avenue, which was encountered in 2010 during construction of the Portland-Washington sweep project. The exact alignment and elevation of these conflicts should be researched and surveyed during the design phase of the Central City Tunnel improvements in order to determine the appropriate approach to resolve these conflicts. See **Figure 7.3** for additional detail.

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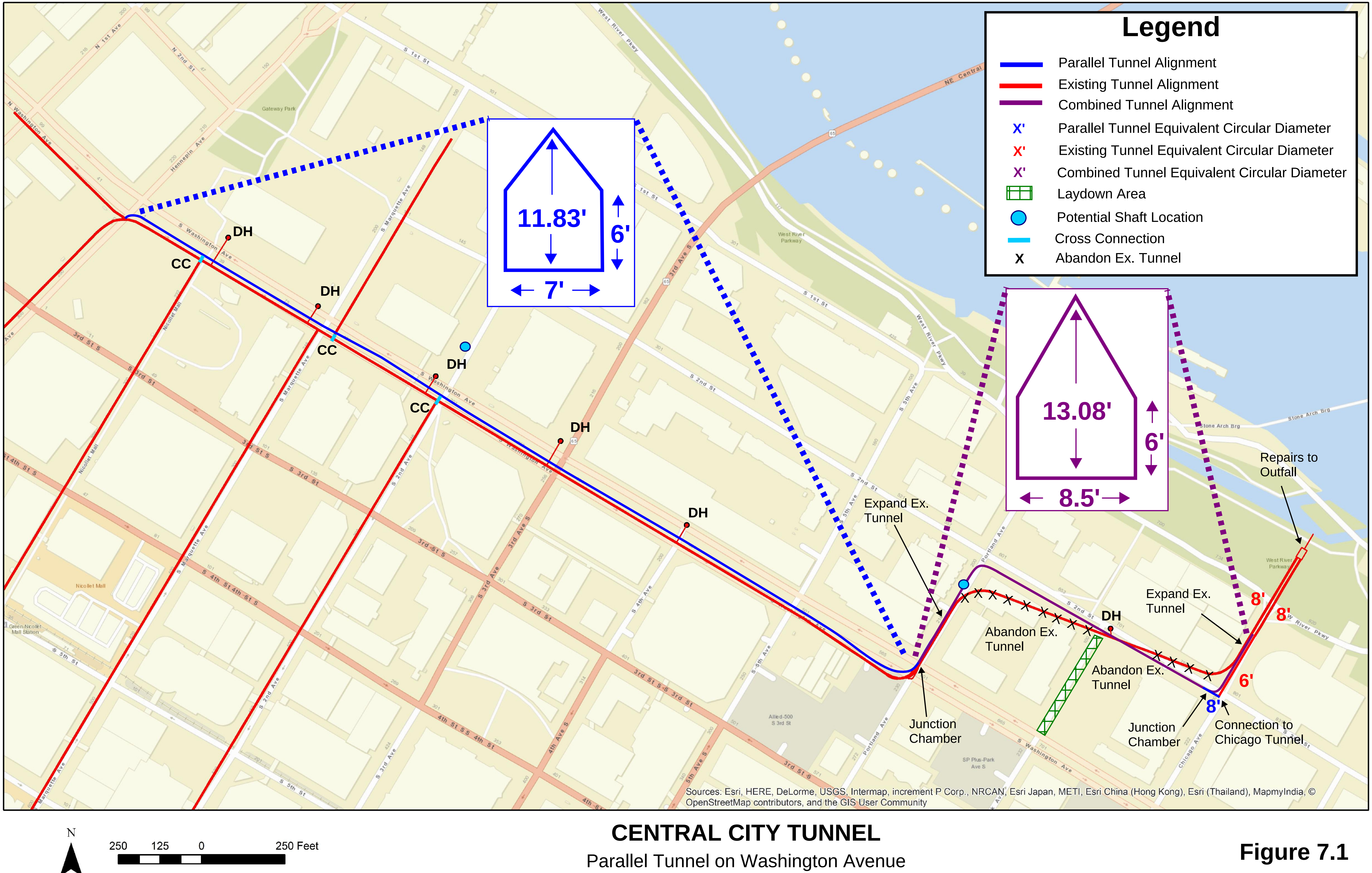


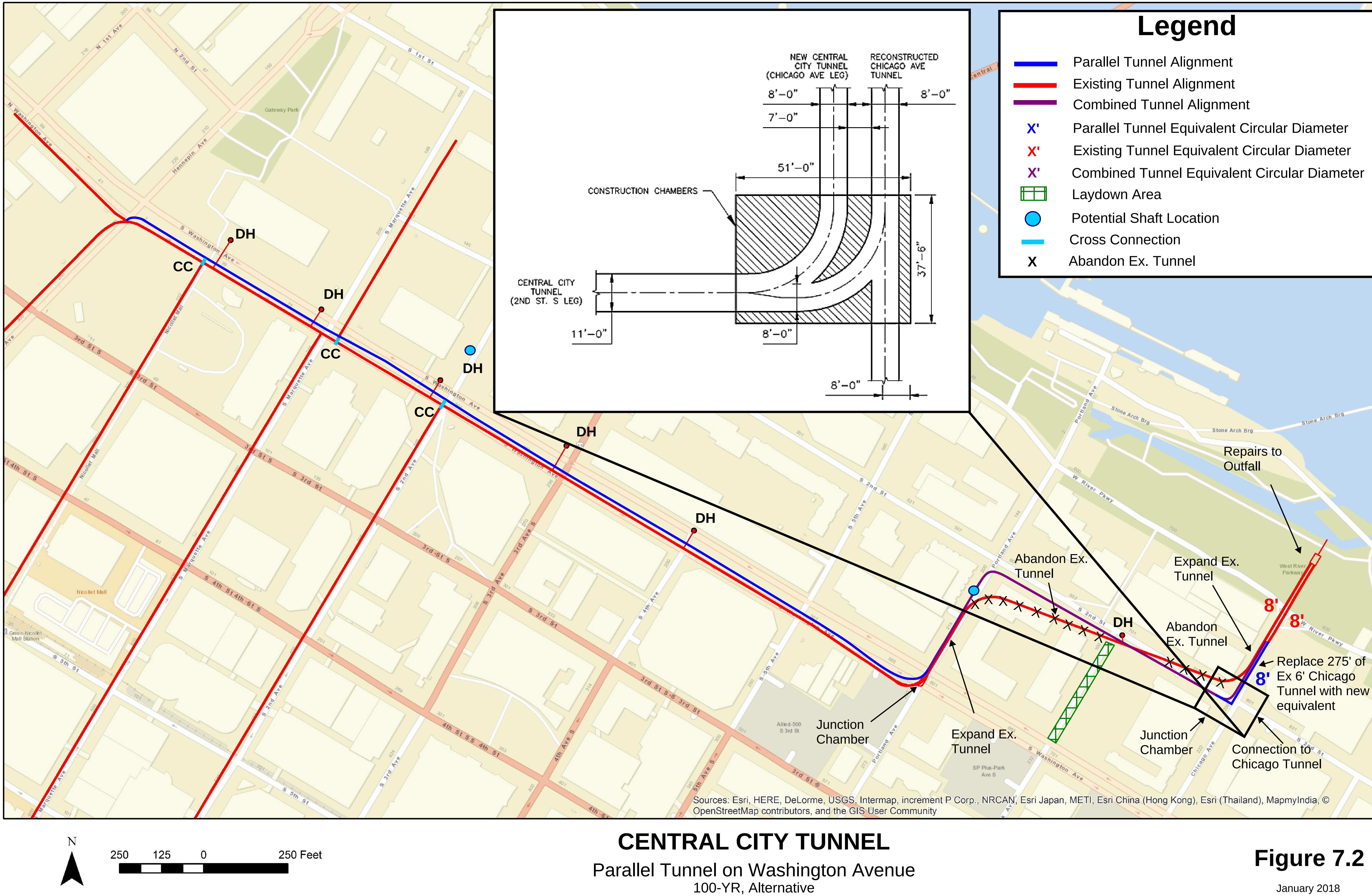
CENTRAL CITY TUNNEL

Parallel Tunnel on Washington Avenue

10-YR Alternative

Figure 7.1

January 2018



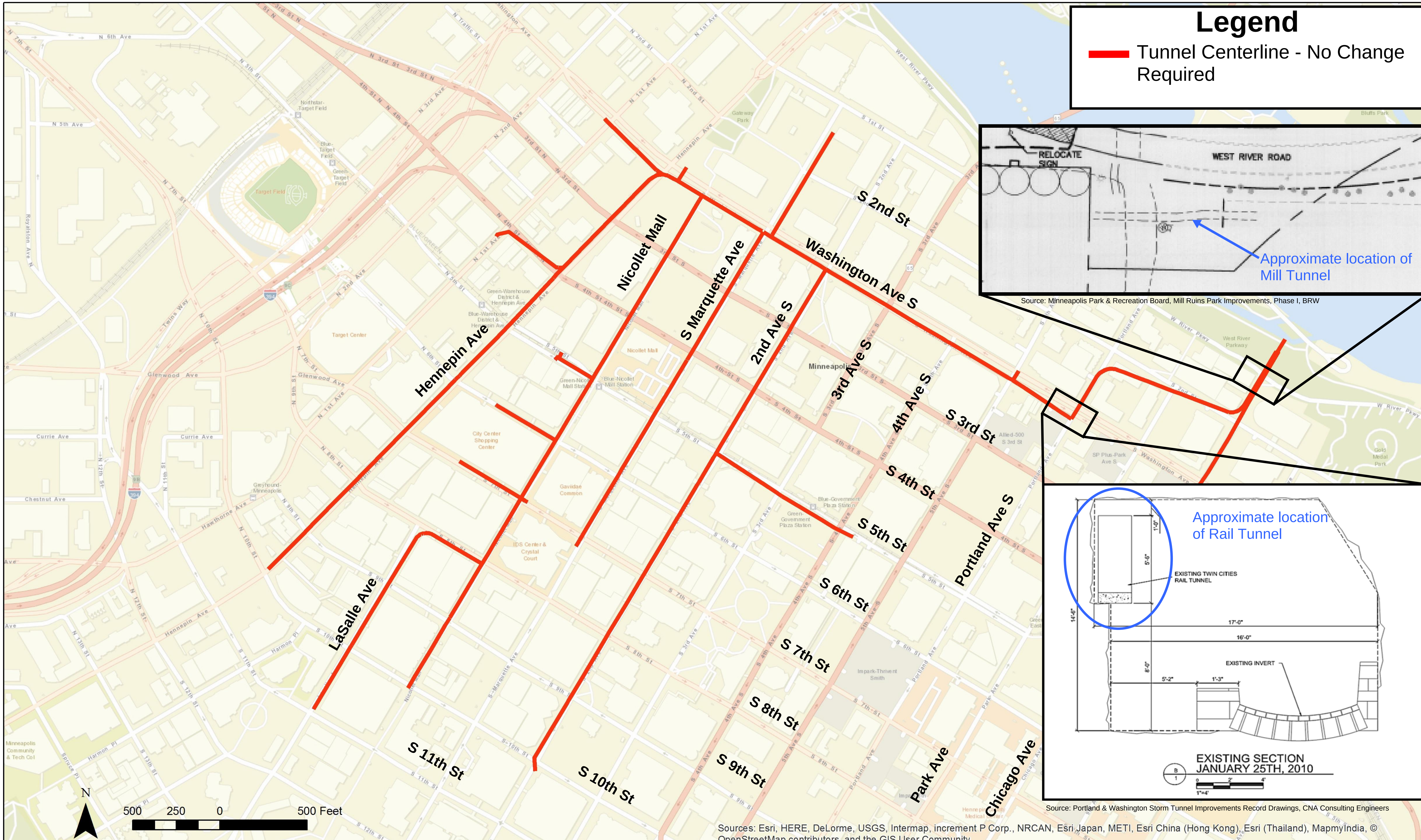
CENTRAL CITY TUNNEL

Parallel Tunnel on Washington Avenue

100-YR, Alternative

Figure 7.2

January 2018



Potential Tunnel Conflicts

Figure 7.3

100-Year Level of Service Improvements

The 100-year level of service contains the same components as the 10-year level of service described above with the following additions:

- Larger-sized Washington Avenue tunnel to accommodate the additional 100-year storm flow.
- Replace 275 feet of the existing 6-foot Chicago tunnel with a new 8-foot equivalent tunnel, between 2nd Street South and the tunnel convergence chamber to address hydraulic constrictions in this area.

Figure 7.4 shows the specific configuration and sizing of the 100-year level of service project area of Washington Avenue from Hennepin Avenue to the Mississippi River. As with the 10-year alignment, the proposed parallel tunnel, convergence/flow splitting structures, and access shafts can be located fully within the City's street rights-of-way. Note that the convergence chamber does not need to be reconstructed for this improvement; however, repairs to the outfall have been included in the project.

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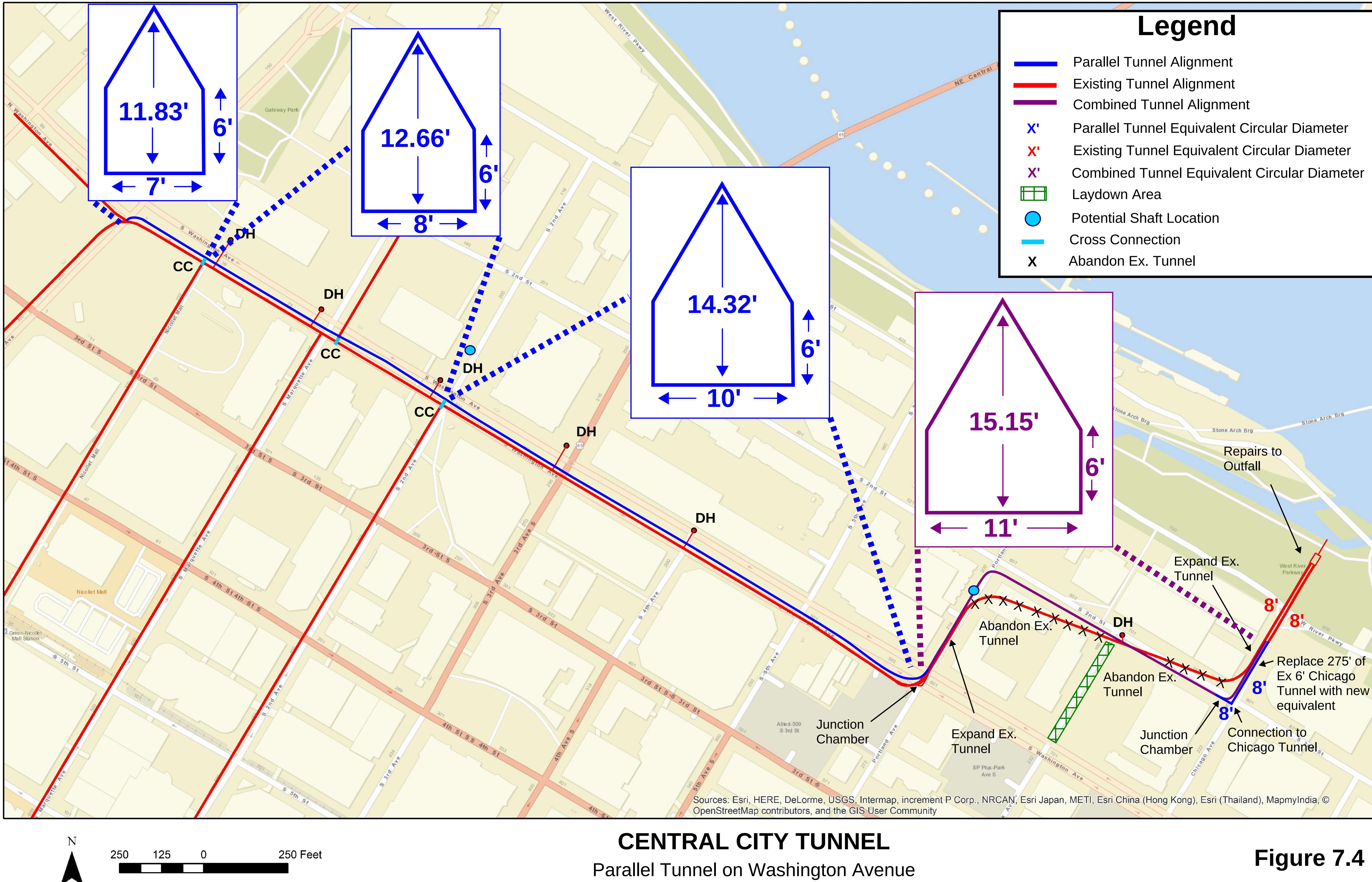


CENTRAL CITY TUNNEL

Parallel Tunnel on Washington Avenue

100-YR, Alternative

Figure 7.4

January 2018

Access Shaft Locations

For the purpose of cost estimation and preliminary design, two proposed access shafts are recommended in the same location for both the 10-year and 100-year level of service, as shown on Figure 7.1 and 7.2. Locations were chosen based on field visits and on information received from Gopher State One Call mapping requests. These two locations were selected to minimize utility relocation, minimize local traffic access, and to keep all construction activities entirely within the existing City rights-of-way. The 2nd Avenue South shaft location will facilitate construction of the Washington Avenue segment of the tunnel such that the Washington Avenue tunnel could be constructed predominantly in dry conditions year-round. The Portland Avenue South shaft location is intended to facilitate construction of the tunnel segment from Washington Avenue to the outfall chamber, which assumes this segment will need to be constructed during winter months while active flow must be bypassed. Each shaft is proposed to be approximately 70 feet deep and 20 feet in diameter for roadheader access. It is assumed that as the project enters the detailed design phase, the location of these access shafts may be adjusted as more detailed site information is developed.

Phase II: 2nd Avenue South & 8th Street South Cross-Connect

The second phase of improvements increases the capacity of the 2nd Avenue South tunnel segment and provides relief to the Nicollet Mall stormwater tunnel through an 8th Street South cross-connect from 2nd Avenue South to Nicollet Mall. The 8th Street South cross-connect is recommended because it eliminates the need for construction of additional tunnel capacity on Nicollet Mall. The 2nd Street South tunnel capacity would be increased to accommodate excess flow from the Nicollet Mall tunnel via 8th Street South, as well as the additional capacity needed to convey the runoff that is directly tributary to 2nd Avenue South. This was only necessary for the 100-year rainfall event, based on the conclusion that the Nicollet Mall tunnel segment had sufficient capacity for the 10-year rainfall event. The recommended alignment and tunnel diameters for Phase II are shown in **Figure 7.5**.

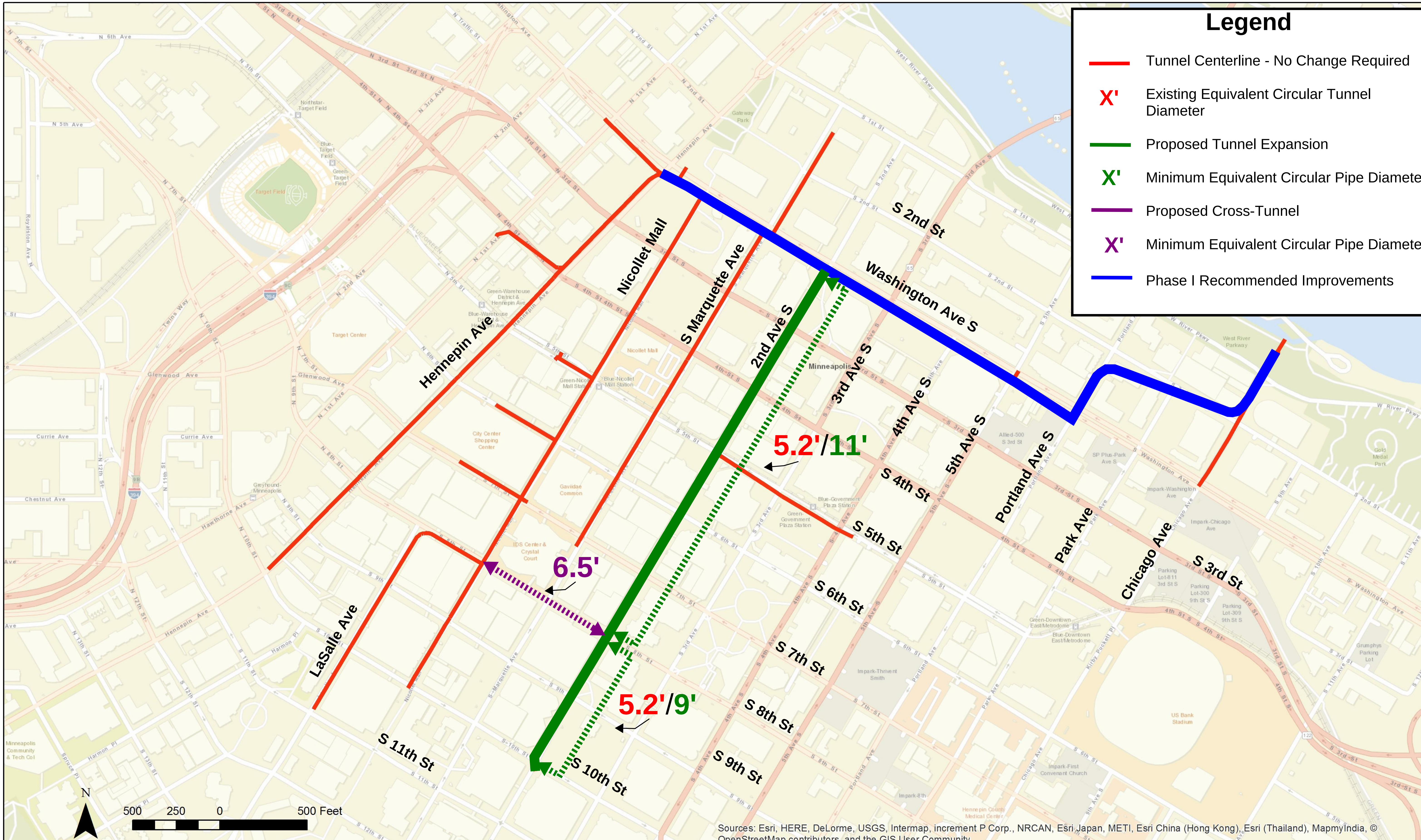
Surge and Pressurization

Surge flow is not predicted to be an issue because the gravity outlet and numerous individual drill holes distributed throughout the tunnel network provide sufficient pressure relief to prevent surge conditions.

The proposed improvements will significantly reduce the surcharge presently predicted for the 10-year and 100-year level of service storms. The new Washington Avenue parallel tunnel is predicted to not pressurize in either design storm because the hydraulic grade line is entirely within the new tunnel. However, some pressurization of the existing Washington Avenue tunnel will continue to occur after all recommended improvements are completed. The worst condition during a 100-year level of service rain event will create a maximum pressure head of 7.9 feet that is predicted to exist for a 44.6-minute duration. This condition will exist because the top of the parallel, new Washington Avenue tunnel will be at a higher elevation than the top of the existing Washington Avenue tunnel. The only method to avoid this pressurization would be to lower the new Washington Avenue tunnel such that the top of both parallel tunnels are the same elevation and the invert of the new parallel tunnel would be 6 feet to 8 feet lower than the existing tunnel. This configuration was determined to be infeasible since it would require full reconstruction of the outfall structure and Chicago Avenue tunnel, and would fully submerge the outfall to an elevation that is lower than the invert of the Mississippi River.

The hydraulic grade line of the proposed tunnel will be within the tunnel and future improvements along 2nd Avenue South will continue to reduce the surcharge presently observed along 2nd Avenue South. A similar condition of pressurization of the existing 2nd Avenue South tunnel, such that the maximum pressurization during the 100-year level of service rain event will equal 8.1 feet that is predicted to exist for a 44.6-minute duration. This condition is unavoidable for a parallel tunnel option for 2nd Avenue South for similar reasons for the Washington Avenue tunnel. Additionally, a lowered invert for a parallel 2nd Avenue South tunnel would conflict with the Metropolitan Council Interceptor 1-MN-310, which crosses under the 2nd Avenue South tunnel at 4th Street South.

Hydraulic profiles for each improved segment of the Central City Tunnel System is contained in **Appendix C**.



Minneapolis City of Lakes

CDM Smith

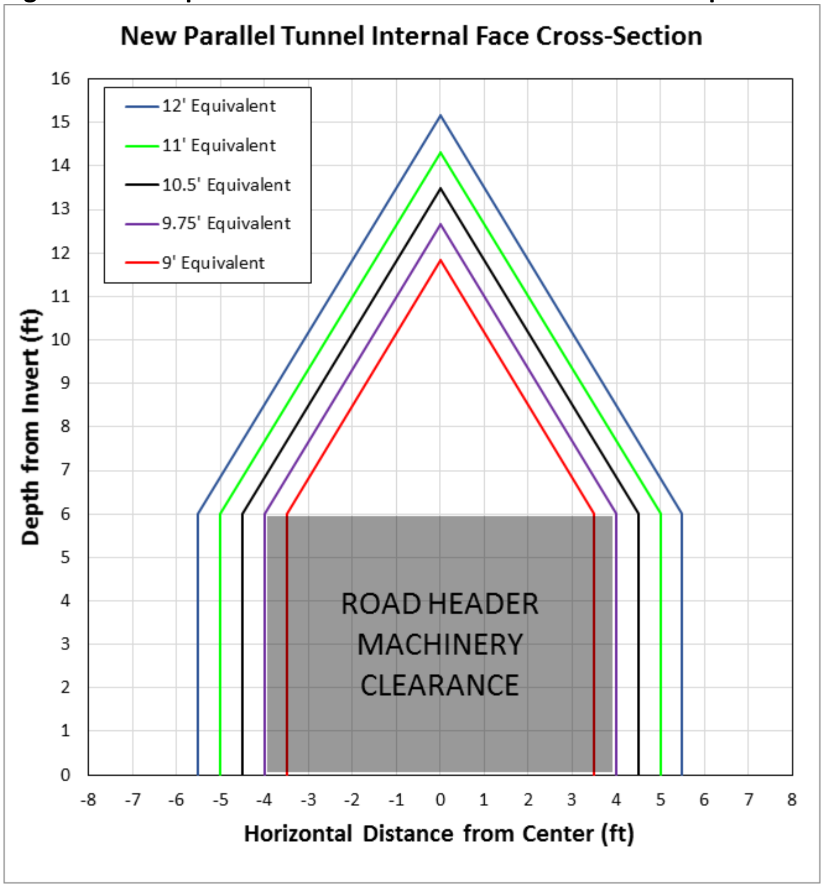
Phase II: 8th Street Cross-Connection Expanded Tunnels

Figure 7.5

Cathedral-Shaped Tunnel

All proposed tunnels in Phases I and II are recommended to have a cathedral shape to take advantage of the natural properties of the St. Peter Sandstone, specifically the angle at the crown of the cathedral is proposed to be 62° to match the natural friction angle of the St. Peter Sandstone. By matching the friction angle, the cathedral shape of the proposed tunnel will mimic the natural angle that the sandstone will degrade along, and provide the most stable of tunnel shapes. **Figure 7.6** represents the proposed tunnel dimensions for tunnels having equivalent circular diameters identified in the figure. The grey box in the figure represents the minimum space needed for a roadheader to access the tunnel. The minimum tunnel equivalent circular cross-section using a roadheader to construct a cathedral shape is 9 feet. All tunnels smaller than 9 feet will generally need to be constructed as a cathedral shape with a 9-foot equivalent circular diameter. Tunnel excavation includes excavating material for the new reinforced concrete liner as well.

Figure 7.6 – Proposed Tunnel Dimensions for Tunnels with Equivalent Circular Diameters



Where insufficient height exists between the desired tunnel cross-section and the above limestone/soapstone, the tunnel will be wider and more rectangular in shape than the cathedral shaped sections of the tunnel. The sandstone faces of the excavated tunnel will be sprayed with sodium silicate and a fiber-reinforced shotcrete liner will be installed as soon after excavation as practical. Rock bolts embedded in the limestone will be utilized to support the crown of the tunnel.

Phase I Detailed Cost Analysis – Washington Avenue Tunnel Improvements

A final estimate of construction costs was developed for the refinements of the recommended Phase I improvements. The following considerations were included in this detailed cost analysis:

- No additional easements or rights-of-way were required.
- Planning-level contingencies applied at 25 percent and undeveloped design details at 10 percent.
- Site improvements, utility relocation, and restoration costs added as a lump sum value ($2 million) because of the high concentration of utilities in the project area.
- Tunnel construction from Hennepin Avenue to Portland Avenue South generally constructed in-the-dry, but the contractor will still need to deal with groundwater infiltration. Tunnel construction from Portland Avenue South to Chicago Avenue will have to be performed in the winter months and requires some bypass pumping to convey drainage and groundwater infiltration.
- Outfall repairs constructed in-the-dry. The total cost included bypass pumping, dewatering the outfall and creating and maintaining a coffer dam in the Mississippi River tailrace ($742,000).
- Two 20-foot diameter access shafts located and sized to accommodate a roadheader excavator.
- Additional cost to abandon segments of the existing tunnel between Washington Avenue/Portland Avenue South intersection and 2nd Street South.
- Additional cost in the 100-year Option 1 to enlarge the Chicago Avenue tunnel to improve the hydraulic grade line ($870,000).

Costs for 10-year and 100-year level of service are summarized in **Table 7.1**.

Table 7.1 – Central City Tunnel System Phase I Detailed Cost Estimate

Items	Parallel Tunnel (10 year)	Parallel Tunnel (100 year)
Shafts (2)	$1,780,000	$1,780,000
Access Tunnel (8' Equivalent Circular Diameter)	$280,000	$280,000
Tunnel (8' Equivalent Circular Diameter)	$5,120,000	--
Tunnel (10' Equivalent Circular Diameter)	$3,910,000	$3,290,000
Tunnel (12' Equivalent Circular Diameter)	--	$11,350,000
Drifts (6 Connections to New Tunnel)	$300,000	$300,000
Cross Connects (3-8' Equivalent Circular Diameter)	$110,000	$110,000
Abandonment of Existing Central City Tunnel Sections	$820,000	$820,000
Chicago to Tail Race (12' Equivalent Circular Diameter)	$470,000	$470,000
Chicago Connection (8' Equivalent Circular Diameter)	$60,000	$90,000
Site Improvements / Utilities / Restoration	$2,000,000	$2,000,000
Junction Chambers (3)	$1,500,000	$1,500,000
Chicago Tunnel Expansion from 6' to 8'	--	$870,000
Outfall Repair	$742,000	$742,000
Subtotal	**$17,092,000**	**$23,602,000**
Undeveloped Design Details	$1,710,000	$2,361,000
Subtotal	**$18,802,000**	**$25,963,000**
Engineering, Legal, Fiscal	$3,761,000	$5,193,000
Total	**$22,563,000**	**$31,156,000**

Interim Condition Hydraulic Analysis

The XPSWMM model was used to assess how the Central City Tunnel System will operate in the interim period between the Phase I improvements (2020) and the Phase II improvements (unscheduled). This analysis was conducted for the three tunnel segments determined to have hydraulic limitations, as described in Section 4: Washington Avenue, 2nd Avenue South, and Nicollet Mall.

The City advised that a near-future improvement on 2nd Avenue South immediately upstream of Washington Avenue was being planned. This improvement would open the top of the tunnel liner and expose a known void that exists between the 2nd Avenue South tunnel crown and the bottom of the overlying soapstone layer. The walls of the void will be sealed with shotcrete, essentially creating an enlarged structure similar to that at the Portland Avenue South/Washington Avenue sweep. It is assumed that the width of this enlarged chamber will remain the same as the 2nd Avenue South tunnel width and the height will average 8 feet. The chamber will exist between 5th Street South and Washington Avenue. The interim conditions analysis assumes the completion of this enlargement of the 2nd Avenue South tunnel segment.

Three scenarios were assessed for each tunnel segment for both the 10-year and 100-year level of service:

- **Ultimate Buildout**: Parallel tunnels are constructed along Washington Avenue based on the final tunnel sizing recommendations. A parallel tunnel is constructed along 2^{nd} Avenue South based on the tributary tunnel sizing recommendations contained in **Table 5.1**. The 100-year level of service for 2^{nd} Avenue South includes the 8^{th} Street South cross-connect tunnel between Nicollet Mall and 2^{nd} Avenue South. The 8^{th} Street South cross-connect is sized to provide relief for the Nicollet Mall tunnel; therefore, additional improvements on Nicollet Mall are not included in the Ultimate Buildout condition.
- **Interim Scenario I**: Parallel tunnels are constructed along Washington Avenue, only. There are no additional improvements to the tributary tunnels.
- **Interim Scenario II**: Parallel tunnels are constructed along Washington Avenue. 2^{nd} Avenue South tunnel is expanded between 5^{th} Street South and Washington Avenue. There are no other improvements to the tributary tunnels in this condition.

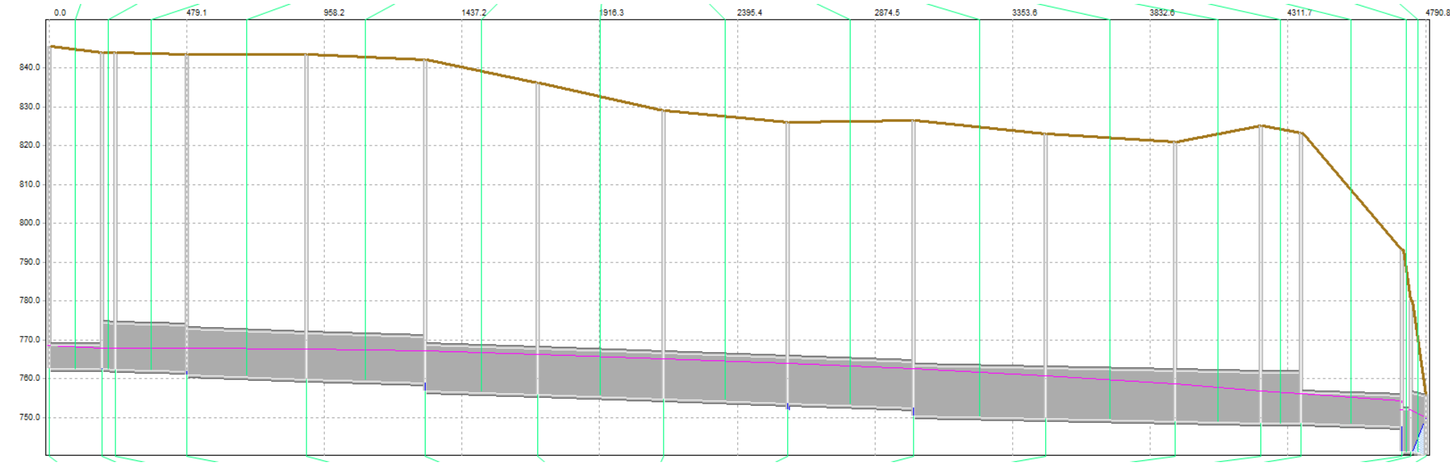
Washington Avenue Interim Scenarios

For purposes of comparison, **Figure 7.7** shows the Hydraulic Grade Line (HGL) for both the 10-year and 100-year level of service for the three scenarios described above. Note that the HGL for the upper reaches of the Washington Avenue tunnel is significantly below the crown of the pipe. This is related to the need to oversize the upper segment to accommodate the space required for the roadheader to excavate. This oversizing has a greater effect on the interim scenarios for the 10-year level of service than for the 100-year level of service. The HGL is below the crown of the tunnel for all three scenarios for the 10-year level of service; however, the HGL does rise above the crown of the Washington Avenue tunnel during the 100-year level of service rainfall event. The HGL is slightly lower for Interim Scenario I, which assumes no improvements to the 2^{nd} Avenue South tunnel between 5^{th} Street South and Washington Avenue. Effectively, the smaller cross-sectional area of 2^{nd} Avenue South serves to throttle the pressurized flow that is discharged from the 2^{nd} Avenue South tunnel into the Washington Avenue tunnel.

