Addendum 1

Central City Tunnel System Feasibility Study

Central City Tunnel System Pressure-Mitigation Options

Prepared for
City of Minneapolis

July 2015

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Certifications

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly License Professional Engineer under the laws of the State of Minnesota.

July 27, 2015

Brandon Barnes

PE #: 49540

Date

1.0 Background

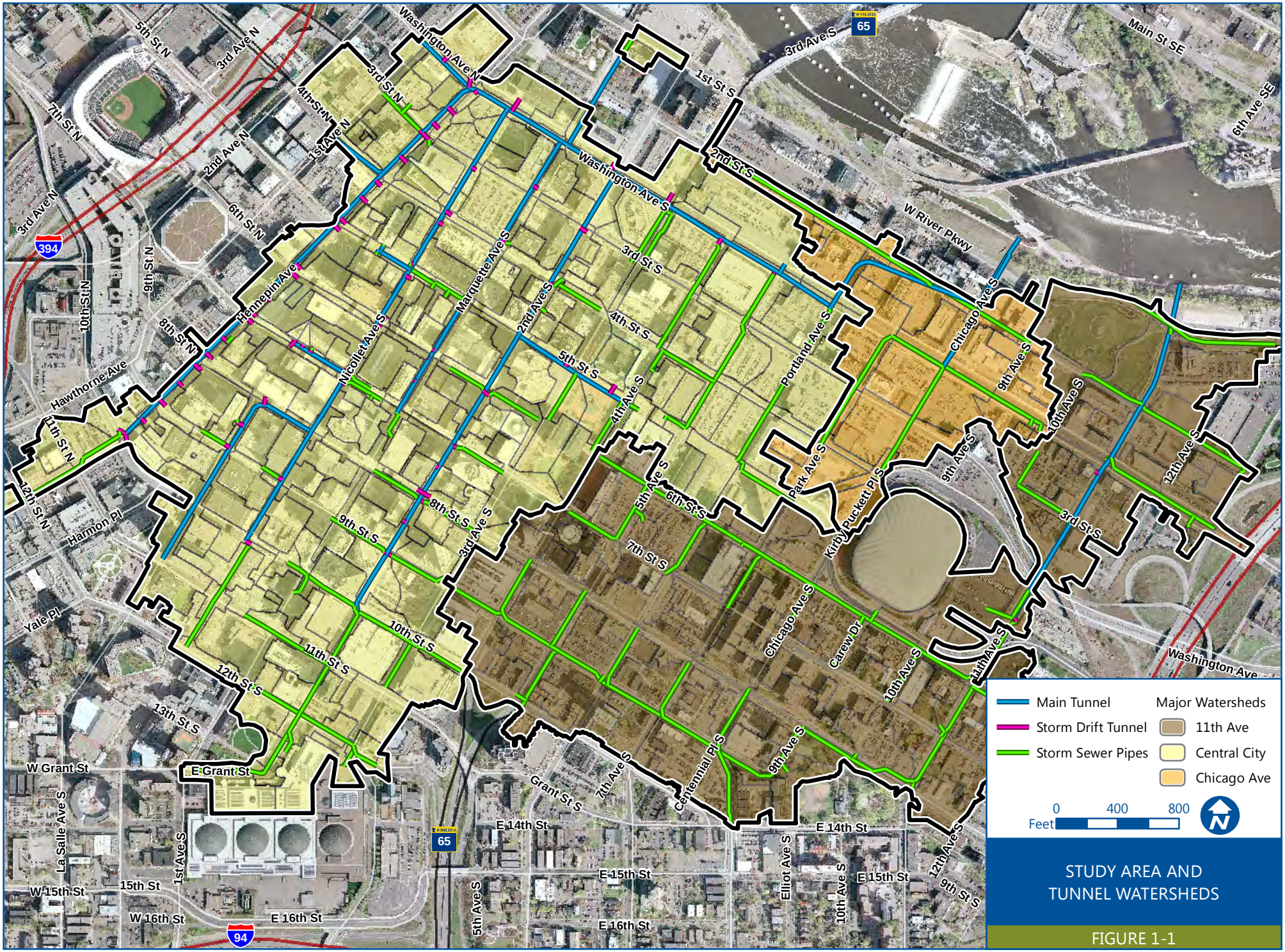
The goal of this project was to assess the feasibility of reducing the pressure within the Central City stormwater tunnel system (Central City tunnel system) during large rainfall events. Several potential improvement options were analyzed, including increasing the tunnel system capacity by increasing the size of existing tunnels and adding parallel tunnels. Each option was evaluated using the calibrated XP-SWMM model for the Central City (west of Chicago Avenue /Eighth Avenue), Chicago Avenue (along Eighth Avenue), and Eleventh Avenue tunnel systems (Figure 1-1)

The Central City tunnel system conveys stormwater runoff from downtown Minneapolis to the Mississippi River. The tunnel system contains three main conveyance components: the main tunnel, drift tunnels, and storm sewer pipes (Figure 1-2). The main tunnel is typically 60–90 feet deep below ground elevation, with invert elevations at or below El. 775 ft. (NGVD29). The main tunnel sections are generally located along city streets and have large, typically non-circular, cross sections. Typical tunnel widths range from 4 to 7.5 feet and heights range from 5.5 to 8 feet.

Drift tunnels are smaller tunnel sections, connected to, and generally located perpendicular to the main tunnel. Drift tunnels in the Central City tunnel system typically have cross-section shapes similar to the main tunnel and are at comparable elevations, but are much shorter in length (typically less than 100 feet). Storm sewer pipes are closer to the surface, typically 3 to 20 feet below ground; they are connected to the main or drift tunnels and generally have a circular cross-section shape. Stormwater collected in manholes and catch basins is conveyed to the storm sewer pipes and, ultimately, the tunnels.

The Central City tunnel system includes tunnels along Hennepin Avenue, Nicollet Avenue, Marquette Avenue, Second (2nd) Avenue S., and Washington Avenue (Figure 1-2). Stormwater is conveyed to a 6-foot-high tunnel located on Washington Avenue between Hennepin and Portland Avenues. The tunnel turns north along Portland Avenue and runs under Second Street S. before discharging to the Mississippi River near Chicago Avenue.

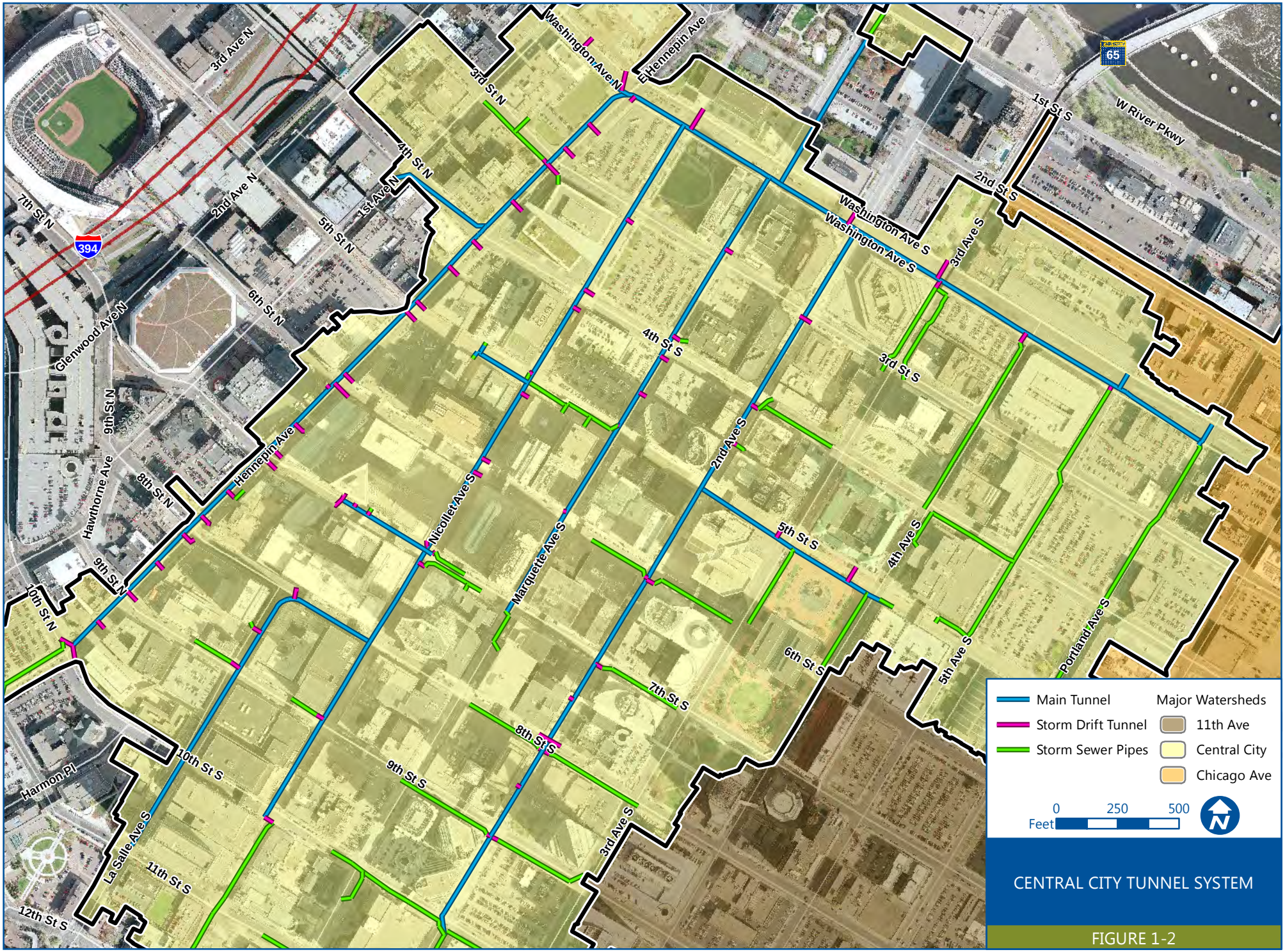
The Chicago Avenue tunnel spans approximately two city blocks and joins the Central City tunnel system just prior to discharging to the Mississippi River. Together these systems comprise approximately 9.5 miles of storm sewer pipes and tunnels.



STUDY AREA AND TUNNEL WATERSHEDS

FIGURE 1-1

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



CENTRAL CITY TUNNEL SYSTEM

FIGURE 1-2

Barr Footer: ArcGIS 10.3, 2015-06-15 12:53 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 1_2 Central City Tunnel System.mxd User: arm2

1.1 Purpose and Existing Issues

Tunnel defects throughout the Central City tunnel system—including the drift tunnels on Fifth Street, Sixth Street, Seventh Street, and Washington Avenue—have occurred for several decades and have recently been documented by the City (Minneapolis 2015). Two of the more common defects are due to (1) fractures and (2) "uplift." Fractures occur when the pressure within the tunnel causes a portion of the tunnel liner to crack, leaving an opening. Uplift occurs when pressure in the tunnel separates the top portion of the tunnel from the invert. Both failures create a conduit for stormwater to leave the tunnel and erode supporting native material behind the tunnel liner. Erosion of this native material creates voids behind the tunnel which can further reduce its structural integrity.

The purpose of this study was to evaluate options to reduce the pressure within the Central City tunnel system. Options were identified during discussions with City staff and evaluated using the XP-SWMM model of the system.

1.2 Model Development

The development of the existing-conditions model is documented in the report *Central City Tunnel System Hydrologic and Hydraulic Modeling Using XP-SWMM* (Barr 2015), hereafter referred to as the Central City XP-SWMM Report. The model includes a total contributing watershed area of 347 acres; 302 acres contribute to the Central City tunnel system and 45 acres to the Chicago Avenue tunnel system. The model was calibrated to pressure measurements in the Central City tunnel system for two storm events and validated using pressure measurements from a third storm event. This calibrated model was used to define the baseline for the alternatives analysis (see Section 4.0).

Model assumptions that affect the alternatives analysis (design rainfall event, downstream boundary condition, and void space surrounding the stormwater tunnel) are described in the following sections.

1.2.1 Design Rainfall Event

In 2013, the National Oceanic and Atmospheric Administration (NOAA) released Atlas 14, Volume 8, which revised precipitation frequency estimates for 11 midwestern states, including Minnesota. The Atlas 14 rainfall estimates were developed for individual rainfall monitoring stations with long, consistent periods of record. After estimates were developed for individual stations, they were interpolated between stations to account for the spatial variability of rainfall depths.

For this analysis, 10- and 100-year, 24-hour rainfall events were modeled using Atlas 14 precipitation depths and the MSE 3 MN rainfall distribution, as recommended by the Minnesota Natural Resource Conservation Service. The 24-hour precipitation depths are included in Table 1-1.

Table 1-1 Hypothetical Rainfall Event Point Precipitation Depth from Atlas 14

	Return Frequency	
Duration	**10-Year Precipitation Depth (inches)**	**100-Year Precipitation Depth (inches)**
24 hours	4.27	7.47

1.2.2 Downstream Boundary Condition (Tunnel Outfall)

The downstream boundary condition of the model is located at the Mississippi River downstream of the combined Central City and Chicago Avenue tunnel systems. The tunnel system discharges directly into the Mississippi River. It was assumed that the peak flood elevation in the Mississippi River would not coincide with the peak flood level in the tunnel system. Therefore, unrestricted flow from the tunnel system into the Mississippi River was applied (i.e., the outfall was modeled as a free outfall without tailwater effects).

1.2.3 Void Space Surrounding Tunnels

During storm events void spaces above and along portions of the tunnel system may convey flow outside of the tunnel walls. While the City is aware of these void spaces, the volume of voids and the potential conveyance capacity has not been quantified. For modeling purposes, it was assumed that the discharge during a rainfall event is confined within the actual tunnel system (i.e. the void space around the tunnel does not convey any flow). This assumption is consistent with the XP-SWMM model of existing conditions which was calibrated to available pressure measurements within the tunnel system. This allows for a direct comparison of the potential improvement options to existing conditions.

2.0 Pressure-Mitigation Options

Nine potential pressure-mitigation options were identified following review of available pressure measurements, discussions with City staff, and review of simulation results from the existing-conditions XP-SWMM model. These included tunnel modifications that will either add storage within the existing system or increase the conveyance capacity of the system. As noted, the City has documented the presence of voids along several sections of these tunnels. Although, many of the following recommendations include oversizing the tunnels to take advantage of existing voids along the tunnel system, the actual limits of the existing voids is not known. The existing tunnel cross sections are shown in the referenced figures.

- Option 1a—Oversize tunnel on Washington Avenue
- Option 1b—Oversize tunnel on Washington Avenue & add parallel tunnel along Portland Avenue to downstream of West River Parkway
- Option 2a—Oversize tunnel on Second Avenue S.
- Option 2b—Oversize tunnel on Second Avenue S., add parallel tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & extend to downstream of West River Parkway
- Option 3a—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue
- Option 3b—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & extend to downstream of West River Parkway
- Option 4a—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue
- Option 4b—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway
- Option 4c—Disconnected parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway

The following sections discuss each mitigation option evaluated as part of this feasibility study.

Option 1a—Oversize Tunnel on Washington Avenue

Option 1a consists of increasing the size (i.e., cross-sectional area) of the existing Washington Avenue tunnel from Nicollet Avenue to Portland Avenue using the existing void spaces above the tunnel. The City has noted the presence of voids along several sections of these tunnels. However, the specific volume and locations of the voids is unknown at this time. The alignment of the modified tunnel system is shown in Figure 2-1.

As shown on the tunnel profile drawings provided by the City, the Washington Avenue tunnel has a semi-elliptical shape with a cross-sectional area of approximately 28 square feet. The proposed expanded tunnel shape is assumed to be circular with a cross-sectional area of approximately 50 square feet. A circular shape is assumed because the location and volume of void space adjacent to the tunnel is unknown. It is also assumed that proposed modifications would not change the existing tunnel slope or invert elevation. This option would involve modifying approximately 2,500 feet of tunnel.

Option 1b—Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway

With Option 1b, the size of the existing Washington Avenue tunnel from Nicollet to Portland Avenues will be increased (similar to Option 1a) and a parallel tunnel will be constructed from the intersection of Washington and Portland Avenues to downstream of West River Parkway. The general alignment of the modified and additional parallel tunnel is shown in Figure 2-2.

The parallel tunnel is assumed to be circular, with an approximate cross-sectional area of 28 square feet (i.e., diameter of 6 feet). It is assumed to have a slope and invert similar to the existing tunnel between the intersection of Washington and Portland Avenues and downstream of West River Parkway. This option would include modification of approximately 2,500 feet of existing tunnel and construction of approximately 1,500 feet of new tunnel.

Option 2a—Oversize Tunnel on Second Avenue S.