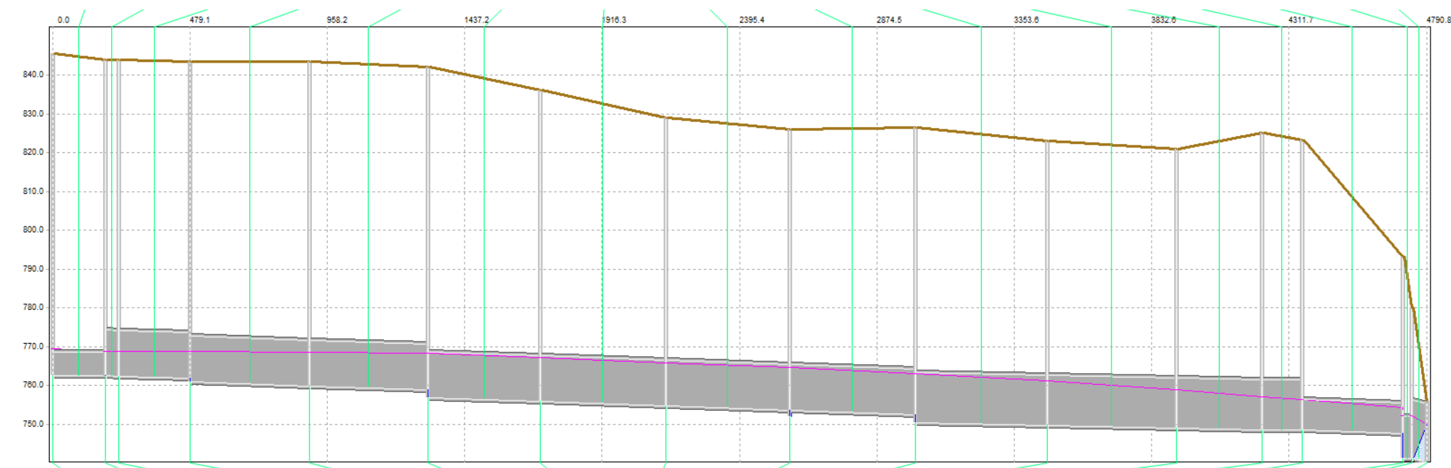
Figure 7.7 - Washington Avenue Interim Scenarios

Washington Ave: 10-year Level of Service

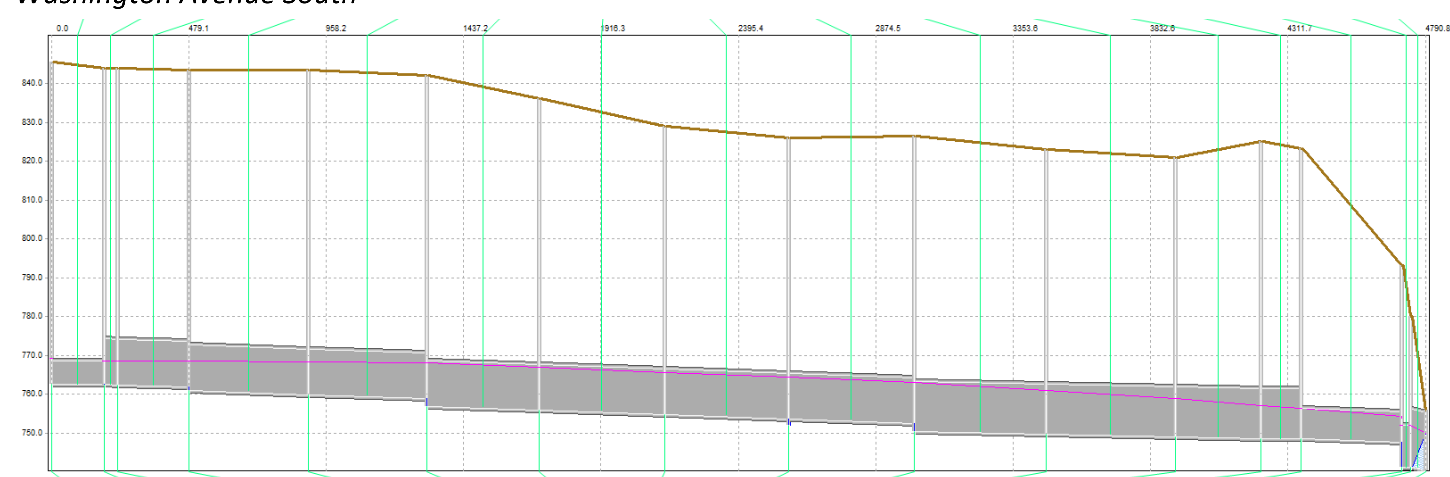
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels

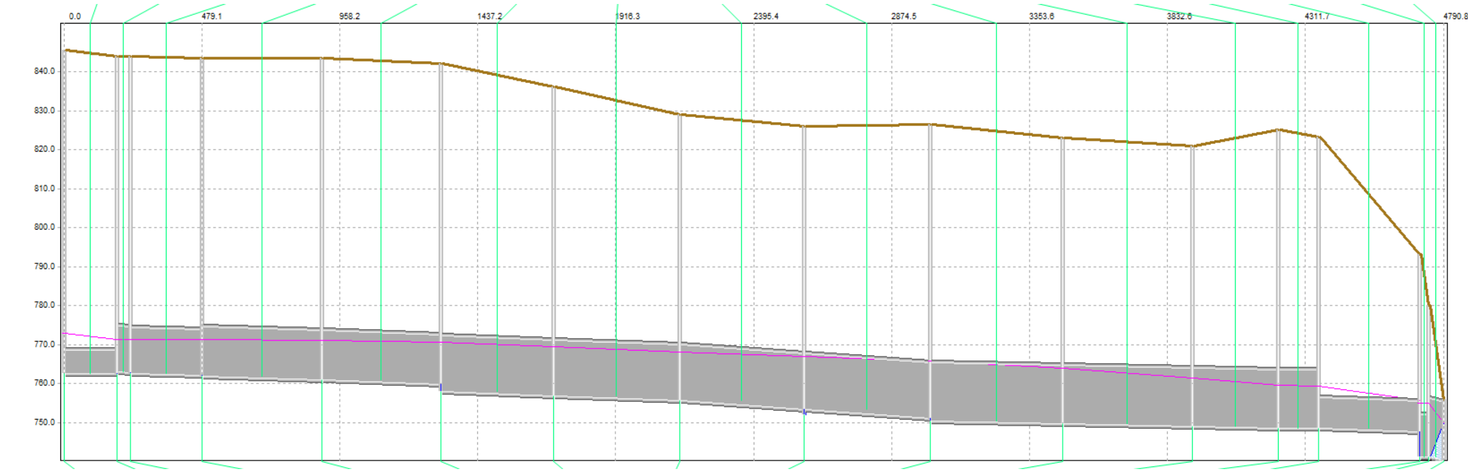


Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South

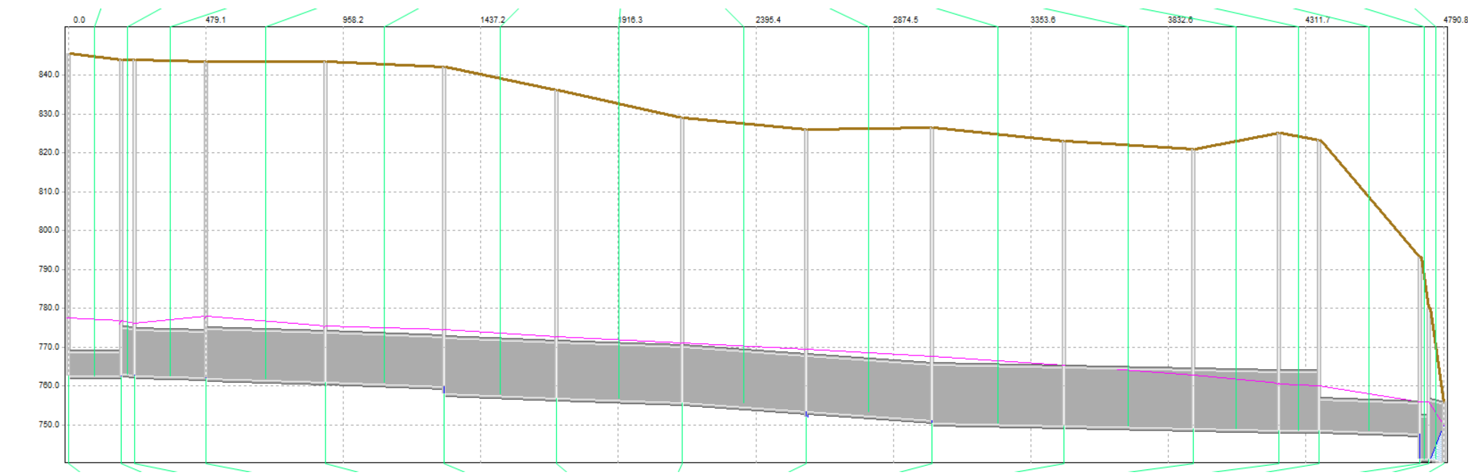


Washington Ave: 100-year Level of Service

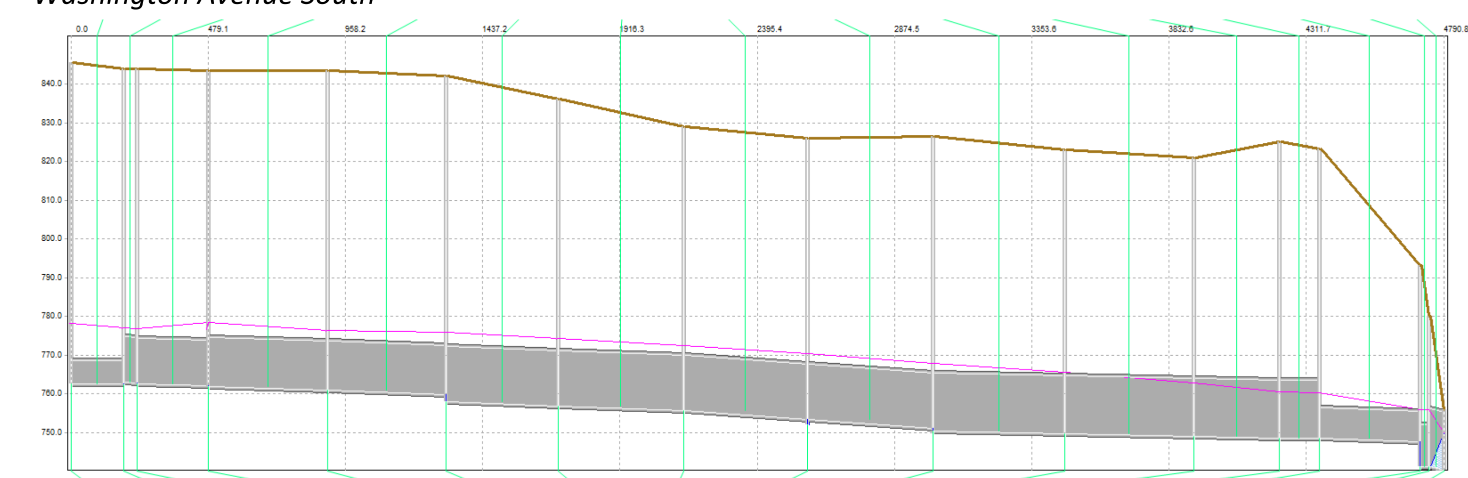
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels



Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South



2nd Avenue South Interim Scenarios

Pressurization of the 2nd Avenue South tunnel would be mitigated with construction of a parallel tunnel, sized to convey the runoff from either a 10-year or 100-year level of service event. As shown in **Figure 7.8**, the HGL for 2nd Avenue South is near or below the crown of the tunnel for the Ultimate Buildout scenario. However, the severe pressurization will remain for both the 10-year and 100-year level of service interim scenarios, with the HGL essentially the same for both Interim Scenario I and Interim Scenario II for the segment of 2nd Avenue South between Washington Avenue and 4th Street South. This is true for both the 10-year and 100-year Level of Service. This result shows how the improved hydraulics of the lower reaches of the 2nd Avenue South tunnel are improved by the additional capacity of the Washington Avenue tunnel segment. This positive influence diminishes in the upper reaches of the 2nd Avenue South tunnel such that the HGL for Interim Scenario I approaches the street elevation during a 100-year level of service rain event. The 2nd Avenue South tunnel improvements between 5th Street South and Washington Avenue does help to reduce the HGL for the upper reaches of the tunnel above 5th Street South for both the 10-year and 100-year level of service.

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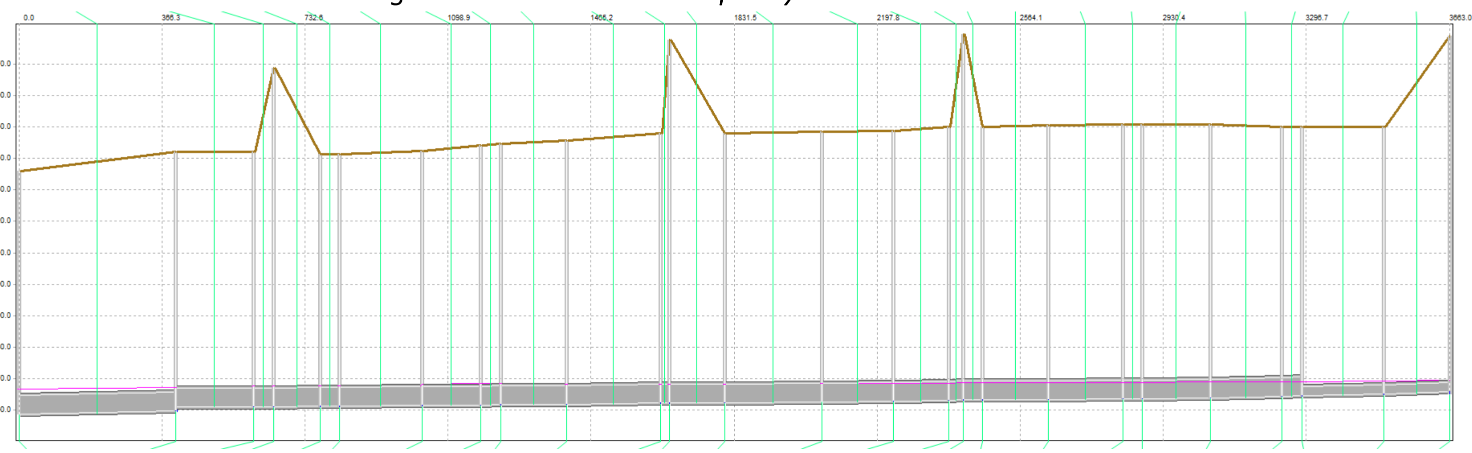
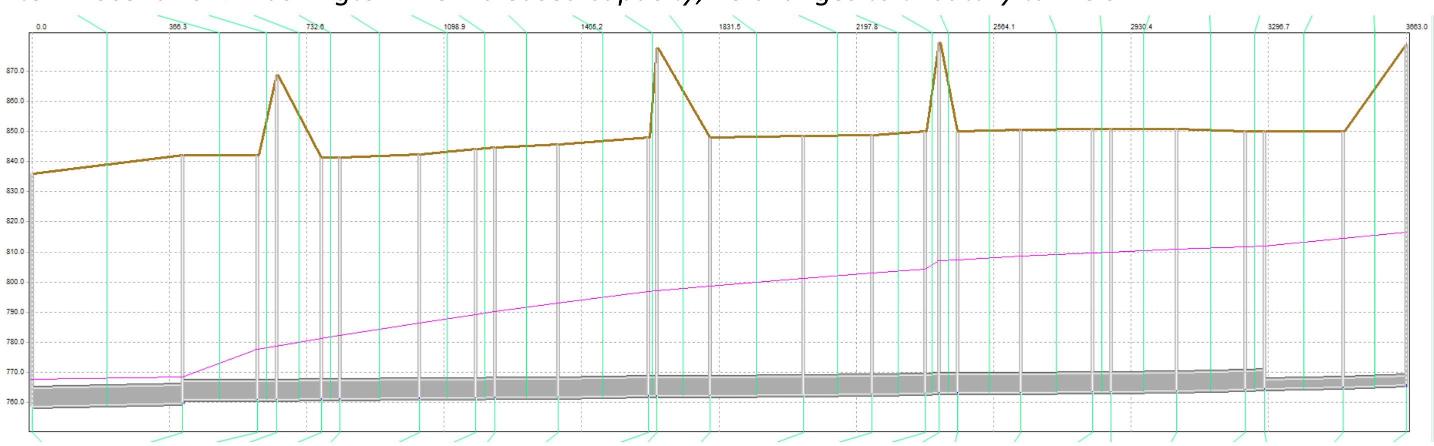
FIGURE 7.8 - 2nd Avenue South Interim Scenarios

2nd Avenue South: 10-year Level of Service

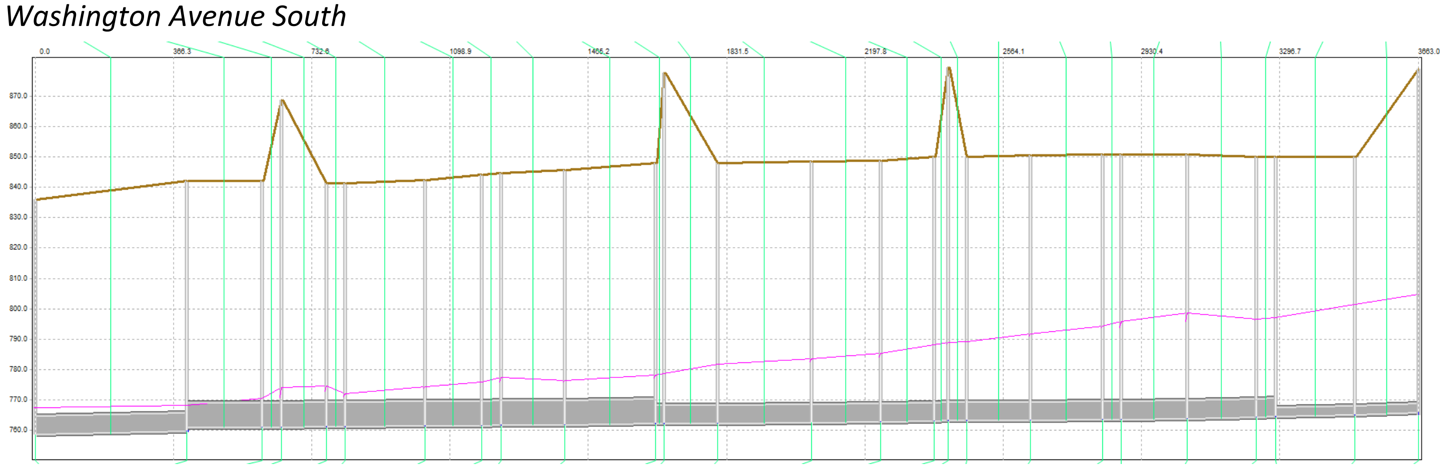
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels

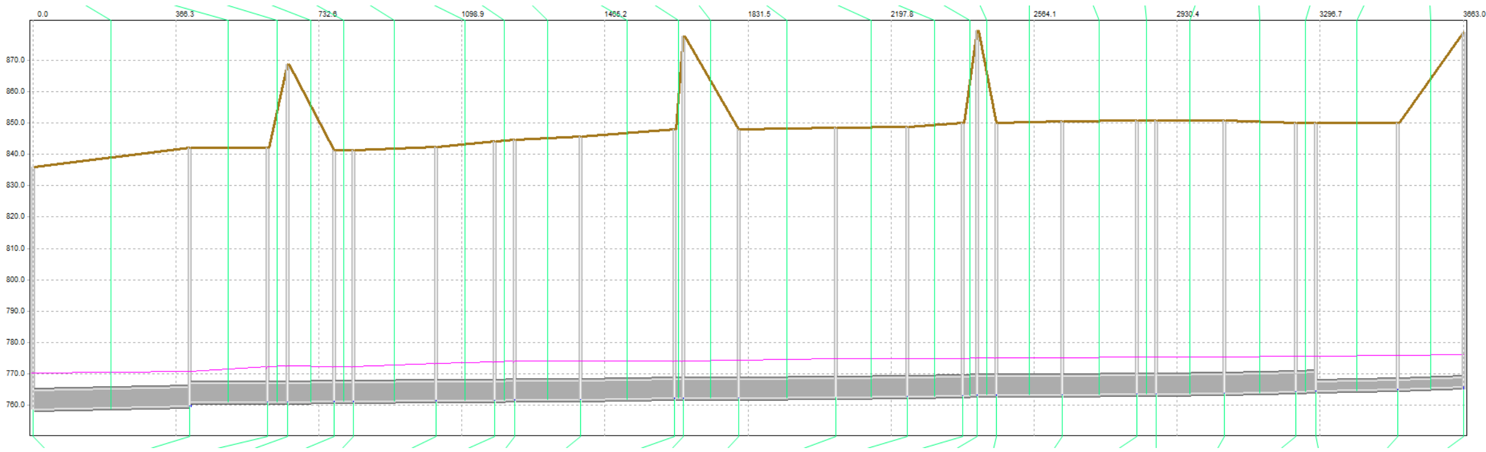


Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South

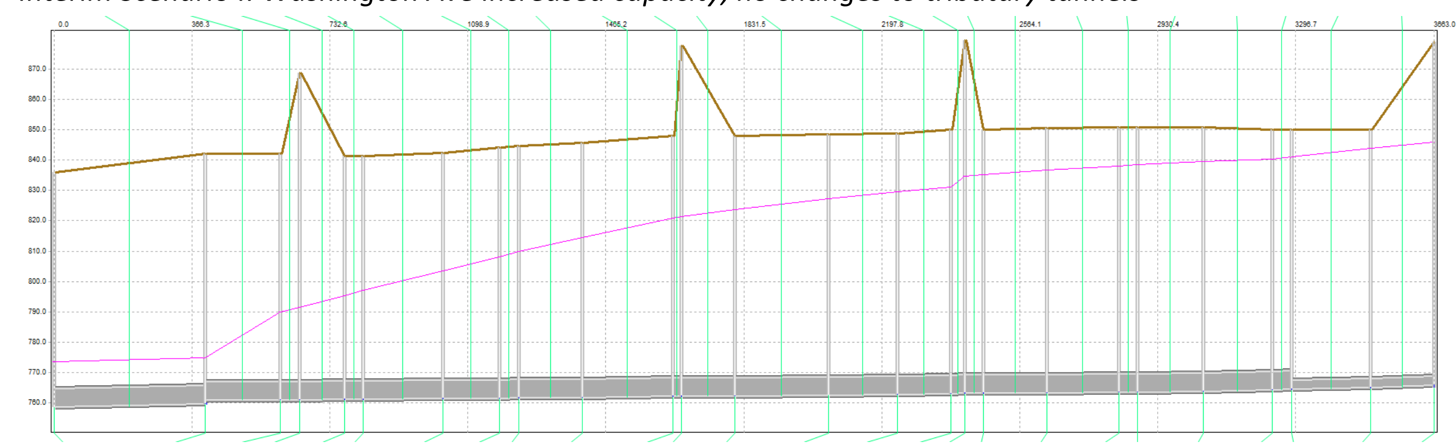


2nd Avenue South: 100-year Level of Service

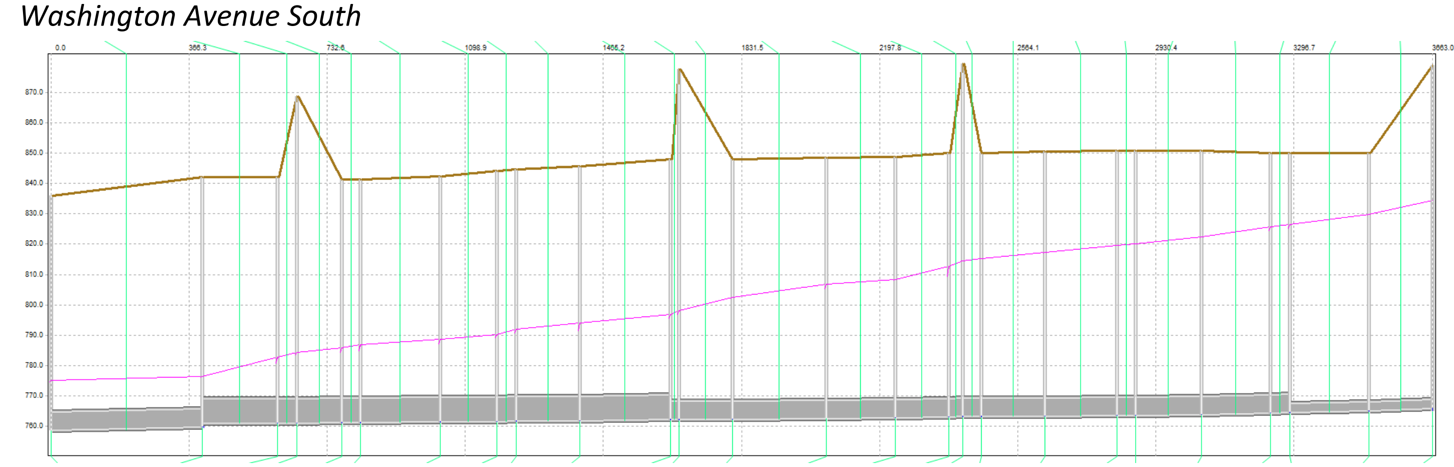
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels



Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South



Nicollet Mall Interim Scenarios

Construction of a parallel tunnel along Washington Avenue has little to no effect on the HGL of the Nicollet Mall tunnel for the 10-year level of service, as shown in **Figure 7.9**. This condition is consistent with the analysis of this tunnel segment discussed in Section 4, which concluded that the Nicollet Mall tunnel has sufficient hydraulic capacity for the 10-year level of service, but insufficient hydraulic capacity for the 100-year Level of Service. The 8th Street South cross-connect tunnel, in conjunction with a parallel tunnel on 2nd Avenue South provides sufficient capacity such that additional improvements are not required for the Nicollet Mall tunnel for the 100-year level of service. Without these improvements, the Nicollet Mall tunnel will continue to pressurize during a 100-year Level of Service rainfall event, without significant differences in the resulting HGL for either Interim Scenario I or Interim Scenario II.

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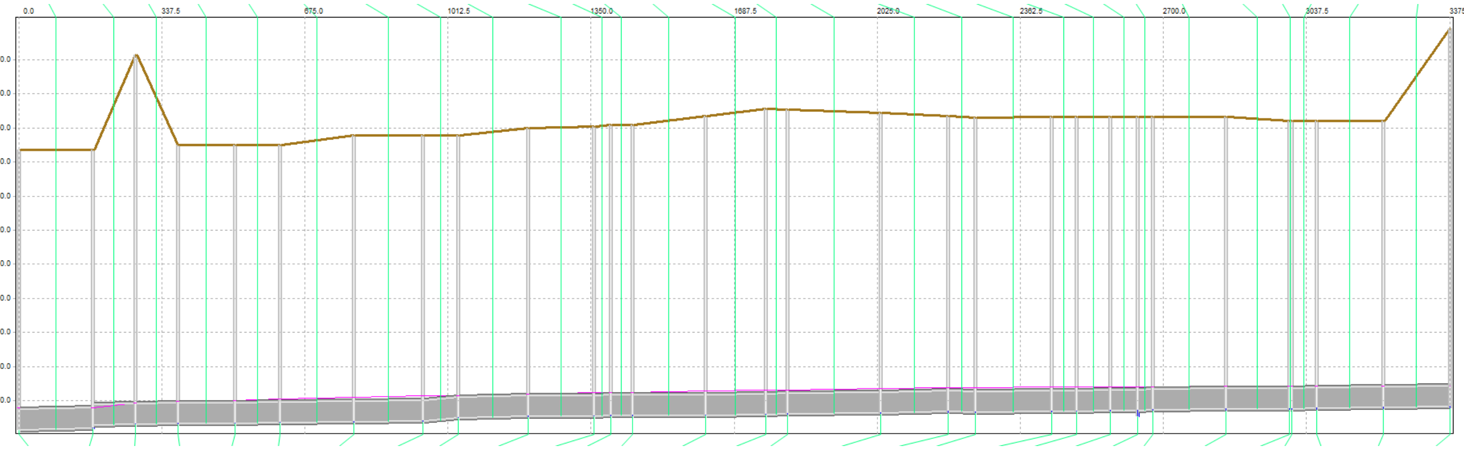
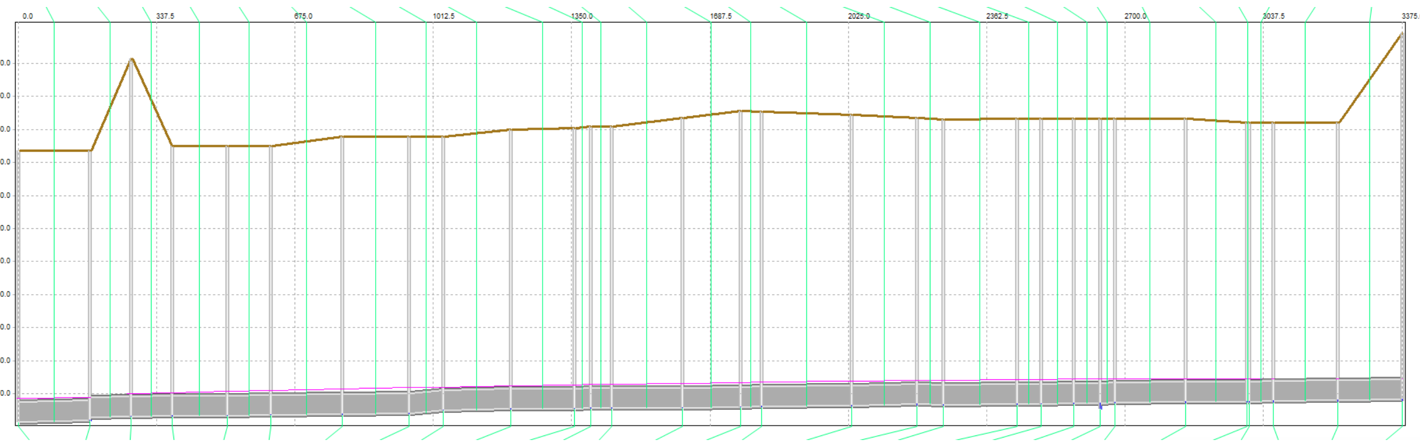
FIGURE 7.9 - Nicollet Mall Interim Scenarios

Nicollet Mall: 10-year Level of Service

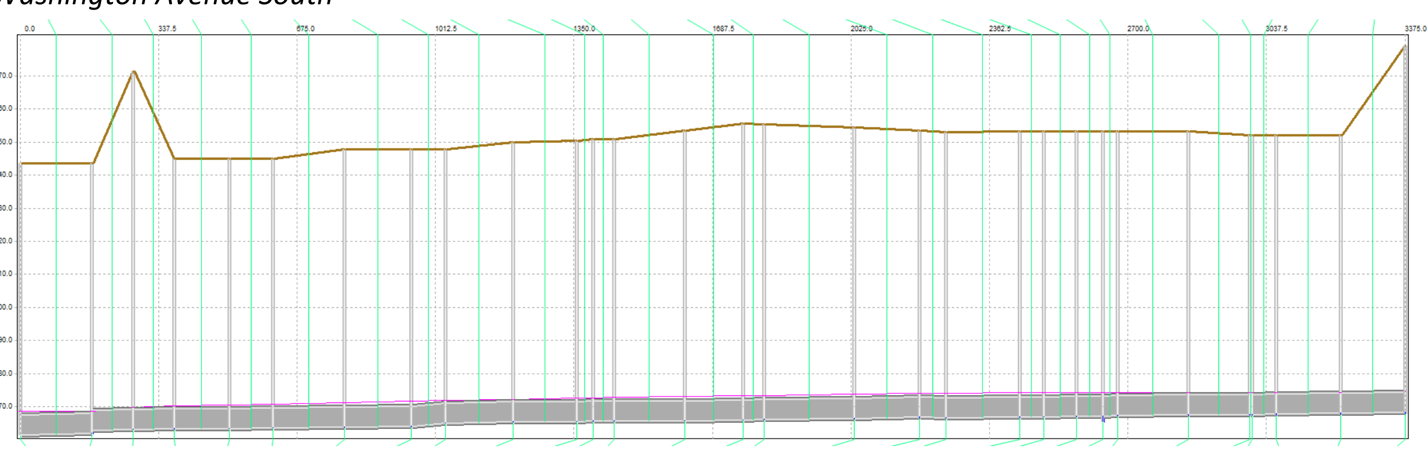
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels

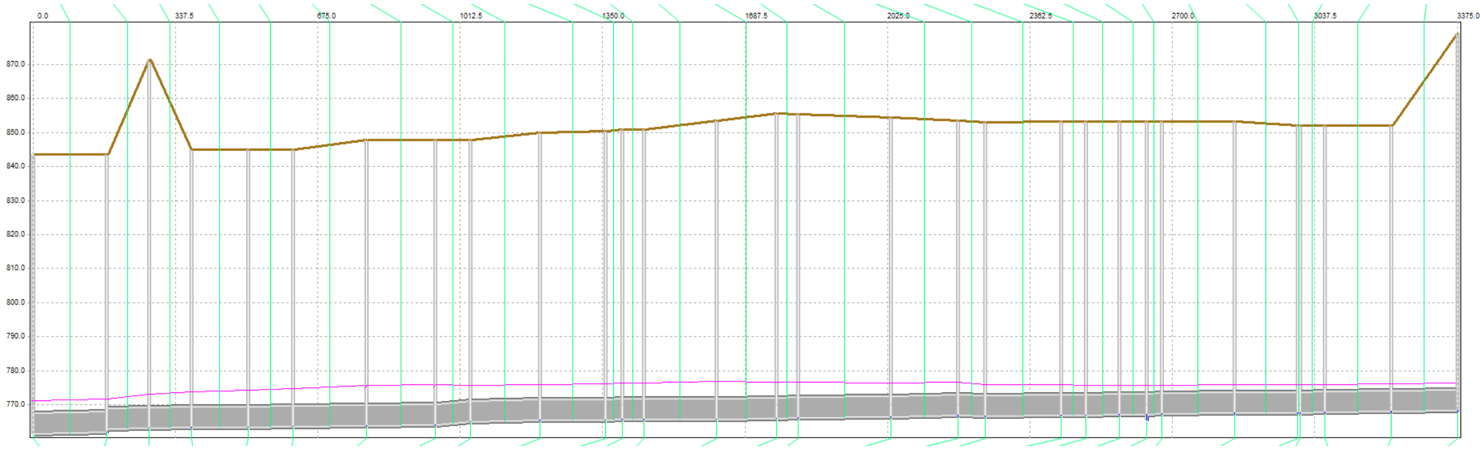


Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South

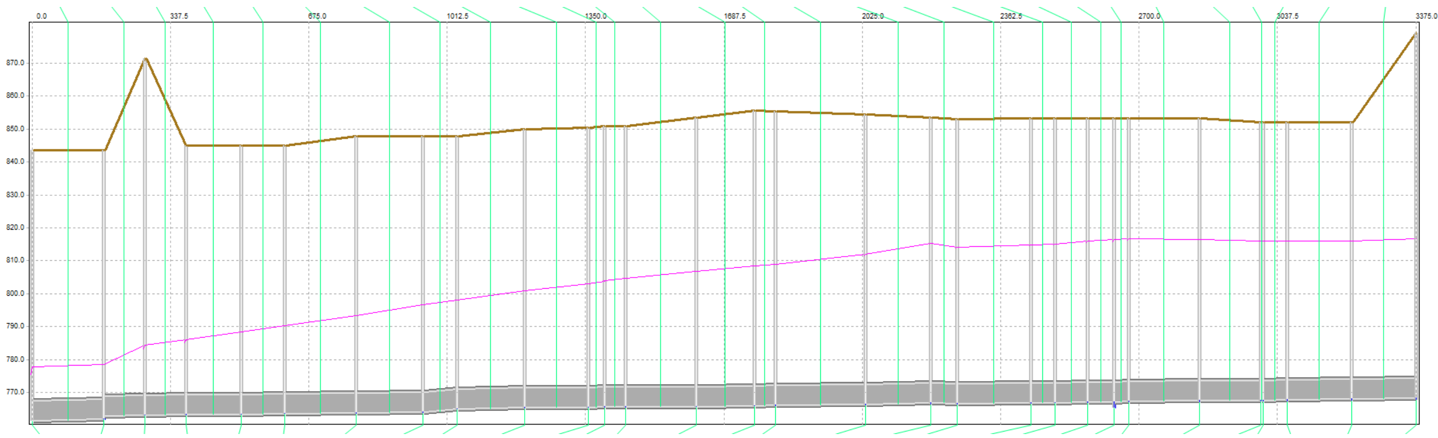


Nicollet Mall: 100-year Level of Service

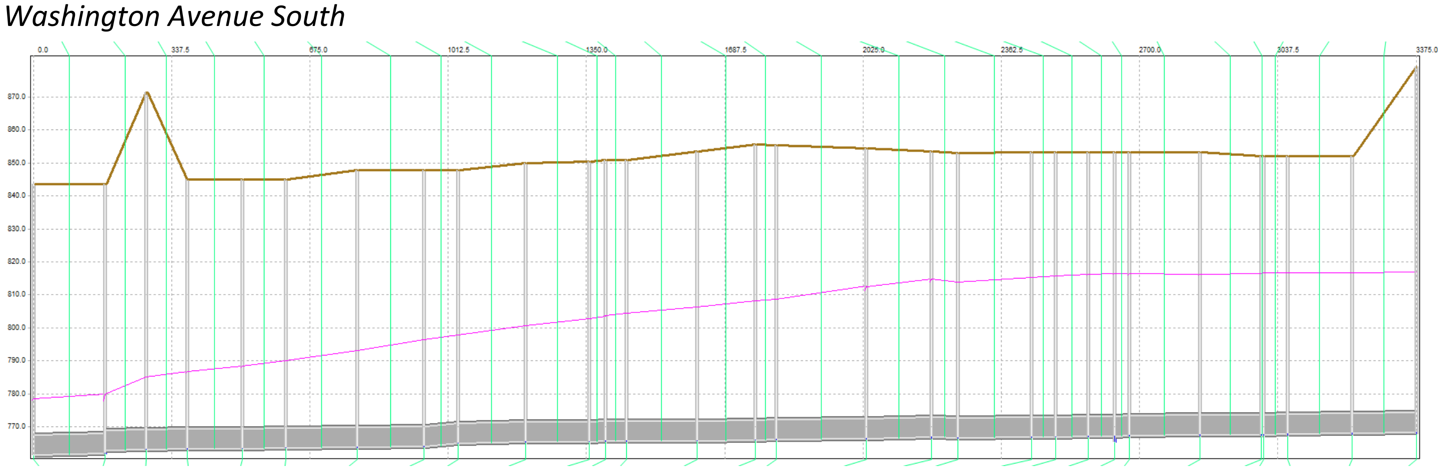
Ultimate Buildout: All tunnel segments with increased capacity



Interim Scenario I: Washington Ave increased capacity, no changes to tributary tunnels



Interim Scenario II: Washington Ave increased capacity, 2nd Avenue reconstruction between 5th Street South and Washington Avenue South



Construction Considerations

Inherent in all construction projects is the need to assess the risk of the project to minimize the probability that poor project development would lead to contractor claims or other unexpected costs. For tunnel projects, it is especially important to consider the risks and mitigation approaches in the earliest stages of project development. The risks associated with the Central City Tunnel System expansion project can be categorized into:

- Worker Safety.
- Tunnel Flooding.
- Surface Management.
  - Traffic Control and Haul Routes.
  - Permits.
- Ground Conditions.

For the Central City Tunnel System, CDM Smith developed an initial risk register, contained in **Appendix D**. A list of risks was developed, based on information available at this preliminary stage of project development. For each risk identified, a probability value was assigned based on the likelihood of occurrence contained in **Table 7.2**.

Table 7.2 – Likelihood of Occurrence Risk Score and Interpretation

Probability Category	Interpretation
Will happen (5)	When you have strong evidence to suggest it will occur.
Will probably happen (4)	You have a factual basis to suggest that it might happen, but can't be positive it will.
Could happen (3)	Just as likely to happen as not happen. You have no factual basis one way or the other.
Unlikely to happen (2)	You have a factual basis to suggest it won't happen, but it is still possible.
Highly unlikely to happen (1)	When you have strong evidence to suggest it won't occur.

Each risk was also assessed for its potential economic value, as defined in **Table 7.3**.

Table 7.3 – Economic Value Risk Scores

	Delays	Goodwill/Third Party Damage	Environmental Threats	Economic Losses	Safety & Security Losses
Disastrous (5)	> 6 mos	National adverse coverage	Long term regional impact	> $15,000,000	Significant injury to public or any fatalities
Severe (4)	3 to 6 mos	Major local impact or minor national impact	Long term local impact	$1,000,000	Multiple major injuries or minor injury to public
Serious (3)	1 to 3 mos	Complaints from local officials/politicians	Major short-term impact	$250,000	Major injury and/or multiple minor injuries, including minor traffic accidents- public
Minor (2)	1 to 4 wks	Inquiry from local officials/politicians	Minor short-term impact	$50,000	Minor reportable injury
Insignificant (1)	<1 wk	Complaints from local public	Perceived impact	$10,000	Minor non-reportable injury or near miss, including minor traffic accidents- public

The economic value score and the risk probability score were multiplied together to create a total score, with a value of 25 having the highest risk and 1 the lowest risk.

According to this analysis, the following risks are the most critical for the Central City Tunnel System project and should be considered in the following stages of project development:

- Rain storm event causes existing drainage tunnel overpressure which breaches into the new excavation resulting in flooding-enlarged sections.
- Excessive groundwater inflow that requires excessive pumping or grouting.
- Rock is harder than expected and requires larger more powerful equipment and results in slower production.
- Rock more abrasive than expected and increases tool wear, resulting in slower production.
- Limestone layer is lower than anticipated, resulting in an inability to construct tunnel cross section as designed.
- Required access shaft location is not available.
- Making drop connections to parallel tunnel.

Staging

Construction of the parallel tunnels along Washington Avenue can be completed year-round by maintaining existing flows in the existing Central City Tunnel System while work on the parallel tunnel proceeds. Construction of the area downstream of Washington Avenue and Portland Avenue South would need to be completed during winter months to deal with existing drainage and avoid larger summer rainfall events. Final connections to the existing tunnel at Hennepin

Avenue cross-connections, and drill holes would then be completed after all downstream improvements are completed.

To accomplish this work, two potential access shafts are needed. A shaft located on 2nd Avenue South north of Washington Avenue would facilitate construction along Washington Avenue, and a shaft located near Portland Avenue South and 2nd Street South would facilitate construction between the outfall and Washington Avenue.

Downstream construction between Washington Avenue and the outfall will need to be completed during winter months with temporary conveyance/bypass segments; final connections along Washington Avenue can then also be constructed in winter months. Existing tunnel segments that are no longer needed could then be abandoned, and outfall repairs could be completed with the installation of a coffer dam and continued bypass pumping.

Construction along Washington Avenue would be completed in the dry with temporary connections to existing drill holes maintained to the existing tunnel only and new cross-connections not installed until downstream work is completed.

A potential laydown area was identified on Park Avenue between Washington Avenue and 2nd Street South to facilitate construction. This location was chosen due to a lack of connected driveway entrances and minimal utilities.

Implementation

Historic Context

The Central City Tunnel System was originally constructed in several phases. The segment between Washington Avenue and the Mississippi River was part of the original sanitary sewer construction in the 1870s and the 1880s. Most of the remaining tunnel system was constructed in the late 1930s, as the City began to construct storm drains to separate stormwater flows from the sanitary flows. Smaller lengths of tunnel were added in later stages. The age of this system, being over 50 years since initial construction, triggers the potential for historic review by permitting agencies. The first step in understanding the historic significance of the system was to review and summarize the historic context of the system. This review was completed by 106 Group and summarized in their report titled: *The Central City Tunnel System Historic Context*, April 2017. This report is attached in **Appendix E**.

The process for determination of historic status starts with delineation of the zone of influence, which is typically decided by the US Army Corps of Engineers (USACE). The Minnesota State Historic Preservation Office will ultimately determine whether any of the structures within the zone of influence recommended for abandonment, removal, or modification meet the definition of historic. If any of the structures are historic, then the design phase of the construction project must include a comprehensive documentation of the existing structure, which would include assembly of the historic construction documents and photographs of the structures.

Determination of which, if any, structures are historic, will be undertaken after the City concurs with the recommendation of this report. CDM Smith and 106 Group will coordinate a meeting between the City and the USACE to define the zone of influence. Detailed information on the recommendations and the historic context will be sent to the State Historic Preservation Office in requesting a meeting to discuss a preliminary determination of historic structures.

Permitting

The construction necessary to expand the capacity of the Central City Tunnel System will require permits, and/or permissions from multiple agencies including:

- Minneapolis Park and Recreation Board.
- US Army Corps of Engineers.
- Hennepin County Department of Transportation.
- Minnesota Department of Natural Resources.
- National Park Service.

CDM Smith will conduct a permit workshop for the City to introduce the recommended alternative to these permitting agencies. The goal of the workshop will be to allow these agencies to describe the specific permits and permissions that would apply to this project. Additionally, these agencies can describe specific design or construction information, if any, that are needed to comply with the permitting requirements.

Easements

At this time, all newly proposed components of the proposed tunnel system appear to be contained within existing rights-of-way and no easements are required for new construction. Access to the outfall will need to be coordinated with the MPRB, likely through a construction permit. There appears to be a relatively small area along the existing outfall that may not be covered by an easement. In addition, one area along Portland Avenue South, where the existing storm tunnel crosses under private property, appears to not have an easement; however, this segment of tunnel is proposed to be abandoned. Easement acquisition work will begin after completion of this report.

Appendix A

Survey Map

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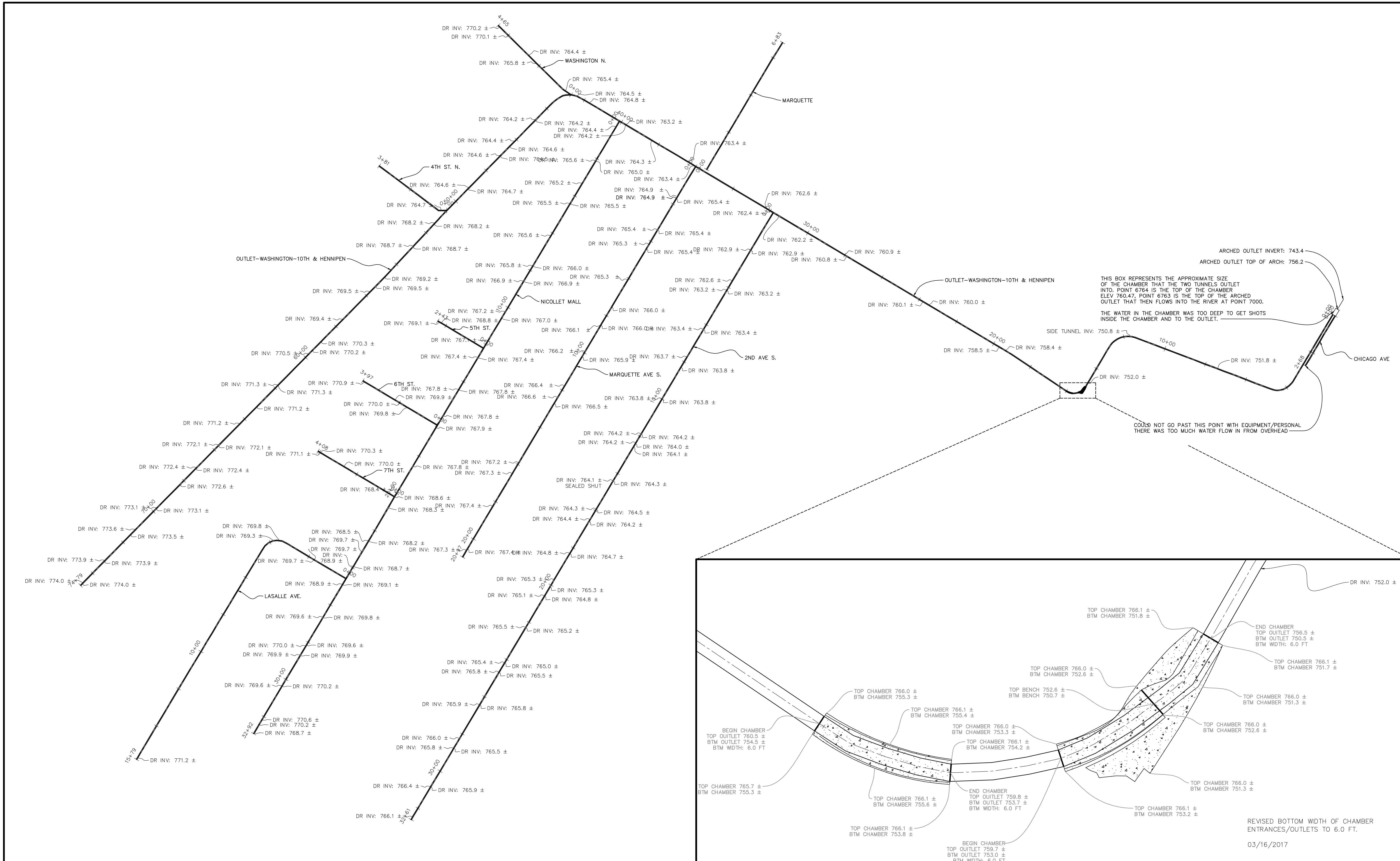

Figure A-1
Existing Tunnel Alignments
OCTOBER 2017

Appendix B

Tunnel Inspection Sketches

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TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 4 (Marquette 1)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 0+00	TO:	DATE 10/31/16	

GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
0+26		11:42. transverse crack / efflorescence / moist
0+40 0+60		transverse crack / efflorescence / moist / drips
0+80 0+95		" "
1+26 1+60 1+72		" "
2+25		
3+60	Concrete defect	Transverse crack ≈ 1mm wide / dry

COMMENTS

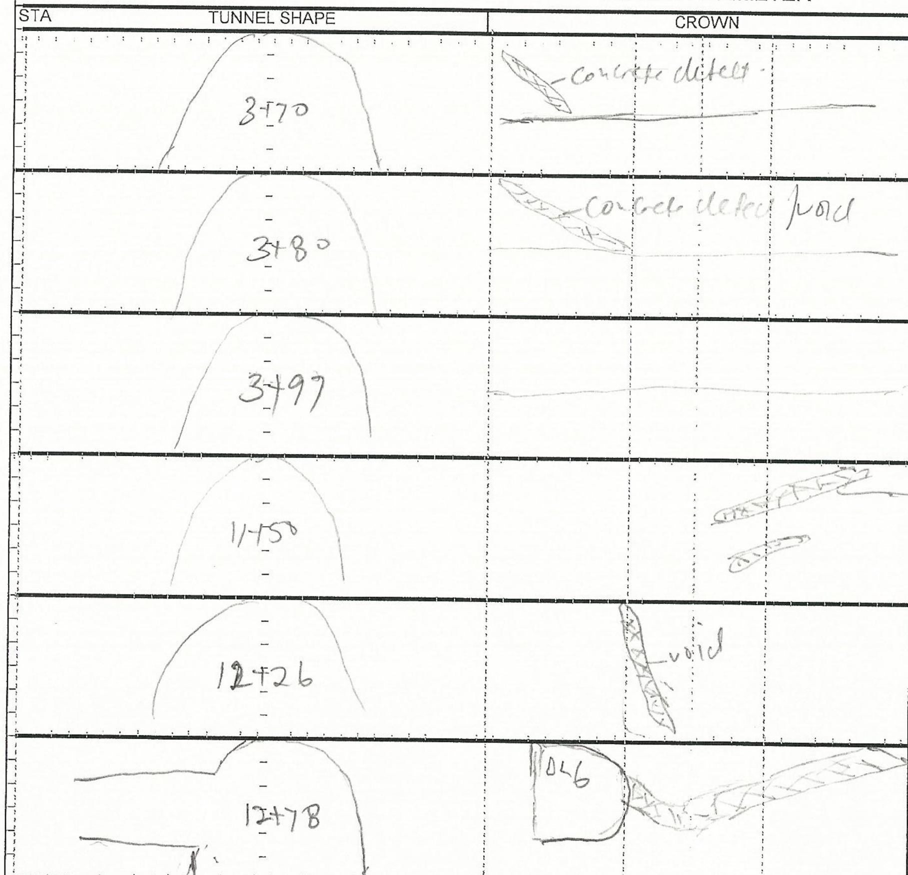
TUNNEL INSPECTION MAPPING RECORD

SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection
CLIENT	City of Minneapolis
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S
TUNNEL	Reach 4 (Marquette 1)
YEAR BUILD	
LINER TYPE	Concrete
CONDITION ASSESMENT	
STATION - FROM:	3+60
TO:	16+50
DATE	10/31/16
GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
3+70	Transverse crack
3+80	Transverse crack/void ≈ 4" dip, sand visible
3+97	Transverse crack ≈ 1 mm/dry.
11+50	Concrete defect, void ≈ 3' long 4" dip
12+26	Concrete defect, void ≈ 4' feet long ≈ 4' dip
12+78	patched concrete defect.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 4 (Marquette 1)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 16+40	TO:	DATE 10/3/16	GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
16+40		Large void in the concrete 5' wide x 3' dip
18+05		13:08 void - 1' long ~ 7" inches dip - sandstone visible
18+10		pressure joint ~ 1 mm wide
End at 21+10		

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of 1

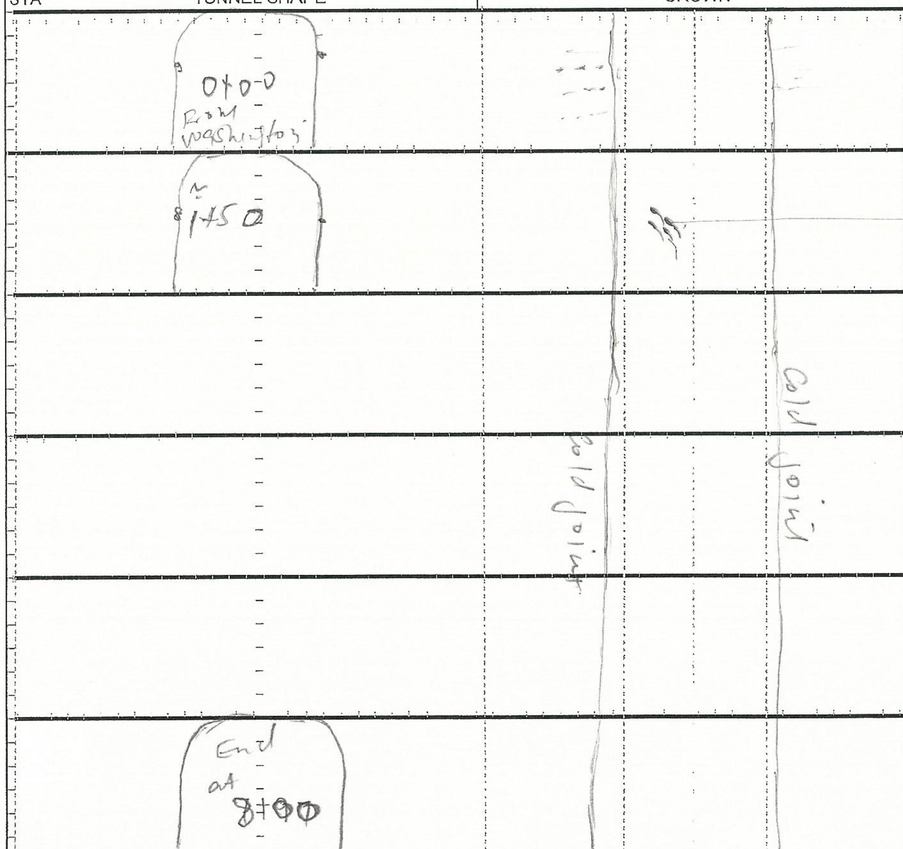
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 4 (Marquette 2)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete.
CONDITION ASSESMENT			
STATION - FROM: 0+00	TO:	DATE	10/31/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES



13:30 water inflow/drips along the cold joint efflorescence.

water inflow ≈ 2gPM

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 2 Hennepin Ave
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 33+12 (10th street)	TO:	DATE 11/1/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	32+74		Transverse crack, moist, efflorescence
	32+15		Transverse crack/grouted, moist, efflorescence.
	31+30		Transverse crack, drips, efflorescence
	31+10		Transverse crack, drips, efflorescence
	30+40		Transverse crack, moist, efflorescence.
	29+30		Transverse crack, moist, efflorescence

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 2 (Hennepin Ave)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 30+00	TO: 23+00	DATE 11/1/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
29+80		Transverse crack, moist, efflorescence
29+30 29+29		Transverse crack, moist, efflorescence, drips
29+24 29+10 28+95 28+74		Transverse crack, moist efflorescence
28+64 28+45 27+80 27+75		Transverse crack, moist, efflorescence
27+60 27+40 26+80 26		
26+70 25+25 23+65 23+05		vertical crack, moist, efflorescence

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 3 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 2 (Hennepin)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 23+00	TO:	DATE 11/1/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	22+60 22+20 22+00 21+49		Transverse crack, efflorescence, moist
	20+14 19+65 19+20 08+46		Transverse crack, efflorescence
	8+06 7+65 7+25 6+97		Transverse crack, efflorescence
	6+65 6+10 5+70 5+10		Transverse crack/efflorescence/drips
3rd St	4+70 4+40 4+10 3+70		Transverse crack/efflorescence/moist
End @ 1+00 - Washington	3+49 3+00 2+55 2+10		Transverse crack/efflorescence moist

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET (1) of

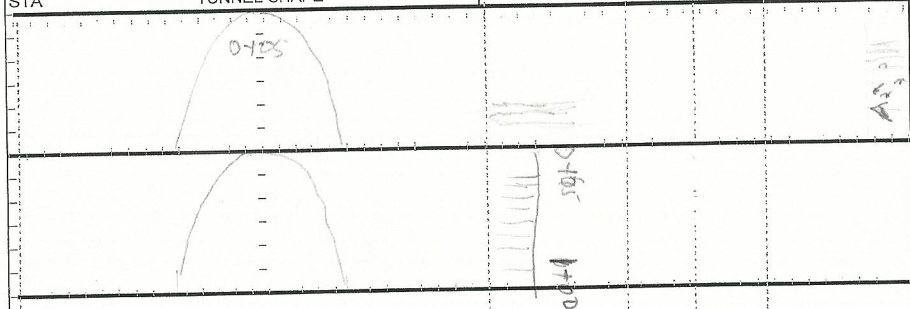
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 2 (Hennepin drift tunnel) 4th Street
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 0+00	TO: end	DATE 11/1/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
			cold joint, water drips, efflorescence
			water inflow from the cold joint, efflorescence/drips



COMMENTS

TUNNEL INSPECTION MAPPING RECORD

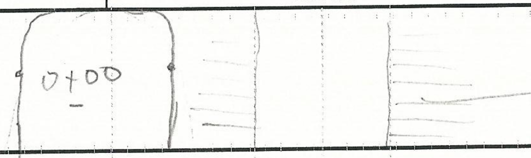
SHEET of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 2 (Hennepin Drift 1 (Washington 14)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 0+00	TO:	DATE 11/1/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	 0+00		14:18 Efflorescence from the cold joint at the springline

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 8 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection
CLIENT	City of Minneapolis
TUNNEL	Reach 5 (2nd Ave)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S
YEAR BUILD	
LINER TYPE	Concrete/[illegible]
CONDITION ASSESMENT	
STATION - FROM:	~27+50
TO:	
DATE	11/2/16 - 11/3/16
GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
27+50		vertical cracks = 1MM.
27+80		14:13 Transverse crack = 1mm, efflorescence
from 28+05, the Tunnel-Shape changes, crown is unlined 9th street 11/3/16		11:04
28+50 to 28+70		Horizontal cracks, & vertical cracks
28+80 to 29+50		End at 11:14 Continuous horizontal cracks with numerous vertical cracks, water drips from the cracks, efflorescence

COMMENTS The tunnel from 28+05 - End reduces in size to approximately 4'

TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Avenue)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 0+00 (Washington 2nd Ave.)	TO:	DATE	11/2/16
GEOLOGIST / GEOTECH. ENG.	B.Okech		

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
0+05-0+10		11:21 efflorescence.
0+10 – 0+20		Horizontal crack, water drips;
1+20 1+25		diagonal crack, efflorescence
1+30 1+35 1+40		small cracks, water drips ≈1mm
1+45 1+50		diagonal crack 1-2mm, efflorescence
2+40	2+40 … 2+50	versicel crack, efflorescence.

COMMENTS

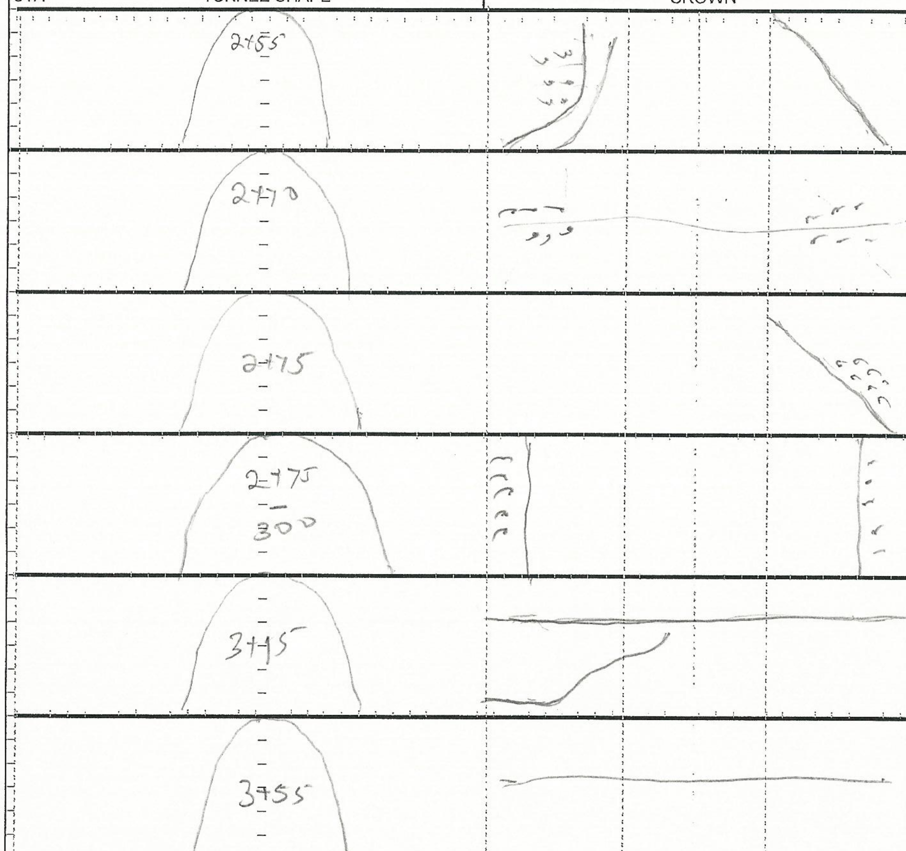
TUNNEL INSPECTION MAPPING RECORD

SHEET 3 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Avenue.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 2+50	TO:	DATE 11:50 11/2/16	
GEOLOGIST / GEOTECH. ENG.	B.Okech		

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
2+55	11:44 diagonal cracks, efflorescence, moist
2+70	Transverse crack, moist efflorescence
2+75	Diagonal cracks, efflorescence.
2+75 – 3+00	Cold joint close to the invert; water drips, moist efflorescence
3+15	Transverse and diagonal cracks.
3+55	Transverse crack ≈ 1 mm, moist

COMMENTS

Cold joint at the base close to the invert – efflorescence; moist; water drips

TUNNEL INSPECTION MAPPING RECORD

SHEET 3 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Avenue)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 4+00	TO:	DATE 11/2/16	GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	4+10 4+20 7+05		Transverse crack ≈ 1MM
	7+80 7+83 8+10		Transverse Crack ≥ 1MM
	8+20 8+45 8+80		Transverse crack ≥ 1MM
	9+15 9+30		Transverse Crack ≥ 1MM
	9+70		Vertical crack ≥ 4ft long & 1mm wide
	10+02 to 10+10		Horizontal crack ≥ 1mm wide

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 4 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Ave)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 11+50	TO:	DATE	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
11+55		Transverse crack ≃ 1MM
12+00 to 12+30	12+00, 12+30	horizontal crack ≃ 1-2 MM, moist
12+45 12+65		Horizontal crack ≃ 1-2MM, M
~16+50 to 17+25		wide crack at the crown CL, repair done to the cracks, diagonal, longitudinal crack and reinforced with steel bars.
17+50 to 18+15		- Longitudinal ≃ 2MM crack, repaired with grout/epoxy and reinforced with steel. - horizontal crack.
From 18+50 to 19+25		13:27 Horizontal crack, ≃ 1-2 MM, seems like some repair done. - efflorescence from the Cold joint

COMMENTS

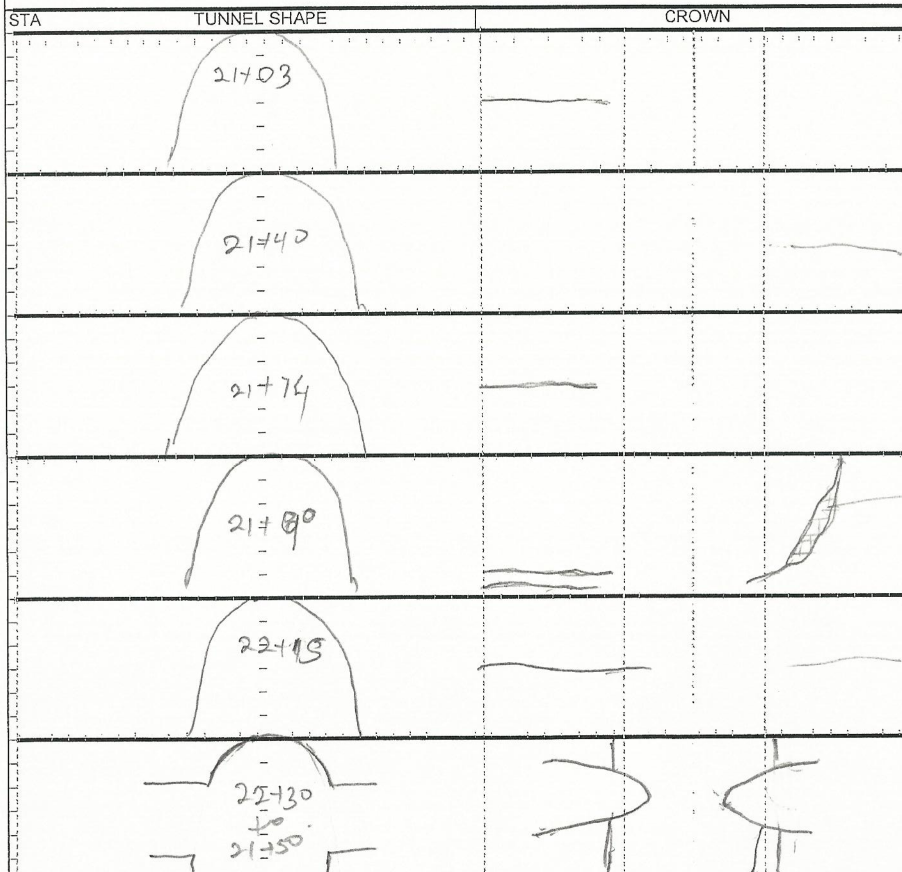
TUNNEL INSPECTION MAPPING RECORD

SHEET 6 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Ave)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 19+50	TO:	DATE 11/2/16	
GEOLOGIST / GEOTECH. ENG.	B.Okech		

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
21+03	vertical crack ≥ 1MM, 3' long.
21+40	vertical crack = 1MM, 3' long.
21+74	vertical crack = 1MM, 3' long.
21+90	13:38 concrete defect, with a diagonal crack. vertical crack = 1mm, 2' long
22+15	Vertical crack ≥ 1MM, 2-3' long.
22+30 to 21+50	Horizontal crack = 1MM

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

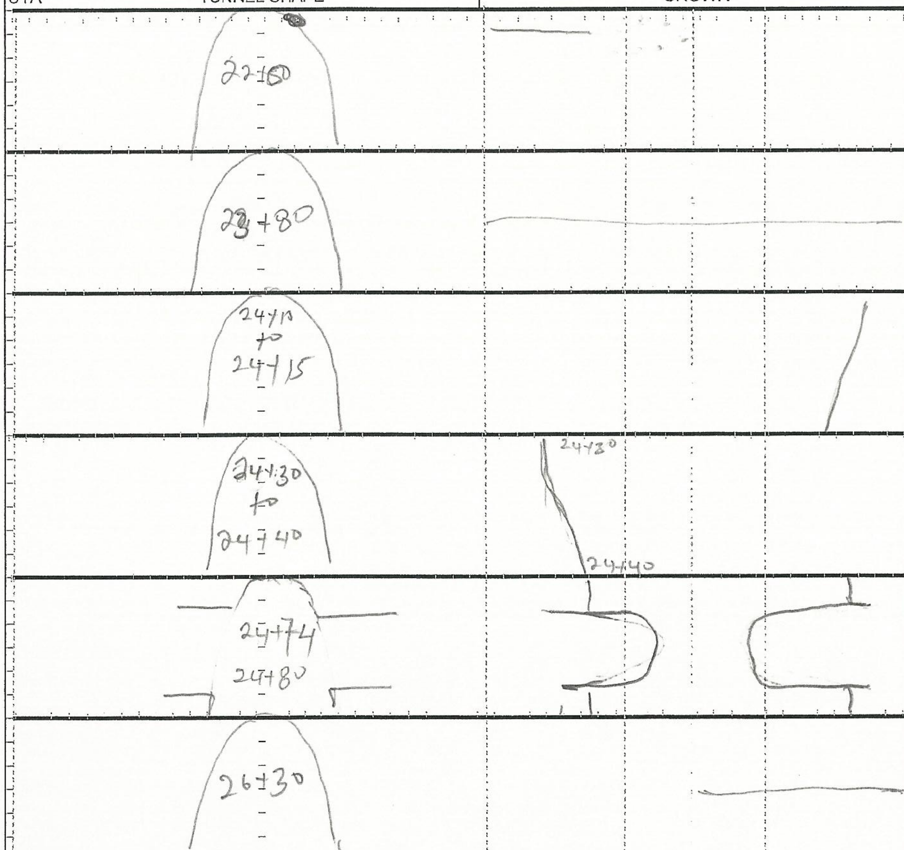
SHEET 7 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 5 (2nd Avenue
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 22+50	TO:	DATE 11/2/16	
GEOLOGIST / GEOTECH. ENG.	B.Okech		

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA | TUNNEL SHAPE | CROWN | NOTES



STA	NOTES
22+80	vertical crack ≈ 1mm, 2' long
23+80	transverse crack, efflorescence.
24+10 to 24+15	diagonal crack, ≈ 1mm
24+30 to 24+40	Horizontal crack ≈ 1mm
24+74 / 24+80	Horizontal crack ≈ 1-2mm, Efflorescence.
26+30	vertical crack ≈ 1-2mm, efflorescence.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 1 (Washington Aves)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 43+70 (Hennepin & Washington)	TO:	DATE	11/3/16

GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	43+70, 43+50		11:46 Transverse crack, moist, water drips
	43+20, 42+95, 42+80, 42+70		Transverse crack, moist, efflorescence
	42+45, 42+10, 41+70, 40+70		Transverse crack, moist, efflorescence
	40+48, 39+75, 39+45, 39+15		Transverse crack, moist, efflorescence, w
	38+75, 38+28, 37+75, 37+45		Transverse crack, moist, efflorescence
	36+75, 36+50, 36+15, 35+75, 35+48		

COMMENTS

Most Cold joints are grouted.

TUNNEL INSPECTION MAPPING RECORD

SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 1 - Washington Ave.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 35+50	TO:	DATE	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
35+15 34+45 34+20 33+75		Transverse crack, moist & wet with some drips white stuff (more like growth)
33+60 32+55 32+30 32+00		Transverse crack, moist, efflorescence
31+50 31+25 31+00 30+60		Transverse crack, grouted, moist; efflorescence
30+20 29+90 29+60 29+40 28+70		Transverse crack, moist.
28+30 27+95 27+65 27+10 26+70		Transverse crack = 1mm, moist efflorescence
26+30 26+05 25+45 25+07 24+75		Transverse crack = 1-2 mm, moist, efflorescence

COMMENTS

Most the cracks are grouted; from 27+10, the cracks are wider.

TUNNEL INSPECTION MAPPING RECORD

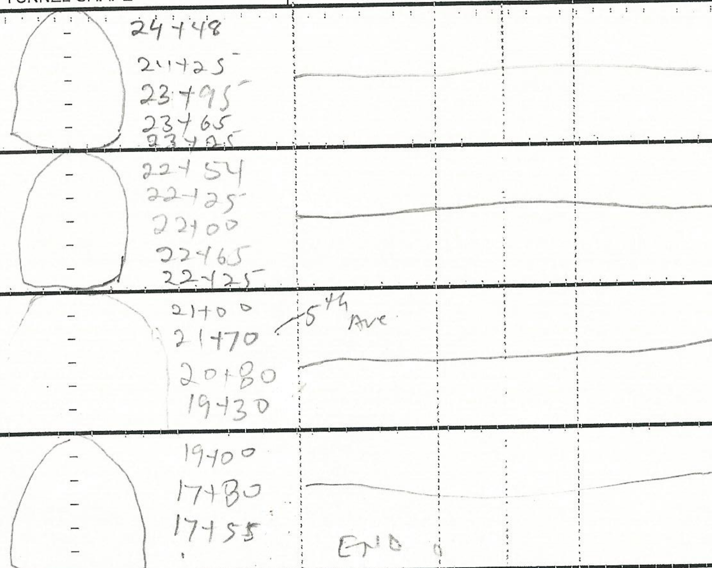
SHEET 3 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 1 - Washington Ave.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 24+50	TO:	DATE 11/3/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA / TUNNEL SHAPE	CROWN	NOTES
24+48, 24+25, 23+95, 23+65, 23+?5		Transverse crack, 1-2mm, moist, efflorescence
22+54, 22+25, 22+00, 22+65, 22+25		Transverse crack 1-2mm moist, efflorescence
21+00, 21+70, 20+80, 19+30	5th Ave	Transverse crack 1-2mm,
19+00, 17+80, 17+55	END	Transverse crack 1-2mm
END OF WASHINGTON A. AT 17+00		

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

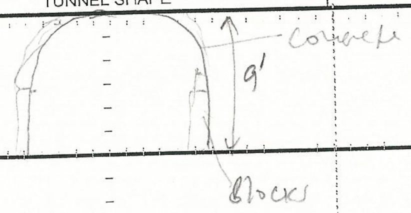
SHEET / of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 1 (Portland)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Block & Concrete
CONDITION ASSESMENT			
STATION - FROM: 16+00 washington	TO:	DATE 11/3/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
			Most cracks are patched with Mortar. End Assessment at Approximate Station 5+00 at the curve due to high waterlevel.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

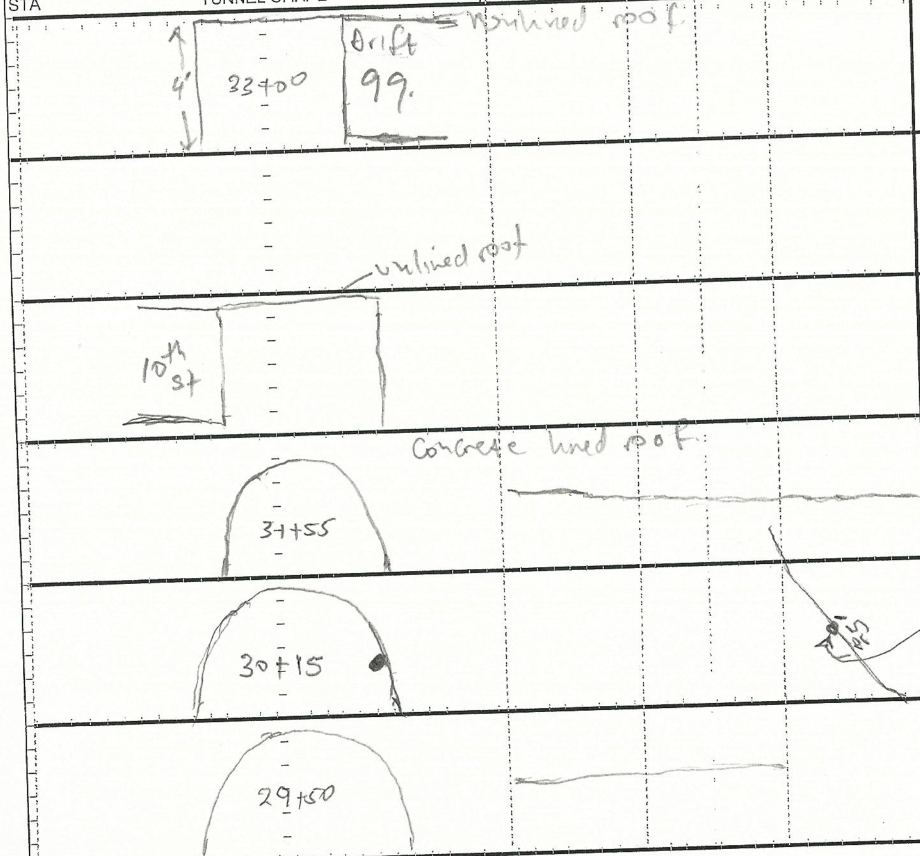
SHEET 1 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 – Nicollet Ave. S.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Bricks, Roof unlined.
CONDITION ASSESMENT			GEOLOGIST / GEOTECH. ENG. B.Okech
STATION - FROM: 33+00	TO:	DATE 10-27-16	

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
			spalling of slabs at drift 99, efflorecence.
			voids behind the 10th street drift (Drift 98) square tunnel end at ≈ 32+10
			transverse joint vertical – minor inflow of water drips, efflorescen
			water jet from a point in the crack ≈ 1GPM
			Thin crack efflorescence.



COMMENTS

TUNNEL INSPECTION MAPPING RECORD

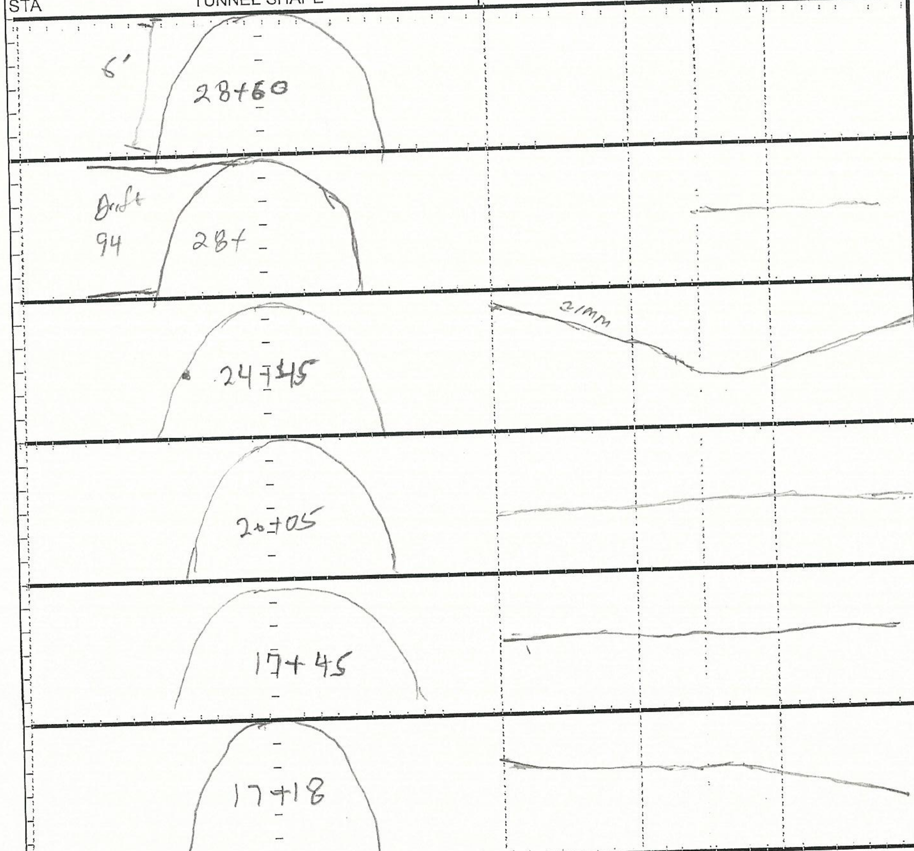
SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 - Nicollet Ave. S
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 28+60	TO:	DATE	10-27-16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	TUNNEL SHAPE	CROWN	NOTES
28+60			Crack in the concrete -efflorescence
28+			close to 9th street. Thin crack ~1mm - efflorescence.
24+45			Thin concrete crack/dry
20+05			Transverse crack ~2mm; efflorescence
17+45			Thin crack ≥1mm transverse crack
17+18			Transverse crack, - efflorescence. (photo ~(13:57))

COMMENTS

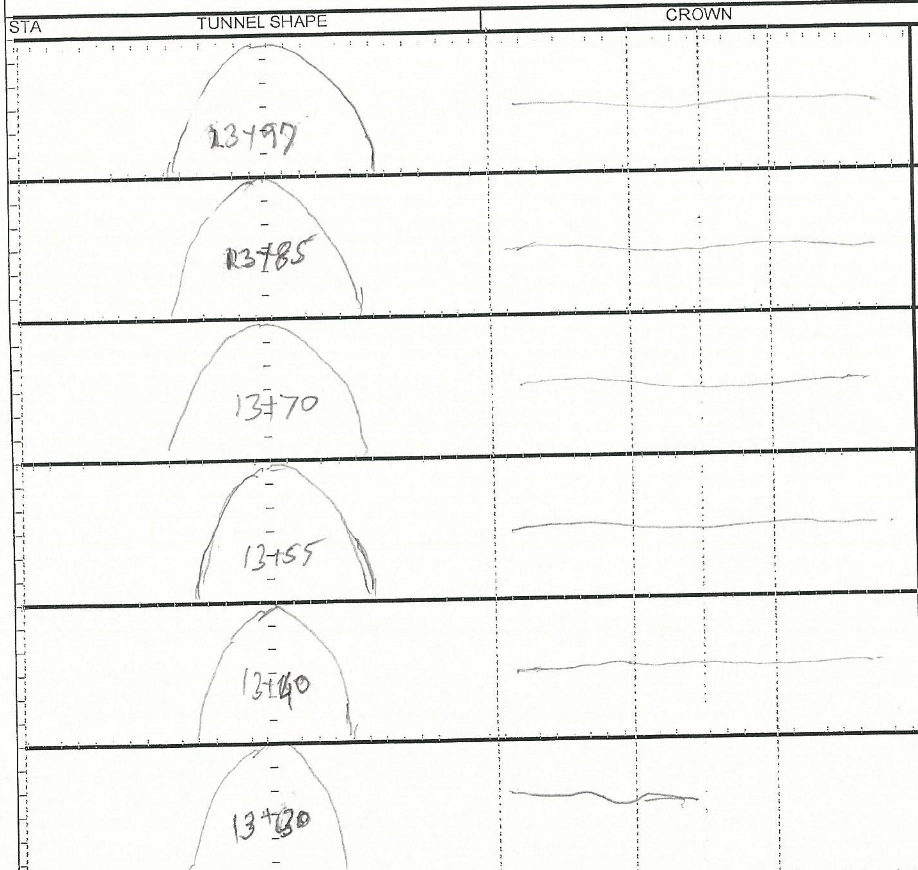
TUNNEL INSPECTION MAPPING RECORD

SHEET 3 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection
CLIENT	City of Minneapolis
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S
TUNNEL	Reach 3 - Nicollet Ave. S
YEAR BUILD	
LINER TYPE	Concrete
CONDITION ASSESMENT	
STATION - FROM:	14+00
TO:	
DATE	10/27/16
GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
13+97	Concrete Crack ≥ 2mm/dry.
13+85	Concrete crack ≥ 2mm/dry.
13+70	Concrete Crack ≥ 2mm./dry.
13+55	Concrete Crack ≈ 2mm /dry
13+40	Concrete Crack ≥ 2mm /dry.
13+30	vesicel crack.