Option 2a involves increasing the size of the existing Second Avenue S. tunnel from Fifth Street to Washington Avenue. The location of the modified tunnel is shown in Figure 2-3.

The Second Avenue S. tunnel is a concrete, poured-in-place semi-elliptical shape, as shown in the tunnel profile drawings provided by the City. The cross-sectional area is approximately 21 square feet. The modified tunnel is modeled as a box culvert (rectangular) with a cross-sectional area ranging from 28 to 36 square feet. The void space above the tunnel in this portion of the system is approximately equal to the distance between the top of the existing tunnel and the soapstone bedrock layer (i.e., the void space was created by eroded sandstone). Therefore, the height of the box culvert is assumed to vary based on the distance to the soapstone bedrock layer above the tunnel. Expanding the tunnel further, beyond the sandstone layer, would likely increase the cost of the project significantly.

It is assumed that the existing tunnel slope and invert will not be modified as a result of the proposed modifications. This option would involve modifying approximately 1,300 feet of tunnel.

Option 2b—Oversize Tunnel on Second Avenue S., Add Parallel Tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & Extend Downstream of West River Parkway

Option 2b consists of increasing the cross-sectional area of the Second Avenue S. tunnel between Fifth Street and Washington Avenue (similar to Option 2a) and constructing a new parallel tunnel from the intersection of Second Avenue S. and Washington Avenue that extends downstream of West River Parkway. The location of the modified tunnel section and new parallel tunnel are shown in Figure 2-4.

The new parallel tunnel is assumed to have a circular geometry with an approximate cross-sectional area of 28 square feet (i.e., 6 foot diameter) and the approximate slope and invert elevation of the existing tunnel between the intersection of Washington Avenue and Second Avenue S. and the Mississippi River. This option includes approximately 1,300 feet of tunnel modifications and construction of approximately 3,200 feet of new tunnel.

Option 3a—Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue

Option 3a involves constructing a new parallel tunnel adjacent to the existing Washington Avenue tunnel between Nicollet and Portland Avenues. The existing tunnel would be repaired and utilized to along with the new parallel tunnel. The alignment of the new tunnel is shown in Figure 2-5.

As discussed (Option 1a), the Washington Avenue tunnel has a semi-elliptical shape with a cross sectional area of approximately 28 square feet. The new parallel tunnel is assumed to have a circular cross-sectional area of approximately 28 square feet (i.e., 6-foot diameter) and approximately the same slope and invert elevation as the adjacent tunnel on Washington Avenue. This option would require constructing approximately 2,500 feet of tunnel.

Option 3b—Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway

With Option 3b, a parallel tunnel adjacent to the existing Washington Avenue tunnel from Nicollet to Portland Avenues (similar to Option 3a) will be added and extended downstream of West River Parkway. The existing tunnel would be repaired and utilized to along with the new parallel tunnel. The alignment of proposed modifications is shown in

Figure 2-6.

The new parallel tunnel is assumed to be a 6-foot-diameter circular shape with the same slope and invert elevation as the existing tunnel. The new tunnel is approximately 4,000 feet long.

Option 4a—Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue

Option 4a consists of constructing a new tunnel parallel to the existing Washington Avenue tunnel between Second Avenue S. and Portland Avenue. The existing tunnel would be repaired and utilized to along with the new parallel tunnel. The location of the new tunnel is shown on Figure 2-7.

The new parallel tunnel is assumed to be a 6-foot-diameter circular shape and have a similar slope and invert elevation as the existing tunnel. Approximately 1,600 feet of new tunnel would be constructed.

Option 4b—Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway

Option 4b comprises a new tunnel parallel to the existing Washington Avenue tunnel from Second Avenue S. to Portland Avenue (similar to Option 4a) extended downstream of West River Parkway. The

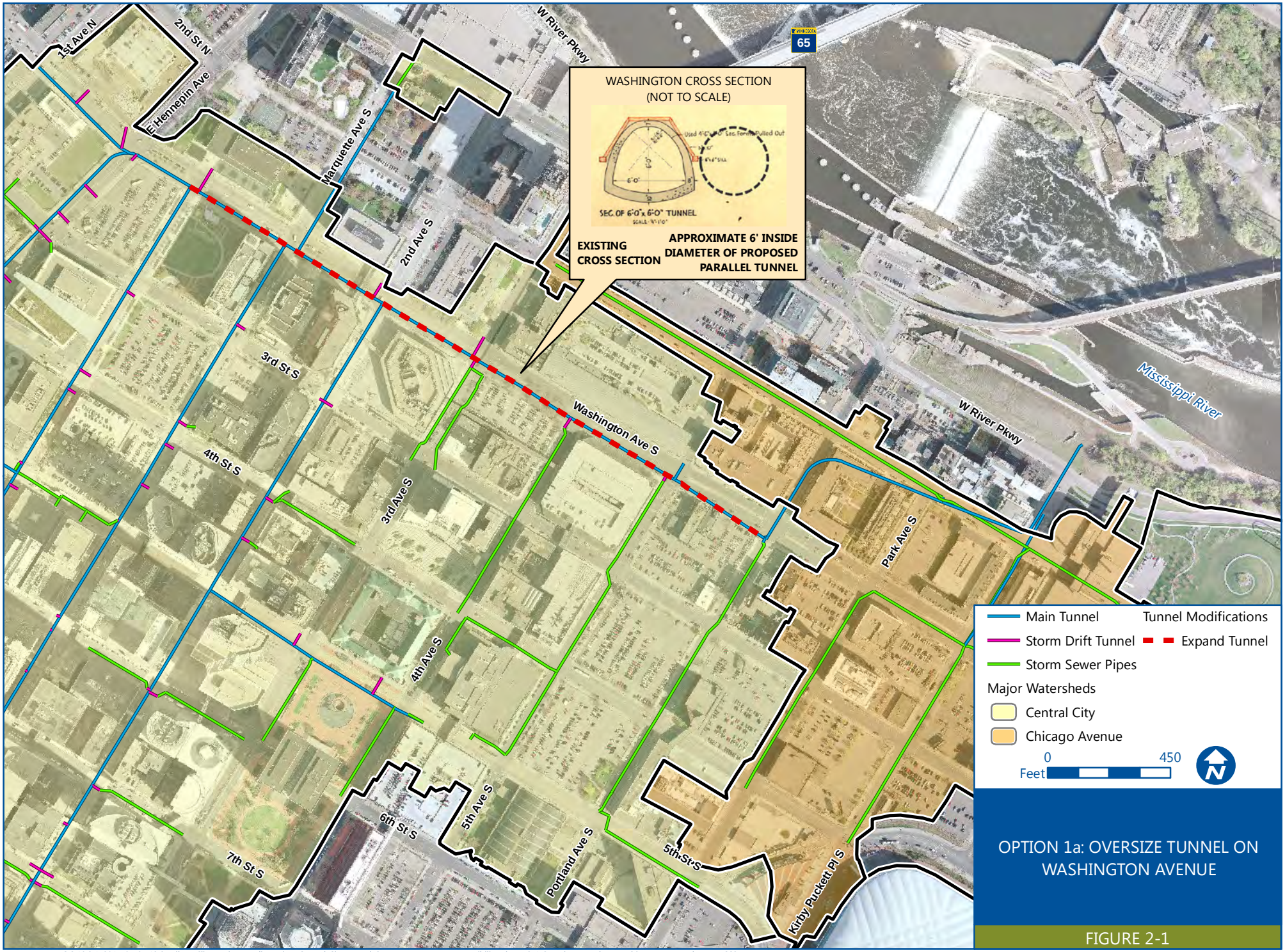
existing tunnel would be repaired and utilized to along with the new parallel tunnel. The locations of modifications are shown in Figure 2-8.

The new parallel tunnel is assumed to be a 6-foot-diameter circular shape with the same slope and invert elevation as the existing tunnel. Approximately 3,200 feet of new tunnel would be constructed.

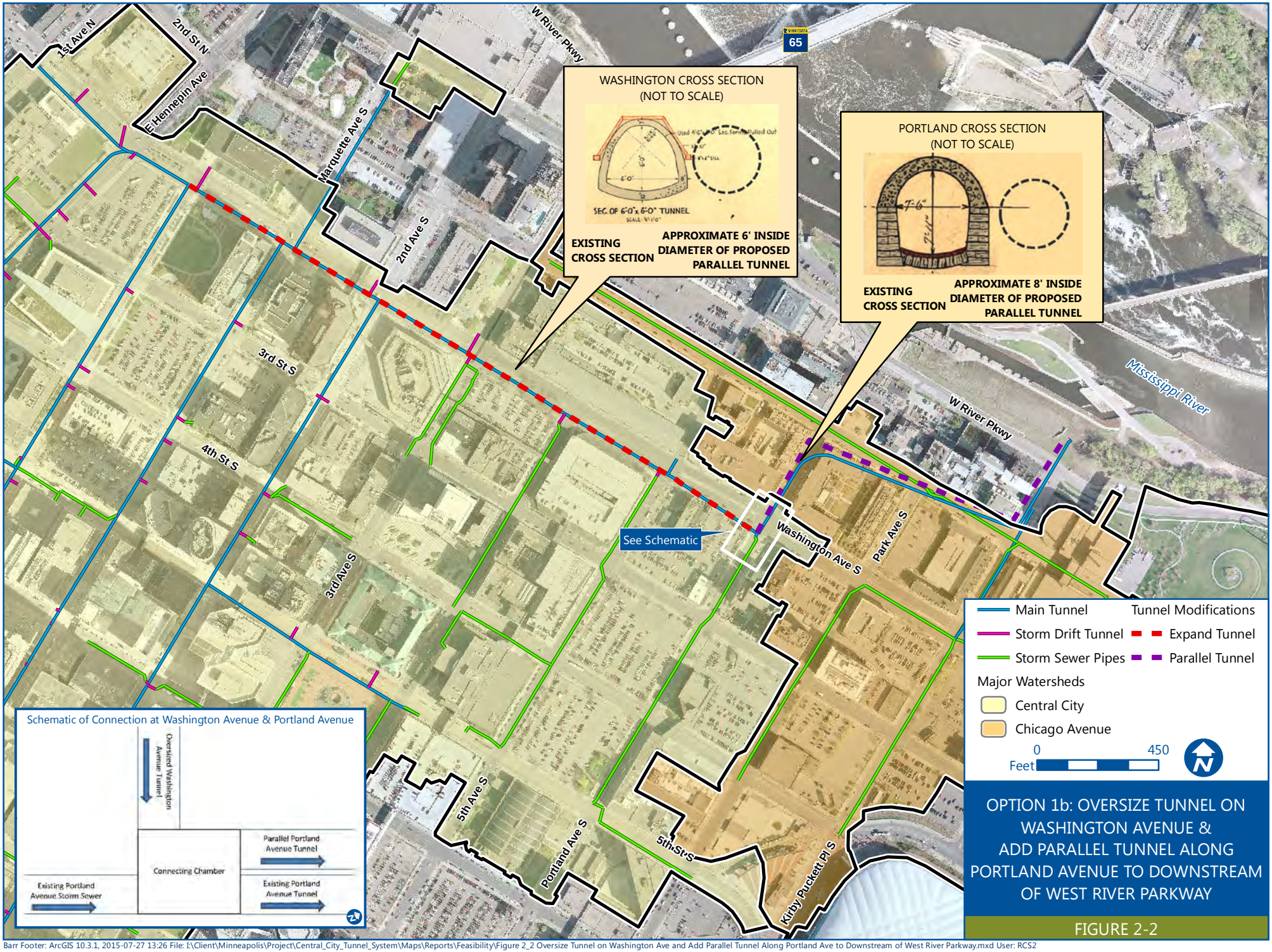
Option 4c—Disconnected Parallel Tunnel on Washington Avenue & Extend to Downstream of West River Parkway

Option 4c consists of splitting the flow at the intersection of Washington Avenue and Second Avenue S. by constructing a parallel tunnel along Washington Avenue (from Second Avenue S. to Portland Avenue) and extending it downstream of West River Parkway. Stormwater upstream of the flow split would be conveyed in the new tunnel system; stormwater collected downstream of the split would be conveyed in the existing tunnel system. The alignment of the new tunnel system is shown in Figure 2-9.

Option 4c includes the same parallel tunnel discussed in Option 4b—but divides the flow at the intersection of Washington Avenue and Second Avenue S. The existing tunnel on Washington Avenue will be connected to the new parallel tunnel, reducing the discharge through the existing tunnel downstream of Second Avenue S. The parallel tunnel would be approximately 3,200 feet long with an approximate cross-sectional area of 28 square feet.



Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:25 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_1 Oversize Tunnel on Washington Ave.mxd User: RCS2



OPTION 1b: OVERSIZE TUNNEL ON WASHINGTON AVENUE & ADD PARALLEL TUNNEL ALONG PORTLAND AVENUE TO DOWNSTREAM OF WEST RIVER PARKWAY

FIGURE 2-2

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:26 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_2 Oversize Tunnel on Washington Ave and Add Parallel Tunnel Along Portland Ave to Downstream of West River Parkway.mxd User: RCS2

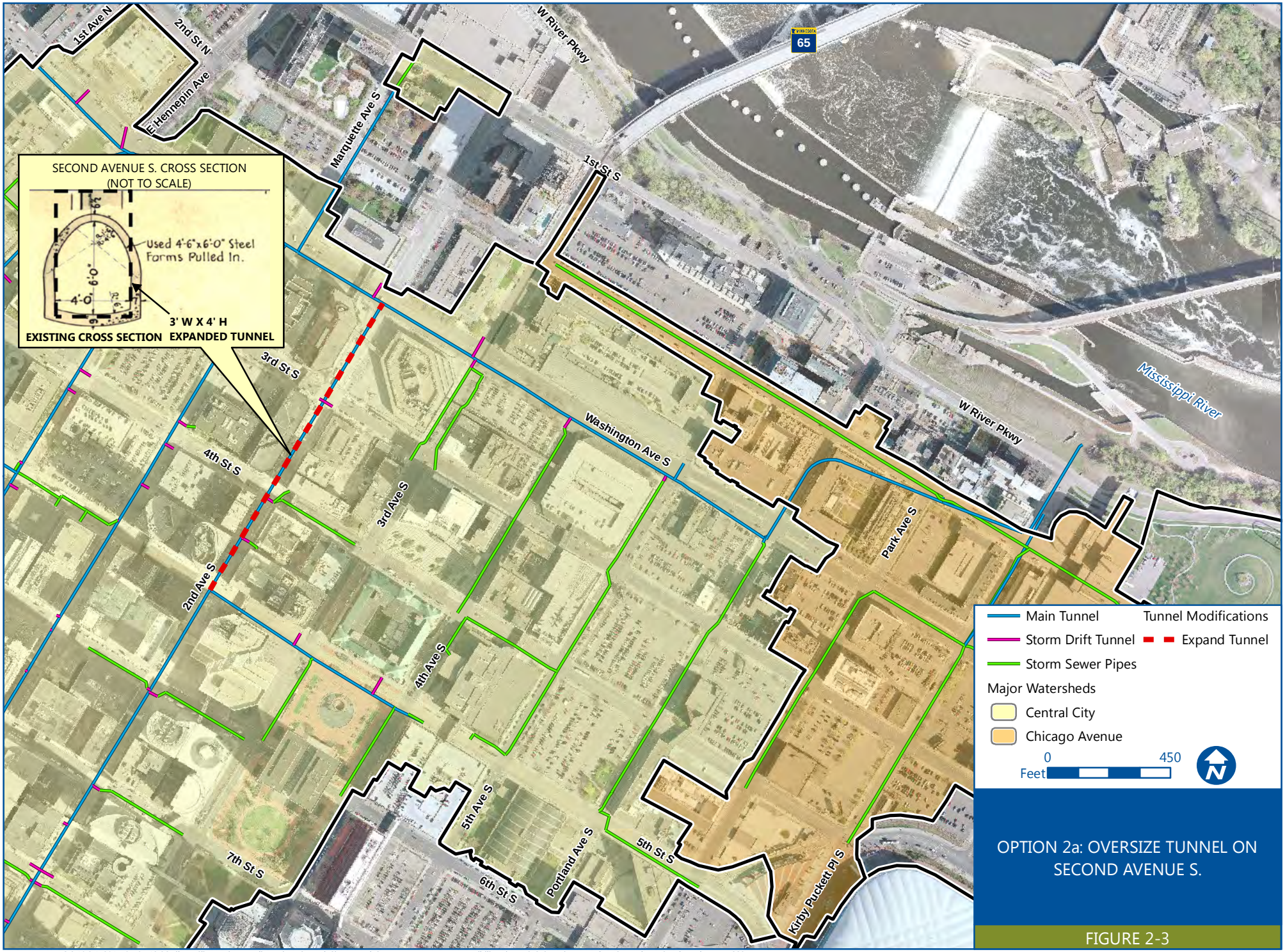
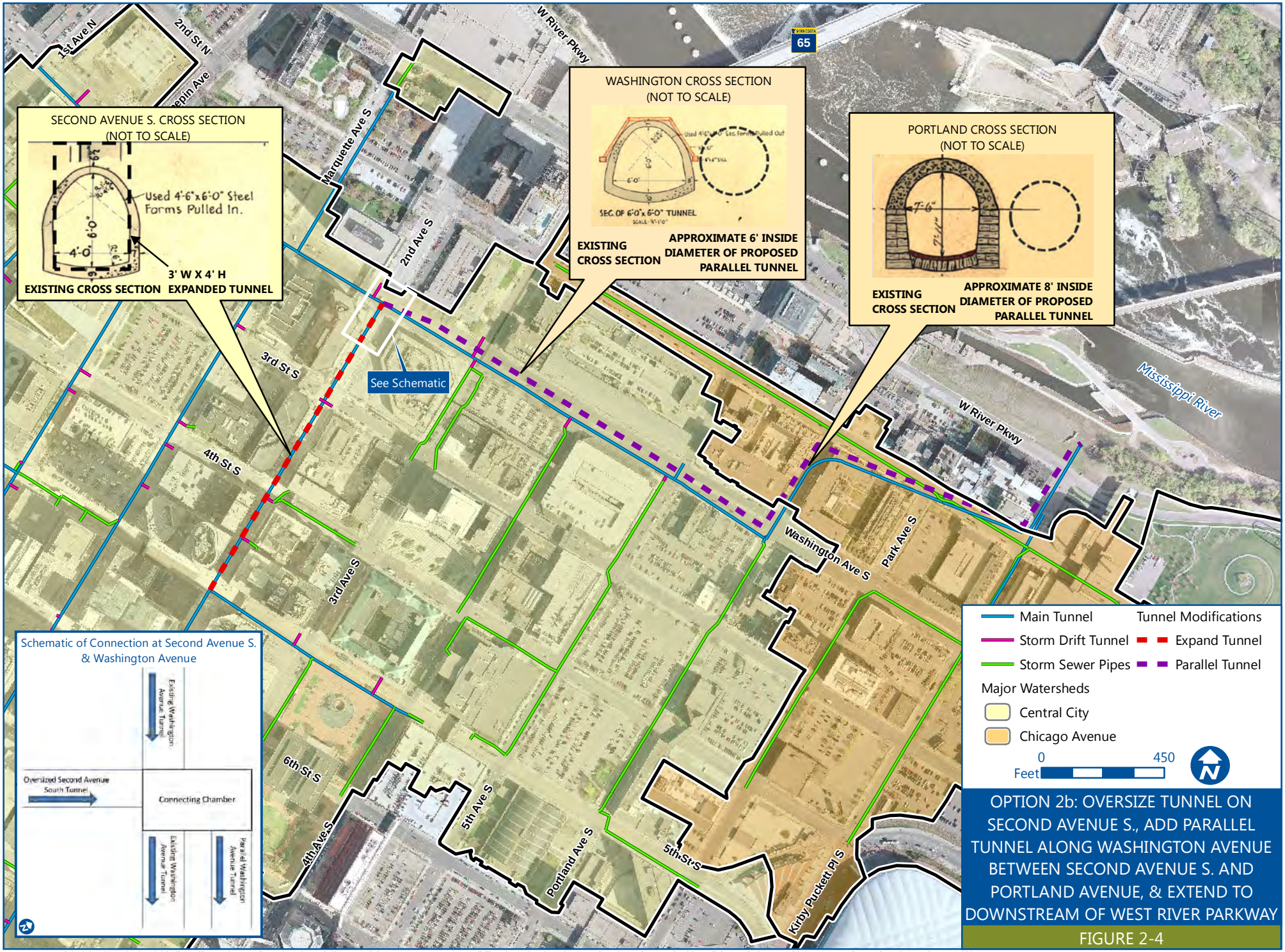


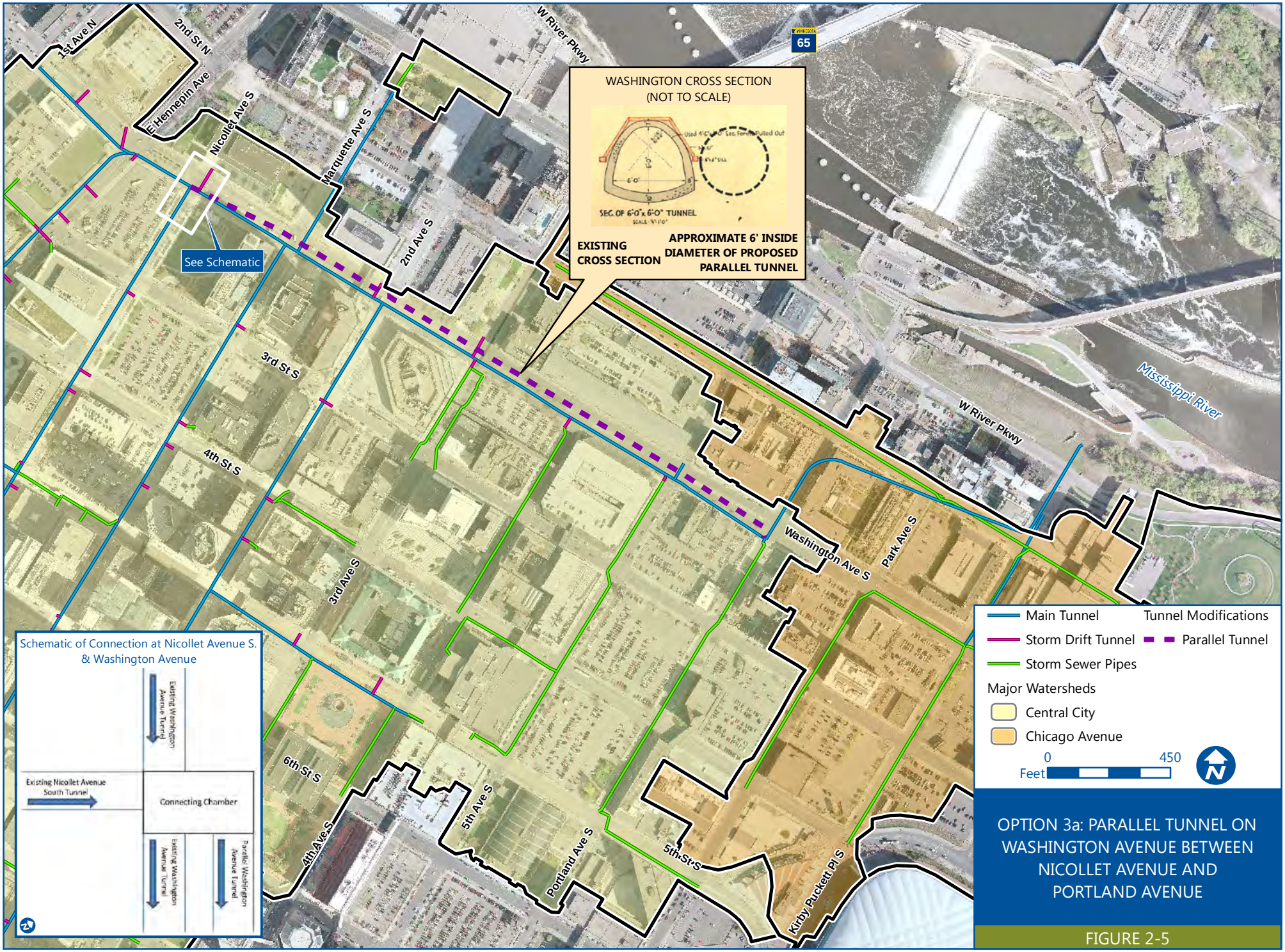
FIGURE 2-3

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:26 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_3 Oversize Tunnel on Second Ave South.mxd User: RCS2

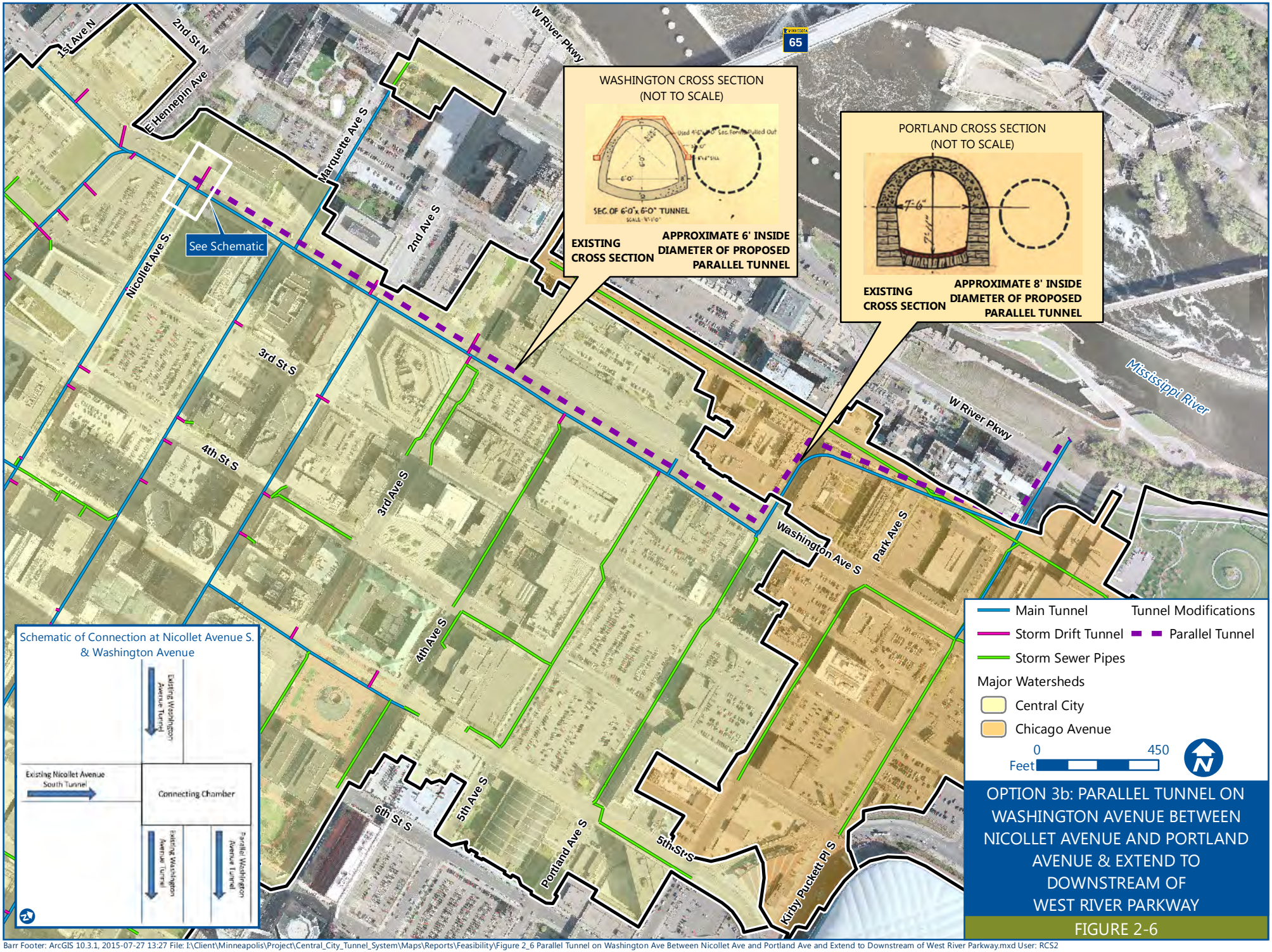


OPTION 2b: OVERSIZE TUNNEL ON SECOND AVENUE S., ADD PARALLEL TUNNEL ALONG WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, & EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

FIGURE 2-4



Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:27 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_5 Parallel Tunnel on Washington Ave Between Nicollet Ave and Portland Ave.mxd User: RCS2



OPTION 3b: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN NICOLLET AVENUE AND PORTLAND AVENUE & EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

FIGURE 2-6

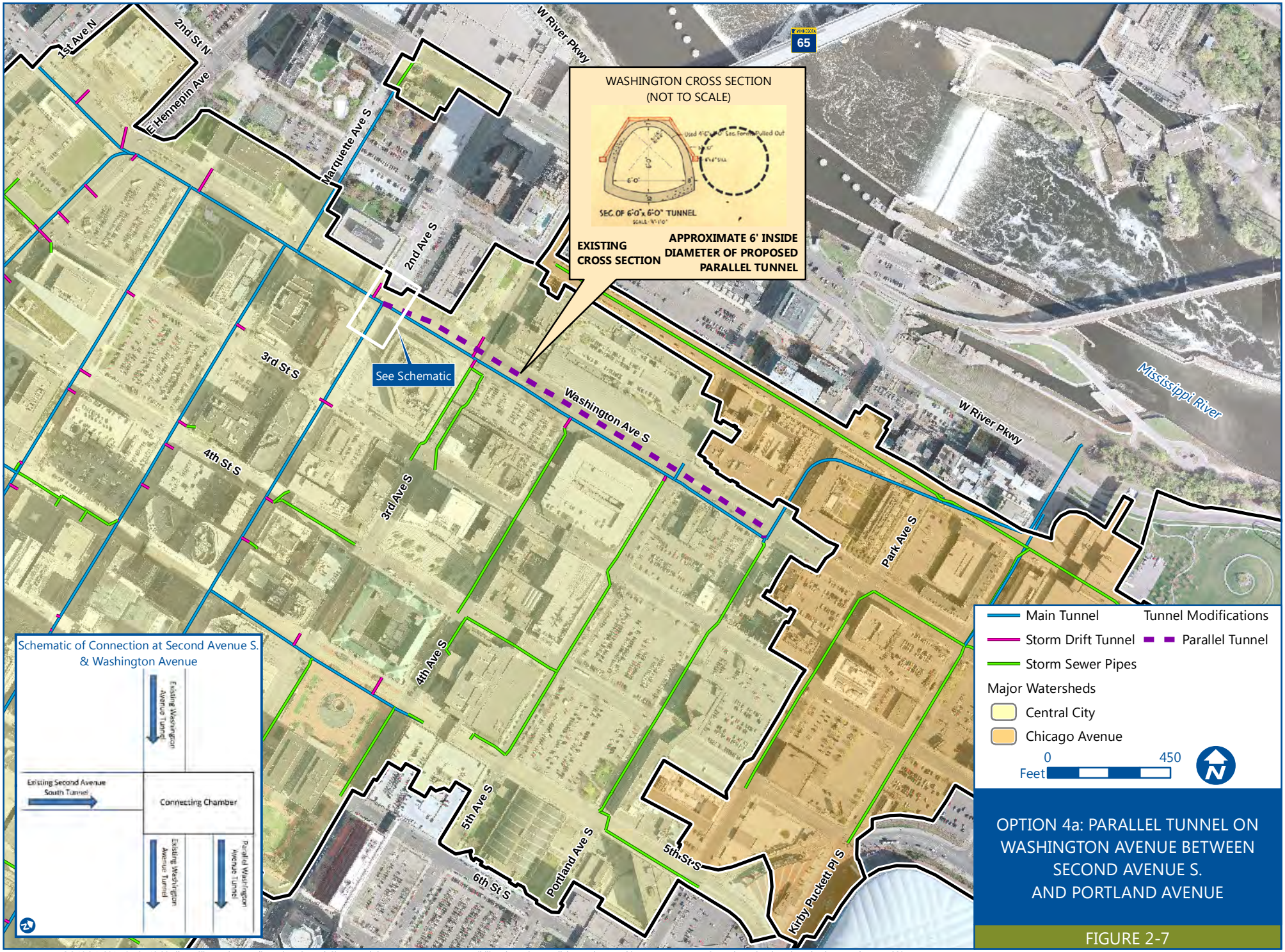
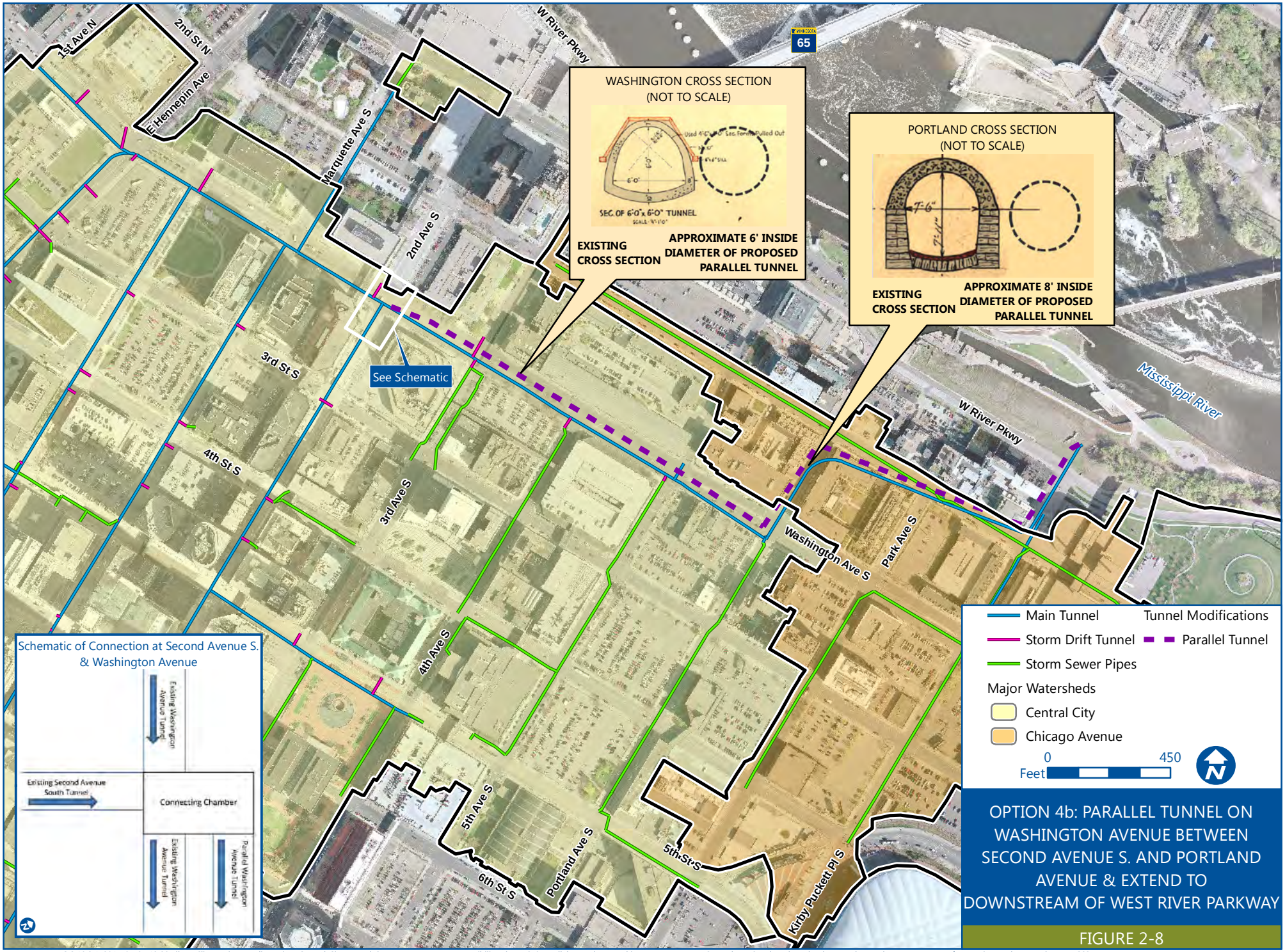