COMMENTS

Between 13+00 - 14+00 - only thin cracks observed.

TUNNEL INSPECTION MAPPING RECORD

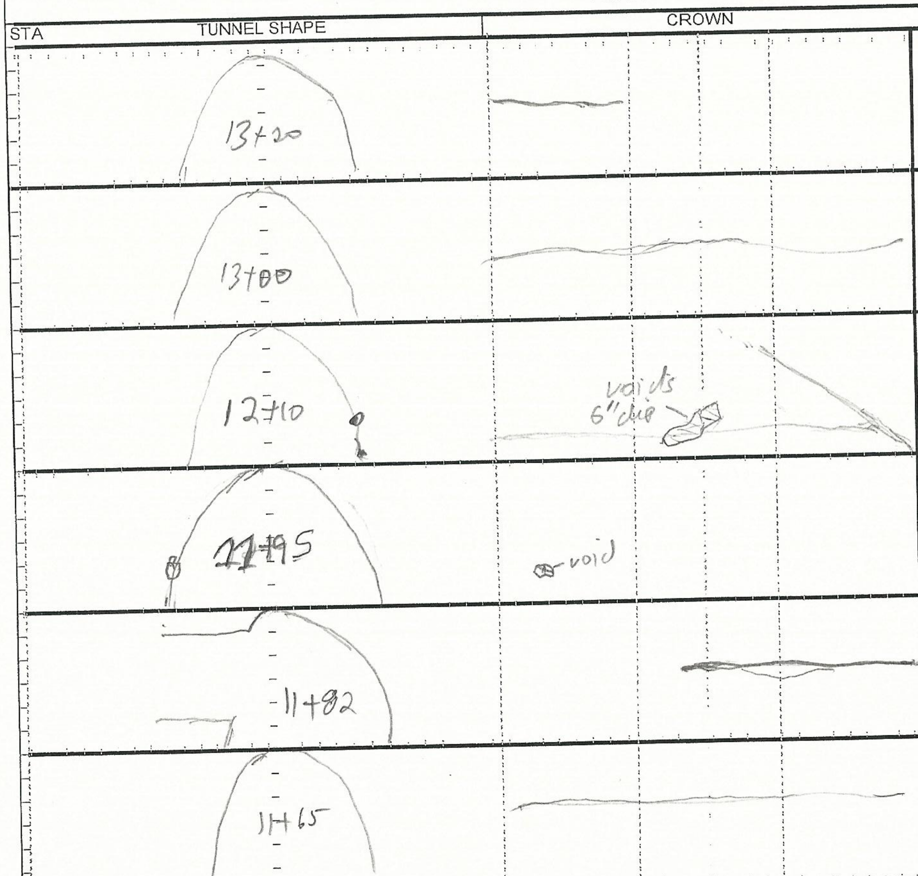
SHEET 4 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 - Nicollet Ave. S
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 13+20	TO:	DATE	10/27/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



NOTES

STA	Notes
13+20	Thin discontinuous crack ~1mm/dry
13+00	# 14:23 Concrete crack ~2mm/dry
12+10	#14:32 diagonal concrete crack 5 ft long, efflorescence. vertical/transverse concrete crack ~1-2mm void.
11+95	void ~ 5" in diameter, 3" dia
11+82	Transverse crack ~2MM
11+65	Transverse crack ~2mm.

COMMENTS

Observed minor cracks & thin cracks ~1-2mm wide

TUNNEL INSPECTION MAPPING RECORD

SHEET 5 of

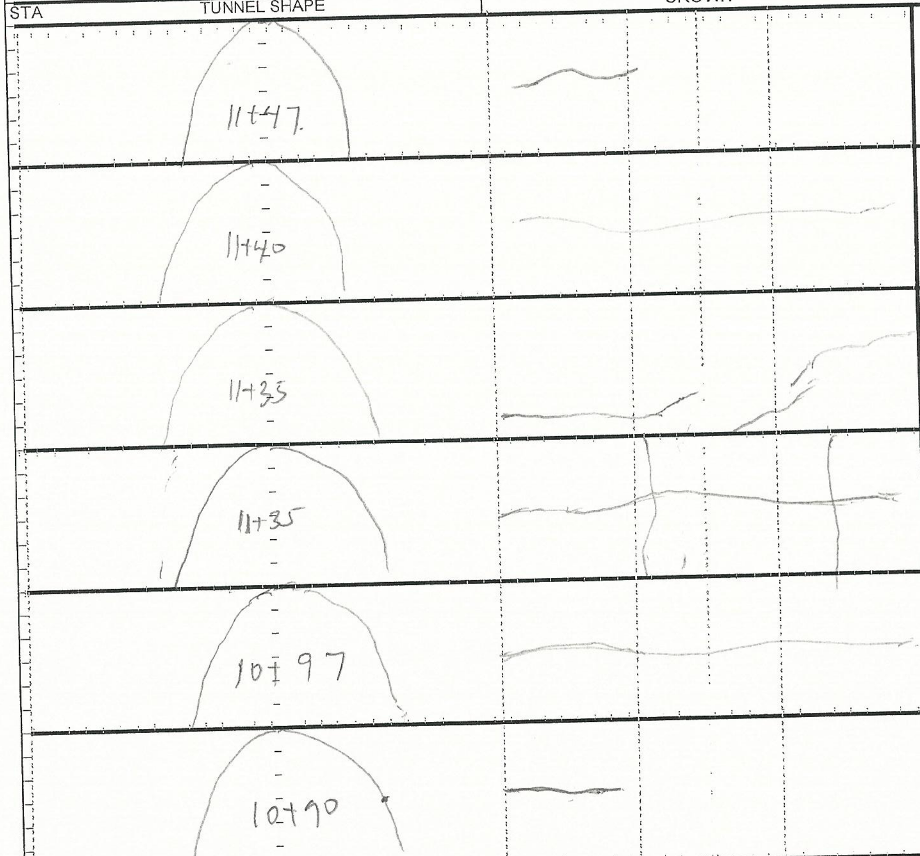
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 Nicollet Ave. S
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 11+50	TO:	DATE 10/27	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA | TUNNEL SHAPE | CROWN | NOTES



STA	NOTES
11+47	Concrete Crack ≈ 3' feet long & 1mm wide
11+40	Transverse Concrete Crack ≈ 1-2mm wide
11+35	Concrete crack ≈ 1mm wide
11+35	Transverse Crack ≈ 1mm wide Horizontal Concrete Cracks ≈ 5'-10' long.
10+97	Transverse Concrete Crack ≈ 1mm wide
10+90	2' long crack thin/dry.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

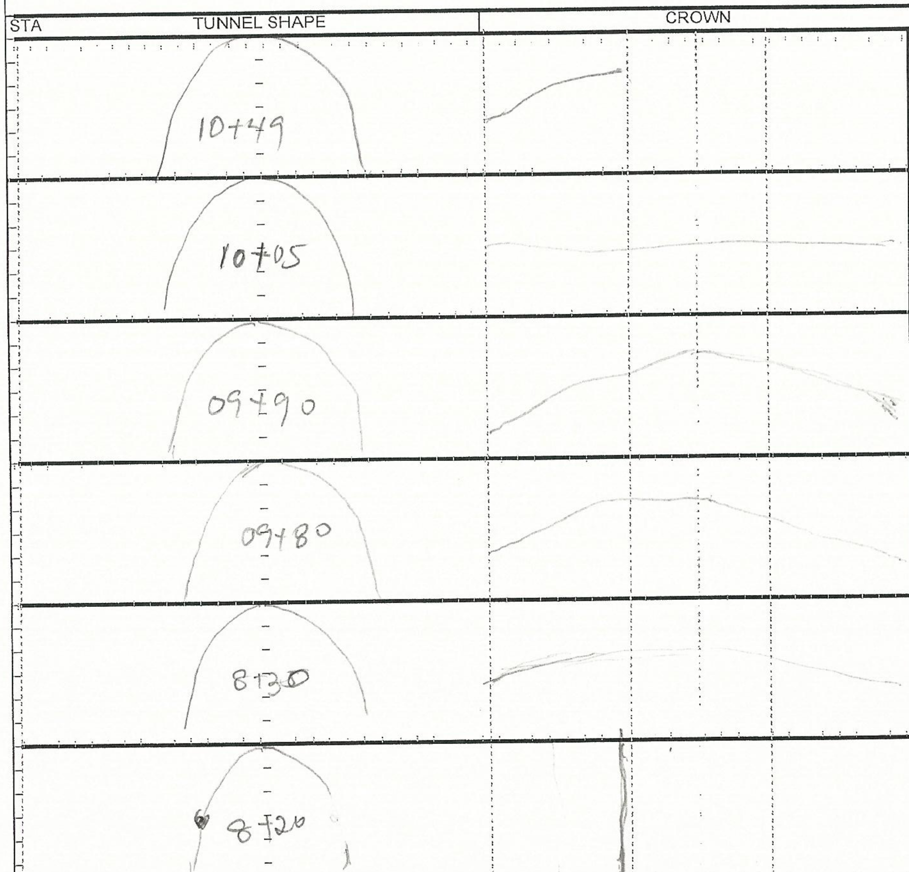
SHEET 6 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 - Nicollet Ave. S.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 10+50	TO:	DATE	10/27/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
10+49	Thin concrete crack ≈ 3' long
10+05	Transverse crack .1mm wide
09+90	Transvese crack ≈ 1mm wide
09+80	Transvese crack ≈ 1 mm wide
8+30	Transvese crack.
8+20	thin Horizontal crack ≈ 5' long / dry.

COMMENTS

#1

TUNNEL INSPECTION MAPPING RECORD

SHEET of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 Nicollet
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 4th Street	TO:	DATE	10/28/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
7+45		# 11:16 patched thin concrete cracks - transverse
		thin transverse cracks ≥ 1mm wide
3+58		# 11:29 Transverse joint - water seepage (moist) Attempts to patch it
2+75		Transverse joint moist - Attempt to seal the joints.
2+55		11:39 Transverse joint - moist - attempt to seal the joint
2+45		11:42 Transverse joint - moist / drips and patched

COMMENTS: most of the joints from 4th street downstream; attempt to seal but water still infiltrate.

TUNNEL INSPECTION MAPPING RECORD

SHEET of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 Chicollet.
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 2400	TO:	DATE	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	2405		Transverse joint moist - water infiltration through the water seal; efflorescence
	1480		11:49 Transverse joint; moist efflorescence.
	Junction between Nicollet & Washington		Concrete Cracks / Staining / efflorescence / water drips.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 1 of

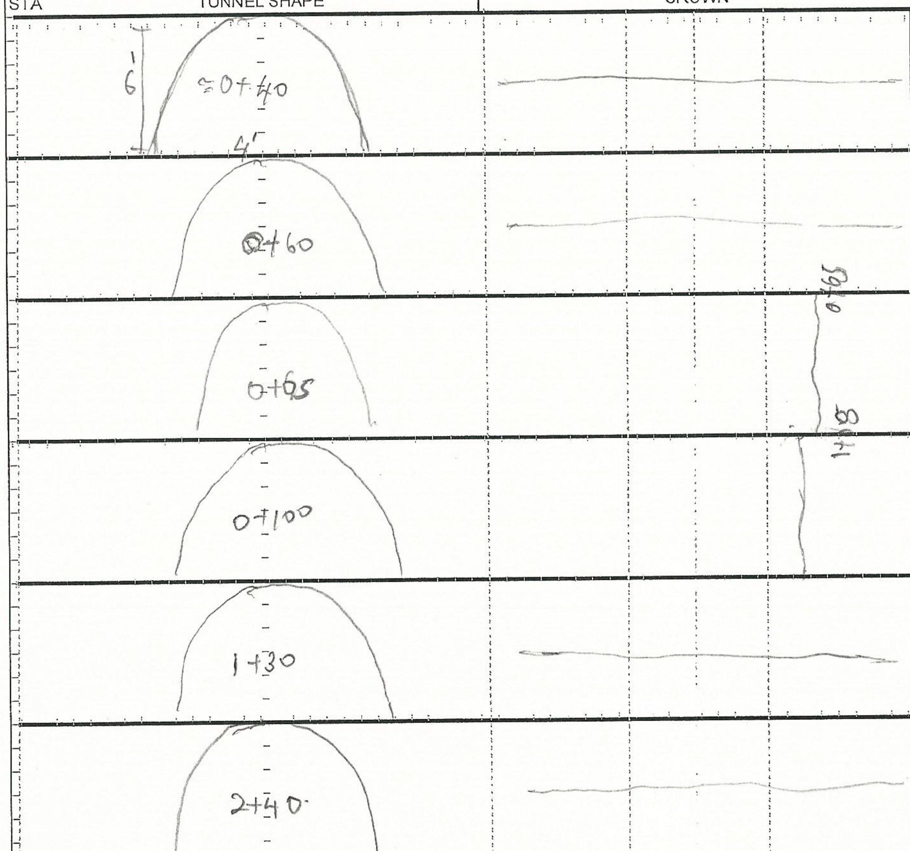
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (La Salle ave S)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 0+00	TO: 2+50	DATE	10/28/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

NOTE: station 0+00 starts from Nicollet tunnel upstream

TUNNEL PERIMETER



STA	NOTES
≈0+40	Transverse Concrete Crack ≈ 1-2mm wide
0+60	Transverse Concrete Crack ≈ 1mm wide.
0+65	(2:31) Horizontal crack ≈ [45] feet long ≈ 1mm wide.
0+100	Horizontal Crack just below the springline extending from 1+00 – 1+25 ≈ 1mm wide
1+30	tight vertical crack 1mm
2+40	Transvers crack ≈ 1mm wide

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 2 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 Lasalle
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 2+50	TO:	DATE	10/28/16

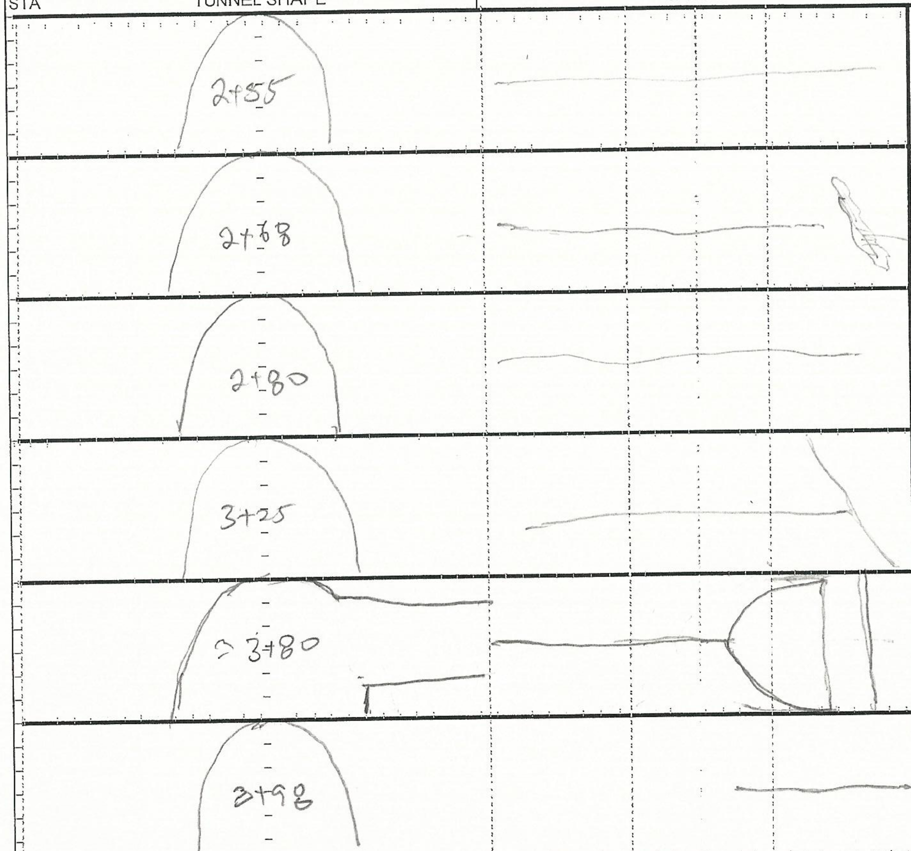
GEOLOGIST / GEOTECH. ENG. B.Okech

Mapped from upstream

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA | TUNNEL SHAPE | CROWN | NOTES



STA	NOTES
2+55	Transverse crack ≈ 1mm
2+68	Transvers Crack ≈ 1 mm Concrete defect
2+80	Transverse Crack.
3+25	Beginning of the curve Transverse and diagonal cracks ≈ 1 mm
≈ 3+80	13:37 Transvers crack / moist ≈ 1mm.
3+98	Vertical crack / moist ≈ 1mm

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

PROJECT NAME & LOCATION	Central City Tunnel Inspection		SHEET 3 of
CLIENT	City of Minneapolis		
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	TUNNEL	Reach 3 (Lasalle)
		YEAR BUILD	LINER TYPE
CONDITION ASSESMENT			
STATION - FROM: 4+50	TO:	DATE 10/28/16	GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
4+50		Transverse crack, moist, efflorescence ≈ 1mm
4+70		Transverse crack, moist, efflorescence ≈ 1mm
4+98		Transverse crack, moist efflorescence ≈ 1mm wide
5+18		Transverse crack, moist, efflorescence ≈ 1mm wide
5+40		13:47 Transverse crack, moist, efflorescence ≈ 1mm wide
6+00		Transverse crack, moist, efflorescence ≈ 1mm wide

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

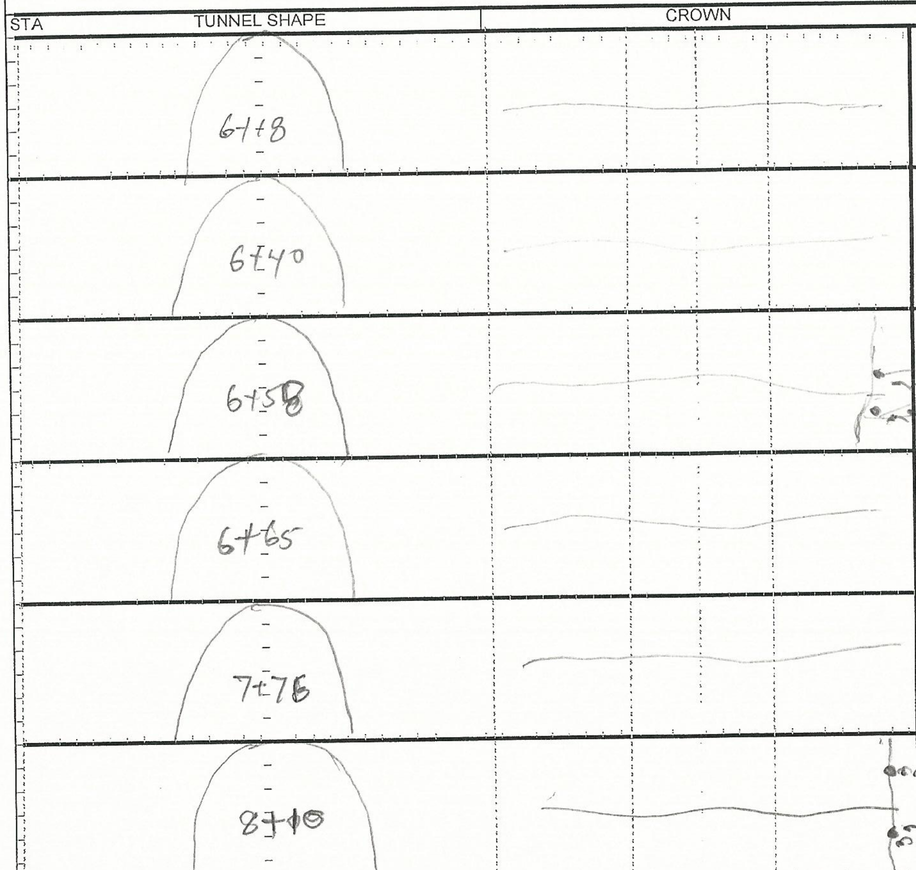
SHEET 4 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (Lasalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 6+00	TO:	DATE 10/28/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
6+18	Transvese crack, moist efflorescence
6+40	transves cracks, moist efflorescence
6+58	13:59. Transverse crack; moist, efflorescence. horizontal joint, water inflow ≈ 0.5 gPM
6+65	Transverse crack, moist efflorescence
7+76	Transvese cracks moist, efflorescence
8+10	14:10 Transverse crack, moist, efflorescence horizontal cracks, water inflow ≈ 1gPM.

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 5 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (Lasalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 8+90	TO:	DATE	10/28/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
	8+51		Transves crack, moist efflorescence ≈ 1mm wide
	8+73		Transverse crack, moist, efflorescence ≈ 1mm wide
	9+09	void	14:18 Transves crack, moist efflorescence ≈ 1mm wide void 4 inch wide and 5' dp.
	9+40		Transverse joint, moist efflorescence ≈ 1mm
	9+80		vertical joints, moist, efflorescence ≈ 1mm
	9+90		vertical joints/dry ≈ 1mm

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 6 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection
CLIENT	City of Minneapolis
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S
TUNNEL	Reach 3 Lasalle
YEAR BUILD	
LINER TYPE	
CONDITION ASSESMENT	
STATION - FROM:	10+00
TO:	
DATE	10/28/16
GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
10+10		transverse crack/moist/efflorescence ≈ 1mm
10+22		transverse crack/moist/efflorescence ≈ 1 mm
10+50		14:30 transvers crack along the coldjoint/moist/efflorescence
10+60		transverse crack/moist/efflorescence.
10+90		transverse crack/moist/efflorescence.
11+10		transverse crack/moist/efflorescence

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 7 of

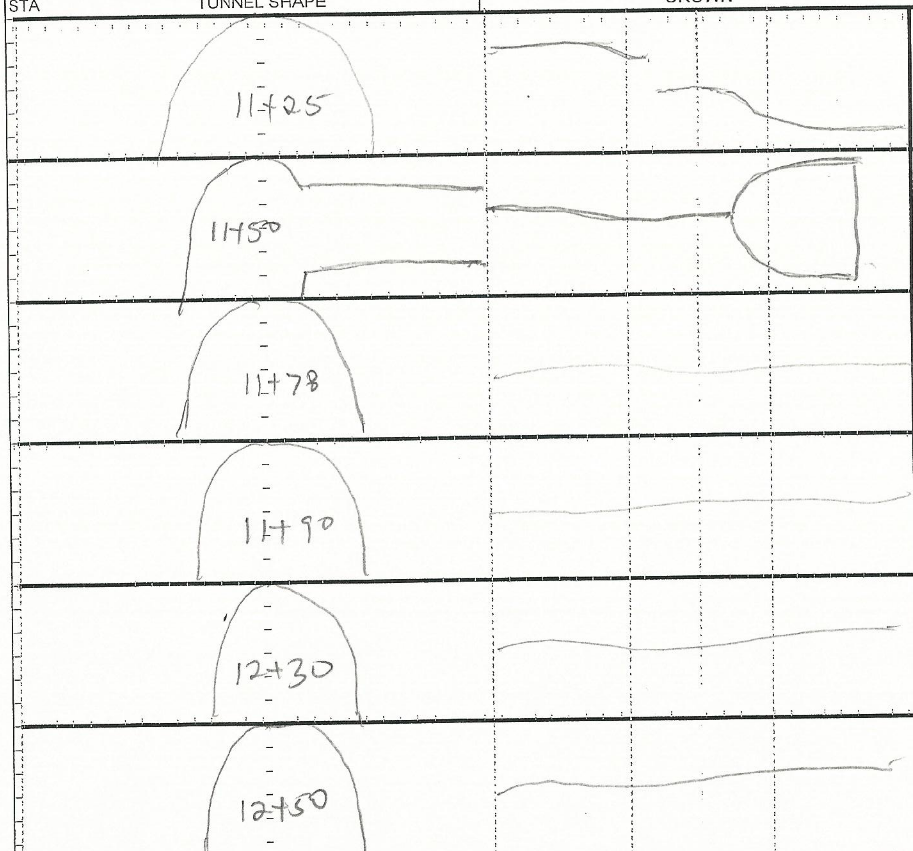
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (Lasalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 11+00	TO:	DATE	10/28/16

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA | TUNNEL SHAPE | CROWN | NOTES



NOTES:

- 11+25: vertical and transverse joint/moist/efflorescence.
- 11+50: transverse crack terminates at the storm drain crown/ moist/efflorescence.
- 11+78: transverse crack/moist/efflorescence.
- 11+90: transverse crack/moist/efflorescence.
- 12+30: transverse crack/moist/efflorescence.
- 12+50: transverse crack/moist/efflorescence

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 8 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (Lasalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 12+50	TO:	DATE 10/28/16	

GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA / TUNNEL SHAPE	CROWN	NOTES
12+76		Transverse crack/moist/efflorescence.
12+95		Transverse crack/moist/efflorescence
13+15		Transverse crack/moist/efflorescence.
13+35		Transverse crack/moist/efflorescence.
13+60		Transverse crack/moist/efflorescence
13+85		Transverse crack/moist/efflorescence.

COMMENTS

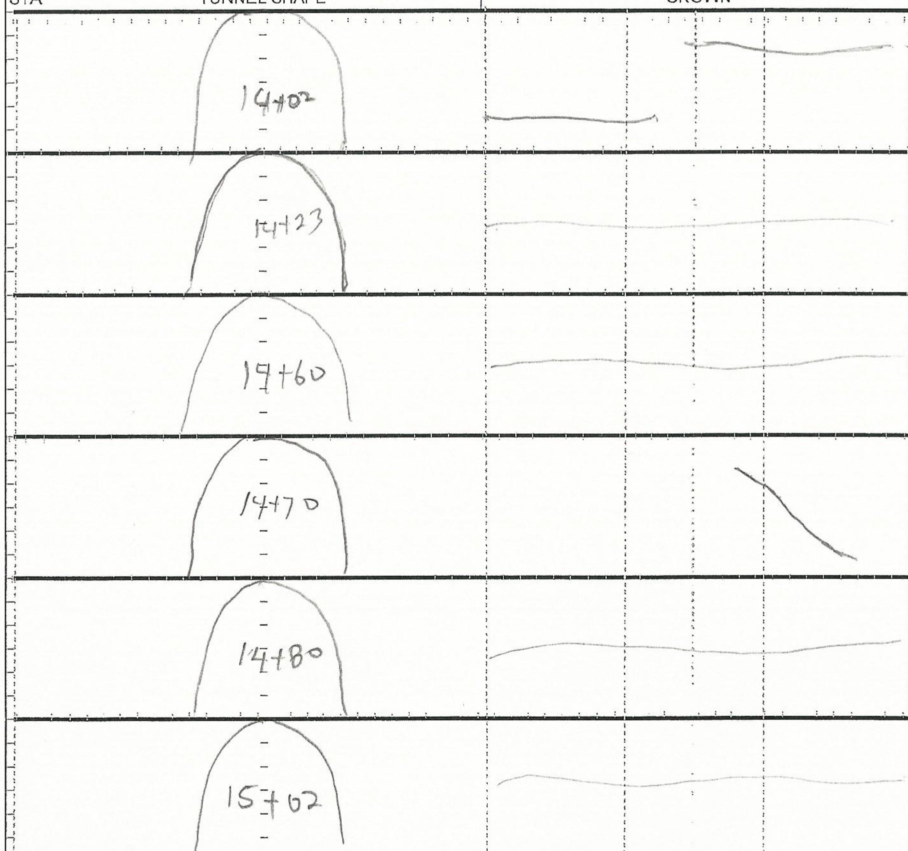
TUNNEL INSPECTION MAPPING RECORD

SHEET 9 of

PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (Lasalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete
CONDITION ASSESMENT			
STATION - FROM: 14+00	TO:	DATE 10/28/16	GEOLOGIST / GEOTECH. ENG. B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER



STA	NOTES
14+02	vertical crack/moist/efflorescence
14+23	transverse crack/moist/efflorescence
14+60	Transverse crack/moist/efflorescence
14+70	diagonal crack/moist/efflorescense ≈ 3' long
14+80	Transverse crack/moist/efflorescence
15+02	15+02 Transverse crack/moist/efflorescence

COMMENTS

TUNNEL INSPECTION MAPPING RECORD

SHEET 6 of

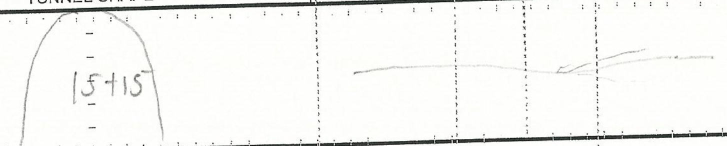
PROJECT NAME & LOCATION	Central City Tunnel Inspection		
CLIENT	City of Minneapolis	TUNNEL	Reach 3 (LaSalle)
PROJECT LOCATION	Downtown Minneapolis between E Hennepin Ave and 10th Ave S	YEAR BUILD	LINER TYPE Concrete.
CONDITION ASSESMENT			
STATION - FROM: 15+00	TO:	DATE 10/28/16	

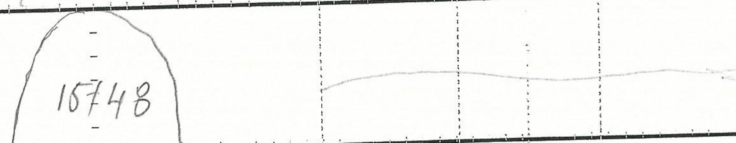
GEOLOGIST / GEOTECH. ENG.	B.Okech

FIELD MAPPING SKETCH

TUNNEL PERIMETER

STA	TUNNEL SHAPE	CROWN	NOTES
			Transverse Crack/moist/efflorescence.
			Transverse Crack/moist/efflorescence.





COMMENTS

Appendix C

Hydraulic Profile

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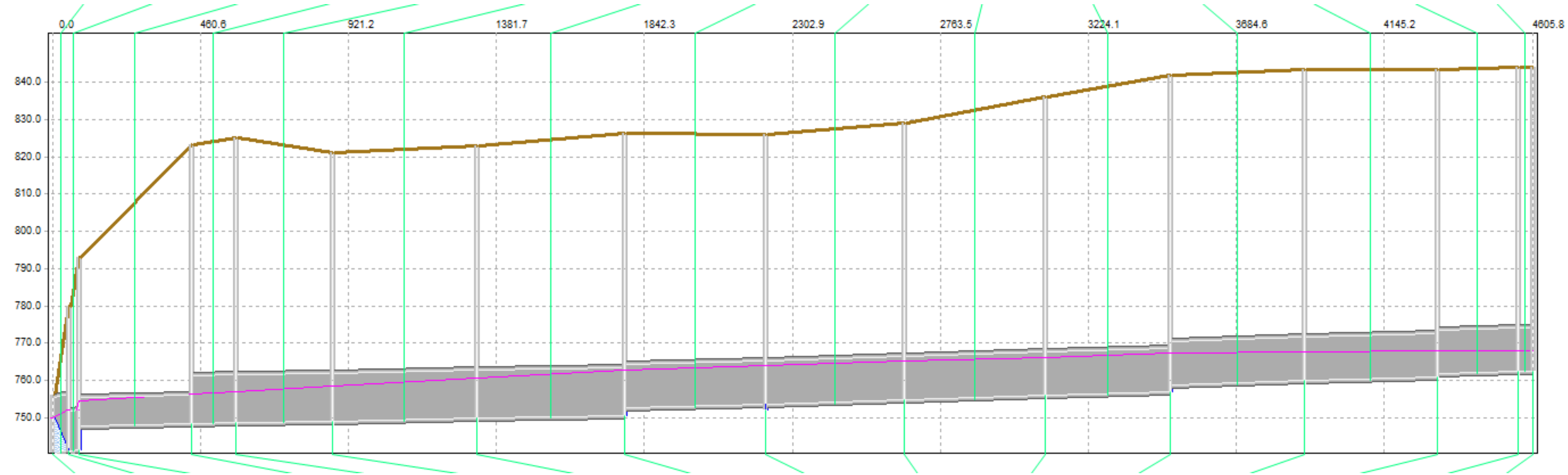
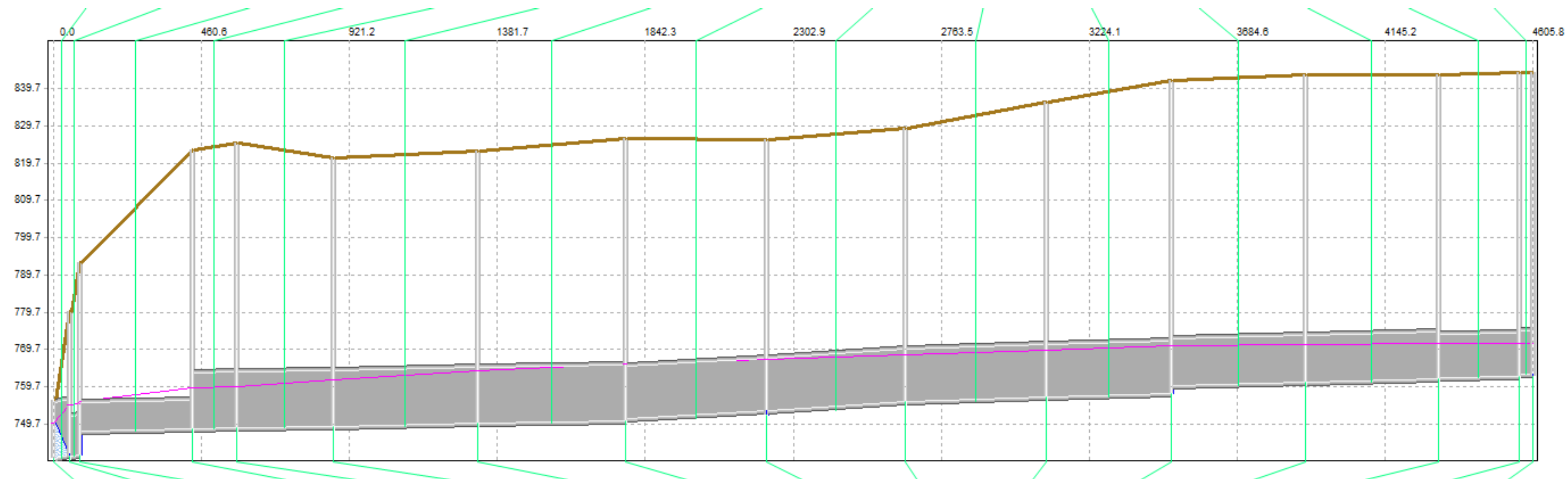
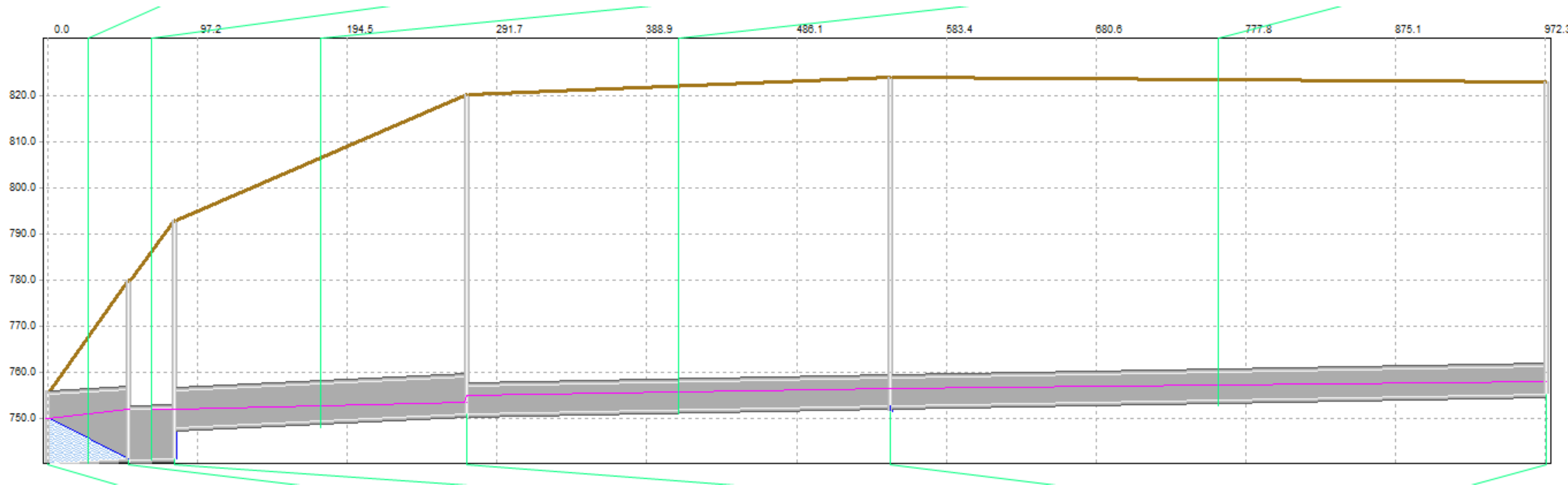
Hydraulic Profile: Washington Avenue South Parallel Tunnel, 10-year Level of Service



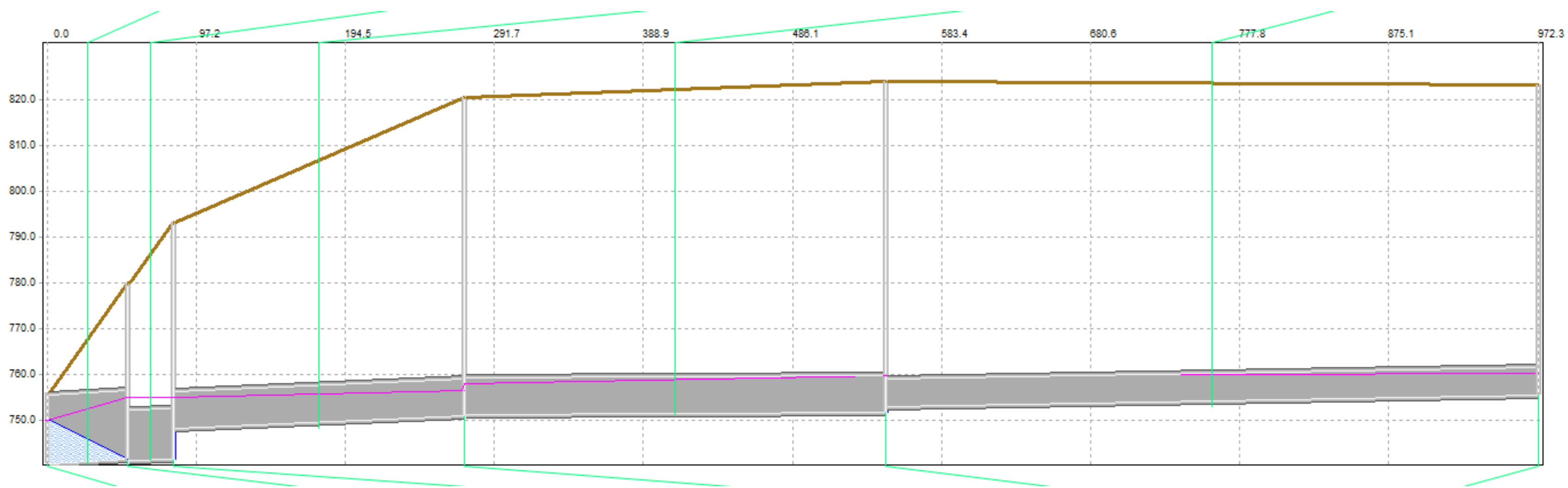
Hydraulic Profile: Washington Avenue South Parallel Tunnel, 100-year Level of Service