FIGURE 2-7

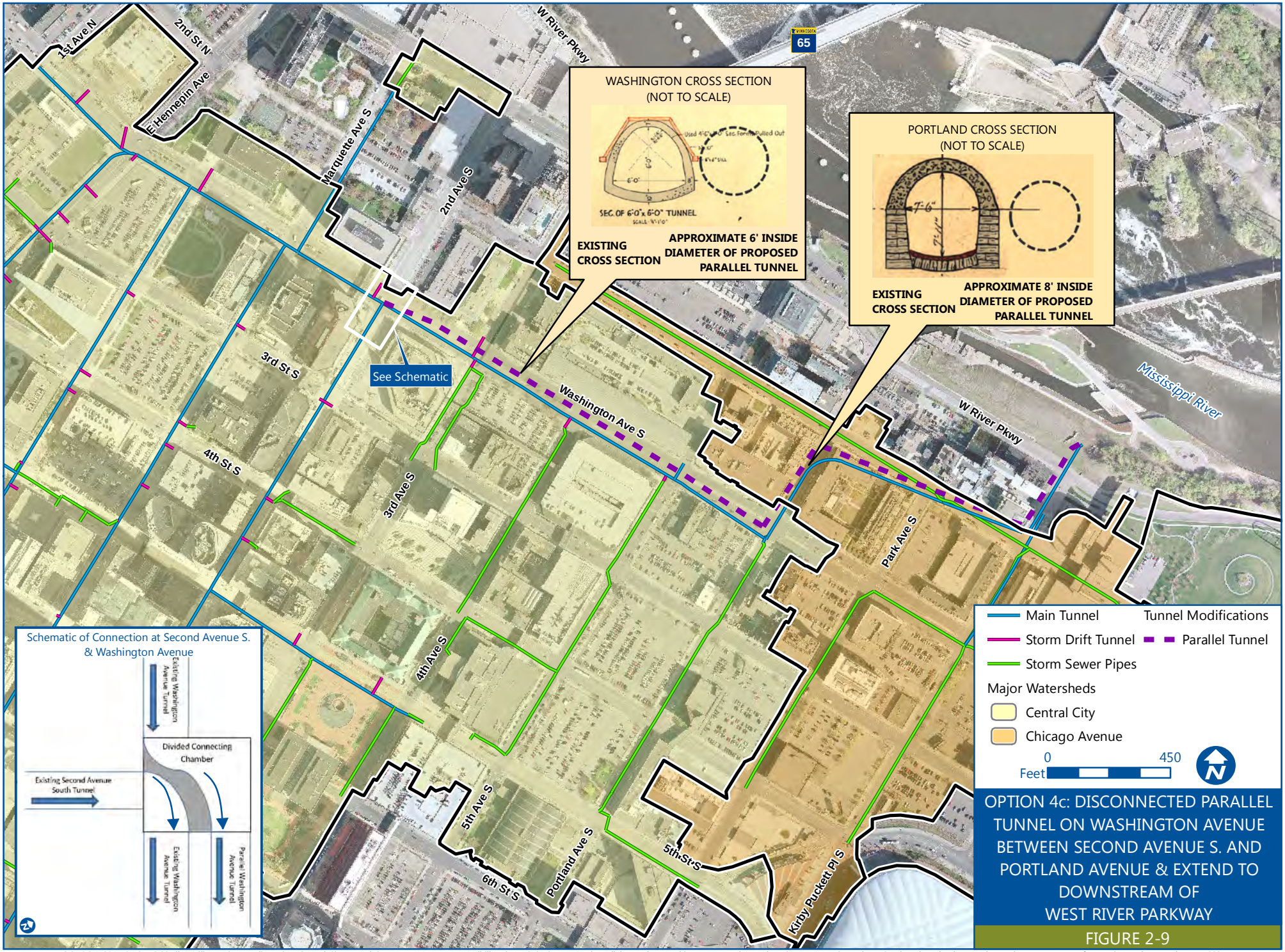
Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:28 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_7 Parallel Tunnel on Washington Ave Between Second Ave South and Portland Ave.mxd User: RCS2



OPTION 4b: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE & EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

FIGURE 2-8

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:28 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_8 Parallel Tunnel on Washington AveBetween Second Ave South and Portland Ave and Extend to Downstream of West River Parkway.mxd User: RCS2



Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:28 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 2_9 Disconnected Parallel Tunnel on Washington Ave and Extend to River Between Second Ave South and Portland Ave and Extend to Downstream of West River Parkway.mxd User: RCS2

3.0 Structural Failure Analysis

The tunnel system was originally constructed by excavation through the existing bed rock. Although specific construction methods for the tunnel of interest are not known, it is likely that the construction occurred through means of high pressure water jet to excavate the St. Peter bedrock. A concrete tunnel liner was then constructed inside the excavated space. Past experience with tunnels in the Twin Cities area indicates that at times the constructed tunnel liner is not always in contact with the excavated bedrock face. In these instances, there is a void space between the outside of the liner and the bedrock. The tunnel liner is designed to contain stormwater and convey flow. During rainfall events the water level in the tunnel increases; the tunnel pressurizes when the water rises above the top of the liner. The pressure in the tunnel is applied to the tunnel liner. If the tunnel liner is in contact with the adjacent bed rock (as designed), the pressure is transferred to the surrounding bedrock, allowing the liner to withstand higher pressures. However, as previously mentioned, there are many locations within the Central City tunnel system where void spaces exist between the tunnel liner and the surrounding bedrock (i.e., the tunnel liner is not in contact with bedrock). In these locations the tunnel liner is more susceptible to defects or failure. Based on observations and past experience, voids are often in isolated locations and not around the entire liner; however, these voids may extend along the alignment of the tunnel for a few feet or many hundred feet. Actual void occurrence, size, and position are difficult to quantify and currently undocumented throughout the Central City stormwater tunnel system.

As noted, two of the more common types of defects are due to fractures and "uplift." Fractures occur when the pressure within the tunnel causes a portion of the tunnel liner to crack, leaving a structural defect (opening) in the tunnel (a series of fractures or cracks is referred to as hinging). Uplift occurs when pressure in the tunnel separates the top portion of the tunnel from the invert. This structural analysis focuses on the fracture failure mode; however, other failure modes (i.e., uplift failure) may occur with a different range of hydraulic pressures.

To evaluate the effectiveness of each pressure-mitigation option, the XP-SWMM simulation results were compared to the estimated pressure that would cause pipe fracturing. The following sections describe how the fracture failure mode was estimated.

3.1 Fracture Defects

Fracture defects are characterized by visible openings in the concrete tunnel liner. In other words, it is a defect of the tunnel liner, as shown in Figure 3-1.

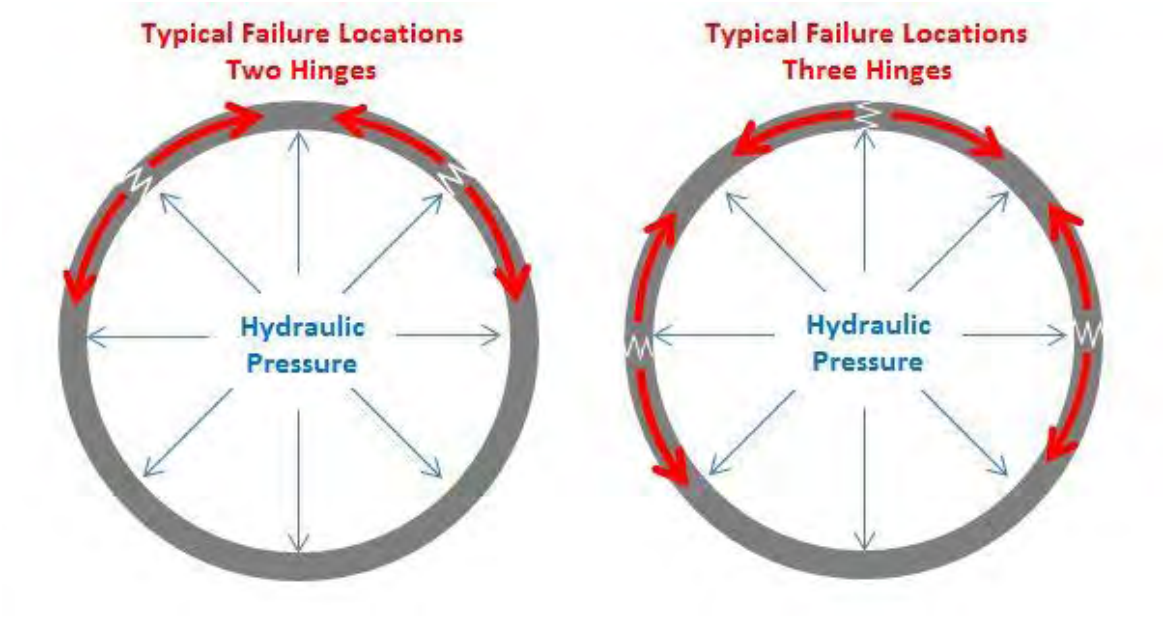


Figure 3-1 Fracture Failure Schematic – Typical Configurations

The hydraulic pressure in a tunnel system, used to estimate a "Tunnel-Failure-Risk Zone," is based on the material type and thickness of the tunnel liner and the tunnel's cross-sectional area. The assumptions used to calculate the Tunnel-Failure-Risk Zone are described below.

The pressure that can be applied to the tunnel liner before failure is a function of the liner's thickness. While the tunnel profile drawings provided by the City show the designed thickness of liners in the Central City tunnel system, the actual liner thickness throughout the system may have varied during construction. A 2-inch liner-thickness buffer, based on construction cores taken and recorded as part of previous work performed for Minneapolis tunnel rehabilitation in St. Mary's/Hiawatha tunnel completed by Barr, was assumed for each tunnel section to estimate the potential variability.

The drawings provided by the City do not include a typical section for the tunnel liner from the intersection of Washington and Portland Avenues to the Mississippi River. Based on a similar tunnel cross section shown on the *Pipe Shapes Minneapolis* document provided by the City, this portion of the tunnel liner was assumed to be 12 inches thick.

The material properties of the tunnel liner also influence how much pressure the liner can withstand prior to failure. The primary tunnel liner material for the Central City tunnel system is concrete; however, there are locations in the system where other materials were used (e.g., granite pavers along the Portland Avenue tunnel). For this preliminary evaluation, the pressure necessary to cause failure was calculated assuming a concrete liner with a compressive strength of 3,000 pounds per square inch (psi). According to the American Concrete Institute (ACI) design code, the resulting modulus of rupture would be 411 psi (ACI 318 eq. 9-10). A factor of safety of 0.6 was applied as a load reduction factor (ACI 318 section 9.3.5).

Tunnel cross-sectional area was based on cross sections shown on tunnel profile drawings provided by the City. Where the tunnel shape was not circular, a circle with an equivalent cross-sectional area was used to represent the tunnel. The shape of the pipe was assumed to be circular.

The estimated pressure values for failure assumed void space around the tunnel and that surrounding bedrock was not in contact with the top or sides of the liner. As discussed in Section 3.0, where there is rock against the tunnel liner or void spaces have been filled, the liner transfers pressure to the surrounding bedrock. This allows it to withstand higher pressures without failure. Therefore, the estimated fracturing failure pressure, summarized in Table 3-1, may be a conservative estimate that should only be used for screening the potential effectiveness of pressure-mitigation options.

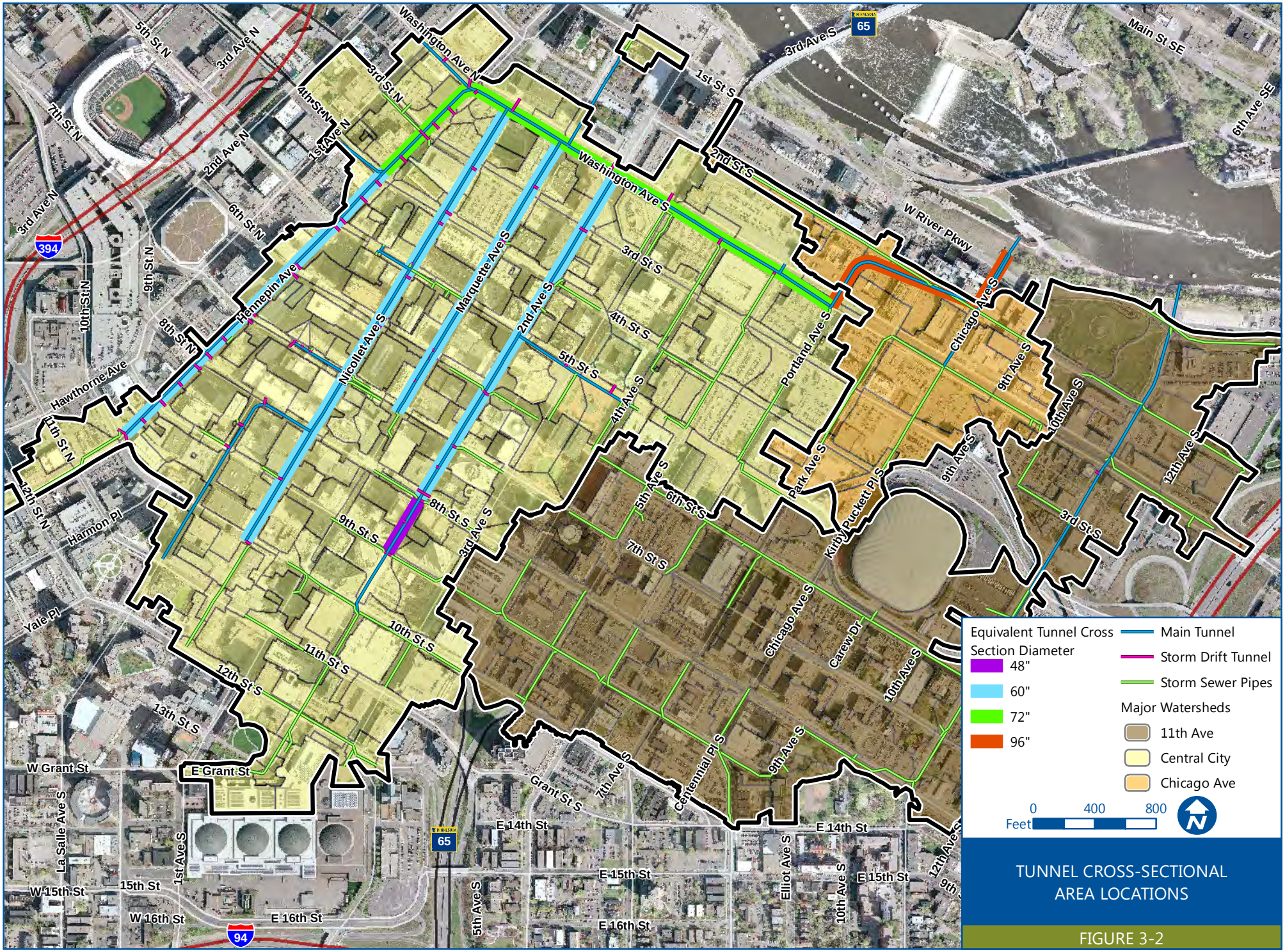
If the City would like a more refined estimate of failure pressure, additional field investigations would be necessary to quantify and map the voids surrounding the tunnel, measure the tunnel cross sections (i.e., liner thickness), and document existing material properties.