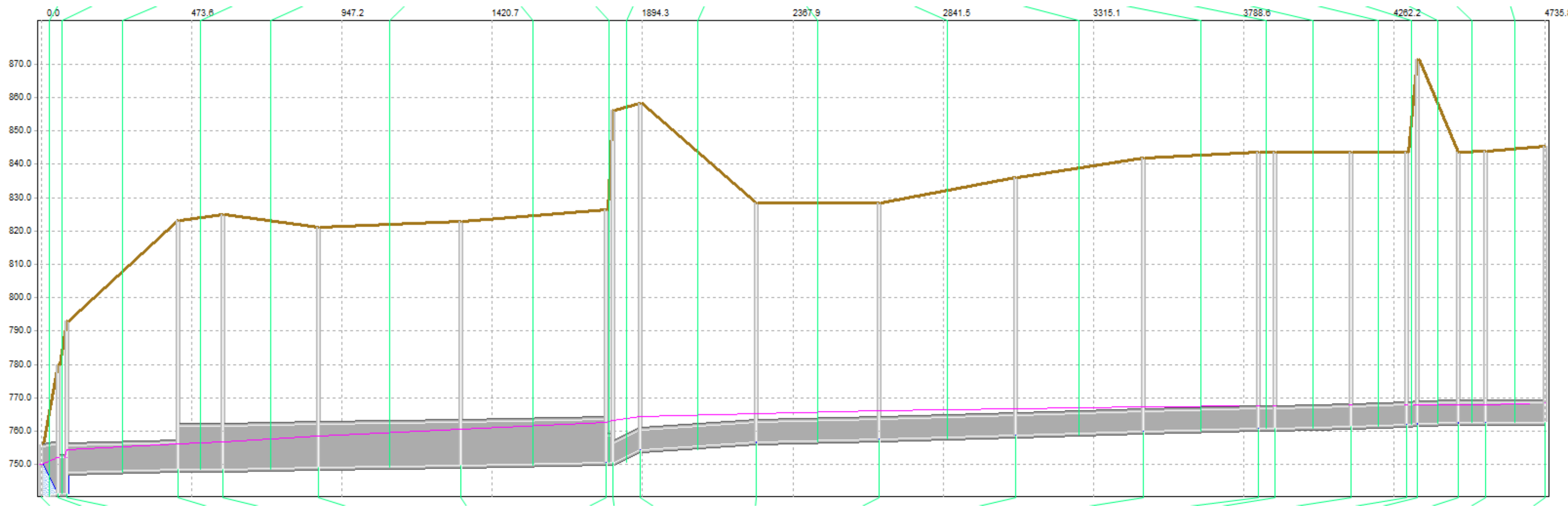
Hydraulic Profile: Chicago Avenue South Tunnel, 10-year Level of Service



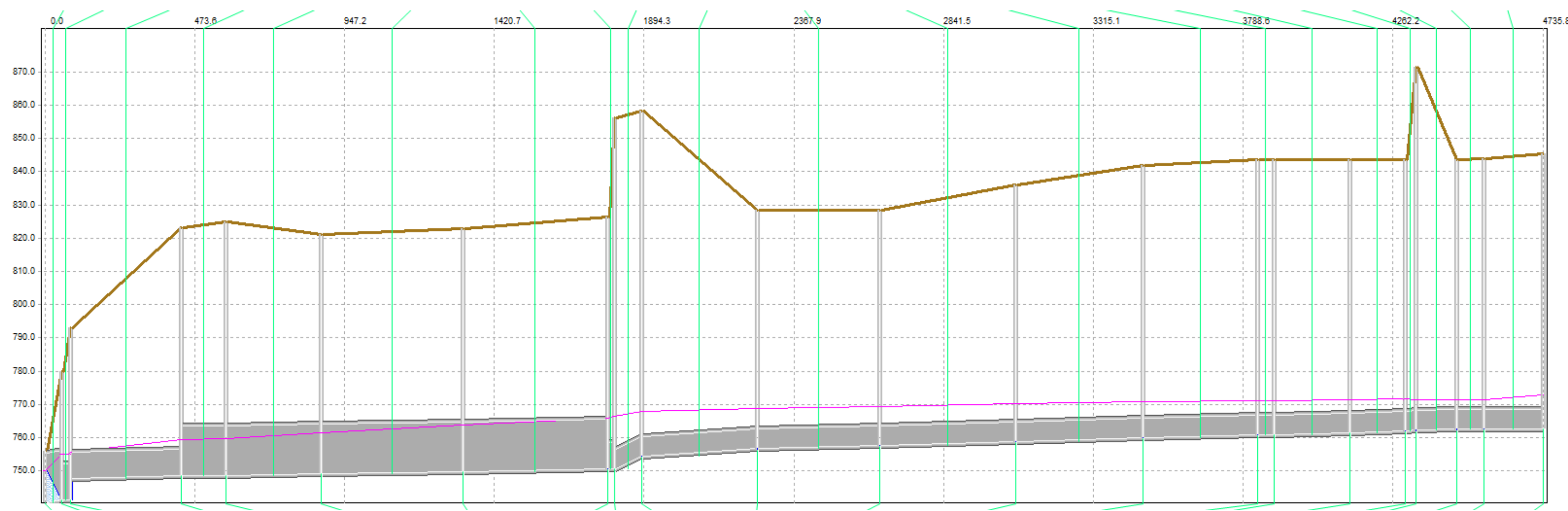
Hydraulic Profile: Chicago Avenue South Tunnel, 100-year Level of Service



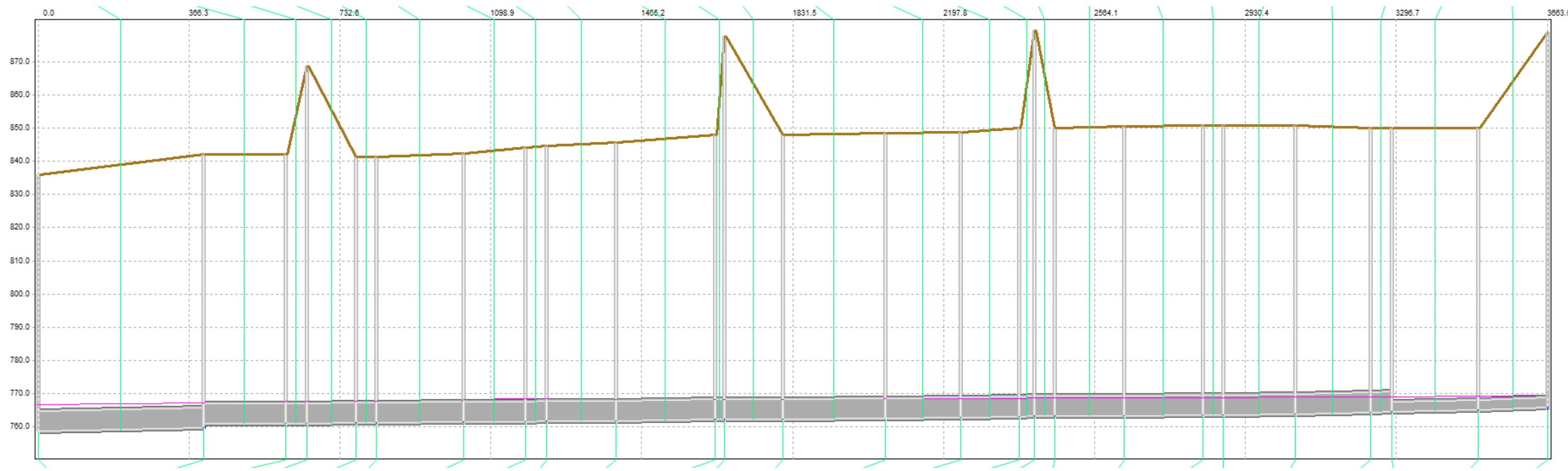
Hydraulic Profile: Washington Avenue South Existing Tunnel, 10-year Level of Service



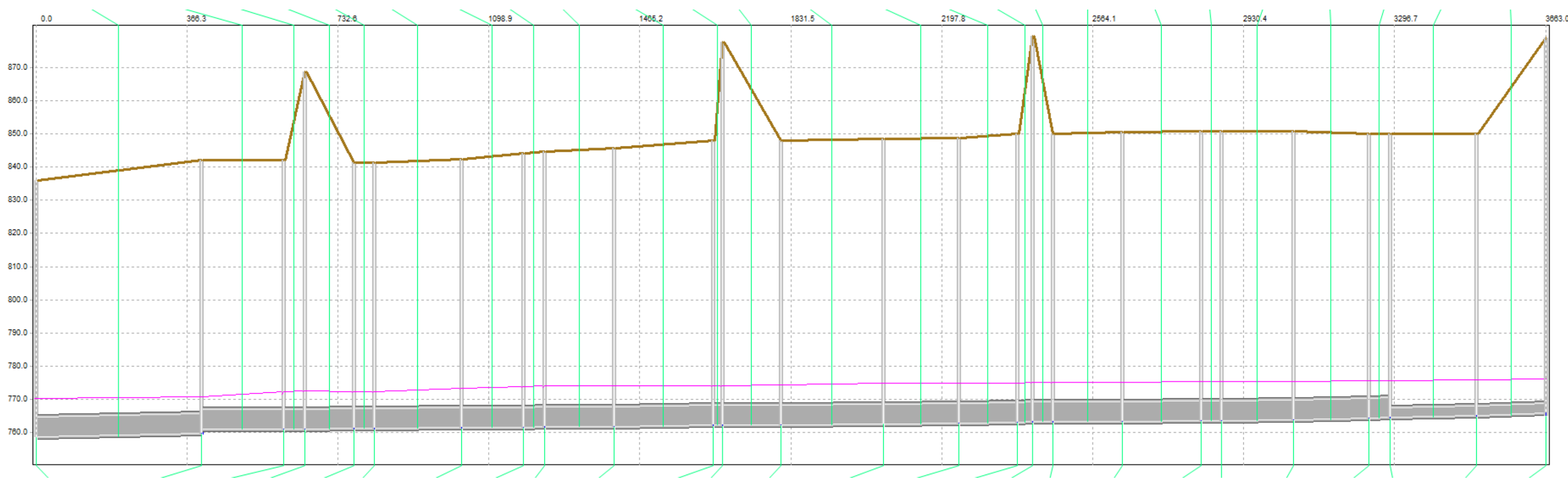
Hydraulic Profile: Washington Avenue South Existing Tunnel, 100-year Level of Service



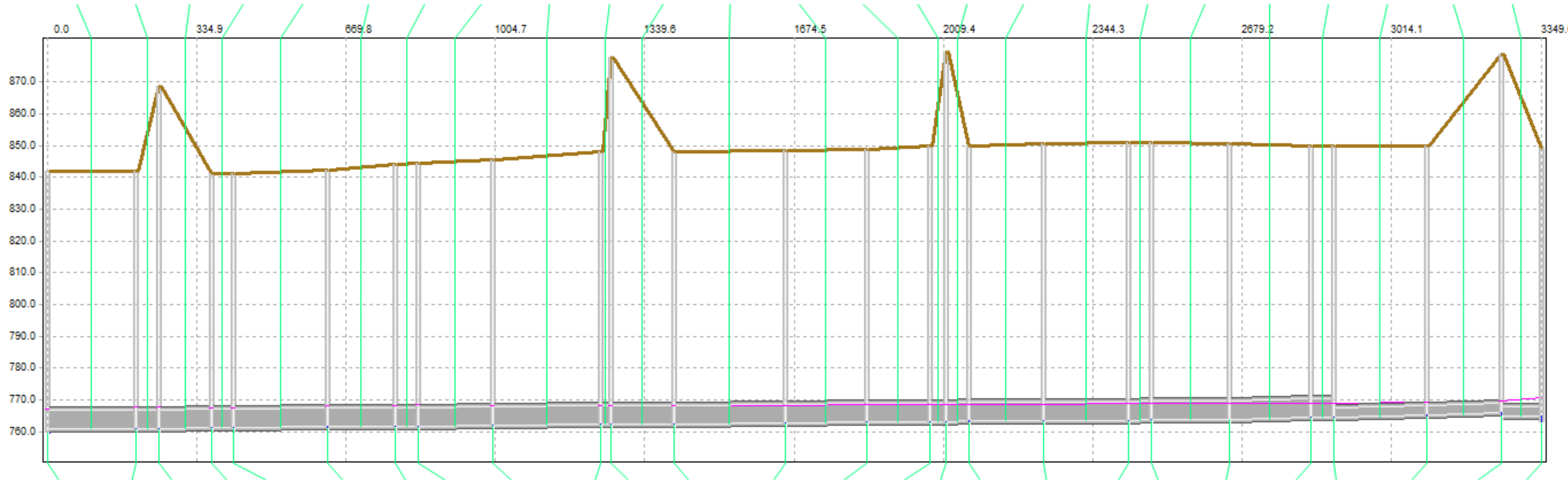
Hydraulic Profile: 2nd Avenue South Parallel Tunnel, 10-year Level of Service



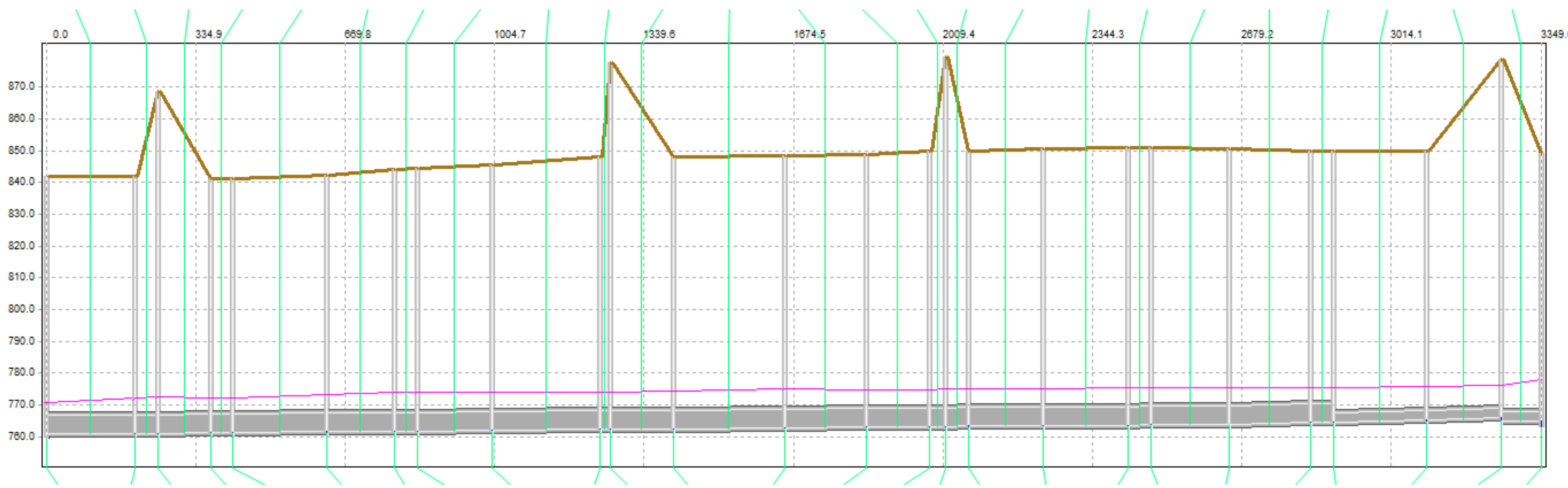
Hydraulic Profile: 2nd Avenue South Parallel Tunnel, 100-year Level of Service



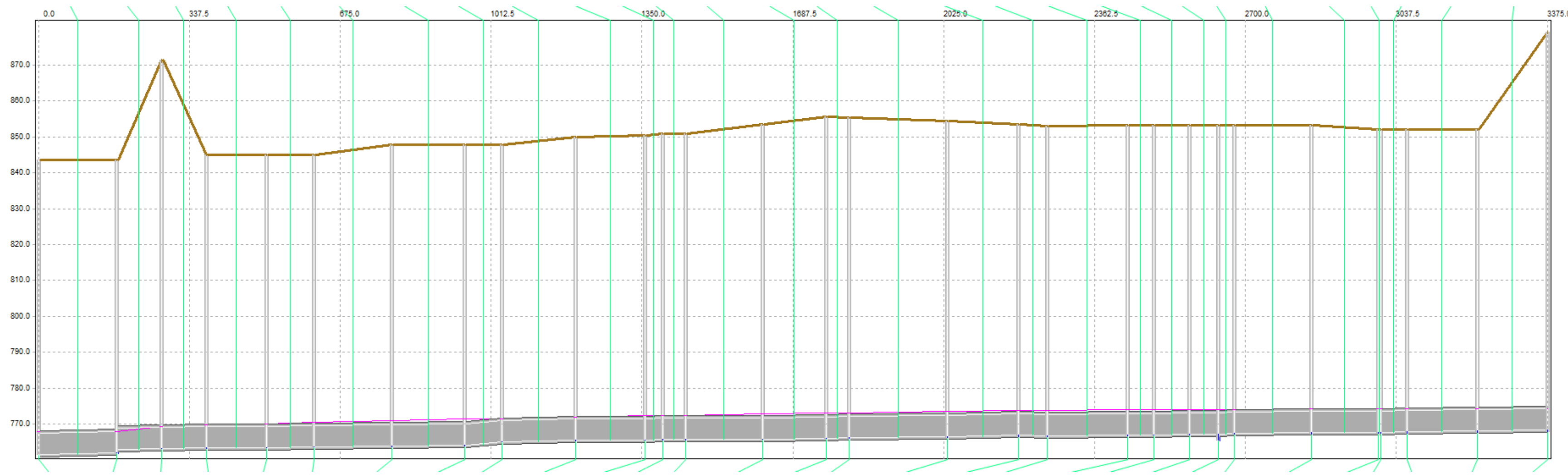
Hydraulic Profile: 2nd Avenue South Existing Tunnel, 10-year Level of Service



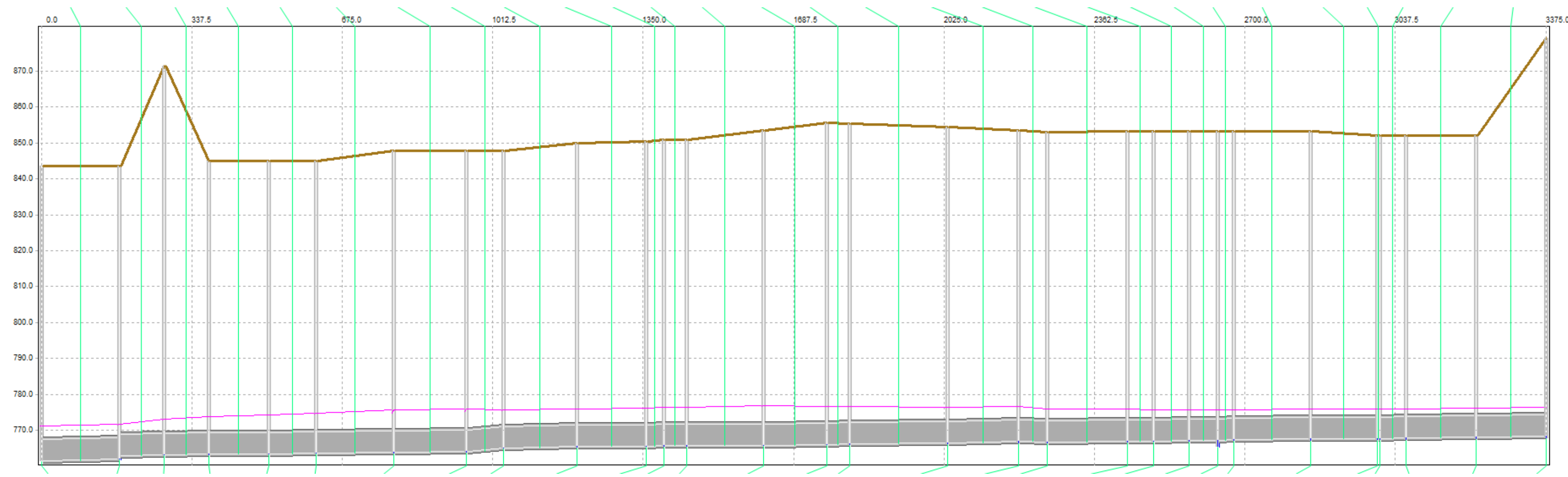
Hydraulic Profile: 2nd Avenue South Existing Tunnel, 100-year Level of Service



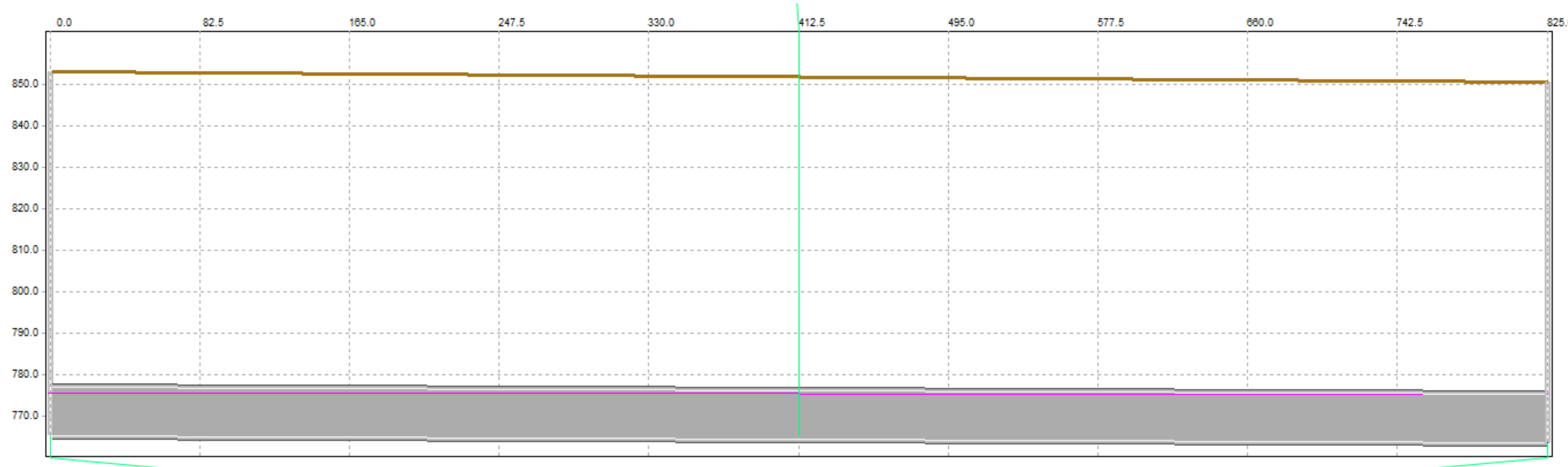
Hydraulic Profile: Nicollet Mall Tunnel, 10-year Level of Service



Hydraulic Profile: Nicollet Mall Tunnel, 100-year Level of Service



Hydraulic Profile: 8th Street South Relief Tunnel, 100-year Level of Service



Appendix D

Risk Register

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CCTS – risk

Option Code for construction method:

- #1(RH): Expand Existing Tunnels with Roadheader
- #2(TBM): Parallel Tunnels with TBM
- #2(MTBM): Parallel Tunnels with Microtunnel
- #4: Ongoing Crack Repair Maintenance
- #5: Common to all alternatives

Risk ID	Alternative #(s)	Risk Description	Risk Occurrence Probability	Cost Impact Factor	Risk Score	Mitigation Approach
1	#1(RH)	Rain storm event causes Drainage Tunnel overpressure causes cracking in lining and breach into excavation resulting in flooding- enlarged section	3	5	15	Add bracing to counter internal hydrostatic pressure
2	#2(TBM) #2(MTBM)	Rain storm event cause Drainage Tunnel overpressure causes cracking in lining and breach into excavation resulting in flooding- parallel tunnel	2	5	10	Maintain separation between tunnels
3	#1(RH)	More main tunnel system flooding events than anticipated.	1	5	5	Assumes #1 not yet mitigated
4	#1(RH)	Over excavation causes collapse of existing tunnel	2	4	8	Borings to confirm profile
5	#5	Rock is harder than expected – requires larger more powerful equipment and results in slower production	3	5	15	More UCS testing of rock cores
6	#5	Rock more abrasive than expected – increased tool wear and results in slower production.	3	4	12	More CAI tests
7	#2(TBM) #2(MTBM)	Voids found within excavation area that require grouting/repair -parallel tunnel	1	4	4	Caves exist, do adequate research on locations
8	#1(RH)	Voids found within excavation area that require grouting/repair -enlarged section	4	2	8	Geophysical survey
9	#2(TBM) #2(MTBM)	Required access shaft location is not available.	3	5	15	Owner to act quickly to obtain required land
10	#2(TBM)	Required retrieval shaft for TBM not available	3	5	15	Owner to act quickly to obtain required land
11	#2(MTBM)	Required retrieval shaft for MTBM not available	3	4	12	Owner to act quickly to obtain required land
12	5	Limestone layer is lower than anticipated	2	5	10	More borings

13	#2(TBM)	Frequent TBM equipment breakdowns due to poor manufacturing/maintenance	1	4	4	Specify maintenance frequency
14	#2(MTBM)	Frequent MTBM equipment breakdowns due to poor manufacturing/maintenance	2	3	6	Specify maintenance frequency
15	#1(RH)	Frequent Roadheader equipment breakdowns due to poor manufacturing/maintenance	4	3	12	Specify maintenance frequency
16	#5	Contractor stops work due to financial reasons	1	5	5	Pre-qualify bidders
17	#5	Increased truck traffic damages roads	2	4	8	Specify limits
18	#5	Lack of interested contractors during bidding.	1	3	3	Evaluate bid climate prior to bid
19	#2(TBM)	Misalignment of excavation due to survey error or guidance system of TBM.	1	4	4	Specify guidance system and operator experience
20	#2(MTBM)	Misalignment of excavation due to survey error or guidance system of MTBM.	1	4	4	Specify guidance system and operator experience
21	#1(RH)	Misalignment of excavation due to survey error or guidance system of RH.	2	4	8	Specify guidance system and operator experience
22	#5	Improper design or installation of tunnel ventilation, electrical etc. results in worker injury	1	5	5	Specify contractor’s designer qualifications
23	#5	Inadequate shaft support results in shaft collapse and or damage to nearby buildings.	1	5	5	Specify contractor’s designer qualifications
24	#5	Pedestrian falls in shaft	1	5	5	Specify fencing
25	#5	Pedestrian injured by construction equipment	2	4	8	Specify construction boundaries
26	#5	Contractor defaults on the Contract	2	5	10	Pre-qualify bidders
27	#5	Contractor is not qualified/inexperienced	2	5	10	Pre-qualify bidders
28	#2(TBM)	Inadequate room in street to stay within public ROW with TBM	4	3	12	Reduce CL/CL tunnel spacing
29	#2(MTBM)	Inadequate room in street to stay within public ROW with MTBM	3	3	9	Reduce CL/CL tunnel spacing
30	#1(RH)	Inadequate room in street to stay within public ROW with RH	1	3	3	Reduce CL/CL tunnel spacing
31	#2(TBM) #2(MTBM)	Making drop connections to parallel tunnel	5	4	20	Very difficult for these options
32	#1(RH)	Making drop connections to enlarged tunnel	1	1	1	Probably not an issue
33	#5	Performance issues with contractor (poor quality final product)	1	5	5	

34	#5	Non-constructible design of connection to existing system (bigger issue for parallel tunnel option)	1	3	3	
35	#5	Muck disposal issues	3	4	12	
36	#2(TBM) #2(MTBM)	Access issues prevent delivery of equipment to launch site. TBM or MTBM	4	3	12	
37	#5	Access issues prevent delivery of equipment to launch site. Roadheader	2	3	6	

Appendix E

Historic Context

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THE MINNEAPOLIS CENTRAL CITY TUNNEL SYSTEM HISTORIC CONTEXT

Minneapolis, Hennepin County, Minnesota

April 2017

THE MINNEAPOLIS CENTRAL CITY TUNNEL SYSTEM HISTORIC CONTEXT

Minneapolis, Hennepin County, Minnesota

106 Group Project No. 2183

SUBMITTED TO:
CDM Smith
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SUBMITTED BY:
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REPORT AUTHOR:
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April 2017

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ACRONYMS AND ABBREVIATIONS

106 Group	The 106 Group Ltd.
CCTS	City of Minneapolis Central City Tunnel System
Clean Water Act	1972 Federal Water Pollution Control Act, as amended
CSO	Combined Sewer Overflow
EPA	Environmental Protection Agency
MCES	Metropolitan Council Environmental Services
MnHPO	Minnesota Historic Preservation Office
MNHS	Minnesota Historical Society
MS4	Municipal Separate Storm Sewer Systems
NEPA	National Environmental Policy Act of 1969, as amended
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRHP	National Register of Historic Places
Project	City of Minneapolis Central City Tunnel System Project
Section 106	Section 106 of the National Historic Preservation Act of 1966, as amended

1.0 INTRODUCTION

This context was prepared under contract with CDM Smith on behalf of the City of Minneapolis, in preparation for proposed parallel stormwater tunnel, and possible rehabilitation of a portion of the existing storm tunnel outfall, within the existing City of Minneapolis Central City Tunnel System (CCTS) (Project). The CCTS is a stormwater tunnel system located in downtown Minneapolis, roughly bounded by the Mississippi River to the north, First Avenue North to the west, Chicago Avenue South to the east, and 12th Street South to the south. As a City project, the proposed redevelopment will need to comply with City policies and ordinances and the City, as a subdivision of the State, will need to comply with applicable state mandates, including the Minnesota Historic Districts Act and the Minnesota Historic Sites Act. If there is federal involvement in the Project, such as funding or permitting, the Project will need to comply with the National Environmental Policy Act of 1969, as amended (NEPA) and Section 106 of the National Historic Preservation Act of 1966, as amended (Section 106) .

In December 2016 and January 2017, The 106 Group Ltd. (106 Group) conducted research on the history and development of the CCTS, and developed this context to assist in the evaluation of eligibility for listing in the National Register of Historic Places (NRHP) of portions of the CCTS which may be affected by the proposed project. This context begins with the construction of the first sewer tunnel in Minneapolis in 1871, which was built within the project area, and continues through 2006, when the City adopted the Local Surface Water Management Plan, which provides guidance on the management of surface waters and stormwater and sanitary sewer networks. The year 2006 was selected as the end date for the context because it is the date of the most recent significant City planning decision regarding the City's stormwater systems. This context addresses the history of the CCTS, identifies construction methods, materials, structure features, and provides guidelines for evaluating components of the tunnel system. Historical information pertaining to sewer systems in the United States is also included to place developments in Minneapolis within a national context, as is information about early developments regarding the water distribution system in Minneapolis and the treatment of wastewater, to provide a framework for understanding the broader history of water distribution, disposal, and treatment, in Minneapolis of which the sewer systems play a large part. Although the CCTS is a stormwater conveyance system, information about the history of the sanitary tunnel system, which was initiated prior to, and evolved alongside, the stormwater system is included as well. Although the research conducted for this study did not locate documents indicating that any storm tunnel system structures were constructed before 1914, if any such structures were found, they may be evaluated for NRHP eligibility using this context. Tunnels that were constructed prior to 1914 as sanitary tunnels, and later converted to storm tunnels, are addressed within this context, and referred to by their usage during the time period in discussion. Portions of this context are based on, and an expansion of, the context developed for the 10th Avenue Southeast Sanitary Tunnel Minnesota Historic Property Record (Mathis 2011). Appendix A contains a list of project personnel.

1.1 Overview of the Current Central City Tunnel System

The current CCTS is located in downtown Minneapolis, roughly bounded by Mississippi River to the north, First Avenue North to the west, Chicago Avenue South to the east, and 12th Street South to the south. It drains a watershed of 302 acres (see Figure 1. Barr Engineering Figure 1-1 Study Area and Tunnel WatershedsFigure 1). Figure 1, which depicts the CCTS and adjacent stormwater tunnel systems, the Chicago Avenue Tunnel System (which shares an outfall with CCTS) and the 11th Avenue Tunnel System, is excerpted from Barr Engineering's 2015 *Central City Tunnel System Feasibility Study: Central City Tunnel System Pressure-Mitigation Options*, prepared for the City of Minneapolis (Barr Engineering 2015a). The CCTS is comprised of storm main tunnels, storm drift tunnels, and storm sewer pipes, as well as connective and operational features such as shaft holes, drill holes, manholes,[1] catch basins,[2] and grit chambers.[3] Primary structures include:

- Main Tunnels: Main tunnels are the largest tunnels in the system, with an average width of 4 to 7.5 feet, an average height of 5.5 to 8 feet, and lengths of around 2,000 to 3,000 feet, comprised of multiple connected segments. They are located an average of 60 to 90 feet below ground, follow the grid of city streets, and typically have a non-circular cross section.
- Drift Tunnels: Drift tunnels are smaller than main tunnels (average width and height not available), are also an average of 60 to 90 feet below ground, typically run perpendicular to main tunnels, and are much shorter than main tunnels, approximately 100 feet in length. They also typically have non-circular cross sections.
- Storm Sewer Pipes: Storm sewer pipes run approximately three to 20 feet below ground (average width and height not available), are perpendicular to main tunnels, and typically have circular cross sections. Their average length is between that of main tunnels and storm drift tunnels, and are connected to the tunnel system by drill holes (average diameter of 16 inches; maximum diameter of 48 inches) and drop shafts (average diameter of greater than 48 inches; maximum diameter not available) (Barr Engineering 2015a; Barr Engineering 2015b).

Surface water is conveyed into storm sewer pipes from inlets. From there, stormwater passes into drill holes or drop shafts, which connect the storm sewer pipes to the tunnel system. The water is then conveyed first through drift tunnels to main tunnels, where it eventually discharges into the Mississippi River at the system's outfall[4] at the foot of 8th Avenue South. The CCTS shares an outfall with the Chicago Avenue Tunnel System, which is located just southeast of the CCTS (see Figure 1) (Barr Engineering 2015a; Barr Engineering 2015b). A separate sanitary tunnel system runs parallel to the CCTS. The sanitary tunnel system originally began as a combined sewer system, meaning it conveyed both sewage and stormwater, but by the second decade of the twentieth century, construction had begun on a separate, parallel stormwater system, and the previously combined system was converted to a sanitary system. Although the systems largely function separately, if the sanitary system exceeds capacity, in certain locations its contents can overflow into the stormwater pipes, an event referred to as a Combined Sewer Overflow (CSO). In these instances, sewage mixes with stormwater and discharges untreated into the Mississippi River. Because of the health and environmental problems posed by these

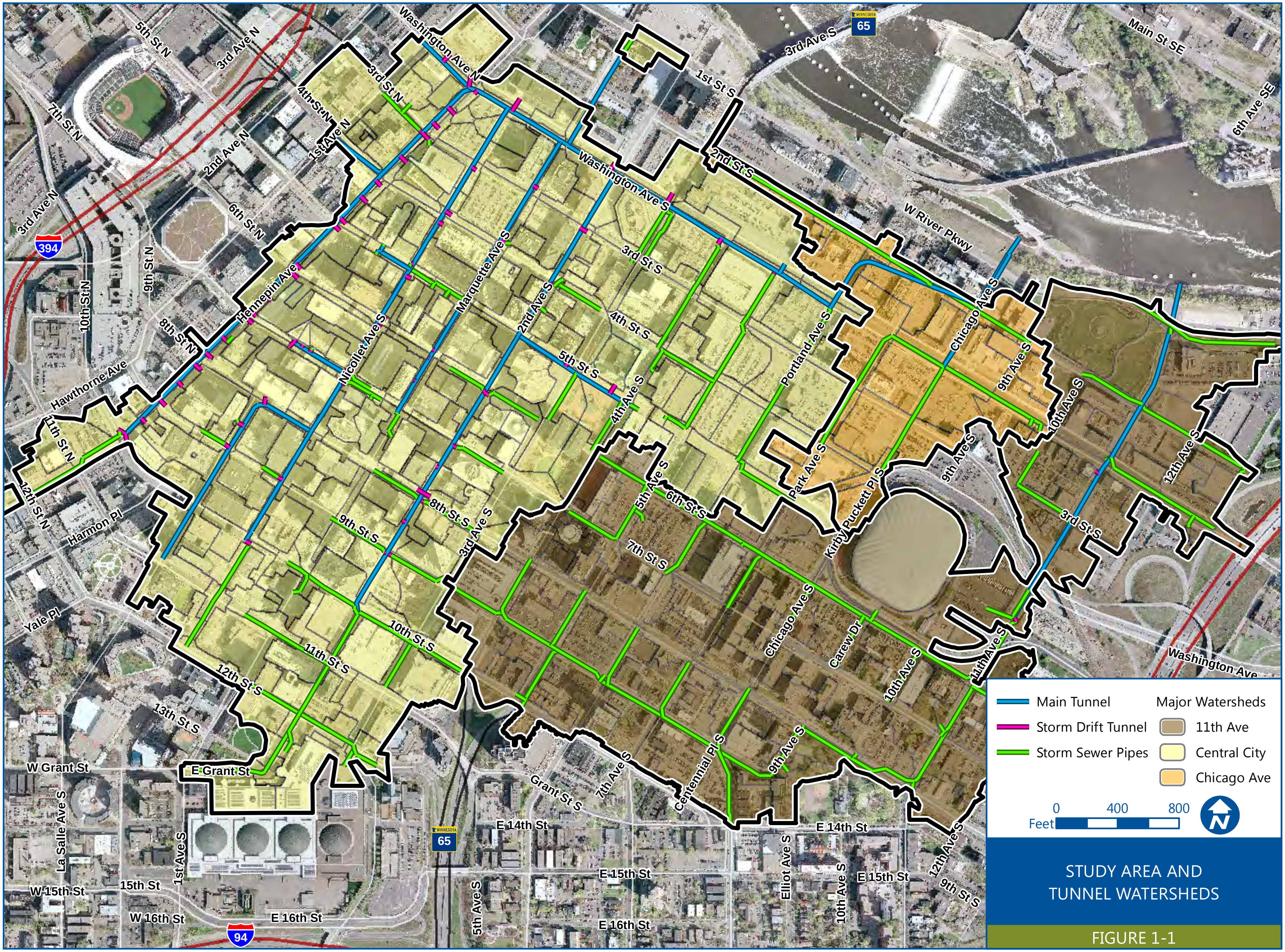
[1] Vertical openings that serve as access holes for sanitary or storm drain infrastructure maintenance.
[2] Storm drain inlets located on curbsides, which serve as an entry point to the storm drain system.
[3] Concrete basins that allow large sediments to settle, while water and smaller sediments continue on through the system.
[4] The point where drainage discharges from a sewer pipe into a body of water.

events, the City of Minneapolis has minimized the possibility of CSO events, which rarely occur (City of Minneapolis 2017).

The CCTS is composed of tunnels and pipes that were constructed over a wide range of time, from the 1880s through 2010 (see Figure 2), although according to tunnel plats on file at the City of Minneapolis the majority of the stormwater tunnels were constructed between 1930 and 1940. The Chicago Avenue Tunnel System is included in Figure 2, as it shares an outfall with the CCTS.

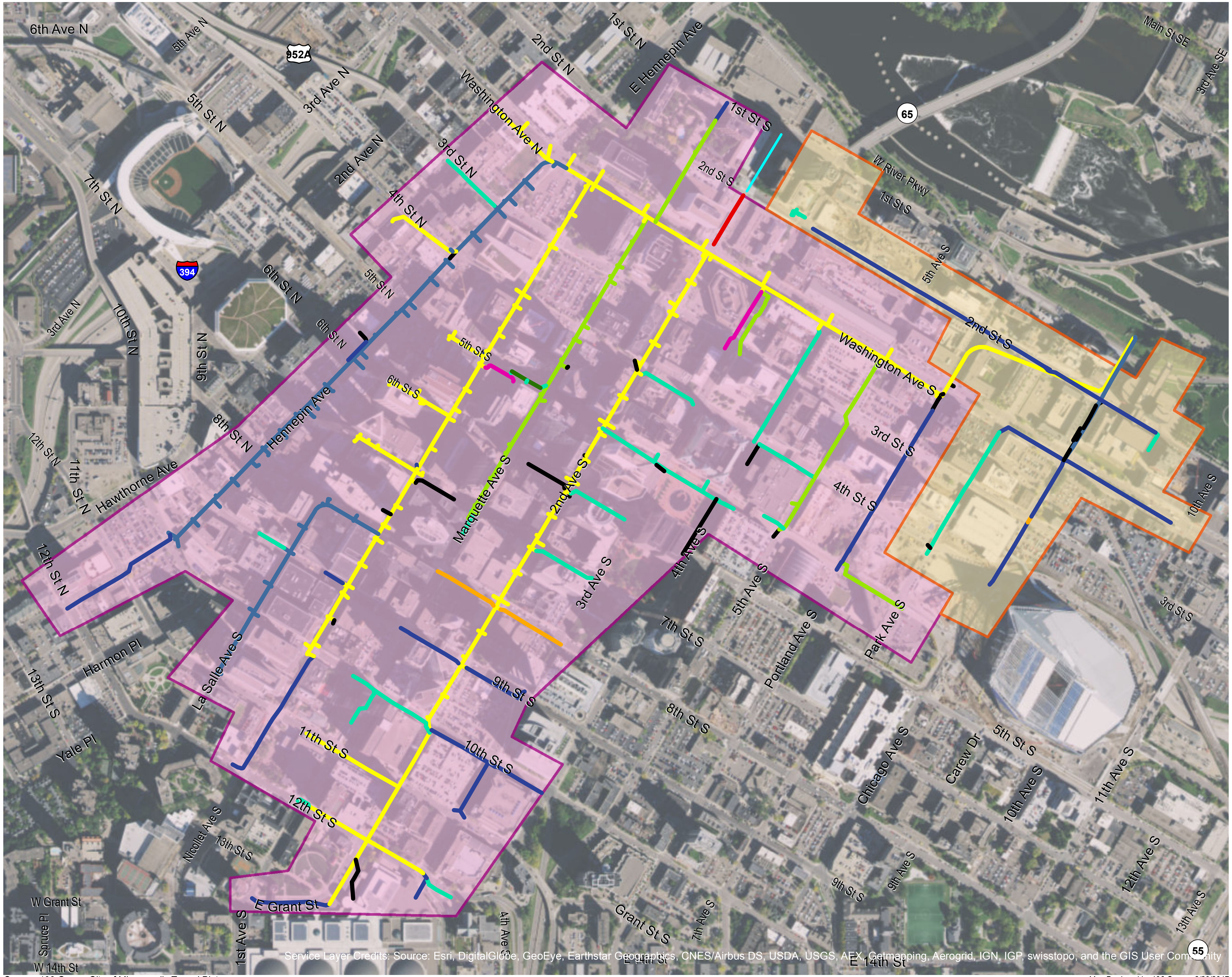
1.2 Purpose of Historic Contexts

A historic context provides the framework for evaluating resources for potential NRHP eligibility. A context is a document "created for planning purposes that groups information about historic properties based on a shared theme, specific time period and geographical area" (National Park Service [NPS] 2014). This context describes the CCTS in Minneapolis to enable evaluation of the system's components, assess their significance, and inform preservation priorities. Historic contexts are an integral component of the preservation planning process which assures that the full range of historic properties are identified and subsequently evaluated, registered, and protected. Contexts help to prioritize preservation decision-making by comparing similar historic resources, describing their prevalence, and ascertaining their relative significance. Historic contexts also help to guide future survey and designation efforts by proactively and objectively identifying geographical areas, resource types, or themes that are likely to be associated with valued historic resources.



Barr Footer: ArcGIS 10.3, 2015-06-05 13:20 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 1_1 Study Area and Tunnel Watersheds.mxd User: arm2

Figure 1



Source: 106 Group, City of Minneapolis Tunnel Plats

Map Produced by 106 Group 3/20/2017

Minneapolis Central City Tunnel System Historic Context

Hennepin County, Minnesota

Central City Tunnel System

Chicago Avenue Tunnel System

Construction Years

- No Year
- 1880 - 1889
- 1890 - 1899
- 1930 - 1939
- 1940 - 1949
- 1950 - 1959
- 1960 - 1969
- 1970 - 1979
- 1980 - 1989
- 1990 - 2010

Includes both tunnels and surface storm drains. Tunnel system boundaries are approximate.

0 130 Meters

0 360 Feet

1:7,000

106GROUP

Construction Date Ranges for Central City and Chicago Avenue Storm Tunnel Systems

Figure 2

2.0 THE MINNEAPOLIS CENTRAL CITY TUNNEL SYSTEM HISTORIC CONTEXT

2.1 History of Sewer Systems in America

In most parts of America during the seventeenth through the mid-nineteenth centuries, wastewater[5] was commonly disposed of in cesspools,[6] dry wells, or on the ground, while sewage was often deposited in cesspools and privies. Once a privy became full, it was either replaced by a new privy in a different location, or periodically emptied by workers known as scavengers, who were employed or contracted by larger cities and usually forbidden from conducting their work during the day time to limit the release of noxious odors when most people were awake. Once collected by the scavengers, the waste was deposited into bodies of water, dumped on designated land outside city boundaries, or recycled into fertilizer (Tarr 1980:60; Burian et al. 2000:34-35).

By the end of the eighteenth century, large cities such as New York and Boston had developed storm sewers for controlling stormwater runoff to prevent flooding, but did not have underground conveyance systems for human waste. Over the first half of the nineteenth century, storm sewers were constructed in a growing number of cities, most of which had ordinances forbidding the deposit of human waste into the sewers. Simultaneous to the development of early stormwater systems was the construction of municipal waterworks, which markedly increased the per capita usage of water, and in turn drastically increased the amount of wastewater being generated (Tarr 1980:62). The gradual adoption of flushing toilets, which were initially connected to cesspools or privy vaults, also dramatically increased the amount of wastewater and sewage going into the soil, and flooding of cellars and ground water sources with sewage became a growing problem. Citizens began to insist on connections between their households and municipal sewer systems (Tarr 1980:63; Burian et al. 2000:38-39). Ultimately, some sewage ended up in the stormwater systems, whether intentionally, through deliberate deposition into storm drains, or unintentionally, through seepage.

Although versions of sewer system technology have been implemented in different locations globally for centuries, the first modern version of the separate sewer system[7] was developed by Edwin Chadwick in England in 1842, and in the 1850s, modern combined sewer systems[8] were constructed in England and Germany (Schladweiler 2002; Burian et al. 2000:43). Beginning in the mid-nineteenth century, American cities increasingly decided to construct combined sewer systems, beginning with Chicago and Brooklyn in the late 1850s (Burian et al. 2000:43). Despite the fact that these systems represented a significant

[5] Water for which the quality has been diminished by human use, such as through domestic or industrial activities.
[6] An underground repository for liquid waste.
[7] Separate system refers to the presence of two separate systems in one area, one which transports sewage, and one which transports stormwater.
[8] A combined sewer system conveys both sewage and stormwater, which become intermixed, in the same system.

capital outlay, cost benefit accrued over time as cities became less dependent on scavengers to empty private privies, and reductions in waterborne illnesses occurred (Tarr 1980:64-65). One of the leading proponents of sewer systems, sanitary engineer George E. Waring, Jr., was a strong promoter of the significant cost savings to cities that sewer systems could bring through improvements to public health (Tarr 1980:65). Others, however, saw sewer systems as a waste of resources, arguing that the human waste that had previously served as fertilizer (and a source of income) was now being washed away (Tarr 1980:67). Ultimately, the benefits of sewer systems soon became apparent, and “the nation’s cities undertook a great wave of sewer-building activity in the late nineteenth and early twentieth centuries, beginning in the 1870s” (Tarr 1980:68).

By the late nineteenth century both combined and separate sewer systems generally consisted of a main line, or trunk line[9], into which lateral lines[10], often originating at individual buildings, discharged. As early sewers became too small, interceptors[11] were needed to combine multiple lines for discharge at a single point. In 1876, Boston, Massachusetts installed the first combined interceptor in the United States. The brick system was based on London’s sewage interception system (Schladweiler 2002). During the late nineteenth century, a number of social movements influenced the development of sewer systems, including the Social and Personal Hygiene Movement, the Public Health Movement, and the Sanitary Movement. These movements led to a growing understanding of the importance of cleanliness and the proper disposal of human waste, laying a foundation for principles that were increasingly applied to the development of sanitary engineering. By 1890, most cities with a population over 10,000 had a sewer system, and by 1907, all American cities had some type of sewer system (Schultz and McShane 1978).

Both separate and combined systems were commonly constructed of stone, brick, or wood, and later, following technological innovations in the late nineteenth century, vitrified clay pipe or concrete. Brick was a popular material for lining the interior of large sewer tunnels, especially main trunks, while clay tile was popular for branches and perpendicular lines. Brick or concrete had to be used for sewers with a diameter greater than 36 inches since clay tile pipe could not be manufactured larger than 36 inches (Van Erem 2008:3; Ogden 1908:29). Hard, smooth, and water-impervious bricks, known as paver bricks, were used for the construction of sewers so that materials did not catch as they flowed through the system. To save on cost, paver bricks were typically used only on the invert, or bottom portion, of the interior of the sewer tunnel, while common bricks were used to line the upper portions and the exteriors of the tunnels (Van Erem 2008:4; Ogden 1908:30).

In many cases, brick sewers were preferable over pipe sewers. One advantage of brick over other materials is that the cross-sections of brick sewers could be designed in many ways to suite special conditions (Ogden 1908:30). One of the most popular early sewer designs in the United States was the egg-shaped brick sewer system. This system, invented by John Phillips in England in 1846, quickly spread to the United States and was in use in several American cities by the 1870s (Ogden 1913:208; Van Erem 2008:4; Ogden 1918). Though they used more bricks and were more difficult to construct compared

[9] The principal sewer to which submains discharge.
[10] A sewer that discharges into a submain and has no other common sewer tributary to it.
[11] Large volume pipes or conduits with deep invert elevations that accept or intercept the flow of smaller sewers.

to a circular system, egg-shaped brick sewers worked well for sewers with varying depths of flow (Van Erem 2008:4; Ogden 1908:30). In 1885, Washington, D.C. built the country's first concrete sewer system, which was lined with brick and clay tile (Schladweiler 2002).

As combined sewer systems replaced or incorporated what were previously stormwater-only systems, it became apparent that combined systems had their drawbacks. As cities grew in size and density, and wastewater output correspondingly grew, systems could reach or exceed capacity quickly when a large amount of stormwater runoff entered the tunnels, resulting in dangerous sewage backups. By the 1880s and 1890s, a debate had begun over whether cities should construct separate rather than combined systems. Though some sanitary engineers such as Waring advocated for separate systems for health benefits, by the beginning of the twentieth century engineers had overall determined that the health differences between combined and separate systems were minimal (Tarr 1980:68; Burian et al. 2000:44). Even health professionals such as Dr. Rudolph Hering, an engineer with the National Board of Health, advocated the construction of combined systems wherever practical due to cost savings (Burian et al. 2000:45; Schladweiler 2002; Waring 1883).

Waring was an early adopter of vitrified clay pipe for the construction of sanitary sewers, because in comparison to brick pipes, clay pipes cost less both in terms of material and labor to install, and reduced leakage of sewage into surrounding soils. Waring built his first separate system in Lenox, Massachusetts in 1875, and in 1880 oversaw the construction of a separate system in Memphis, Tennessee following a series of yellow fever outbreaks. The separate sanitary system proved an effective solution to the public health crisis (Burian et al. 2000:44-45). Despite the success of Waring's separate system design, combined sewers continued to be common in large cities, where the cost of constructing a separate system was not considered warranted, and the widespread belief that running water was self-purifying justified the dumping of raw sewage and stormwater into streams and rivers. Even so, some cities did construct separate sanitary sewers, and in smaller cities, it was common for stormwater to be diverted along surface channels, while underground sewers were reserved for the transportation of sewage (Tarr 1980:69).

While the health benefits of sewer systems were widely touted, they were also found to have significant health drawbacks. Though sewage was conveniently transported away from residences, it was often transported directly into the water source of the city itself, or that of its downstream neighbors. This redistribution of sewage into sources of drinking water resulted in ballooning mortality rates as typhoid epidemics broke out in the late nineteenth and early twentieth centuries. It soon became apparent that the belief that running water was self-purifying was false. State boards of health, which were increasingly established in American cities throughout the late nineteenth century, searched for solutions. Eventually, technology caught up to the crisis, and effective methods were developed for treating drinking water, the first of which was filtration in combination with chlorination. Jersey City in New Jersey was the first city in the United States to permanently chlorinate its water supply in 1908, and the typhoid death toll tapered off as a result (Anfinson 2011:124).

While filtration and chlorination together proved to be an effective treatment for drinking water, it also had an unintended drawback by seemingly lessening the need for cities to reduce water pollution, since the water would be treated before being consumed. This fed into a debate that emerged between public health professionals, who advocated for the treatment of sewage, and sanitary engineers, who saw no reason to spend money treating sewage before its disposal, since the water in which it ended up would be treated before being consumed (Anfinson 2011:128). Eventually, the growing amounts of sewage that built up in large bodies of water began to have an effect on aesthetics and recreation, as well as wildlife and game animal populations, finally prompting cities to begin to adopt methods for treating sewage before it entered nearby rivers or lakes. In time, wastewater treatment became required by environmental regulations with legislation such as the Water Pollution Control Acts of 1948, 1952, and 1956 (Burian et al. 2000:53). It was the burden of having to treat large amounts of both sewage and stormwater—which could quickly exceed the capacity of combined sewer systems—and increasingly stringent environmental regulations during the mid-twentieth century that finally prompted cities to separate sewage and stormwater disposal into separate systems.

2.2 Overview of the Development of the Minneapolis Central City Tunnel System

Access to a reliable source of clean water and the disposal of waste are key to the growth and development of a city. The distribution of clean drinking water and the disposal of sewage are two components of a larger equation. One part of this equation is water systems which treat and deliver a needed commodity to consumers while the other, sewers, take away the waste products for disposal. Without both parts, any urban area, especially one as dense as Minneapolis, could not exist. The growth and evolution of the sanitary sewer system, and later the development of a separate stormwater drain system, in Minneapolis is a reflection of the growth of Minneapolis and its inextricable relationship with the Mississippi River, which bisects the city. The tunnel system's growth and evolution also embody the city's responses to changing public health and environmental concerns and increasingly stringent federal and state regulations.

The need for sewer systems was the direct result of the rapidly expanding population of Minneapolis. Starting with a few settlers in 1848, by 1860 Minneapolis had grown to a population of 2,564. The city’s population grew nearly 410 percent during the 1860s to 13,066 in 1870. As the city established itself as a center of commerce and industry, the population grew to 46,887 in 1880, 164,738 in 1890, to 202,718 by 1900, and to 301,408 in 1910. Minneapolis’ population continued to grow at a steady rate through 1950, when it reached its high point of 521,718 residents (US Department of Commerce 1963:14). It is within this context of a rapidly increasing population, increasing per capita consumption of water, the overburdening of the septic systems, and the resultant increase of disease due to increasing volumes of sewage that the Minneapolis sewer system was conceived.

The tunnel systems of Minneapolis were originally built as combined systems, which conveyed both wastewater and stormwater. However, as public health and later environmental concerns evolved, so did the system to address these concerns. As the system grew, new features were incorporated and older portions altered to meet new public health and environmental concerns and regulations. As a result, the system has evolved from a combined system that originally dumped effluent and stormwater directly into the Mississippi River, to one where wastewater and stormwater now have separate systems and wastewater is treated before being released back into the natural environment.

The City of Minneapolis has identified five chronological themes that comprise the tunnel system's growth and development from its inception in the late nineteenth century through the present day. Each theme reflects a significant period in the evolution of the system. The five themes are:

- Drain It All to the Mississippi River: Combined Sewers (1870–1938);
- Treat or Release It to the River: Combined Sewers Drain to a Treatment Plant (1938–1959);
- Begin Combined Sewer Separation: Residential Paving Projects Include Storm Drains (1960–1985);
- Completing the Separation of Storm and Sanitary Systems: Great Reduction in CSOs (1986–1996); and
- A Minneapolis Separated Drainage System: Light at the End of the Tunnel (1997–Present) (City of Minneapolis 2012).

2.3 History of Minneapolis Sewer Engineering

2.3.1 DESIGN

The Minneapolis sewer system was originally designed as a gravity-based combined system that took advantage of the geological foundation of the city and its natural drainage. The actual design for the Minneapolis sewer system, according to Andrew Rinker, City Engineer from 1877–1893 and 1902–1913, was based on knowledge gained from studying the other systems and from knowledge about conditions unique to Minneapolis (Rinker 1910; Steward 1918). The City Engineer's office utilized a formula used to determine the size of sewers for a specific area drained based on the experiences of Chicago and Milwaukee, but modified it to account for Minneapolis' peak annual rainfall and precipitation rates of 1.5 to 2 inches per hour (Rinker 1910).

The early combined sewer system included circular and non-circular tunnels. Non-circular shapes include horseshoe, semi-elliptical, semi-circular, parabolic, and egg-shaped cross sections (see Figure 3 through Figure 8). The early tunnels are typically 6 to 8 feet in diameter and located deep underground in the bedrock (Rinker 1910). They were constructed by excavating a linear void through the bedrock, building the sewer tunnel within the excavated space, and backfilling the voids around the sewer tunnel. The lower portions of the sewers were designed to handle sewage, while the top sections provided additional capacity for carrying stormwater.

The system included large trunk sewers, typically 6 to 8 feet in diameter, and smaller lines that ranged from less than 1 foot to 2.5 feet in diameter. These smaller lines were typically constructed by digging an open trench, constructing the line, and then backfilling over the line (Rinker 1910). Most trunk sewers were circular, 6 to 8 feet in diameter, and constructed of brick. Egg-shaped sewers ranged from 1 to 8 feet in diameter, with a smaller section at the bottom that carried sanitary flows and a larger section at the top that provided extra capacity for larger flows that occurred during rainstorms (City of Minneapolis 2012a).

Egg-shaped sewers were typically of brick or reinforced concrete construction. The oval shaped sewers were smaller, 1 to 2 feet in diameter, and typically constructed of vitrified clay pipe (Rinker 1910). The CCTS includes circular, semi-elliptical (including parabolic), horseshoe, and semi-circular shaped tunnels.

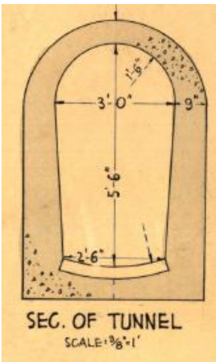


Figure 3. Horseshoe shaped tunnel. Segment 2-TUN-1, constructed 1931.

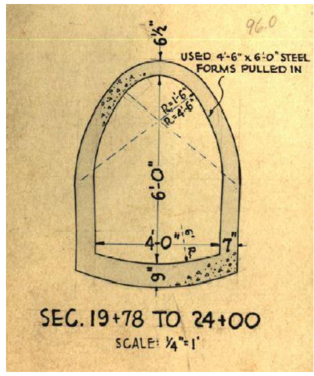


Figure 4. Semi-elliptical shaped storm drain tunnel. Segment 2-TUN-5, constructed 1939-1940.

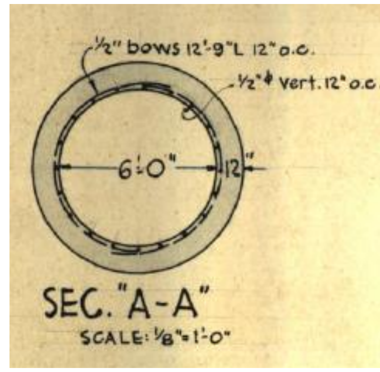


Figure 5. Circular shaped storm drain. Segment 2-TUN-6, constructed 1939-1940.

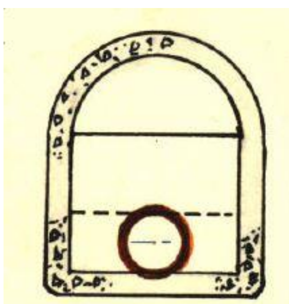


Figure 6. Semi-circular shaped storm drain pipe-in-pipe tunnel. Small sanitary pipe in storm drain's invert. Segment M-TUN-1. constructed 1960-1961.

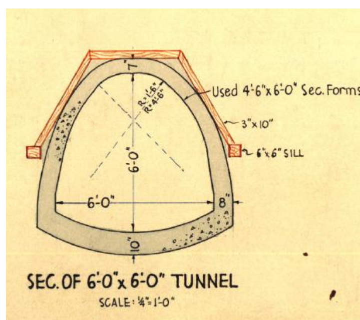


Figure 7. Parabolic or semi-elliptical shaped emergency tunnel. Segment 4-TUN-6, constructed 1939-1940.

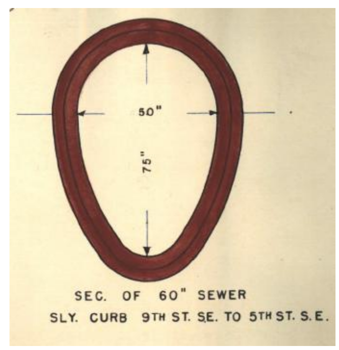


Figure 8. Egg shaped sewer. Segment S-10A-19, constructed c.1882.

2.3.2 CONSTRUCTION MATERIALS

The materials used to construct the Minneapolis tunnel system vary. Materials were selected based on the size and use of a particular tunnel or pipe. Materials used to construct the system also changed over time as new materials became available that were more durable and cost effective in terms of labor and material costs. Tunnels, located deep in the bedrock, were initially constructed of sewer brick, while small branch pipes were built of concrete (Rinker 1910:427). Egg-shaped sewers were constructed of either non-reinforced concrete or brick. Smaller sewers, those measuring 1 to 2 feet in diameter, were built with concrete while larger ones, 2 to 8 feet in diameter, were built with brick (City of Minneapolis 2012a).

In 1884, vitrified clay pipe became the standard material for all pipes up to 21 inches in diameter, and beginning in 1892, for brick sewers up to 2 feet in diameter as well (City of Minneapolis n.d.; Rinker 1910:427). Most larger pipes, trunk sewers, and manholes were constructed of brick (City of Minneapolis n.d.). Beginning around 1896, vitrified clay pipe started to replace non-reinforced concrete as the preferred material for construction of smaller egg-shaped sewers. Since its introduction in the late nineteenth century, vitrified clay pipe has remained through to the present day the preferred material for constructing sewers up to 33 inches in diameter. In 1896, the City began installing vitrified paving brick in the lower sections of brick sewers in which wastewater ran at six feet or more per second when half full, and started utilizing vitrified paving that was three feet in length rather than two feet in length, resulting in less joints (City Engineers Office 1897).

The invention of reinforced concrete in the late nineteenth century also had a significant and permanent impact on development of the Minneapolis sewer system. Starting in the late nineteenth century and continuing through the early decades of the twentieth century, as the durability and structural capabilities of reinforced concrete became better understood, there was a rapid increase in its practical application to engineering projects. Reinforced concrete proved to be a material that was more flexible in terms of use and application than many materials of the day, was cheaper and more durable than other materials, and resulted in faster construction that was also less labor intensive (Mathis 2011:19-20).

Given the high cost and labor-intensive nature of brick construction, by 1904, Minneapolis City Sewer Engineer Carl Illstrup was considering the cost benefits of constructing sewers out of reinforced concrete rather than brick (Municipal Engineering Company 1904:296). According to Rinker, reinforced concrete construction was used to construct the 22nd Avenue Northeast 6.5 feet diameter sewer in 1904. He further notes that since that time reinforced concrete "has been found less expensive and more satisfactory than brick construction for all sewers larger than 4 feet" (Rinker 1910). Consequently, after 1904, reinforced concrete was increasingly used to construct sewer lines and catch basins; however, brick continued to be used to build sewers between 2.5 and 4 feet in diameter and manholes until around 1930, when the City began to construct those as well out of reinforced concrete (Rinker 1910; City of Minneapolis 2012a).

2.4 Drain It All to the Mississippi River: Combined Sewers (1870-1938)

In 1860, Minneapolis was a small frontier town, incorporated in 1856, with a population of 2,564. However, with the development of the lumber industry and, soon thereafter, flour milling at St. Anthony Falls, which enabled Minneapolis (incorporated as a city in 1867) to become the economic and industrial center of the northwest, the population of the city skyrocketed to 13,066 in 1870, 46,887 in 1880, and to 164,738 in 1890 (United States Department of Commerce 1963; Kane 1987:60). As the demand for water grew during this period, the City of Minneapolis turned to the Mississippi River as a source of municipal water. In 1867, the City of Minneapolis Water Works was authorized by the City Council; its primary role was as an auxiliary to the fire department. That same year, a small pump was installed at the Holly Saw Mill to ensure a supply of water for firefighting (Minneapolis Water Works 1919:3). In 1872, Pump

Station No. 1, which had a daily capacity of 2.5 million gallons, was constructed at the foot of Fifth Avenue South above the falls. By 1884, five additional pumps were added at the station, increasing its capacity to 33 million gallons per day. The station was in operation for 27 years (Minneapolis Water Works 1919:3). Pump Station No. 2 was completed on Hennepin Island in 1885, with a capacity of 10 million gallons per day, and Pump Station No. 3 was built in 1888 at Camden, increasing the City's pumping capacity by 30 million gallons per day (Minneapolis Water Works 1919:3-4).

As the water system grew, so did per capita water usage. Prior to the development of municipal water systems in American cities, residents used an average of two to three gallons of water per day. Consumption was limited by the fact that water had to be obtained by manually pumping it from a well and carried to a home or business for use. For those fortunate enough to have an indoor outlet, water was still pumped manually. However, as municipal water systems were constructed to provide ready access to potable water in homes and businesses, per capital consumption increased to 50 to 100 gallons per day (Pursell 2007:140-141). With increased water consumption came increased wastewater. Prior to the development of the sanitary sewer system in Minneapolis, wastewater was dumped in yards and streets, deposited in outhouses, or piped to cesspools. However, as water consumption grew, the amount of waste outgrew the capacity of privies, streets, and cesspools. As a result, the ground became saturated and waste began to seep into basements and wells. One observer of Washington Avenue South in downtown Minneapolis prior to the advent of the sewer system described a street "adorned" with "immense piles of manure, privies, old barrels, boxes, and refuse of back yards" (Jordan 1953:135). To address the growing problem of sewage disposal, the City of Minneapolis decided to build a sewer system to remove the waste.

2.4.1 ESTABLISHMENT OF THE SEWER DIVISION

On June 23, 1869, Minneapolis alderman George A. Brackett introduced a resolution to the Minneapolis City Council calling for the establishment of a sewer system (Hudson 1908:481). The following year, the Minneapolis City Engineer's Department established the Sewer Division. W.D. VanDuzee was appointed the first Sewer Engineer that same year, a position he held until 1894 (Rinker 1910). Carl Illstrup was hired in January 1882 to serve as Assistant Engineer for the Sewer Division as the City embarked on an ambitious plan to expand the sewer system. Illstrup was the Sewer Engineer from 1894 until his retirement on January 1, 1933 (Bjork 1947:51-53). Collectively, VanDuzee and Illstrup were responsible for overseeing the design and growth of the Minneapolis sewer system during this first period of development. Their work was overseen by City Engineer Andrew Rinker (Rinker 1910:422; Stewart 1918).

The Minneapolis sewer system was designed as a combined, gravity-based system which would carry both stormwater and sanitary sewage directly to the Mississippi River (Rinker 1910). Combined systems were built across the nation because the prevailing thought of the time was that separate systems were simply too expensive to build. Moreover, most sanitary engineers of the day believed that rivers would wash away the waste and repurify themselves (Anfinson 2011:116). In preparation for the development of the sewer system, a topographical survey was conducted and scientific data was collected regarding the city's topography and its underlying geology, including the varying elevations of the geological strata to ensure proper flow of the system's contents (Rinker 1910). The system was designed by the sewer engineer to allow sewage to flow at an average rate of 2.75 miles per hour without the use of pumps, which were not included in the system at that time. The city's surface was divided into separate trunk systems based on topographical divisions, and taking into account “the irregular growth and varying necessities of the districts of a western city” (Rinker 1910:423).

2.4.2 EARLY SEWER SYSTEMS IN THE CENTRAL, SOUTH AND SOUTHEAST PARTS OF MINNEAPOLIS

Construction on the first phase of the tunnel system began in 1871 by contractor Spink & Nichols. The first sewer was built along Washington Avenue from 8th Avenue South to Hennepin Avenue, with the outlet at the foot of 8th Avenue South. This first system was designed to drain an area bounded by 8th Avenue South, 7th Street South, Third Avenue North, and the river, with a loop encompassing Glenwood Avenue (then Western Avenue) to the Great Northern railway and Hawthorne Avenue to Lyndale Avenue. From 1871 to 1882, 2.5 miles of trunk and connecting branch sewers (drains) were built as part of this first system (Rinker 1910: 423), which roughly corresponds to the present-day CCTS, and the western portion of the Chicago Avenue tunnel system (see Figure 1).

In 1882, construction began on a second sewer system, designed to drain a district bounded by 13th Avenue South, Franklin Avenue, Nicollet Avenue, 8th Street South, and the river. The outlet was a six-foot brick sewer at 11th Avenue South, which ran up that avenue. That same year, construction of a third system was initiated, designed to drain a district bounded by 14th Avenue South, Franklin Avenue, Fourth Street South, and the river, with a loop between Bloomington and Chicago Avenues out to 25th Street South. The outlet was a six-foot brick sewer coming up 4th Street South from the river and turning up 15th Street South (Rinker 1910:423). This system roughly corresponds to the present-day 11th Avenue tunnel system and the eastern portion of the Chicago Avenue Tunnel System (see Figure 1).

Sewer construction on the east side of the river also began in 1882, with a 15-inch sewer on Central Avenue to drain an area bounded by 4th Avenue Southeast, the river, Second Avenue Northeast, and Division Street; the outlet was later modified so that it discharged into the mill race of the Pillsbury A Mill at Fourth Avenue Southeast rather than emptying directly into the river. Another east side sewer system started that same year began at the foot of 10th Avenue Southeast, to drain a district bounded by Fifth Avenue Southeast, the river, 16th Avenue Southeast, and Spring Street. In 1882 over 3.5 miles of new sewers were constructed, more than the previous eleven years combined. From 1882 to 1888, new construction was limited to branch sewers for the systems constructed up to that point (Rinker 1910:424). The southeast area of the city south of 16th Avenue Southeast was drained by the Oak Street system, on which the city began construction in 1888, and the Hamline Avenue system near Prospect Park in Minneapolis, which was constructed in 1904 (Rinker 1910).

From 1871 to 1886, the City of Minneapolis hired private contractors to construct the sewer tunnels, but in 1885, the receipt of contract bids $40,000 over the City Engineer's estimate prompted the City Engineer's Department to undertake construction using day labor. As a result, while the first, second, and part of the third systems were built by private contractors (including Spink & Nichols; E.T. Sykes & Co.; J.J. Palmer;

Trainer, Forestall & Brandt; J. Gleason & Co.; Tobin Fallon; Thomas Daley; Andrew Dolan; J. Burnes; J.H. Nevins; and R.M. Riner), the remainder of the third system, from 15th Street South to Franklin Avenue, and subsequent sewer systems constructed during the nineteenth and early twentieth centuries, with a few exceptions, were constructed by the City (Rinker 1910:423).

2.4.3 EARLY SEWER SYSTEMS IN THE NORTH AND NORTHEAST PARTS OF MINNEAPOLIS

After Minneapolis built water pumping stations at St. Anthony Falls and on Hennepin Island, it was no longer safe to empty sewage into the river above the falls where it would be taken up into the pumping systems. This, combined with the low elevation of the Bassett Creek valley in North Minneapolis, presented a challenge for constructing sewers in areas that naturally drained into the river upstream of the falls. As a solution, in 1889 a tunnel was constructed from 4th Avenue North to an outfall at the foot of 8th Avenue South, below the falls, to drain the area around Bassett Creek. The tunnel alternated between running northwest-southeast, and north-south, passing through the sandstone beneath the Platville limestone at an average of 81 feet below the street surface. Over 1,000 seepage pipes were inserted into the tunnel's masonry to prevent excess water from filling the tunnel, and a pump was installed at 1st Avenue North to remove additional excess water (Rinker 1910).

Subsequent tunnel construction for north Minneapolis commenced in the 1880s through the early 1900s, and included the North Minneapolis Tunnel in the Basset Creek valley, the 5th Street North system, the 20th Avenue North system (1889), and the 26th Avenue North system (1900). Systems which had just started construction or were planned by 1910 included the 33rd Avenue North, 38th Avenue North, and 42nd Avenue North systems (Rinker 1910). With the construction of new pumping stations for the city water supply at 42nd Avenue North in Camden Place in 1889 and the North East Station further up the river in 1904, which replaced the old pumping stations at the falls and on Hennepin Island, there was no longer anything preventing the construction of outfalls above the falls, since the city water was now pumped from further upriver. As a result, systems such as the 20th Avenue North system which drained approximately 400 acres between 20th and 25th Avenues North, had an outfall at the foot of 20th Avenue North, above the falls. As Rinker noted, “the surface deposit of clay all over North Minneapolis makes these rapid extensions of the sewer systems of the utmost necessity in order to drain the many sloughs formed in every pocket depression of the clay, to make the streets passable in wet weather, and to afford house connections where cesspools have no filtration” (Rinker 1910).

Following the completion of the initial lines at Tenth Avenue Southeast and Central Avenue on the east bank of the river, construction began on a sewer system for Northeast Minneapolis that same year, in 1889. Because the city's water pumping stations were still located near the falls at that time, the first system for Northeast Minneapolis were designed to discharge below the falls. By 1910, Northeast Minneapolis still was served by only one system, which discharged at the mill race of the Pillsbury A Mill at 4th Avenue Southeast, and had an overflow added at the foot of 3rd Avenue Northeast when the pumping stations at the falls and Hennepin Avenue were closed (Rinker 1910).

2.4.4 CONTINUED GROWTH AND DEVELOPMENT OF THE SEWER SYSTEM

Early construction was slow. In just over a decade, between June 1871 and the end of 1881, only 2.5 miles of tunnels had been constructed. However, 1882 was a watershed year for the development of the system (Rinker 1910). From that point on, the pace of construction rapidly accelerated, corresponding with the booming population of the city and its insatiable appetite for water. Annual reports of the City Engineer provide a picture of the growth of the system. In 1892, the City constructed 7.316 miles of new sewers. By the end of 1892, the system consisted of 101.215 miles of sewers and 4.726 miles of tunnels, for a total system length of 105.941 miles. By 1895, a total of 124 miles of egg-shaped sewers were in operation and by 1910, the sewer system was over 200 miles in length and represented an expenditure of $5,371,567 (Rinker 1893; Rinker 1910).

Municipal laws kept pace with the expanding sewer development. In 1877, a law was passed prohibiting the disposal of garbage, dead animals and butchers' offal, and solid refuse of any kind in "any catch-basin, sewer, or drain" (Cooley 1877:106). In 1895, sewer hook-ups to existing buildings was required prior to street paving, and in 1901, it became illegal to construct privies or cesspools on properties on streets where sewer and water connections were available. In 1905, sewer connections became required for all buildings with access to sewers, and if no sewers were available, buildings were required to connect to onsite cesspools (McCarthy and Ward 2000:125; Healy et al. 1905).

The system continued to rapidly develop through the 1910s. In 1914, 21.245 miles of new sewer lines were constructed at a cost of $716,923.22. At the end of 1914, the total length of the system was 376.009 miles, which was comprised of 369.919 miles of sewers and 6.090 miles of tunnels, representing a total investment of $9,847,399.64 (Cappelen 1915). In 1916 alone, 39.653 miles of new sewer lines were constructed. By the end of 1916, the system included 409.572 miles of sewers and 6.381 miles of tunnels, for a total system length of 415.977 miles. In 1918, the City expended $479,907.93 to construct 12.6 miles of sewers, which included 0.418 miles of trunk sewers. At the end of 1918, the system was 441.52 miles in length, representing a total investment of $11,908,198.33 (Cappelen 1921).

It was during the mid-1910s that the city of Minneapolis began construction of a separate storm drain system. The 1914 annual report of the city engineer lists the total length in feet of combined, separate (likely sanitary), and storm water sewer systems constructed prior to January 1, 1915. It includes 117,757.4 feet of the combined system (reinforced concrete), 52,995.7 feet of the sanitary system (vitrified clay pipe and cement pipe), and 1,208.1 feet of the storm water system (vitrified clay pipe) (Cappelen 1915:26). Early construction of these separate systems was initially limited to newly developing areas in Minneapolis and areas around the lakes in the city, where they were needed to relieve local flooding and prevent pollution of the lakes (City of Minneapolis 2012a).

Construction of the sanitary and stormwater systems continued at a steady rate through the 1920s and into the late 1930s as the City of Minneapolis strove to complete the system by 1940 (Fitzsimmons 1931). While construction moved forward at a slightly slower rate than the 1910s, by 1933 the City of Minneapolis had completed approximately 800 miles of sanitary and stormwater sewer lines, representing a total expenditure of $24,100,000 (Bjork 1947:52). It should be noted however, that up until the 1930s, the primary focus had been on growing the system to serve all areas of the city and address capacity concerns. While the system continued to grow in the 1930s, the focus of expansion shifted and a substantial amount of the growth of the Minneapolis sewer system in the 1930s was related to efforts to treat sewage to curb pollution of the Mississippi River (Mathis 2011:17).

2.4.5 THE GROWING PROBLEM OF RIVER POLLUTION

While Minneapolis' combined sewer system greatly improved sanitation and living conditions in the dense urban city, it had one significant drawback—pollution. When the Minneapolis sewer system was first conceived, the primary goal was to develop a system to flush waste out of the city to improve sanitation and allow for further development. At the time, dumping waste into the river to be washed away was commonplace as it was the cheapest and most expedient solution for dealing with refuse and effluence. In 1888, it was observed that Minneapolis was dumping from two to seven hundred wagonloads of refuse into the river each day, not counting the sewage that was entering the river from the city's burgeoning sewer system (Hillman 1887:187). Although some, including University of Minnesota political science professor William Watts Folwell cautioned that "the cleanings of a city are not to be dumped into rivers, lakes, or other waters", little consideration overall was given to how this would affect the river and communities downstream (Folwell 1888:187). Many even believed that the river was self-purifying, and therefore dumping effluence and waste into the river would have no impact downstream.

By this time, increasingly large cities and towns upstream of Minneapolis were emptying waste and sewage into the Mississippi, increasing the level of pollution and resulting in an unsafe water supply for Minneapolis, while Minneapolis in turn polluted the water for its downstream neighbors. With increasing levels of contamination, outbreaks of typhoid fever became common. The period between 1895 and 1910 was characterized by small epidemics interspersed with massive outbreaks. On average, during this period, there were 950 cases of typhoid fever in Minneapolis each year with a mortality rate of 10 percent (Anfinson 2010). That same year, engineer Frederic Bass, the director of the Division of Engineering for the State Board of Heath, published an overview of the importance of purifying sewage by using mechanical filtration and disinfection. He also noted that compared to the combined sewer system, the separate sewer system "is usually the most economical as well as the best adapted for purification works" (Bass 1910:264-265). Also in 1910, City Engineer Andrew Rinker instructed that "where a natural means of surface drainage is at hand it is good policy to utilize this means and thus tax the sewer systems only with house sewerage" (Rinker 1910:425). Even so, it would be a few years before Bass' advice was heeded.