Table 3-1 Fracturing Failure Pressure (Feet of Hydraulic Head)

	Wall Thickness (inches)									
Tunnel Diameter (inches)	**4 in**	**5 in**	**6 in**	**7 in**	**8 in**	**9 in**	**10 in**	**11 in**	**12 in**	**14 in**
48 inches	45	56	67	77	88	98	107	117	126	145
60 inches	37	45	54	63	71	79	88	96	103	119
72 inches	31	38	45	53	60	67	74	81	88	101
84 inches	26	33	39	45	52	59	64	70	76	88
96 inches	23	29	34	40	45	51	56	62	67	77

* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is $\pm$ 2 inches from what is shown on the tunnel profile drawings provided by the City.
* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).
* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

A map showing the approximate cross-sectional areas of the existing tunnels in the Central City tunnel system is included in Figure 3-2.



TUNNEL CROSS-SECTIONAL AREA LOCATIONS

FIGURE 3-2

Barr Footer: ArcGIS 10.3, 2015-06-24 12:50 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Figure 3_2 Tunnel Cross-Sectional Area Locations.mxd User: arm2

4.0 Pressure-Mitigation Options Evaluation

The objective of each mitigation option is to reduce the pressure in the tunnel system. The nine options were simulated using the XP-SWMM model of the Central City tunnel system. Simulated peak water-surface elevations for the modified systems were compared to the simulated elevations for the existing system to quantify how each option would affect water-surface elevation (i.e., hydraulic pressure) within the tunnel system.

Each of the nine options reduces the peak pressure in the tunnel system. However, for several options the reduction magnitude was limited—and possibly not enough to prevent future tunnel failures. To estimate how effective each option could be in preventing tunnel failures, the simulated peak water-surface elevations are compared to the results of the preliminary structural analysis discussed in Section 3.0.

4.1 Conversion of Pressure Measurements to Water Depth

Monitoring gauges installed by the City measure pressure within the tunnel. High pressure in the tunnel can cause defects or failure of the tunnel liner. Tunnel pressure can be related to a water-surface elevation using Equation 4-1.

Equation 4-1 $$WSEL = Z + t_i = \frac{(\mathrm{p}_{meas} - \mathrm{p}_{atm}) * 144}{g\rho}$$

Where: $WSEL$ is the water-surface elevation

Z is water depth (foot)

t_i is the tunnel invert

p_{meas} is absolute pressure measurement (psi)

p_{atm} is atmospheric pressure (average pressure before event ~14.2–14.3 psi)

144 is conversion from square inches to square feet

g is gravitational acceleration (32.2 ft/sec^2)

ρ is density of fluid (slugs/ft^3)

The change in water-surface elevation in the model will be used to quantify the estimated reduction in tunnel pressure for each mitigation option.

4.2 Model Results

The calibrated XP-SWMM model of the existing Central City tunnel system was modified to model each of the nine pressure-mitigation options for the 10- and 100-year, 24-hour storm events. Simulation results for each option were used to quantify the hydraulic pressure that could be applied to the tunnel liner. Simulation results were summarized and presented in two different formats: (1) peak water-elevations (i.e., hydraulic grade lines) within the tunnel system and (2) the difference in peak water-surface elevation when comparing the existing-conditions model results with the results of each pressure-mitigation option.

The following sections discuss the simulation results.

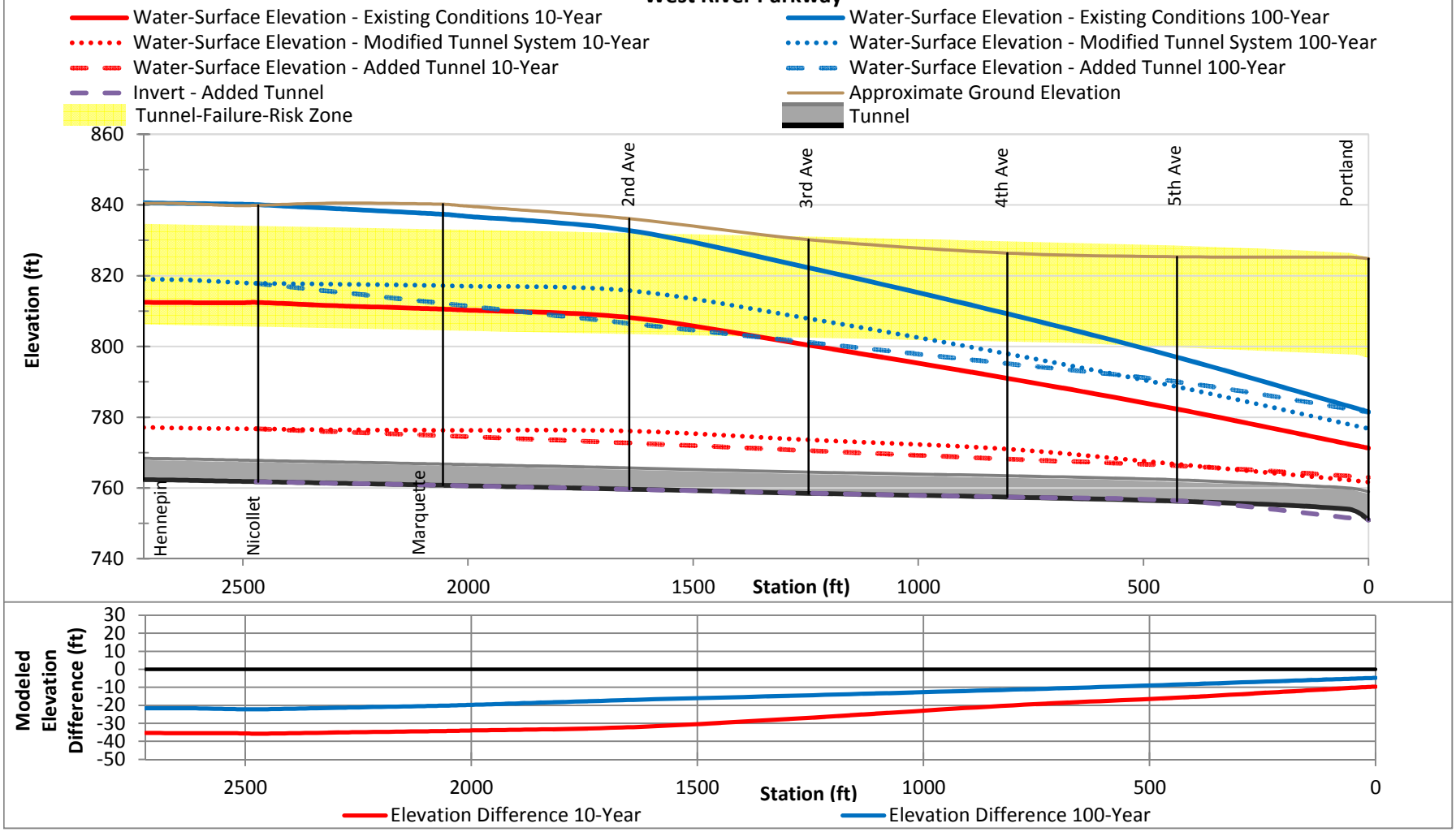
4.2.1 Hydraulic Grade Lines

Water-surface profiles along Hennepin Avenue, Nicollet Avenue, Marquette Avenue, Second Avenue S., Washington Avenue, and the tunnel that runs from the intersection of Washington and Portland Avenues to the river are included in Appendix A for each pressure-mitigation option. The water-surface profile along Washington Avenue is shown in Figure 4-1 for Option 3b. The stationing along the x-axis runs from the downstream end of the tunnel at station 0 to the upstream end of the tunnel. Figure elements are represented as follows:

- Cross streets are shown as black vertical lines and labeled.
- All elevations reference the NGVD29 vertical datum.
- The ground is shown as a brown line.
- The existing tunnel is shown as a gray-shaded area with a black line for the tunnel invert.
- Peak water elevations for the 10-year, 24-hour storm event are shown as red lines; elevations for the 100-year, 24-hour storm event are shown as blue lines.
- The existing-conditions model peak water-surface elevation results are shown as solid lines.
- The peak water-surface elevations in the modified tunnel system for each option are shown as dotted lines.
- For options with a new parallel tunnel, as is shown in the example Figure 4-1, the peak water-surface elevation in the new tunnel is shown as a dashed line, and the new tunnel invert is shown as a light purple dashed line.
- The Tunnel-Failure-Risk Zone, where the tunnel has the potential for structural failure due to fracturing, is shown as a yellow-shaded area. The areas shown are based on the structural assumptions discussed in Section 3.0.

Figure 4-1 Example Hydraulic Grade Line Figure (Washington Avenue - Option 3b)

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).
* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

4.2.2 Modeled Difference in Water Elevation at Model Nodes

Many of the options also reduced peak water-surface elevations throughout the system, indicating that the modifications will also provide benefits to the drift tunnels (i.e., lower pressure) and the storm sewer system (i.e., reduction in surface inundation at storm sewer inlets).

The difference between the peak water-surface elevations in the existing-conditions model and the peak water-surface elevations for each pressure-mitigation option are shown on the figures in Appendix B. The figures show the change in elevation at manhole locations and throughout the storm sewer network connected to the Central City tunnel system.

4.2.3 Results Summary

Overall, each pressure mitigation option was more effective in reducing water-surface elevations related to the 10-year, 24-hour storm than elevations related to the 100-year, 24-hour storm.

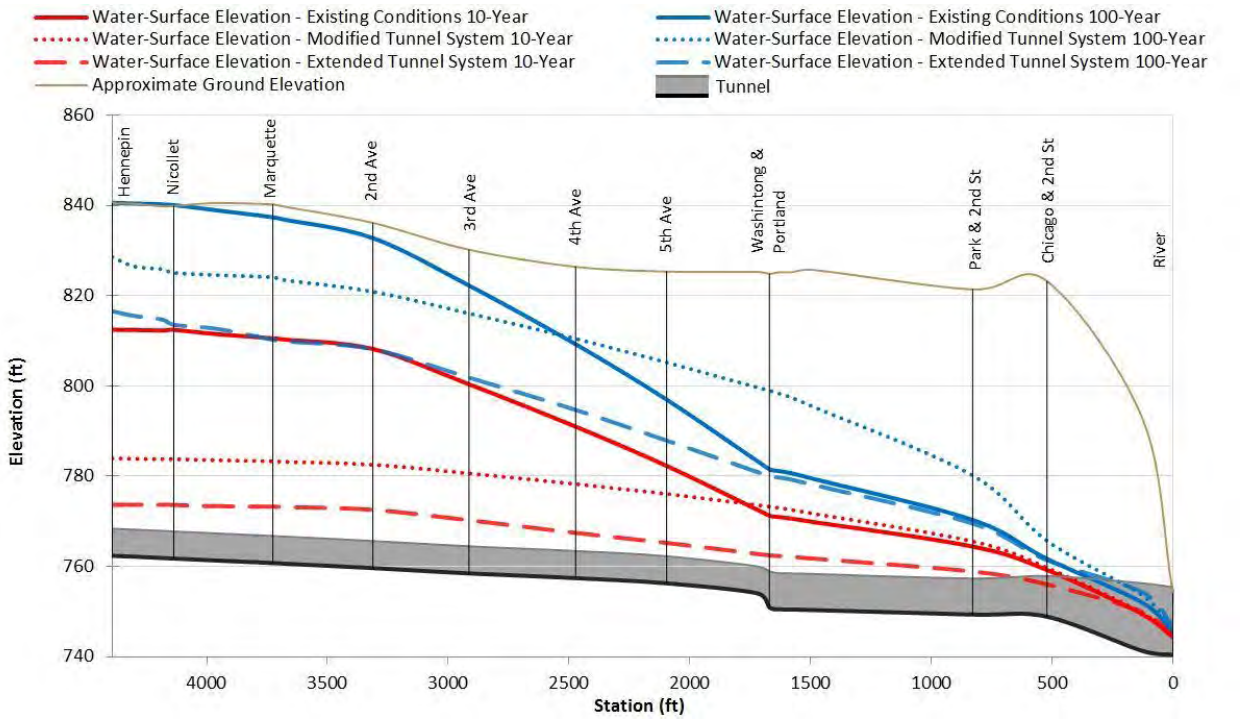
During the 10-year event, the water surface profile is generally below the ground surface. And, since there is less surface flooding with the 10-year event (or no surface flooding in some locations), there is no additional volume entering the tunnel system. During the 100-year event, the water surface profile is above the ground surface in portions of the system. This indicates that stormwater has exceeded the capacity of the tunnel system and is being stored above the ground surface until capacity in the tunnel system becomes available. However, when the existing system is modified to increase conveyance and/or storage capacity, there is less water stored above the ground surface during the 100-year event (i.e., less street/surface flooding, or less inundated area).

Mitigation options are re-summarized (below) with option-specific results following:

- Option 1a—Oversize tunnel on Washington Avenue
- Option 1b—Oversize tunnel on Washington Avenue & add parallel tunnel along Portland Avenue to downstream of West River Parkway
- Option 2a—Oversize tunnel on Second Avenue S.
- Option 2b—Oversize tunnel on Second Avenue S., add parallel tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & extend to downstream of West River Parkway
- Option 3a—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue
- Option 3b—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & extend to downstream of West River Parkway
- Option 4a—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue
- Option 4b—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway

- Option 4c—Disconnected parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway

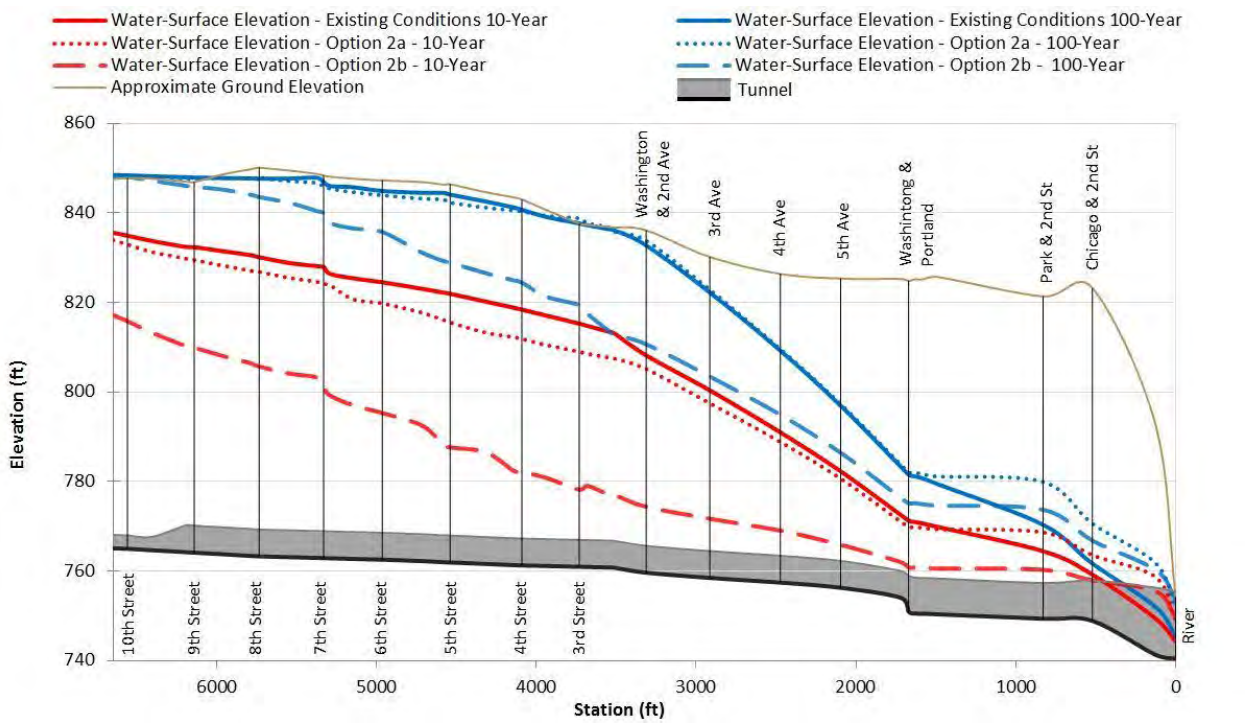
Options 1a, 3a, and 4a result in increased peak water-surface elevations at the downstream end of the Washington Avenue tunnel; Option 1a also produces an increase along the Portland Avenue tunnel (Figure 4-2). This indicates that the Portland Avenue tunnel does not have sufficient capacity to convey the additional discharge to the river. Therefore, Options 1b, 2b, and 4b include modifications to the tunnel system downstream of the intersection of Washington and Portland Avenues to mitigate this increase.