Between 1904 and 1910, Minneapolis studied several options for developing a safe water supply. Two options that were quickly rejected included building a pipeline from Lake Superior or developing a well system. Other options included a pipeline from Lake Mille Lacs or continuing to draw from the Mississippi River. As the debate continued, and as the City sought cheaper solutions, another option emerged in 1908 when Jersey City, New Jersey became the first city in the United States to permanently chlorinate its water supply. As city leaders delayed action, a typhoid epidemic overtook the city at the start of 1910. By mid-March 1910, over 400 people had contracted typhoid, resulting in 45 deaths. After the *Minneapolis Tribune* pleaded with the public to sue the City to take action, the City started to add chlorine to its water, which killed the typhoid bacilli and put a quick end to the epidemic (Anfinson 2010). Soon after the typhoid epidemic ended, the City developed plans for a water treatment facility, which opened in 1913 (Anfinson 2010). While this helped reduce illnesses borne from contaminated drinking water, it did nothing to solve the problem of the large amounts of waste being deposited in the river. In 1927, the Metropolitan Drainage Commission was created by the Minnesota legislature to study pollution in the Mississippi along the Twin Cities (1927 Minnesota Statute Chapter 181).

The turning point in the debate came in 1930, when the U.S. Army Corps of Engineers completed Lock and Dam No. 2 in Hastings. Upon its completion, raw sewage and garbage could no longer continue its trek down the river. Effluence and garbage quickly backed up all the way to the Twin Cities, and the river was described as having floating islands of sewage solids, scum on the water surface, and an abundance of dead fish (City of Minneapolis 2012). It also had a very offensive odor that was noticeable from blocks away (Anfinson 2010). Since the problems were beyond the capabilities of one city, in 1931, the Minnesota Legislature approved $30,000,000 for the construction of the first sewage treatment plant in the Twin Cities. In 1933, the Minnesota State Board of Health ordered the creation of the Minneapolis-St. Paul Sanitary District. The joint sanitary district was established to construct and operate the treatment plant and interceptor lines which would divert the wastewater to the plant. The trunk sewer connections to the interceptors were designed to prevent stormwater from entering the interceptors (City of Minneapolis 1953:XII-b-2). The $30,000,000 project included the treatment plant and interceptor lines that connected with the sewer systems in Minneapolis and St. Paul (*Minneapolis Star* 1938a).

Construction began on the Pig's Eye Treatment Plant in 1935. The prior year, construction began on interceptor sewers on both sides of the Mississippi River at a cost of $16,000,000 to connect all existing combined sewers and convey dry weather flows to the treatment plant (*Minneapolis Star* 1938b; Minneapolis-St. Paul Sanitary District 1938). The opening of the Pig's Eye Treatment Plant in St. Paul in 1938 ushered in a new era of sanitation in the Twin Cities, one based on a coordinated effort to manage sewage on a regional basis.

2.5 Treat or Release It to the River: Combined Sewers Drain to a Treatment Plant (1938–1959)

The start of the "treat or release" period in the history of the Minneapolis sanitary sewer system begins with the opening of the Pig's Eye Treatment Plant in St. Paul in 1938. When this facility opened, flows from the combined sewers systems in Minneapolis and St. Paul were diverted from the Mississippi River to the treatment plant by a system of interceptor sewers located on either side of the Mississippi River. The interceptors on the west side of the river were connected to the ones on the east side by an interceptor under the Mississippi River located just north of Lake Street. As part of this system, 34 overflow regulators[12] were constructed to divert normal dry weather flows to the interceptor sewer. The regulators

[12] A device designed to divert dry-weather flow to the treatment plant, and excess flow to CSOs.

also allowed relief overflows from heavy rain events to empty directly into the Mississippi River (City of Minneapolis 2012b).

Throughout the majority of the “treat or release” period, combined sewers continued to serve most of Minneapolis, including many of the first ring suburbs that bordered the city, although, as previously mentioned, the City had first began construction of separate storm sewers in the mid-1910s. The result of the combined system for most of Minneapolis was that all sewage and nearly all stormwater was conveyed to the Pig’s Eye facility for treatment before being released into the river. As Minneapolis and these first ring suburbs grew, extreme stress was placed on the combined sewer system and the new interceptors to the treatment plant (City of Minneapolis 2012b). Catch basins and roof drains on many buildings were connected to the sanitary sewer lines, resulting in substantial amounts of runoff being diverted into the sanitary sewer system. As a result, even small storms were exceeding the system’s capacity. A consequence was that combined sewer overflows became a regular occurrence. Overflows also resulted in increased flooding of streets and basements throughout the city as the system reached capacity and backed up (City of Minneapolis 2012b).

As a result of the the capacity problems experienced by the combined system, Minneapolis established a separate sanitary district in the newer, southern portion of the city around 1930 (Erickson 1952:34). However, the new stormwater tunnel systems constructed in the early 1930s were predominantly located in the outer portions of the city, and therefore did little to address capacity issues in the city’s core (City of Minneapolis 2012a; Erickson 1952:34). From 1934 on, separation of stormwater and sanitary sewers has been maintained on new construction (City of Minneapolis 1953:XII-a-4). Beginning in 1936 and continuing through 1940, the City completed significant portions of an extensive stormwater drain system (City of Minneapolis 2012a). It was during this time that the majority of the CCTS was constructed (tunnel plats on file at the City of Minneapolis; City of Minneapolis 2016). By the end of 1950, the Sewer Division of the Minneapolis Engineer’s Department was operating two systems that had a combined length of 1,022.62 miles, representing a total investment of $36,076,253.96. This included 786.51 miles of sanitary sewers, 204.34 miles of storm drains, 17.67 miles of interceptors, and 14.1 miles of tunnels (Erickson 1952:34).

The City of Minneapolis’ 1953 city plan stated “the various areas indicated as now served by combined storm and sanitary sewers should be reduced as rapidly as possible by the installation of separate storm drains as funds become available” (City of Minneapolis 1953:XII-c-2). Even though the plan went on to state that “justification for the installation of separate storm drains must be reviewed from time to time as the cost of operation of the sewerage disposal plant varies as does the cost of installation of storm drains,” it concluded that the sewer separation project “can be justified on the basis of operating savings” (City of Minneapolis 1953:XII-d-2). This speaks to the City’s growing commitment to separate storm and sanitary sewers as quickly as was economically feasible.

In 1945, the Water Pollution Control Commission, a branch of the State Board of Health, was established to regulate water pollution (Metropolitan Waste Control 1988:36). Within three years, the first major federal law to address water pollution, the Water Pollution Control Act, was passed in 1948. It was extended in 1952, became permanent legislation in 1956, and was amended in 1965 and 1972 (1972 amendments are discussed in the following section) (Burian et al. 2000:53; EPA 2017a). The Act, and its 1965 amendments, “established a uniform set of water quality standards,” and had as its primary goal the protection of public health, but it was also aimed at preserving the aesthetics of water resources and environmental quality, including the protection of aquatic life (Burian et al. 2000:53). The creation of the Water Pollution Control Commission and the Water Pollution Control Act coincided with, and affirmed, the beginning of the City of Minneapolis’ efforts to reduce the amount of untreated sewage that entered the Mississippi River via CSOs through the switch to separate sanitary and stormwater systems.

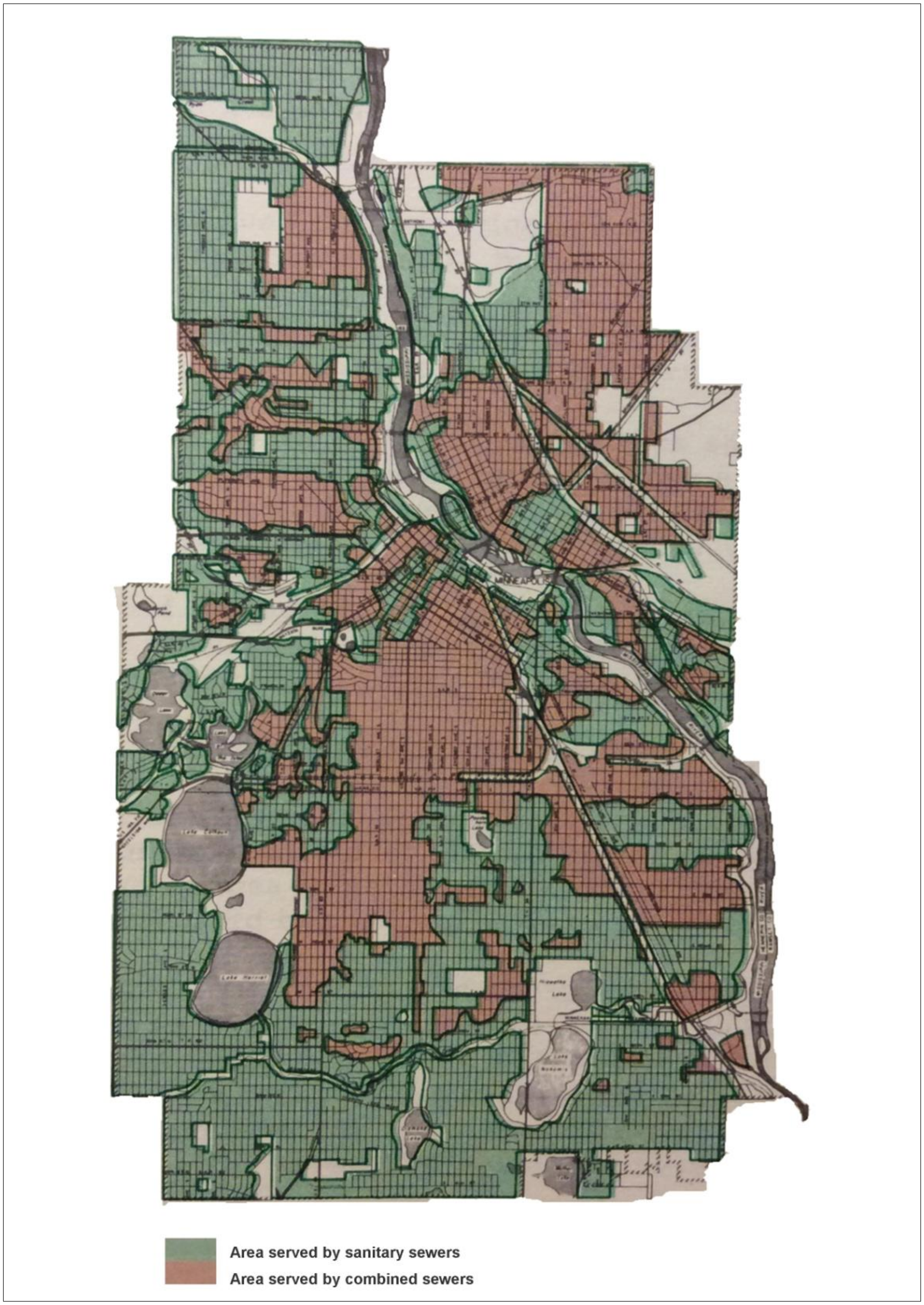


Figure 9. City of Minneapolis Areas Served by Separate Sanitary Sewers Compared to Areas Served by Combined Sewers, 1959. From Toltz, King, Duvall Anderson and Associates, Inc.,1960.

2.6 Begin Combined Sewer Separation: Residential Paving Projects Include Storm Drains (1960–1985)

Substantial portions of south and southwest Minneapolis developed in the 1930s through the 1950s had separate sanitary sewer and stormwater drain systems from the beginning. However, most of the older areas of the city were still served by combined sewers through the late 1950s. By 1960, as the population of the city's core increased and became denser and the number of paved roads and impervious surfaces increased, the amount of storm runoff draining into the combined sewers also increased. These increases in volume resulted in ever-increasing backups into basements and more combined system overflows into the Mississippi River (City of Minneapolis 2012a).

In 1960, the City of Minneapolis began work on a major public works initiative, the reconstruction of almost all of its 600 miles of residential streets. A key component of this major undertaking was the construction of new storm drains in all the areas that were still being served by combined sewers. Areas that were prone to severe flooding were given the highest priority. Hennepin County and the Minnesota Department of Transportation also helped with this effort by including the construction of storm drains with their projects in order to separate existing combined sewers and to add capacity for future separation of upstream combined sewers (City of Minneapolis 2012a). While these major initiatives did not eliminate CSOs into the Mississippi River, major strides were made towards reducing the amount of untreated sewage being dumped into the river.

In 1967, the Metropolitan Council was established by the Minnesota legislature as a regional agency to "plan for the orderly and economical development of the seven-county metro area, and coordinate the delivery of services that couldn't be provided by any one city or county," including transportation and wastewater (Metropolitan Council 2017a). Two years later, the legislature created the Metropolitan Sewer Board of the Twin Cities area, which replaced regional sanitary districts and joint boards, including the Minneapolis-St. Paul Sanitary District (created in 1933), the North Suburban Sanitary Sewer District (created in 1961), and the Southwest Sanitary Sewer District (created in 1968) (1969 Minnesota Laws Chapter 449). That same year, the Minnesota Pollution Control Agency was established, replacing the Water Pollution Control Commission and assuming "authority and responsibility for air and water pollution control and solid waste disposal" (Minnesota Laws 1967 Chapter 882).

These local changes were soon followed by environmental advances at the federal level. In 1970, congress created the Environmental Protection Agency (EPA), and in 1972, the Federal Water Pollution Control Act, commonly known as the Clean Water Act, was passed. The law established a basic structure for regulating pollutant discharges, gave the EPA authority to implement pollution control programs, maintained existing requirements to set water quality standards for surface water contaminants, made it unlawful to discharge pollutants into navigable waters without a permit, funded the construction of sewage treatment plants, and recognized the need for planning to address nonpoint source pollution[13] problems (EPA 2017a). It also gave the EPA authority to establish federal regulations and permit

[13] Pollution resulting from contaminated rainfall or snowmelt runoff.

programs relating to CSOs and Municipal Separate Storm Sewer Systems (MS4) (City of Minneapolis 2016:1-8). The law also advanced the goal of "eliminating all water pollution by 1985 and authorized expenditures of $24.6 billion in research and construction grants" (Burian et al. 2000:53). By providing funding, the federal government reduced pressure on cities to resort to the most cost effective choices for wastewater disposal, thereby supporting their efforts to reduce water pollution (Burian et al. 2000:53).

In 1974, the Metropolitan Sewer Board was renamed the Metropolitan Waste Control Commission. Its purpose was to plan, construct, and operate the wastewater treatment system in the Twin Cities, and coordinate with the Metropolitan Council, Office of Waste Management, and Pollution Control Agency regarding waste collection and treatment (MS 473.141; MS 473.503). This added another layer of coordination and oversight to the development of the separate Minneapolis sewer systems. In the late 1970s, the EPA and the Minnesota Pollution Control Agency worked with the City of Minneapolis to help accelerate the separation project (City of Minneapolis 2006:1-3).

2.7 Completing the Separation of Storm and Sanitary Systems: Great Reduction in CSOs (1986–1996)

In spite of the rapid construction of new storm drains throughout Minneapolis in the 1960s and 1970s, millions of gallons of combined stormwater and sewage were still overflowing directly into the Mississippi River. In 1986, Minneapolis Public Works began an accelerated 10-year program of sewer separation construction aided by state and federal funds called Minneapolis Combined Sewer Overflow Program (CSO Program)—Phase I. Components of the CSO program included roof rainleader[14] disconnection from the storm sewer system, capital improvements, and community outreach and education to minimize runoff and pollution to surface waters (City of Minneapolis 2012a). Under this program, the City completed separation of storm and sanitary sewers for over 96% of Minneapolis, and disconnected more than 2,500 residential and commercial rainleaders that drained directly into the sanitary sewer system. In addition, as a result of this program, all but eight of the original 34 overflow regulators were removed (City of Minneapolis 2012a).

In 1990, the EPA published the rules for Phase I of the National Pollutant Discharge Elimination System (NPDES) stormwater program. The program requires Phase I municipalities, which have populations of 100,000 or more, to implement a stormwater management program to control discharges from MS4; Minneapolis is a Phase I city. The NPDES stormwater program sets requirements that municipalities must meet to discharge stormwater from MS4s into the nation's waters. Cities must apply for permits, which require them to monitor stormwater discharges and control storm drain system pollutants. In 2003, Phase II of the NPDES stormwater program was initiated, which requires smaller municipalities to implement stormwater management programs as well. The Minnesota Pollution Control Agency administers the MS4 permit program in Minnesota (Metropolitan Council 2015:22; EPA 2017b; Omaha Stormwater 2016). On April 19, 1994, the EPA issued the CSO Control policy, which provided a national framework for the control of CSOs through the NPDES permit program (FR Vol. 59, No. 75). The policy required

[14] Rooftop drains or downspouts.

municipalities to drastically reduce or eliminate CSOs and reach the goals set by the Clean Water Act (Tibbetts 2005). This federal permitting program provided another impetus for the continued reduction of CSOs. Regionally, in May 1994, the Metropolitan Waste Control Commission was abolished and its functions were transferred to the Metropolitan Council, under the name Metropolitan Wastewater Services (1994 Minnesota Laws Chapter 628).

2.8 A Minneapolis Separate Drainage System: Light at the End of the Tunnel (1997–Present)

In November 1997, following widespread flooding that occurred in July as a result of torrential downpours, the City of Minneapolis adopted a nine-year flood mitigation program to prevent future flooding caused by overtaxed storm drains. As part of the program, the City sought to ensure that equal levels of drainage protection were in place throughout Minneapolis (City of Minneapolis 2012a). In 1999, the Minneapolis City Council added Chapter 54, "Stormwater Management" to the Minneapolis code of ordinances. Its purpose is to "to minimize negative impacts of stormwater runoff rates, volumes and pollutants on Minneapolis lakes, streams, wetlands, and the Mississippi River by guiding future significant development and redevelopment activity, and by assuring long-term effectiveness of existing and future stormwater management constructed facilities" (City of Minneapolis 2017b). The addition of this ordinance is indicative of the City's ongoing efforts to implement processes that contribute to an increase in water quality in the Metro area by better managing stormwater.

As a result of a 1999–2000 comprehensive planning process and a 2002 study entitled *Combined Sewer Separation Evaluation*, conducted by Brown & Caldwell and jointly funded by the City of Minneapolis and the Metropolitan Council, the Minneapolis CSO Program Phase II was developed. Brown and Caldwell identified inflow rather than infiltration as the major contributor to CSOs, and recommended that the City disconnect public and private sector inflow sources, and study and implement storage and conveyance improvements (City of Minneapolis 2012c:3-4). In 2003, Chapter 56 was added to the Minneapolis Ordinances. The purpose of this ordinance "is to prevent discharges from homes and commercial buildings, that can contribute to the occurrence of a CSO event" (City of Minneapolis 2017a). This ordinance pertains to existing connections, whereas previous city ordinances and state plumbing codes only pertained to new construction. Prohibited connections include "both new and pre-existing roof drains, area drains, and other clear water connections, such as sump pump and foundation drains" (City of Minneapolis 2006a). As part of implementation of this ordinance, the city is authorized to conduct property inspections for private stormwater connections to sanitary sewers (City of Minneapolis 2006a), thereby further ensuring the reduction of stormwater that makes its way into sanitary sewers.

Also in 2003, the Metropolitan Council created the Environment Committee, a "permanent committee consisting of at least six members of the Metropolitan Council," to "provid[e] oversight and review of the Metropolitan Council regional wastewater system and water resource management programs; serv[e] as an informed voice on the Metropolitan Council and other standing committees by relaying the committee perspective when water or system related issues are brought before those committees; [and] serv[e] as a direct channel of communication for the customers of the regional wastewater system" (Metropolitan

Council 2003). Currently, the Metropolitan Council's Environmental Committee "addresses issues of sewer policy and planning, environmental reviews, wastewater facilities and treatment, water supply, nonpoint source pollution, and federal and state regulations" (Metropolitan Council 2017b). The Metropolitan Council Environmental Services (MCES) Division owns and operates the regional sanitary sewer interceptor program (City of Minneapolis 2006). In 2006, the City adopted the Local Surface Water Management Plan. The plan provides guidance on the management of surface waters and stormwater and sanitary sewer networks (City of Minneapolis 2006b).

According to the City of Minneapolis' 2012 report on the Minneapolis CSO Program, which identified remaining CSO sources, all CSO sources in the CCTS were eliminated between 1982 and 2011 (City of Minneapolis 2012c:5), although one of the eight remaining regulators is located at Portland Avenue and Washington Avenue South, within the CCTS area (City of Minneapolis 2012c:8). Storm drains now serve over 95 percent of the City. CSOs have been greatly reduced, but they still occur. The last CSO event was in 2010 (Metropolitan Council 2016:6). Currently, the City of Minneapolis has 55,000 catch basins, 10 stormwater ponds, 565 miles of storm drains, and 22 miles of deep storm tunnels, draining over 50 square miles of storm runoff (City of Minneapolis 2017c). The storm sewer system is operated and maintained by the Surface Water and Sewers Department of Public Works.

3.0 GUIDELINES FOR EVALUATION

NAME OF PROPERTY TYPE: STORMWATER TUNNEL SYSTEM STRUCTURES

The property type consists of stormwater tunnel structures, including storm main tunnels, storm drift tunnels, and storm sewer pipes, as well as connective and operational features such as shaft holes, drill holes, manholes, and catch basins, constructed between 1871 and 1967. The beginning date of 1871 is the date construction began on the first sewer tunnel in Minneapolis, which was built within the project area. The later date reflects NPS guidelines that most properties be at least 50 years old to be eligible for inclusion on the NRHP, unless exceptionally important. Because some of the original combined sewer system structures appear to have become incorporated into the CCTS (see Figure 2, which shows that some components were constructed in the 1880s, and other components have unknown build dates), it is possible that tunnel structures from the earliest time period in the construction of sewer tunnels in Minneapolis are included in the CCTS. Therefore, the earliest build date for sewer tunnels in Minneapolis is used as the beginning date for this context. The latter date reflects NPS guidelines that most properties be at least 50 years old to be eligible for inclusion on the NRHP, unless exceptionally important. Although the research conducted for this study did not locate mention of storm tunnel system structures constructed before 1914, if any such structures were found, they may be evaluated for NRHP eligibility using this context. Tunnels that were constructed prior to 1914 as sanitary tunnels, and later converted to storm tunnels, are addressed within this context, and referred to by their usage during the time period in discussion.

In order to be eligible for listing in the NRHP, a stormwater tunnel system structure must retain sufficient integrity to be able to convey its historical significance. The seven aspects of integrity for stormwater tunnel system structures are defined as follows:

- Location: the place where the stormwater tunnel system structure was constructed
- Setting: the physical environment of the stormwater tunnel system structure
- Design: the combination of elements that create the form, plan, space, structure, and style of the storm tunnel system structure
- Materials: the physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form the stormwater tunnel system structure
- Workmanship: the physical evidence of the crafts of a particular culture or people during any given period in history
- Feeling: the stormwater tunnel system structure’s expression of the aesthetic or historic sense of a particular period of time
- Association: the direct link between an important historic event or person and the stormwater tunnel system structure (NPS 1997).

The NRHP criteria, which are used to assess the significance of properties, are summarized below:

- Criterion A – association with the events that have made a significant contribution to the broad patterns of our history;
- Criterion B – association with the lives of persons significant in our past;

- Criterion C – embodiment of the distinctive characteristics of a type, period, or method of construction; representation of the work of a master; possession of high artistic values; or representation of a significant and distinguishable entity whose components may lack individual distinction; or
- Criterion D – potential to yield information important to prehistory or history (NPS 1997).

Under NRHP Criterion A, a stormwater tunnel system structure may be eligible for its association with events that have made a significant contribution to the broad patterns of local history, especially in relation to municipal services and the development of the City of Minneapolis's stormwater tunnel system, which was constructed over nearly a century to address changing understanding of, and needs related to, public health and environmental quality. A stormwater tunnel system structure needs to retain sufficient integrity of location, setting, feeling, and association in order to convey its significance under Criterion A.

This context and research has not identified any individuals who were significant within the development and construction of stormwater tunnel system structures to make a particular structure eligible under Criterion B. However, further research may allow for a stormwater tunnel system structure to be eligible under Criterion B for association with an individual if it can be demonstrated that the structure illustrates this individual's historic contributions to the stormwater tunnel system.

Under NRHP Criterion C, a stormwater tunnel system structure must meet one or more of the following:

- The structure must be the best extant example of a particular type, period, or method of construction, or
- The structure must represent a significant and distinguishable entity whose components may lack individual distinction. It should retain the distinctive form, proportion, and material characteristics to be a true representative of a certain method of engineering.

A stormwater tunnel system structure needs to retain sufficient integrity of design, materials, workmanship, and feeling in order to convey its significance under Criterion C.

This context and research has not identified any stormwater tunnel system structure that has the potential to answer important research questions about human history such that it would be eligible under Criterion D. The construction methods, materials, and locations of stormwater structures in Minneapolis are generally well understood and well documented, therefore, it is unlikely that they would yield information important in prehistory or history. However, further research may allow for a stormwater tunnel system structure to be eligible under Criterion D if it demonstrates the potential to contribute to our understanding of the development of the stormwater tunnel system.

Based on this context, stormwater tunnel structures in Minneapolis built between 1871 and 1967 have the potential to be eligible for listing in the NRHP under Criteria A and/or C.

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APPENDIX A: PROJECT PERSONNEL

LIST OF PERSONNEL

Project Manager	Jennifer Bring, B.A.
Principal Investigator	Saleh Miller, M.S.
Historian	Nicole Foss, M.A.
Researchers	Nicole Foss, M.A. Erin Que, M.A.

Appendix F

Drawings

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CITY OF MINNEAPOLIS, MINNESOTA
CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS
CITY PROJECT NO. CSW1740STCCDES2

CONSTRUCTION PLAN FOR EXPANSION AND IMPROVEMENTS

LOCATED ON WASHINGTON AVENUE FROM PORTLAND AVENUE S. TO HENNEPIN AVENUE

GOVERNING SPECIFICATIONS

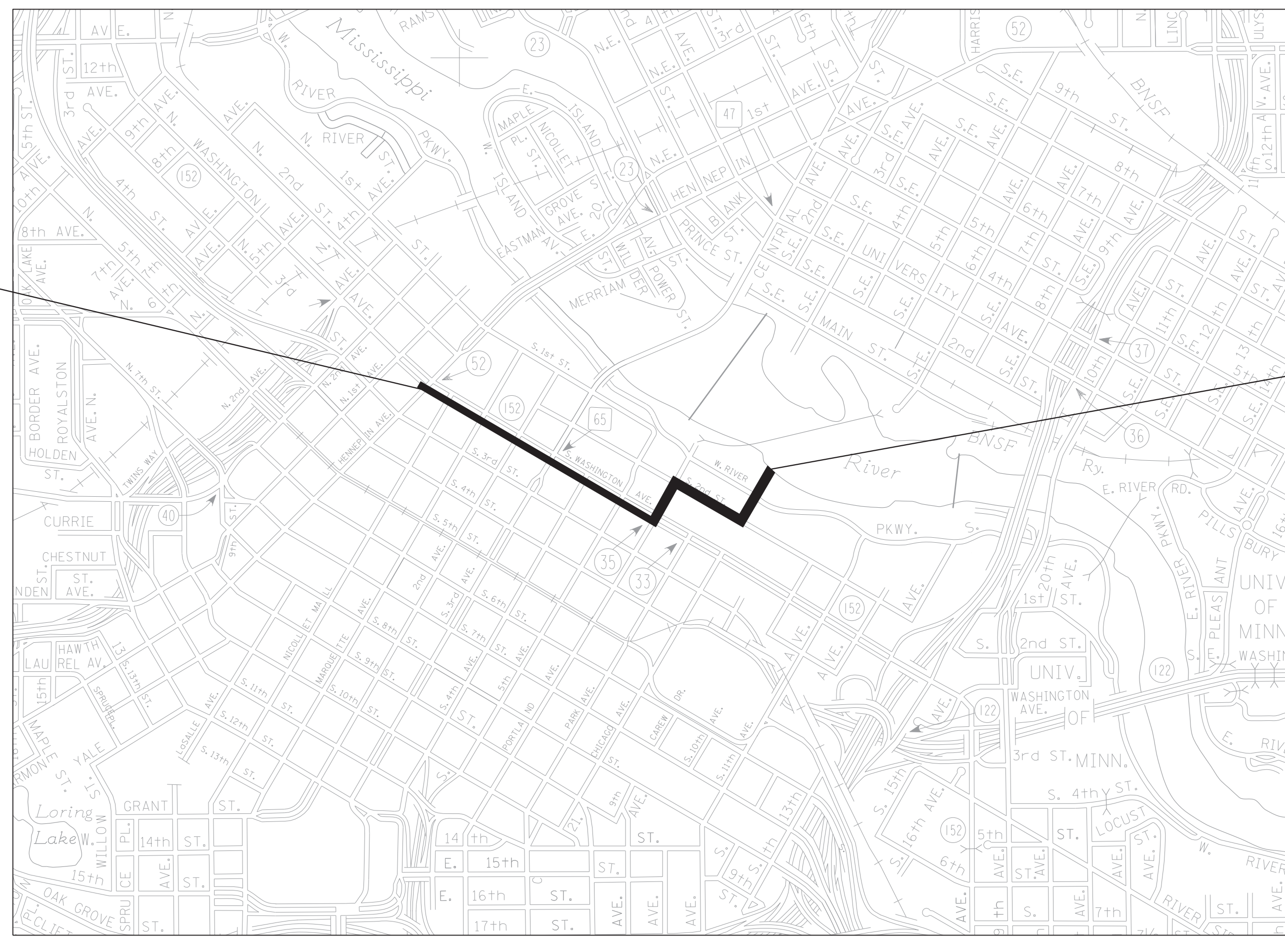
THE 2014 EDITION OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION "STANDARD SPECIFICATIONS FOR CONSTRUCTION" AND THE 2014 EDITION OF THE "MATERIALS LAB SUPPLEMENTAL SPECIFICATIONS FOR CONSTRUCTION" SHALL GOVERN.
ALL TRAFFIC CONTROL DEVICES SHALL CONFORM AND BE PLACED IN ACCORDANCE TO THE "MINNESOTA MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES" (MN MUTCD) AND PART VI, "FIELD MANUAL FOR TEMPORARY TRAFFIC CONTROL ZONE LAYOUTS".

INDEX

THIS PLAN CONTAINS 12 SHEETS

END PROJECT
℄ STORM TUNNEL
STA. 55+45

BEGIN PROJECT
℄ STORM TUNNEL
STA. 10+00.00



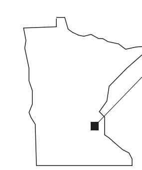
CDM Smith

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE ____________

DATE - LIC. NO. - PRINT NAME -

PLAN REVISIONS		
DATE	SHEET NO.	APPROVED BY



PROJECT LOCATION
COUNTY : HENNEPIN
DISTRICT : METRO

APPROVED: MINNEAPOLIS CITY ENGINEER OR DEPUTY CITY ENGINEER ____ DATE

APPROVED: DIRECTOR, TRAFFIC & PARKING SERVICES ____ DATE

APPROVED: DIRECTOR, TRANSPORTATION ENGINEERING & DESIGN ____ DATE

APPROVED: DIRECTOR, TRANSPORTATION PLANNING & PROGRAMMING ____ DATE

APPROVED: DIRECTOR, TRANSPORTATION MAINTENANCE & REPAIR ____ DATE

APPROVED: DIRECTOR, SURFACE WATER & SEWERS ____ DATE

APPROVED: DIRECTOR, WATER TREATMENT & DISTRIBUTION ____ DATE

N

SCALES

INDEX MAP		1000'
GENERAL LAYOUT		-
PLAN		-
PROFILE	20' HORIZ.	10' VERT.
X-SECTION	- HORIZ.	- VERT.

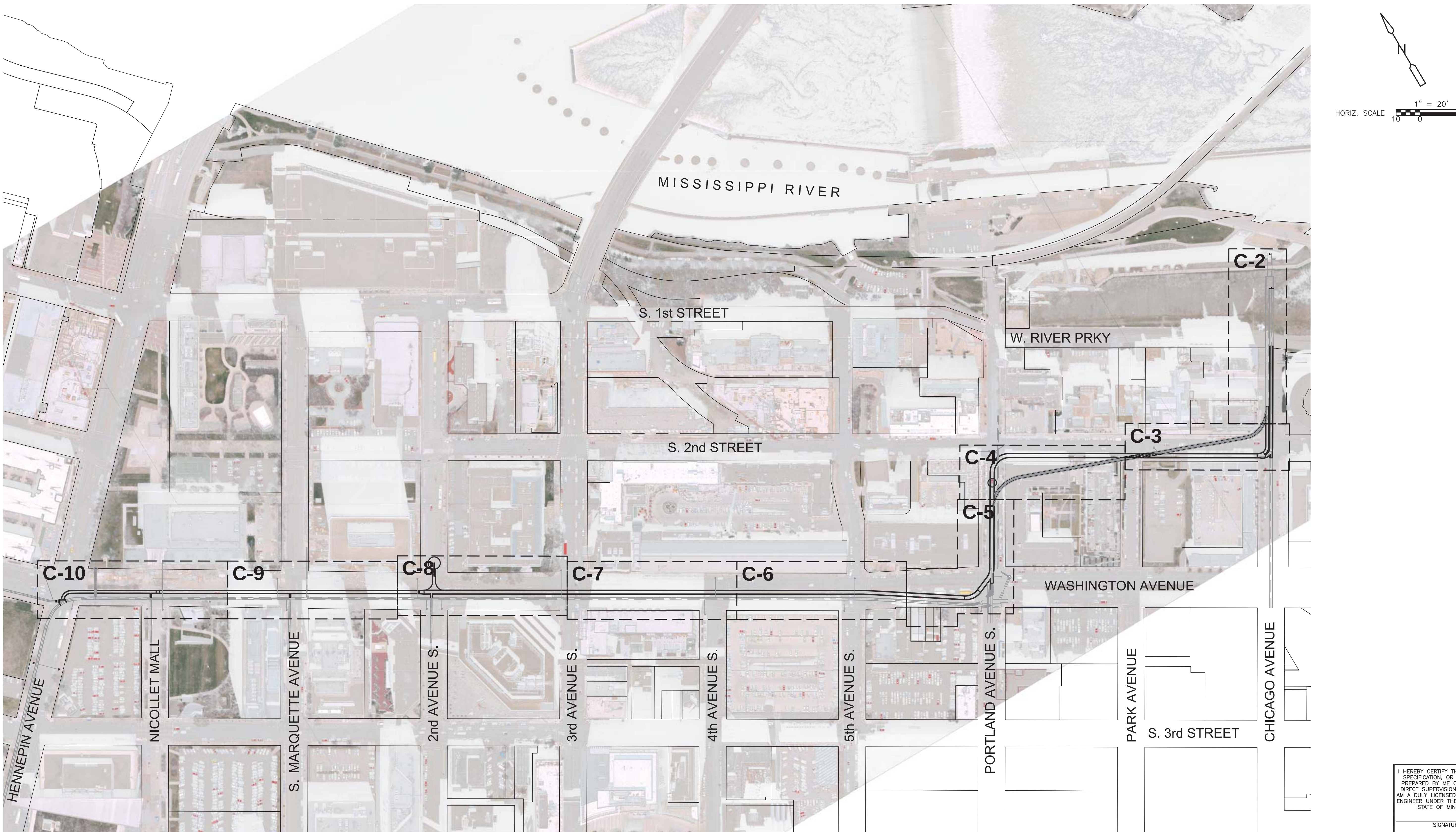
HORIZONTAL DATA;
HENNEPIN COUNTY COORDINATE SYSTEM
DATUM: NAD83, 1986 ADJUSTMENT
UNITS: US SURVEY FEET
VERTICAL DATA: NGVD 29

I HEREBY CERTIFY THAT THE FINAL FIELD CHANGES, IF ANY, OF THIS PLAN WERE MADE BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE ____________

DATE ______ LIC. NO. ______ PRINT NAME ______

THE SUBSURFACE UTILITY INFORMATION IN THIS PLAN IS UTILITY QUALITY LEVEL D. THIS QUALITY LEVEL WAS DETERMINED ACCORDING TO GUIDELINES OF CI/ASCE 38-02, ENTITLED "STANDARD GUIDELINES FOR THE COLLECTION AND DEPICTION OF EXISTING SUBSURFACE UTILITY DATA".



I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE

TYPED NAME

REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

CDM Smith
7650 Currell Boulevard, Suite 300
Woodbury, MN 55125
Tel: (651) 252-3800

DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

SHEET LAYOUT PLAN

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO.

C-1

2 OF 12

10% SUBMITTAL - NOT FOR CONSTRUCTION - JANUARY 2018

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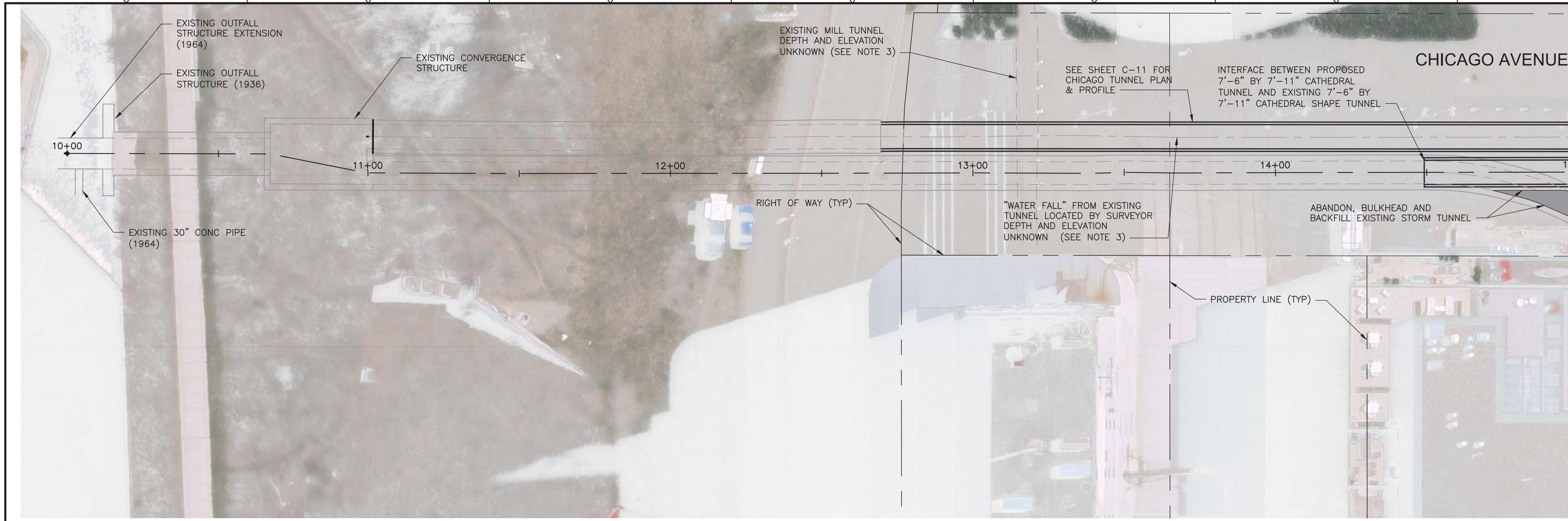


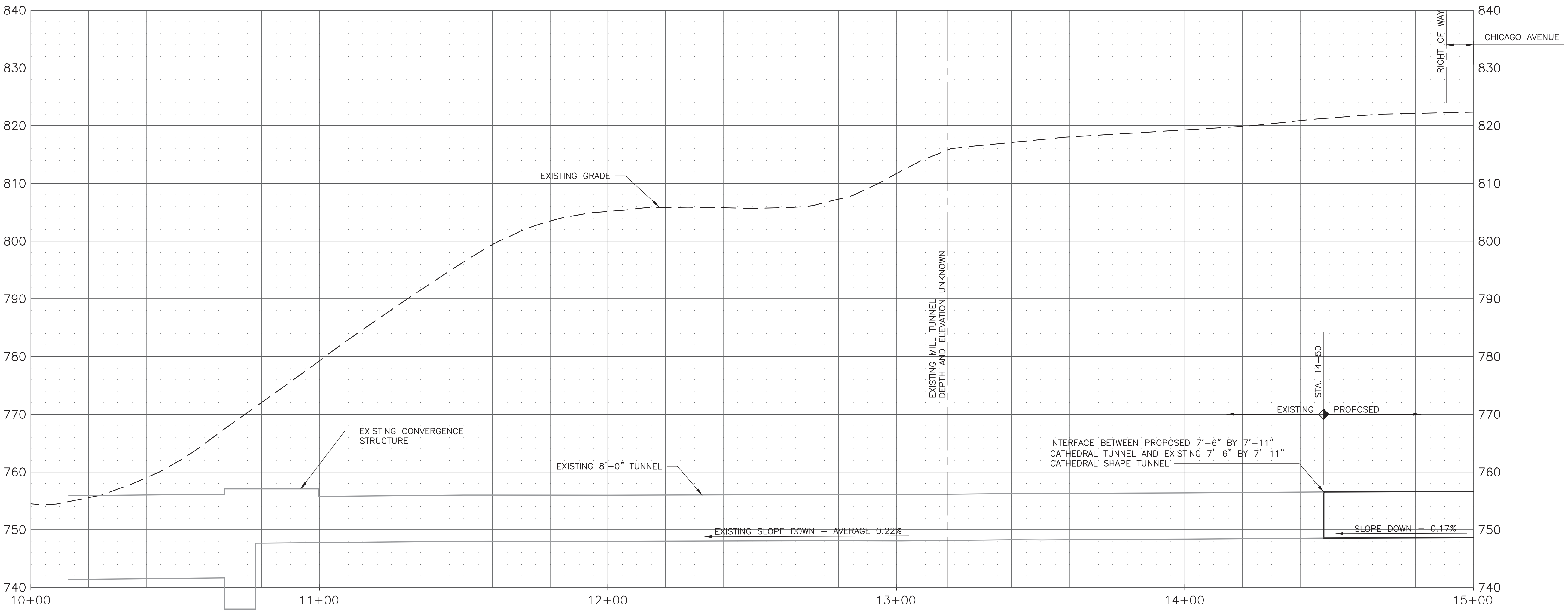
MATCH LINE STA. 15+00
SEE SHEET C-3 FOR CONTINUATION

N

HORIZ. SCALE 1" = 20' (10 0 20)

VERT. SCALE 1" = 10' (5 0 10)

NOTES
1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.
3. CONFLICTS WITH MILL TUNNEL TO BE RESOLVED DURING DESIGN PHASE BASED ON SURVEY RESULTS.