*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Figure 4-2 Hydraulic Grade Line Figure of Washington Avenue and Portland Avenue Comparing Option 1a and Option 1b

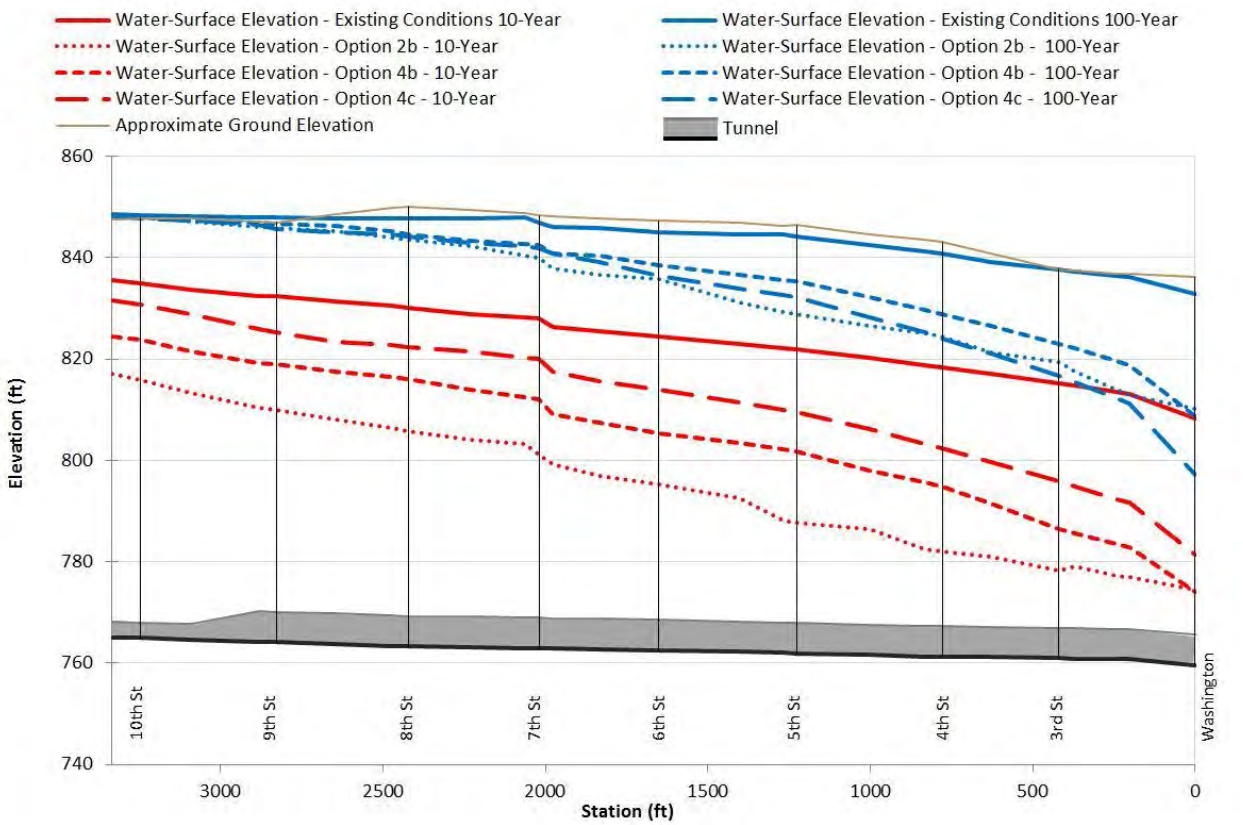
Option 2a has minimal impact across the tunnel system. While increasing the tunnel along Second Avenue S. does create an additional 0.35 ac-ft of storage, this is only about one-percent of the total volume of stormwater in the system during the 100-year event (35 ac-ft). Since Option 2a does not modify the conveyance capacity of the downstream system, the additional storage volume has a minimal impact on water-surface elevations within the Central City tunnel system. Option 2b expands the capacity in the Second Avenue S. tunnel and allows for larger conveyance routes to the discharge. This helps lower the water-surface elevation not only along Second Avenue S., but across much of the entire tunnel system. The comparison of Option 2a and Option 2b is shown in Figure 4-3.



*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Figure 4-3 Hydraulic Grade Line Figure of Second Avenue S., Washington Avenue, and Portland Avenue, Comparing Option 2a and Option 2b

None of the pressure-mitigation options evaluated significantly reduces the peak water-surface elevation on Second Avenue S. upstream of Ninth Street during the 100-year, 24-hour storm. Option 4c produced the largest reduction in water-surface elevation furthest upstream along the Second Avenue S. tunnel; Options 2b and 4b resulted in the next-largest reduction. The results of these three options are compared in Figure 4-4. These results indicate that this portion of the tunnel does not have additional capacity. To reduce peak water-surface elevations in the tunnel, further modifications would be required to tunnel geometry. Modifications to tunnel geometry were not evaluated upstream of Fifth Street because the City recently filled the voids behind the existing tunnel.



*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Figure 4-4 Second Avenue S. Hydraulic Grade Lines for Options 2b, 4b, and 4c

As shown in Appendix A, the existing-conditions peak water elevation is below the Tunnel-Failure-Risk Zone downstream of Third Avenue S. and Washington Avenue for the 10-year storm and downstream of Fifth Avenue S. and Washington Avenue for the 100-year storm. The existing conditions peak water levels are near the lower bound of the Tunnel-Failure-Risk Zone upstream of the intersection of Second Avenue S. and Washington Avenue for the 10-year storm and above or near the upper bound for the 100-year storm. As previously discussed, Option 2a minimally reduces the peak water levels in the system. For every other option, the 10-year peak water levels are below the Tunnel-Failure-Risk Zone along Hennepin, Nicollet, Marquette, and Washington Avenues. The 10-year peak water levels are within the Tunnel-Failure-Risk Zone along Second Avenue S., starting between Ninth and Tenth Street and extending downstream 1 to 5 blocks, based on the varied options.

Option 1b produced the greatest reduction in peak water-surface elevations at the most locations throughout the tunnel system. Options 2b, 4b, and 4c have similar results for the 100-year, 24-hour storm, with only slight variations in the location of peak water level. Option 3b was slightly more effective in reducing the peak water level along Hennepin, Nicollet, and Marquette Avenues, but produced a slightly smaller reduction along Second Avenue S.

For the 10-year, 24-hour storm event, Option 4c and Option 1b resulted in the greatest reduction in peak water-surface levels. Option 4c has a greater impact further upstream than Option 1b. Options 2b, 3b, and

4b—the remaining options that include the parallel tunnel from the intersection of Washington and Portland Avenues to the river—all produced slightly smaller reductions.

5.0 Engineer's Opinion of Probable Construction Cost

The Engineer's opinion of probable construction cost for each alternative is summarized in Table 5-1; detailed opinions of probable construction cost are included in Appendix C. These are intended to provide the City with background information for a conceptual-level assessment of options and a relative comparison of the options.

Quantities are estimated based on available information presented in Section 2.0. Estimated dimensions, areas, and volumes for construction were determined using the Minnesota Department of Natural Resources 2011 light detection and ranging (LiDAR) elevation dataset for the Twin Cities metro region. Neither a topographic survey nor field investigation were completed as part of this analysis, but should be completed if the City intends to further evaluate the feasibility of any pressure-mitigation options presented.

Unit cost assumptions are based on previous City of Minneapolis tunnel projects and published construction cost-index resources. Assumptions related to unit costs are included along with each opinion of cost in Appendix C. Opinions of cost were developed and discussed with City staff. Engineering and construction observation costs are based on percentages of estimated construction costs. Costs to manage the construction process are assumed, but may change depending on actual services are requested.

The opinions of cost include tasks and items related to engineering, design, and construction of each alternative. Estimates for operation and maintenance, permitting, or other tasks following construction of each option are not included.

The cost of time escalation is not included in the opinions of probable cost. All costs presented reflect 2015 U.S. dollars.

Contingencies used in these opinions of probable costs are intended to account for minor items in the current project scope that have not yet been quantified. Stated another way, contingency is the result of the pluses and minuses that cannot be estimated at the current level of project definition. A 30 percent construction contingency is applied to ancillary items not currently itemized in the quantity summaries but commonly identified in more detailed design and required for completeness of the work.

An additional 30 percent project contingency has also been applied to account for coordination and management tasks that have not been defined at this level of project definition.

Industry resources for cost estimating (*AACE International Recommended Practice No. 18R-97*, and *ASTM E 2516-06 Standard Classification for Cost Estimate Classification System*) provide guidance on cost uncertainty, depending on the level of project design. The opinion of probable cost for the options evaluated generally corresponds to a "Class 4" estimate, characterized by limited project definition and the wide-scale use of parametric models to calculate estimated costs. As the level of design detail

increases, the level of uncertainty is reduced. Figure 5-1 provides a graphic representation of how uncertainty (or accuracy) of cost estimates can be expected to improve as more detailed design is developed.

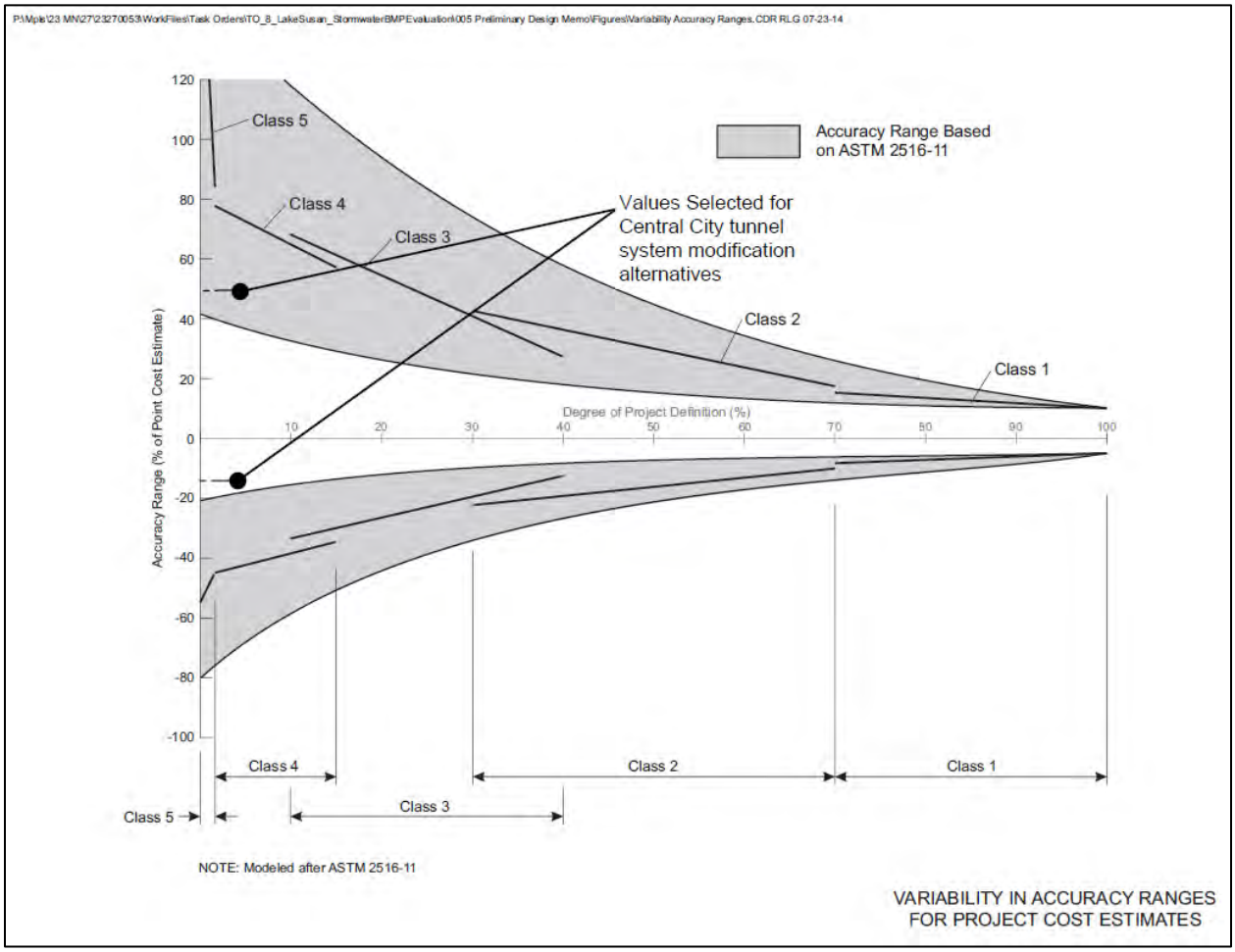


Figure 5-1 Relationship between Cost Accuracy and Degree of Project Definition

At this conceptual stage of design, the range of uncertainty related to total project cost is high. Standard practice at the early design stage is to place a broad accuracy range around the point cost estimate.

The accuracy range is based on professional judgment considering the level of design completed, complexity of the project, and uncertainties in the project scope; it does not include costs for future scope changes that are not part of the project as currently defined or risk contingency. The estimated accuracy range for this point estimate is -15% to +50%.

The opinion of probable construction cost provided in this report is made on the basis of Barr's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. It is acknowledged that additional investigations and additional site-specific information that become available in the next stage of study or design may result in changes to the proposed configuration, cost, and functioning of project features. This opinion is based on project-

related information available to Barr at this time and includes a conceptual-level design of the project. The opinion of cost may change as more information becomes available and further design is completed. In addition, because we have no control over the eventual cost of labor, materials, equipment, or services furnished by others, or over the contractor's methods of determining prices, or over competitive bidding or market conditions, Barr cannot and does not guarantee that proposals, bids, or actual costs will not vary from the opinion of probable construction cost presented in this report. If the City wishes greater assurance as to the probable project cost, it should authorize further investigation and design of a selected option.

Table 5-1 provides a comparison of the opinion of costs for each of the nine pressure-mitigation options. For additional details regarding the opinions of probable cost see Appendix C. The City should review components of each option and verify the assumptions that were used to develop the opinions of probable cost, including the assumption that additional property will not need to be purchased for any of the options evaluated. Opinions of cost for options that include a parallel tunnel do not include the cost for maintenance to the existing tunnel that may be required for the existing segment of tunnel to continue to function.