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REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

CDM Smith
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DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL
PLAN & PROFILE
STA 10+00 TO STA 15+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO.

C-2

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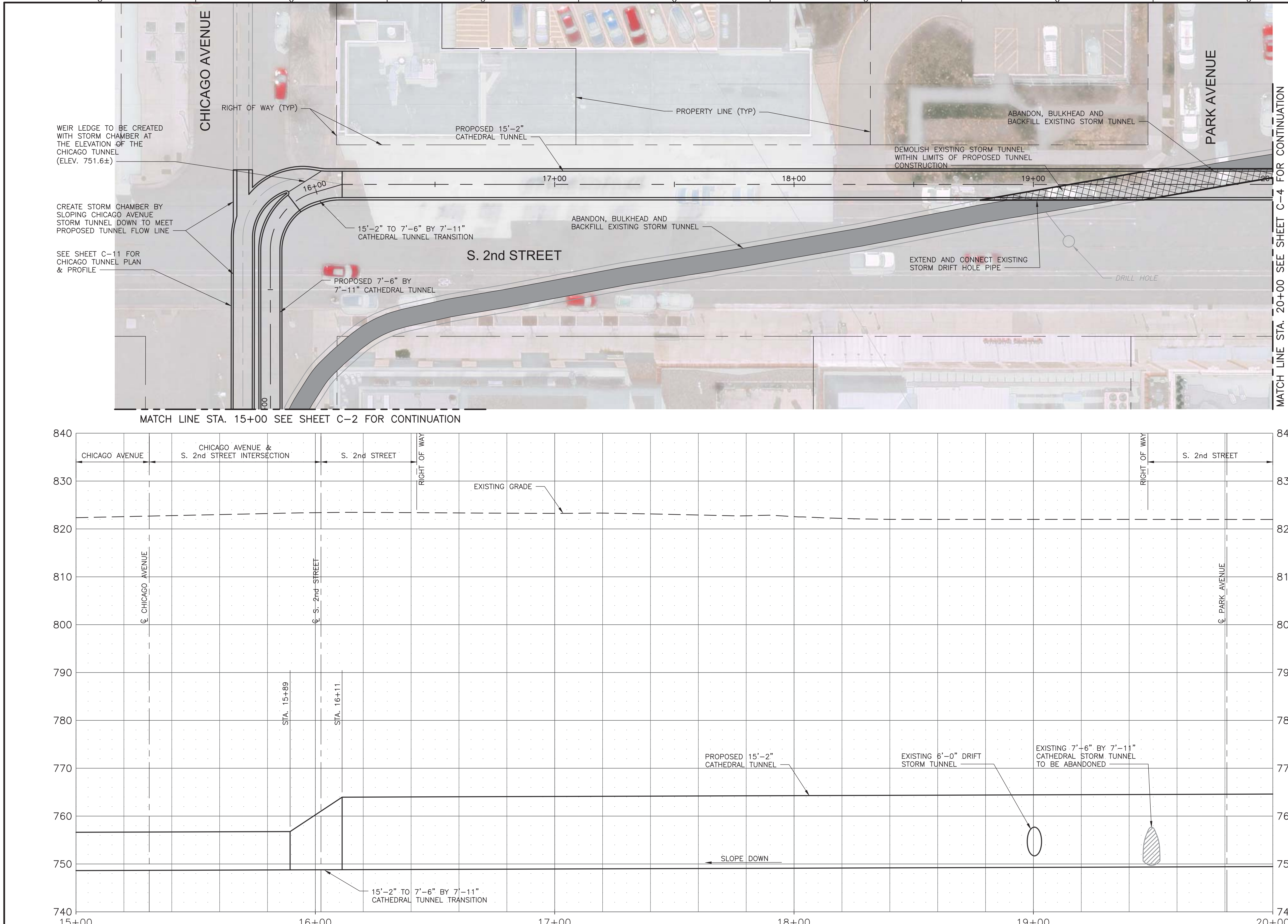

N

HORIZ. SCALE 1" = 20' (10 0 20)

VERT. SCALE 1" = 10' (5 0 10)

NOTES

1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.

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SIGNATURE

TYPED NAME

REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

CDM Smith
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Woodbury, MN 55125
Tel: (651) 252-3800

DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL PLAN & PROFILE STA 15+00 TO STA 20+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO.

C-3

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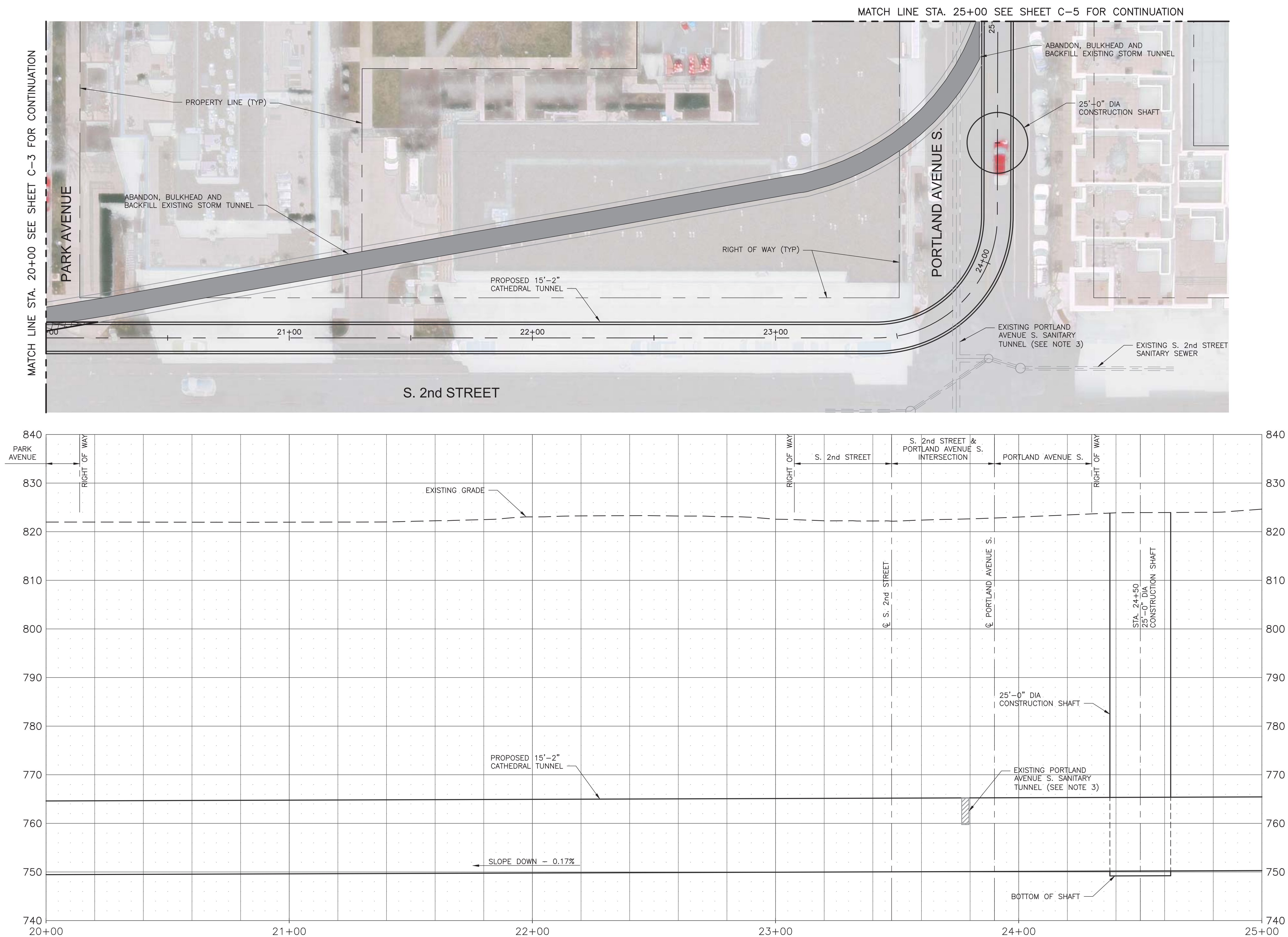

N

HORIZ. SCALE 1" = 20' (10 0 20)

VERT. SCALE 1" = 10' (5 0 10)

NOTES

1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.
3. CONFLICTS WITH EXISTING SANITARY TUNNEL TO BE RESOLVED DURING DESIGN PHASE BASED ON SURVEY RESULTS.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE

TYPED NAME

REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

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DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL PLAN & PROFILE STA 20+00 TO STA 25+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO. C-4

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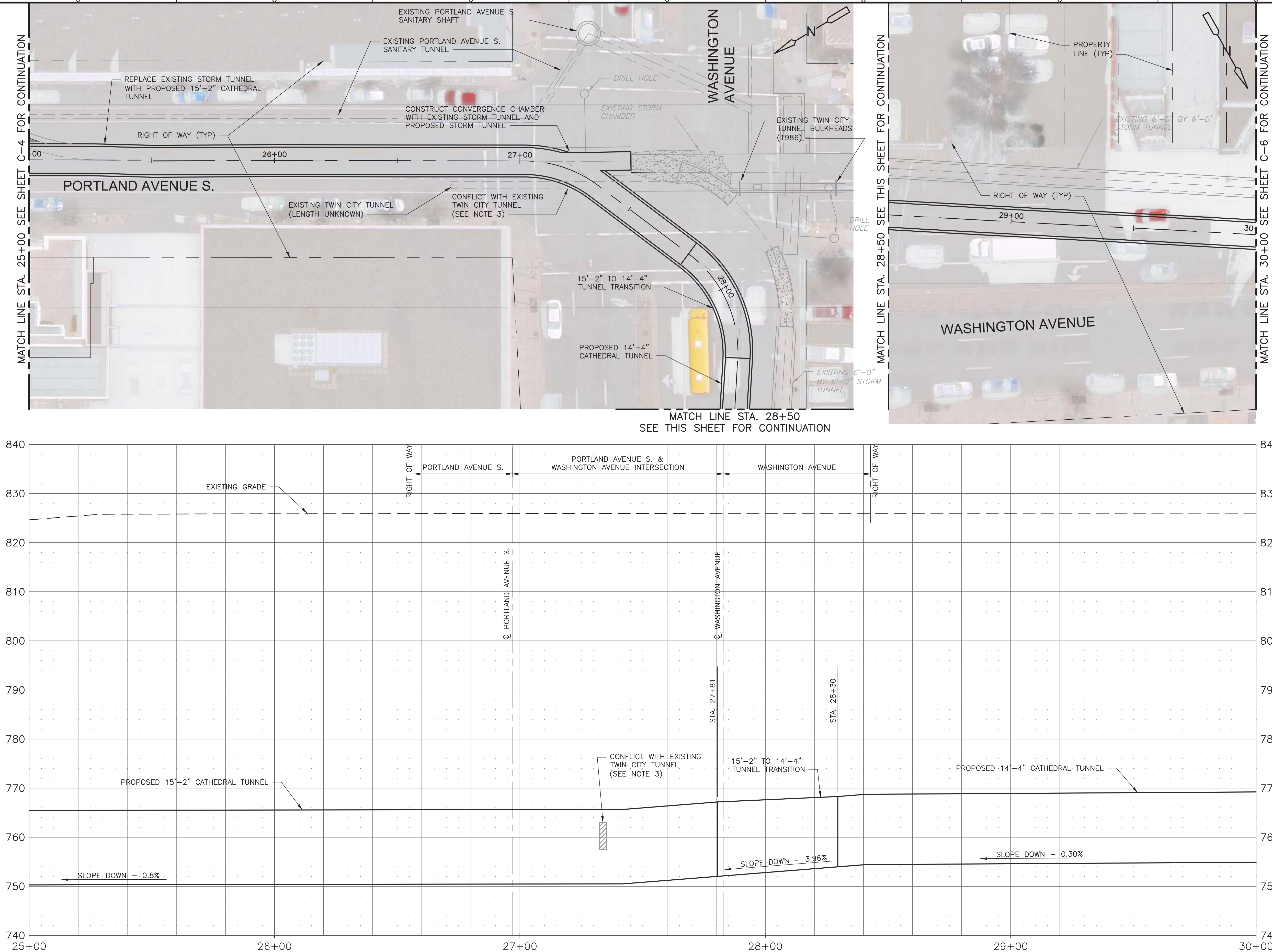

HORIZ. SCALE 1" = 20' (10 0 20)

VERT. SCALE 1" = 10' (5 0 10)

NOTES

1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.
3. CONFLICTS WITH TWIN CITY TUNNEL TO BE RESOLVED DURING DESIGN PHASE BASED ON SURVEY RESULTS.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

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TYPED NAME

REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

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Woodbury, MN 55125
Tel: (651) 252-3800

DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL PLAN & PROFILE STA 25+00 TO STA 30+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO. **C-5**

10% SUBMITTAL - NOT FOR CONSTRUCTION - JANUARY 2018

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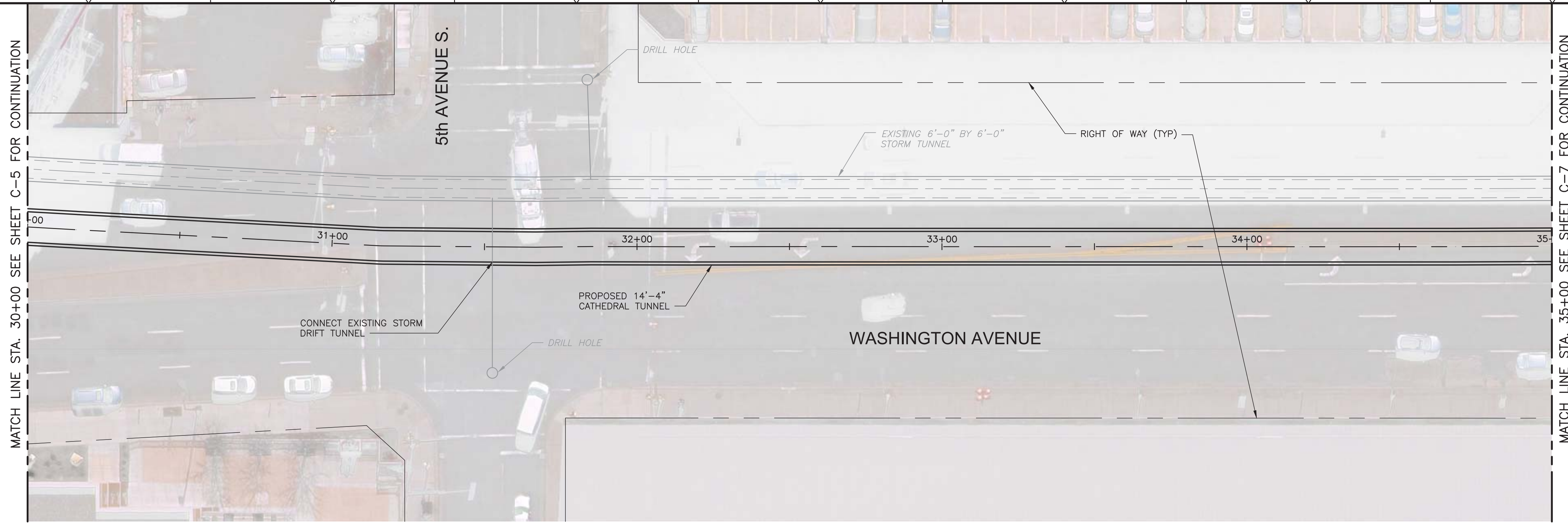

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VERT. SCALE 1" = 10' (5, 0, 10)

NOTES
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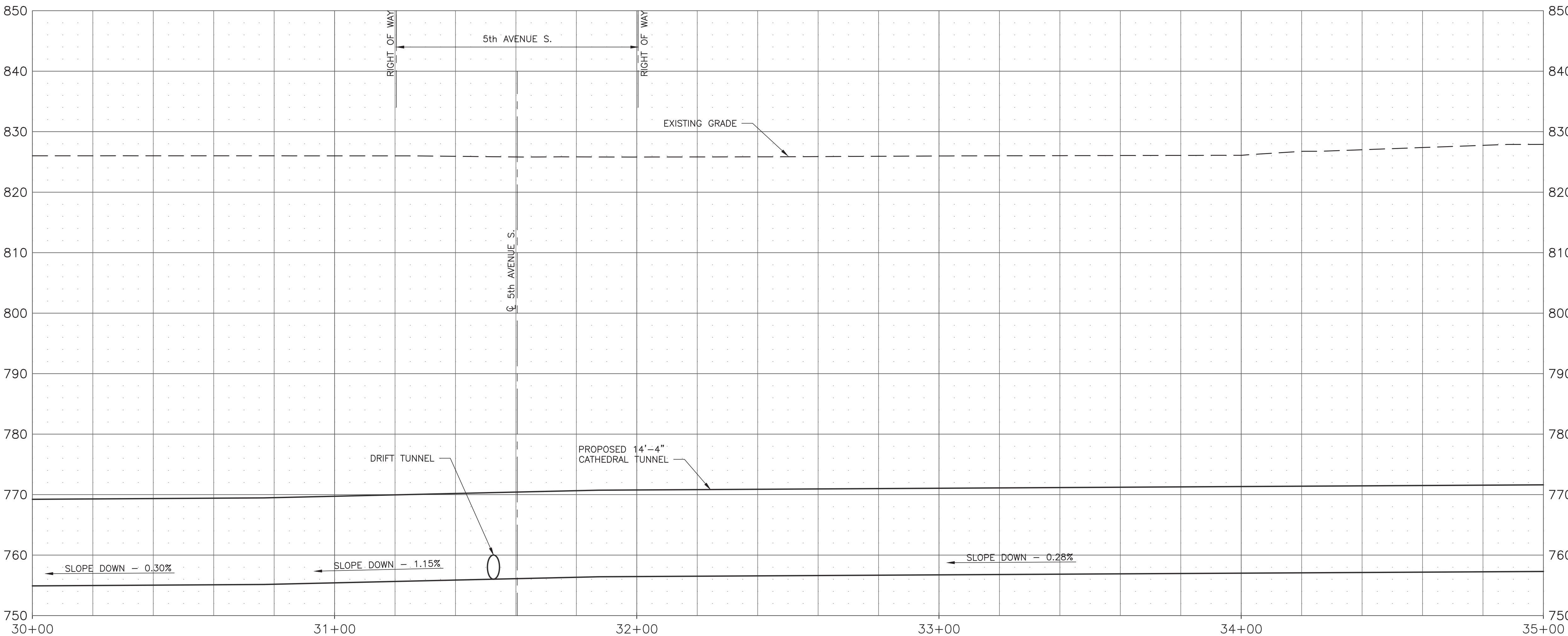
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.



I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE

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REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

CDM Smith
7650 Currell Boulevard, Suite 300
Woodbury, MN 55125
Tel: (651) 252-3800

DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL PLAN & PROFILE
STA 30+00 TO STA 35+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP
SHEET NO.
C-6
7 OF 12

10% SUBMITTAL - NOT FOR CONSTRUCTION - JANUARY 2018

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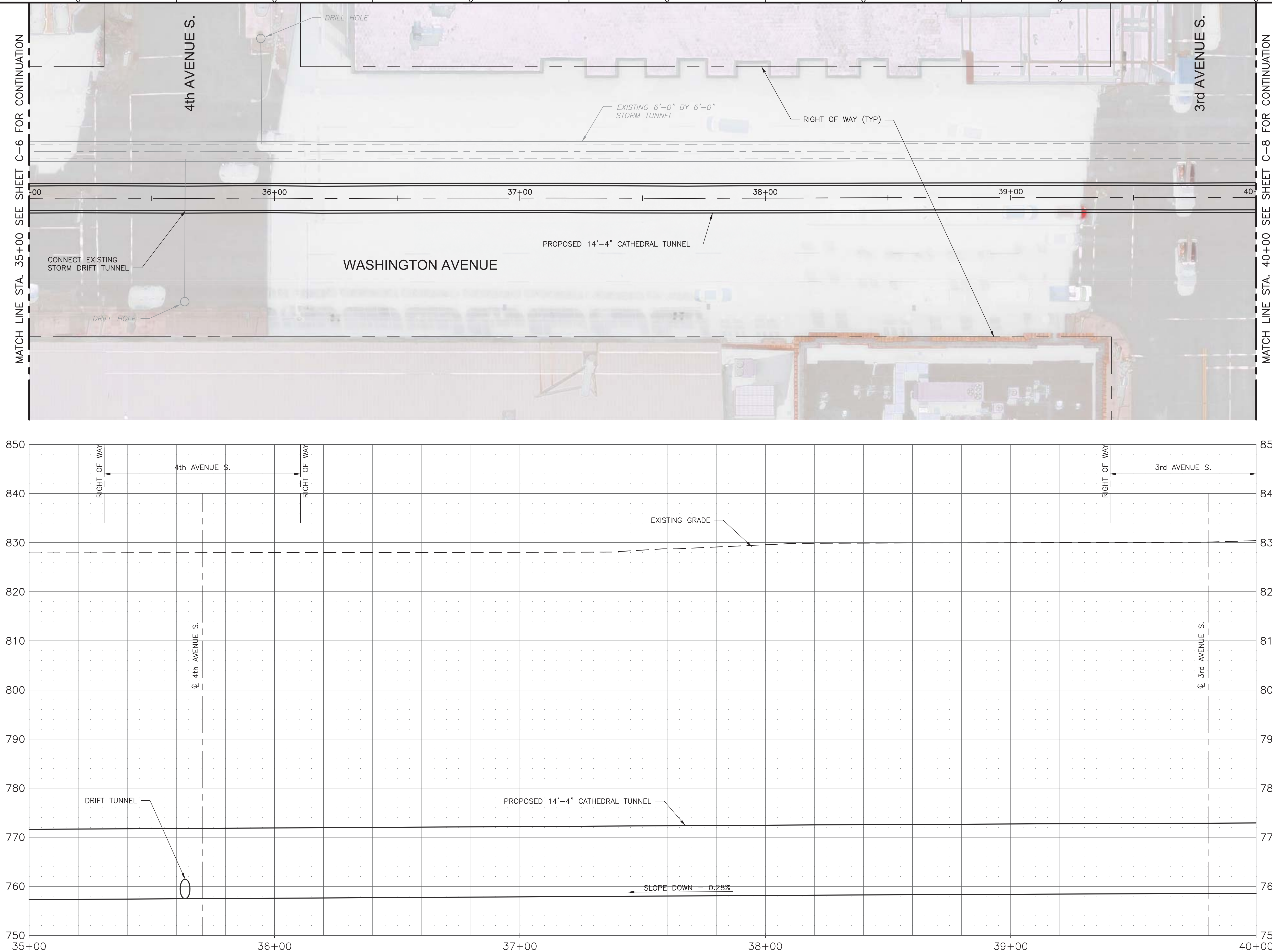

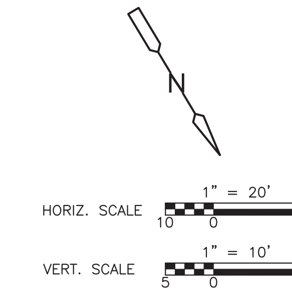

NOTES
1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE

TYPED NAME

REGISTRATION NUMBER

DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

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Woodbury, MN 55125
Tel: (651) 252-3800

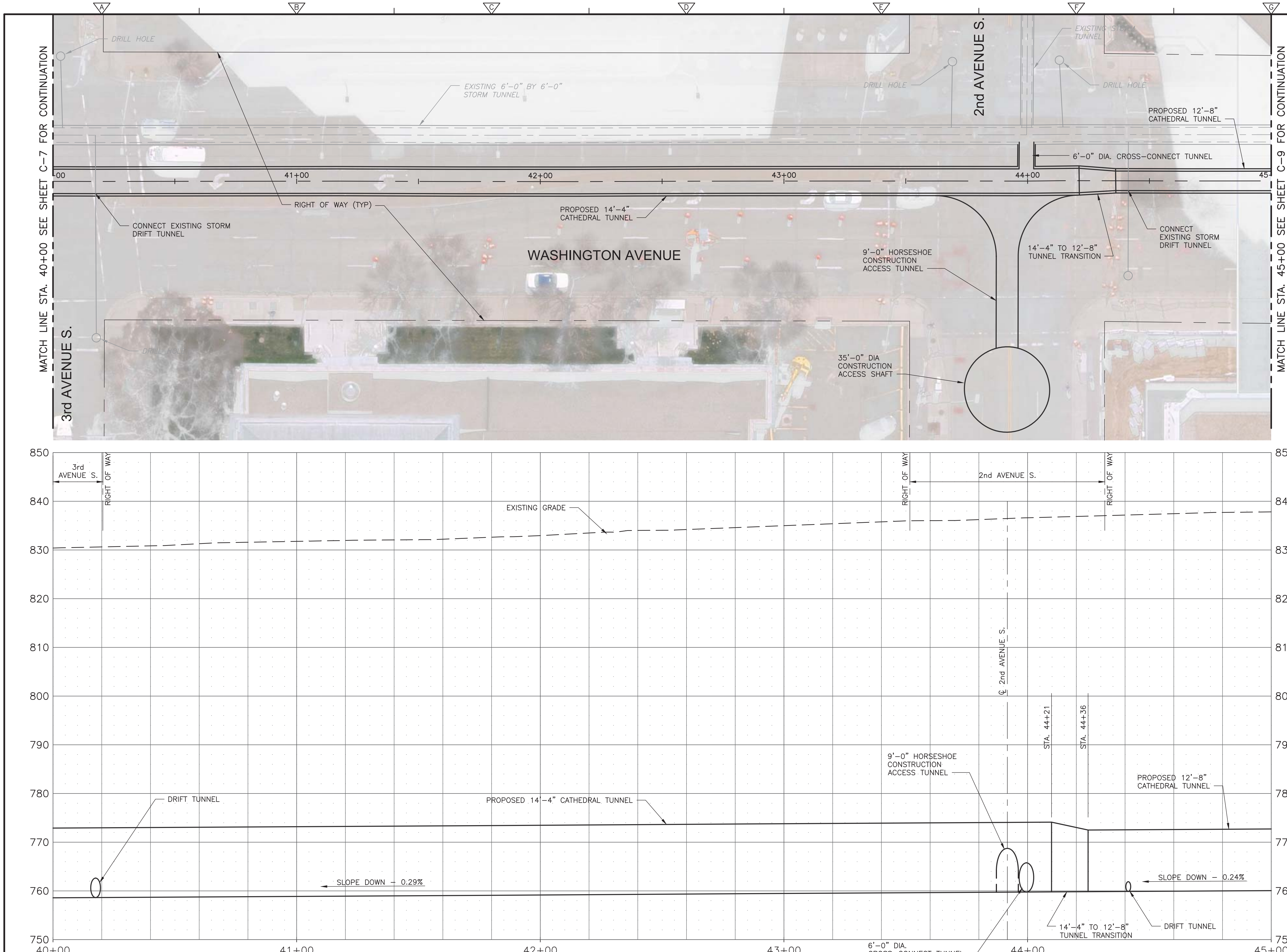
DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL
PLAN & PROFILE
STA 35+00 TO STA 40+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO.
C-7



HORIZ. SCALE 1" = 20'

VERT. SCALE 1" = 10'

NOTES
1. UTILITIES NOT SHOWN.
2. TOP OF ROCK AND OTHER GEOLOGIC DATA TO BE DETERMINED BY SUBSURFACE BORINGS DURING DESIGN PHASE.
3. DURING THE FINAL DESIGN IT WILL BE DETERMINED IF THE CONSTRUCTION ACCESS TUNNEL AND SHAFT WILL BE BACK FILLED.

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISIONS AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE
TYPED NAME
REGISTRATION NUMBER
DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
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APPROVED BY: J. POLZIN
DATE: JANUARY 2018

CDM Smith
7650 Currell Boulevard, Suite 300
Woodbury, MN 55125
Tel: (651) 252-3800

DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL PLAN & PROFILE STA 40+00 TO STA 45+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP
SHEET NO.
C-8
9 OF 12

10% SUBMITTAL - NOT FOR CONSTRUCTION - JANUARY 2018

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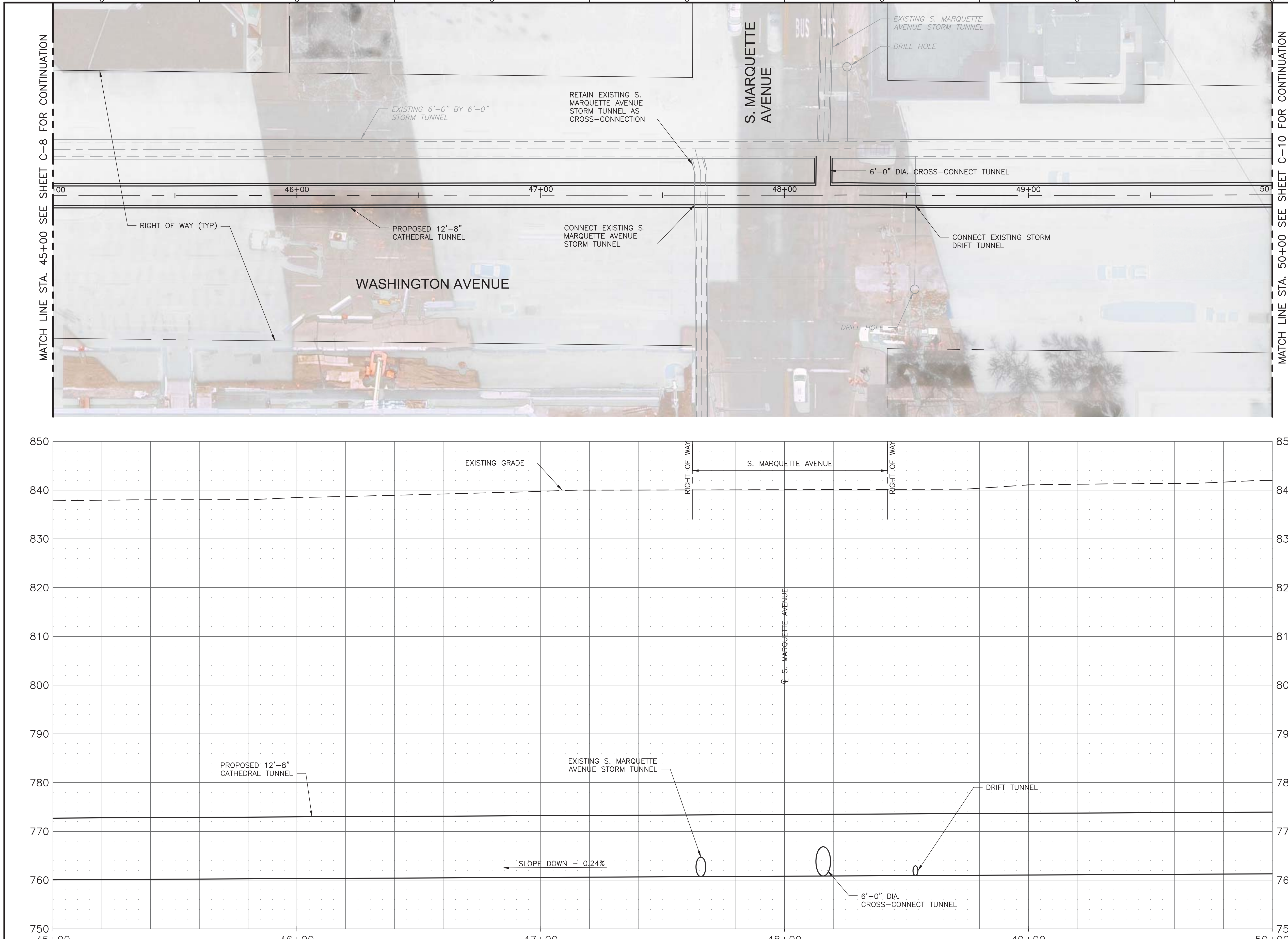

N

HORIZ. SCALE 1" = 20' (10 0 20)

VERT. SCALE 1" = 10' (5 0 10)

NOTES
1. UTILITIES NOT SHOWN.
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DATE

REV. NO.	DATE	DRWN	CHKD	REMARKS

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DATE: JANUARY 2018

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Woodbury, MN 55125
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DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL
PLAN & PROFILE
STA 45+00 TO STA 50+00

PROJECT NO. 33011-212367
FILE NAME: C001STPP

SHEET NO.
C-9
10 OF 12

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NOTES
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DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED TUNNEL
PLAN & PROFILE
STA 50+00 TO STA 55+45

PROJECT NO. 33011-212367
FILE NAME: C001STPP
SHEET NO.
C-10
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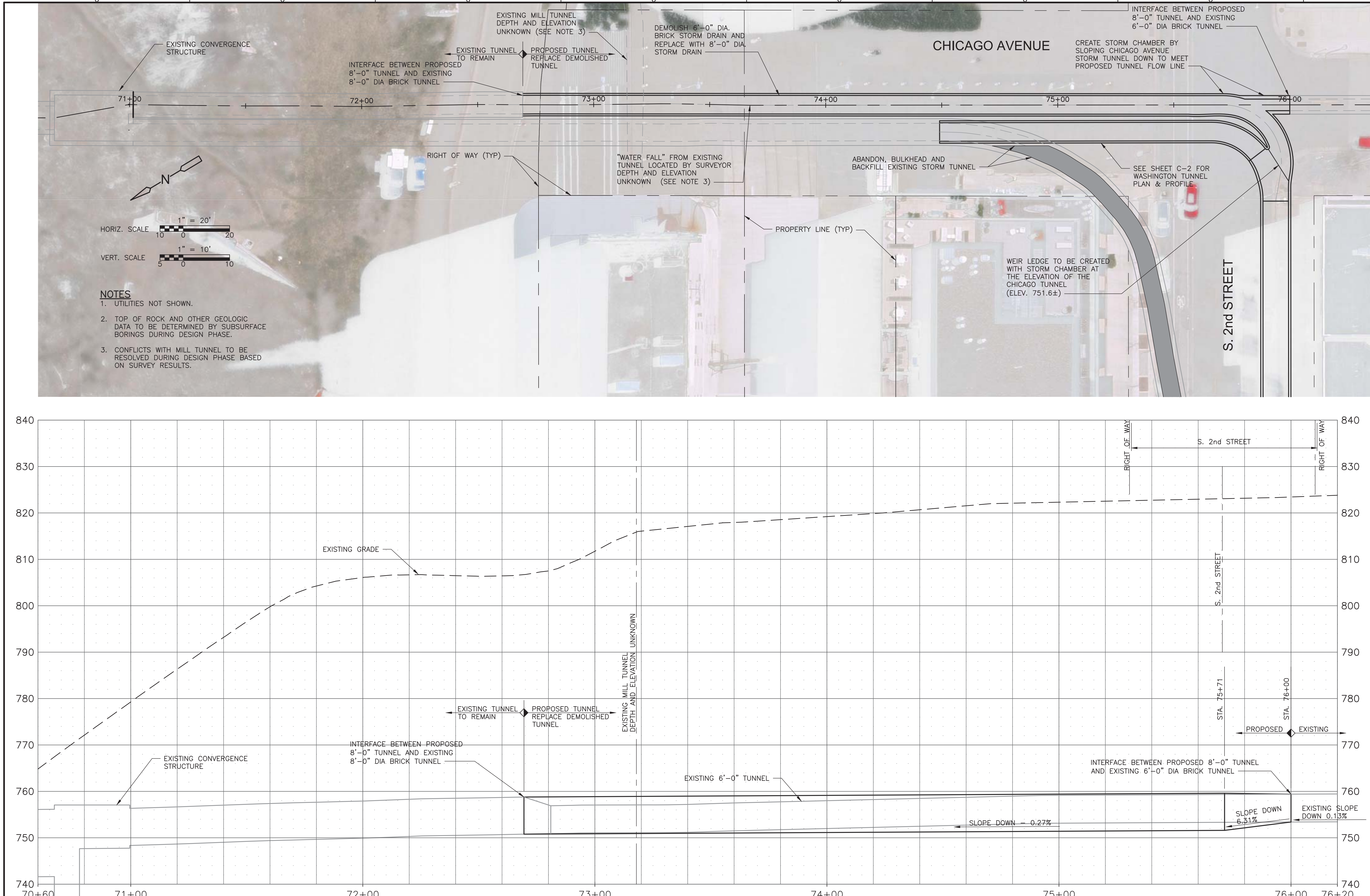

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SAVE DATE: Feb 5, 2018 9:31 AM BY: Zeilerbs
XREFS: CEP000ST 212367-CDMS_2234 CEP102ST CWP100ST
PLOT DATE: Feb 5, 2018 9:48 AM BY: Zeiler, B. Sid

REV. NO.	DATE	DRWN	CHKD	REMARKS

DESIGNED BY: G. SANDERS
DRAWN BY: S. ZEILER
SHEET CHK'D BY: A. PROK
CROSS CHK'D BY: M. KHWAJA
APPROVED BY: J. POLZIN
DATE: JANUARY 2018

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DEPARTMENT OF PUBLIC WORKS, CITY OF MINNEAPOLIS

CENTRAL CITY TUNNEL SYSTEM
EXPANSION AND IMPROVEMENTS

PROPOSED CHICAGO TUNNEL MODIFICATIONS
PLAN & PROFILE
STA 70+00 TO STA 76+20

I HEREBY CERTIFY THAT THIS PLAN, SPECIFICATION, OR REPORT WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY LICENSED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF MINNESOTA.

SIGNATURE

TYPED NAME

REGISTRATION NUMBER

DATE

PROJECT NO. 33011-212367
FILE NAME: C001STPP
SHEET NO.
C-11
12 OF 12

10% SUBMITTAL - NOT FOR CONSTRUCTION - JANUARY 2018