Table 5-1 Engineer's Opinion of Probable Construction Cost

Pressure-Mitigation Option	Probable Range of Construction Cost	
	-15%	+50%
Option 1a—Oversize tunnel on Washington Avenue	$17,300,000	$30,500,000
Option 1b—Oversize tunnel on Washington Avenue & add parallel tunnel along Portland Avenue to downstream of West River Parkway	$25,100,000	$44,200,000
Option 2a—Oversize tunnel on Second Avenue S.	$7,300,000	$12,900,000
Option 2b—Oversize tunnel on Second Avenue S., add parallel tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & extend to downstream of West River Parkway	$20,500,000	$36,200,000
Option 3a—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue	$13,100,000	$23,100,000
Option 3b—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & extend to downstream of West River Parkway	$19,800,000	$35,000,000
Option 4a—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue	$9,700,000	$17,000,000
Option 4b—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway	$16,000,000	$28,200,000
Option 4c—Disconnected parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway	$16,000,000	$28,300,000

6.0 Conclusions and Recommendations

An analysis was completed to evaluate how nine pressure-mitigation options effect peak pressure in the Central City tunnel system during the 10- and 100-year 24-hour rainfall events. This included:

- Hydraulic analysis
- Conceptual level estimate of pressure that could cause tunnel failure
- Opinion of cost

The analysis was based on information available at this time. It did not include site investigations or collection of new data. Collection of additional data (i.e., tunnel inspections, as-built survey, tunnel-void inventory, measurement of tunnel liner thickness, etc…), or additional site-specific information may result in modifications to the configuration, cost, or functioning of the pressure-mitigation options presented. The analysis indicated that:

- Increasing the storage volume in the tunnel system without increasing the conveyance capacity to West River Parkway minimally reduces the peak water-surface elevations (e.g., pressure) within the system (i.e., Option 2a)
- Based on the pressure reductions and the estimated range of project costs, the following options were identified as providing the greatest reductions in water-surface elevation throughout the system and could be considered by the City for further evaluation:
    - Option 3b—Parallel tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & extend to downstream of West River Parkway
    - Option 4b—Parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway
    - Option 4c—Disconnected parallel tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & extend to downstream of West River Parkway
- In addition, if reduction in peak pressure along Second Avenue S. is critical, the City should also evaluate Option 2b—Oversize tunnel on Second Avenue S., add parallel tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & extend to downstream of West River Parkway
- Additional information will be necessary to identify a recommended modification to the tunnel system. Additional investigations that the City should consider include:
    - Complete an as-built drawing of the Central City tunnel system. Or, at a minimum, the section of tunnel from Hennepin Avenue to West River Parkway. The as-built drawing would be required to determine the alignment of a parallel tunnel.

- Quantify the volume and location of void spaces in the tunnel system. Additional information on the void spaces will be required to identify when the reduction to peak pressure is sufficient to prevent future tunnel failures.
- Utility information along the proposed alignment of the parallel tunnel.

Whichever option the City selects, it is important to bring the tunnel liner back into contact with the surrounding bedrock for the long term performance of the tunnel system. Filling the void spaces and other repairs should be included in any modification to the tunnel system.

7.0 References

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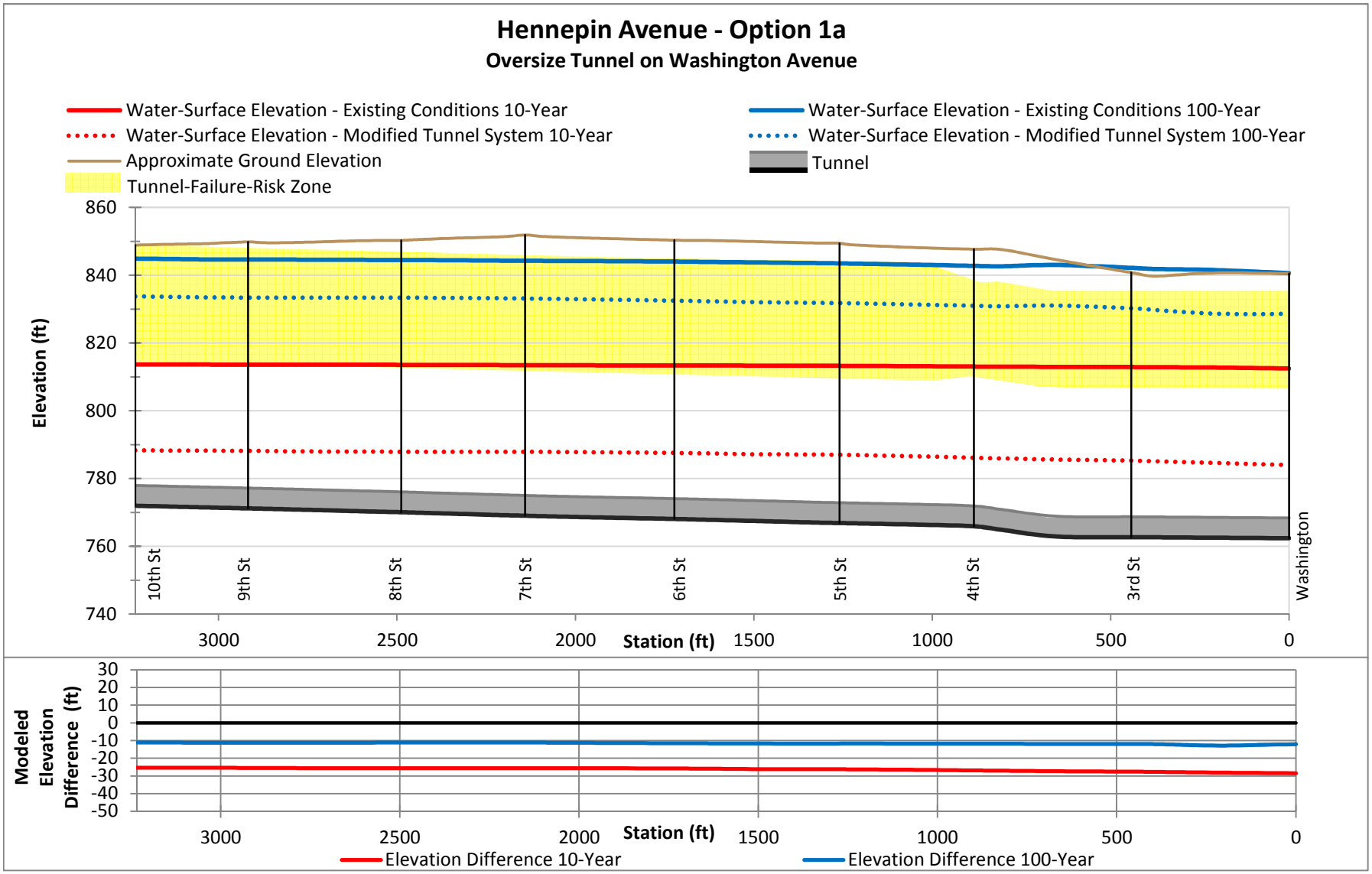
Appendix A

Water Surface Profile Plots for Pressure-Mitigation Options



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.

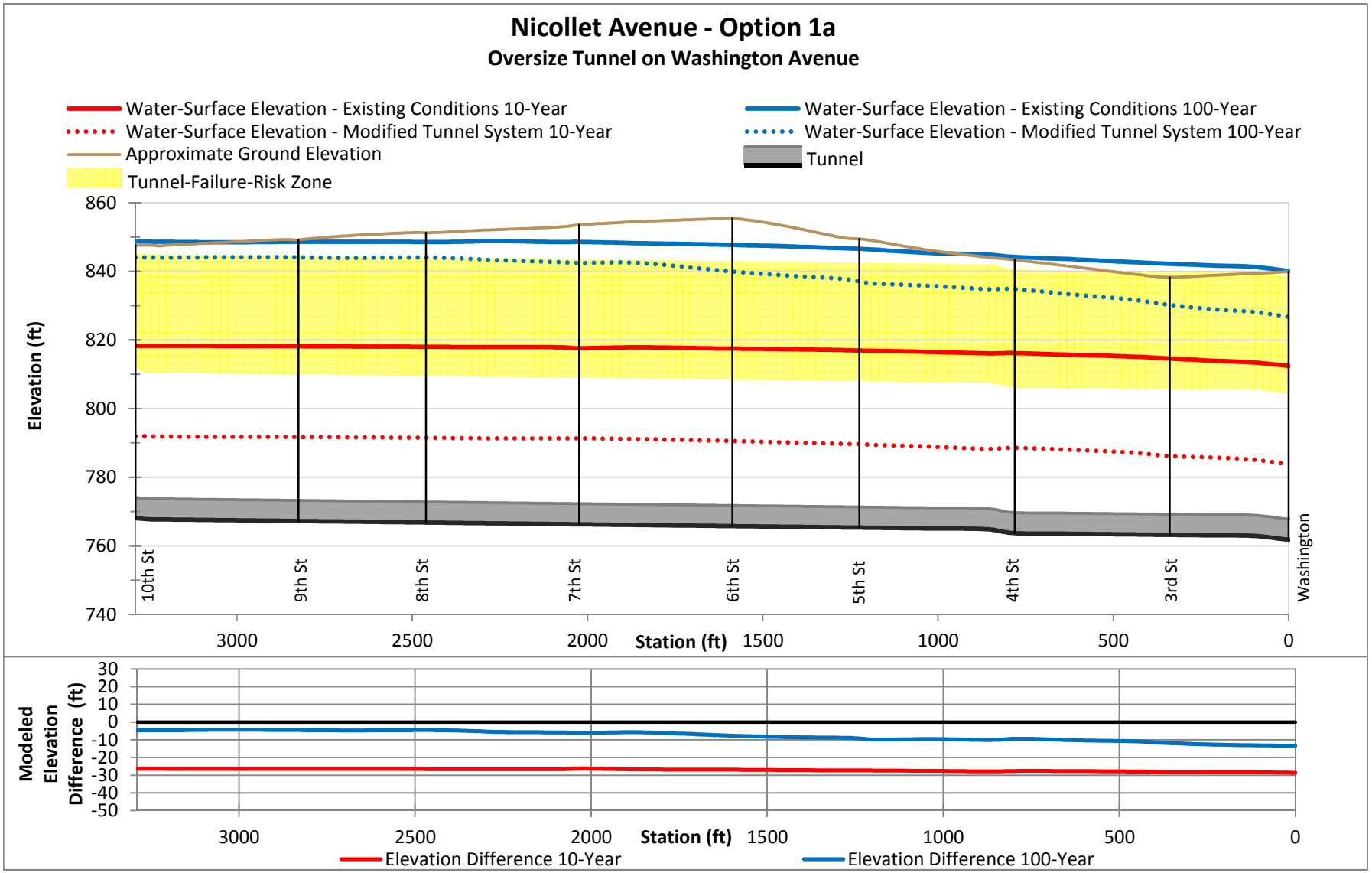
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.

* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).

* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.

* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

*The water-surface elevation profile is based on the maximum elevation during the design event(s).



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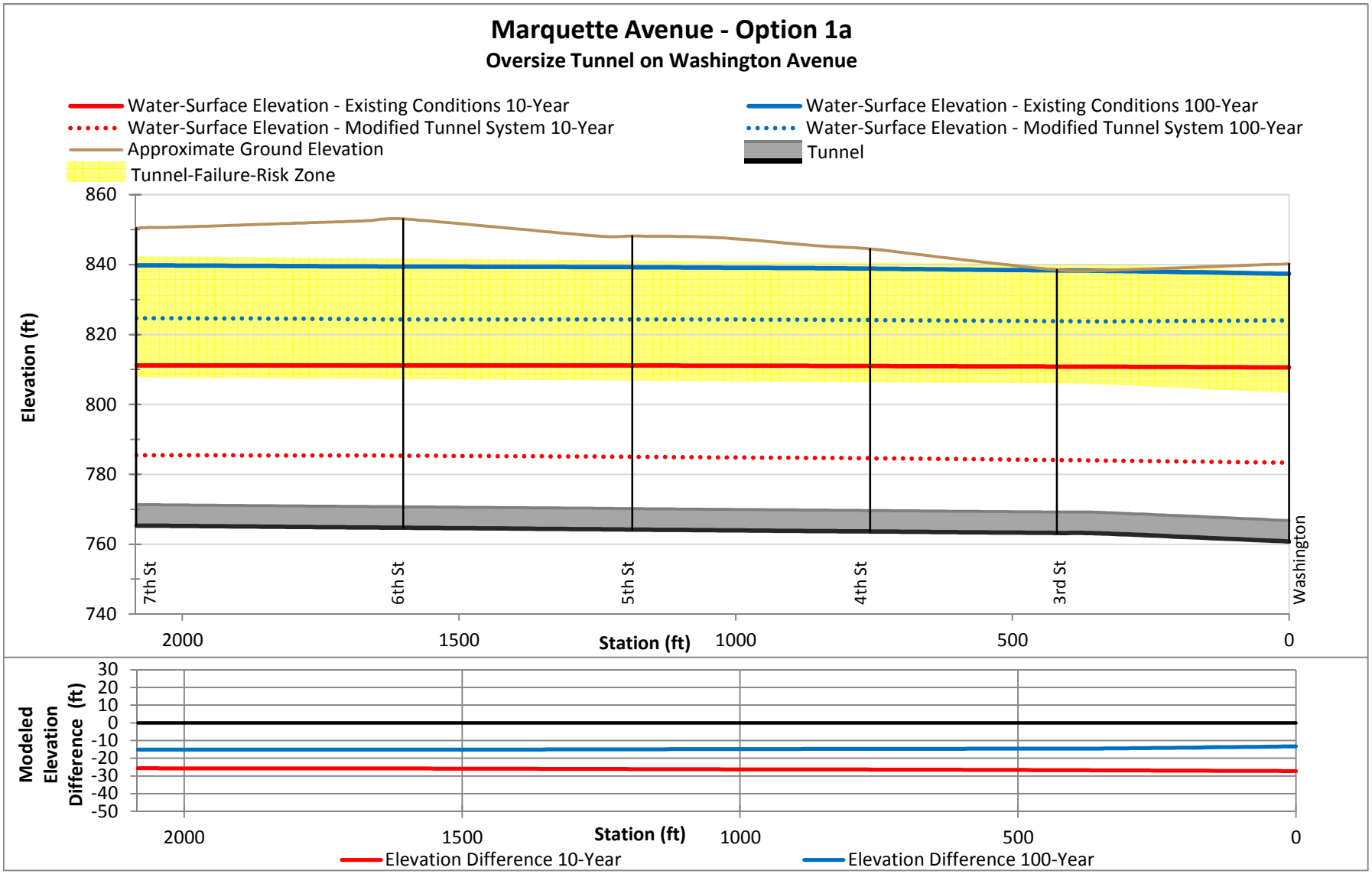
*The water-surface elevation profile is based on the maximum elevation during the design event(s).



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.

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* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.

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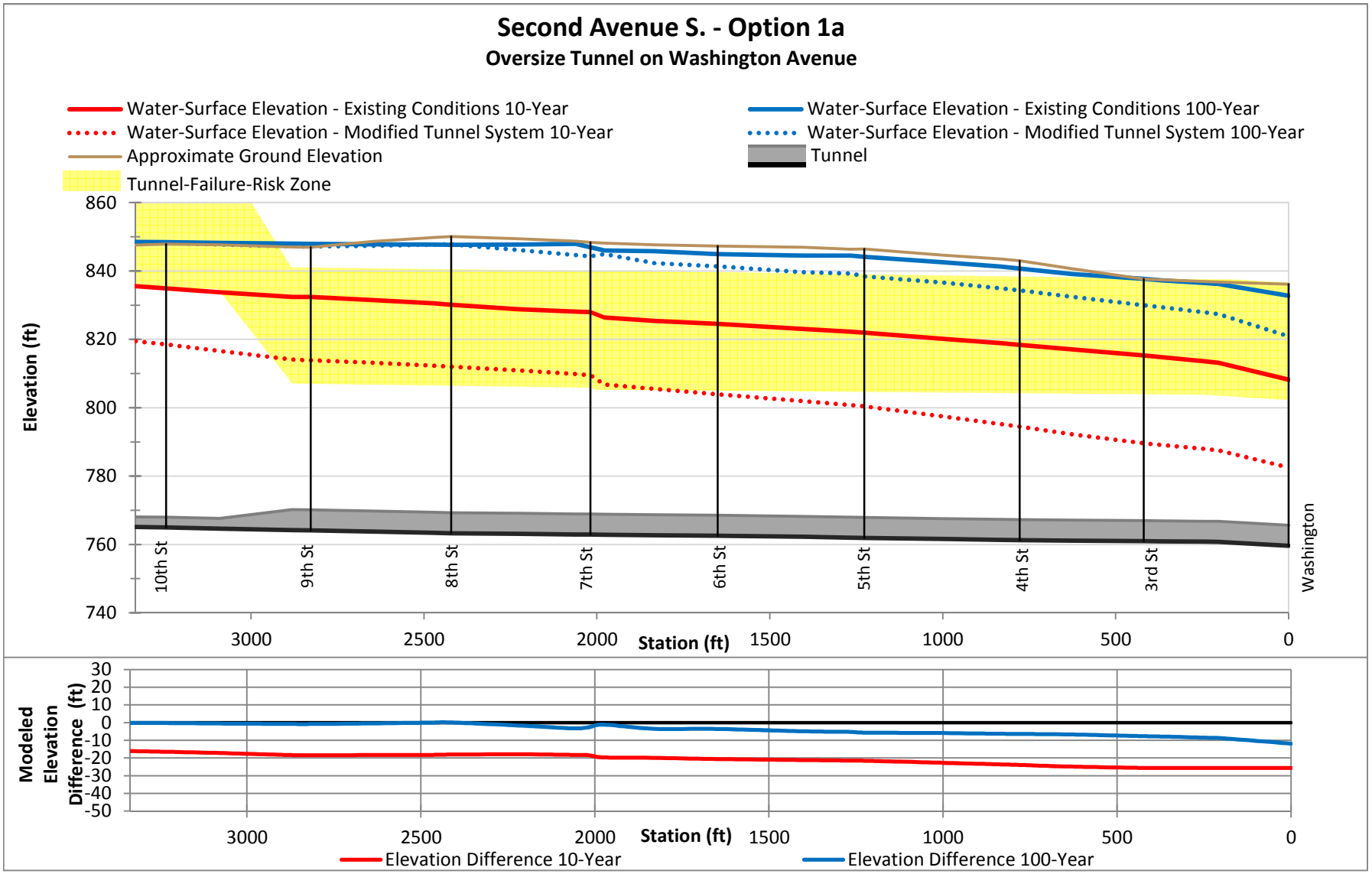
*The water-surface elevation profile is based on the maximum elevation during the design event(s).



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.

* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.

* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).

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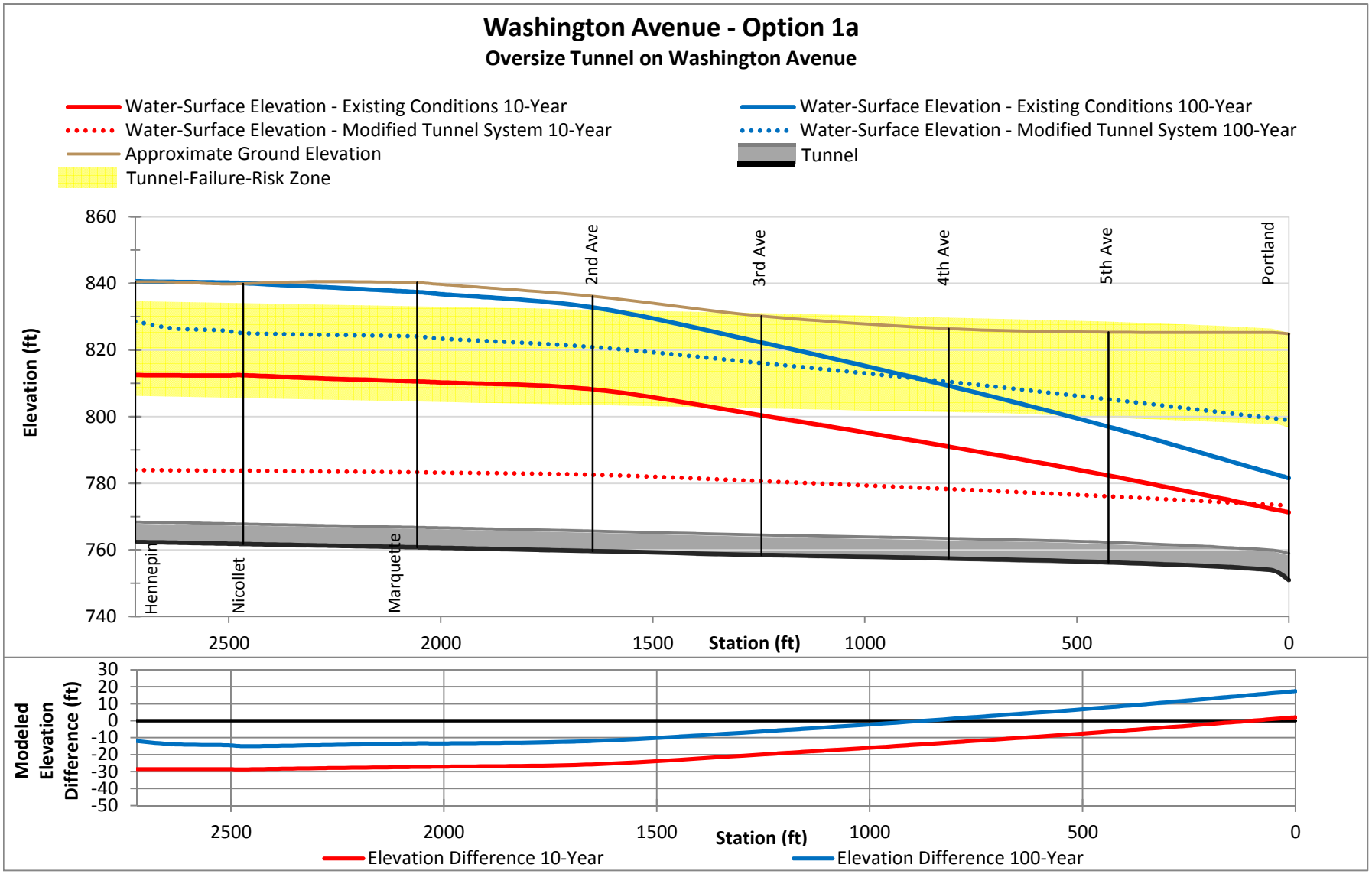
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

*The water-surface elevation profile is based on the maximum elevation during the design event(s).



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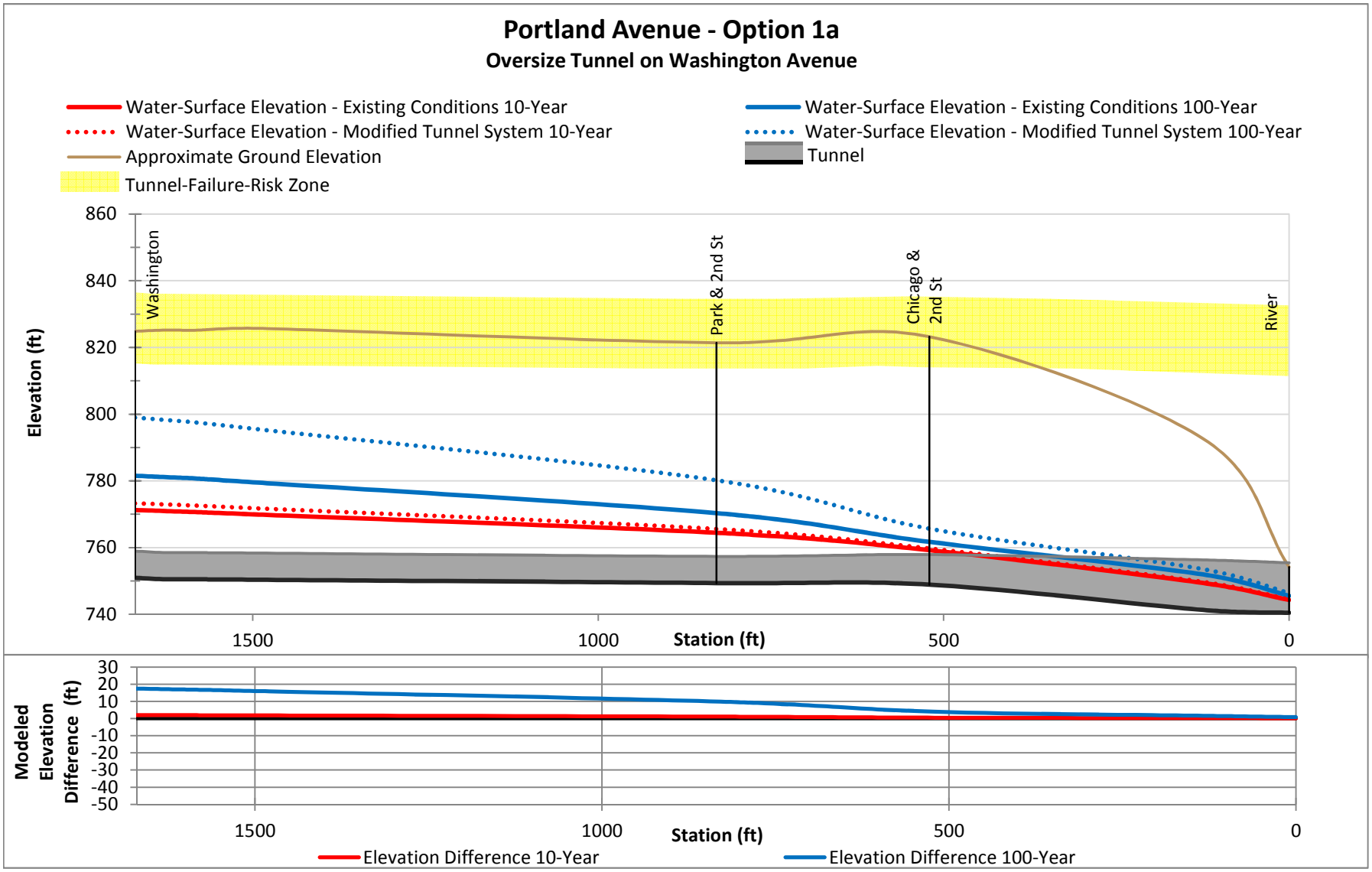

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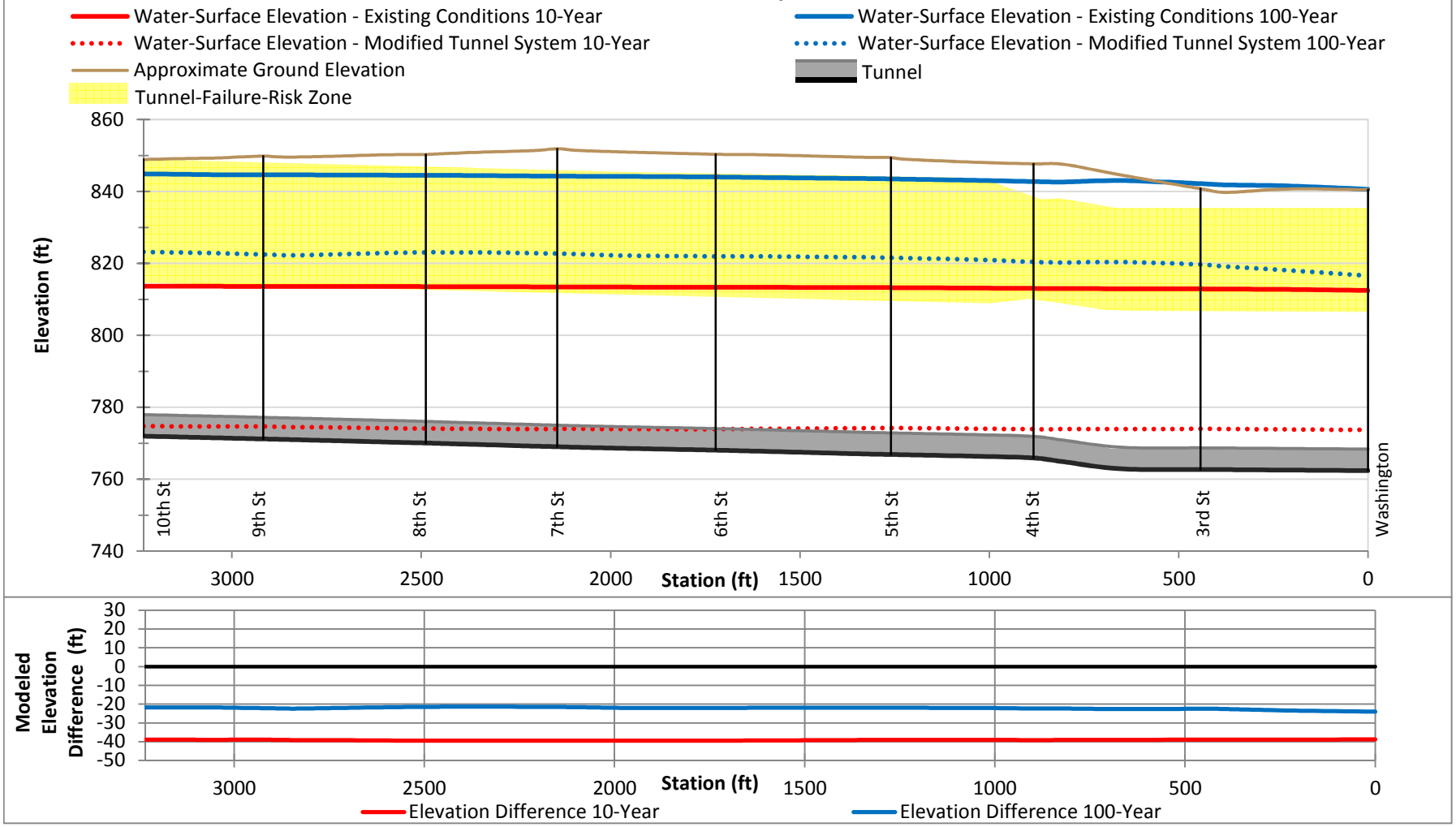
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



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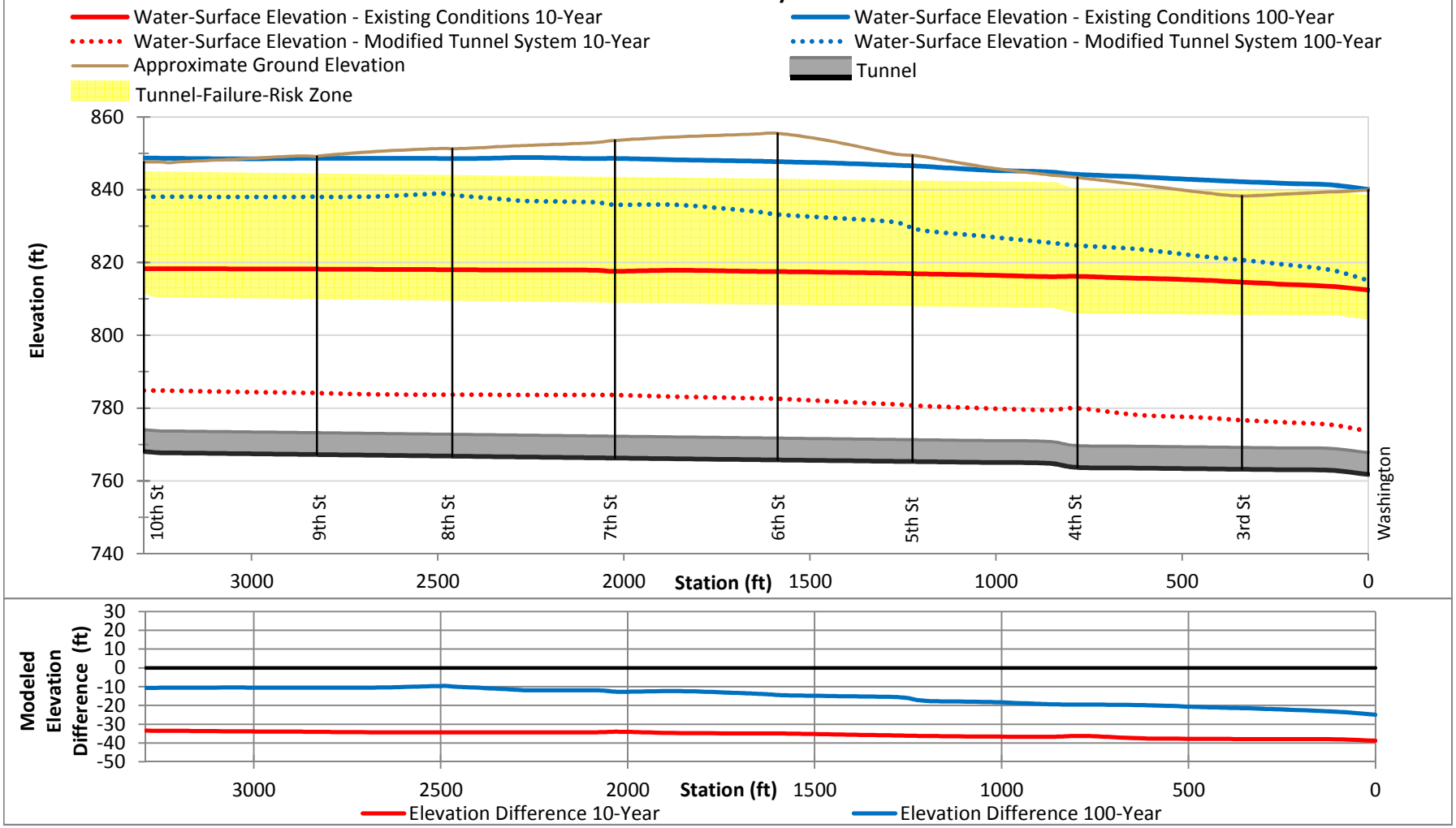
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Nicollet Avenue - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



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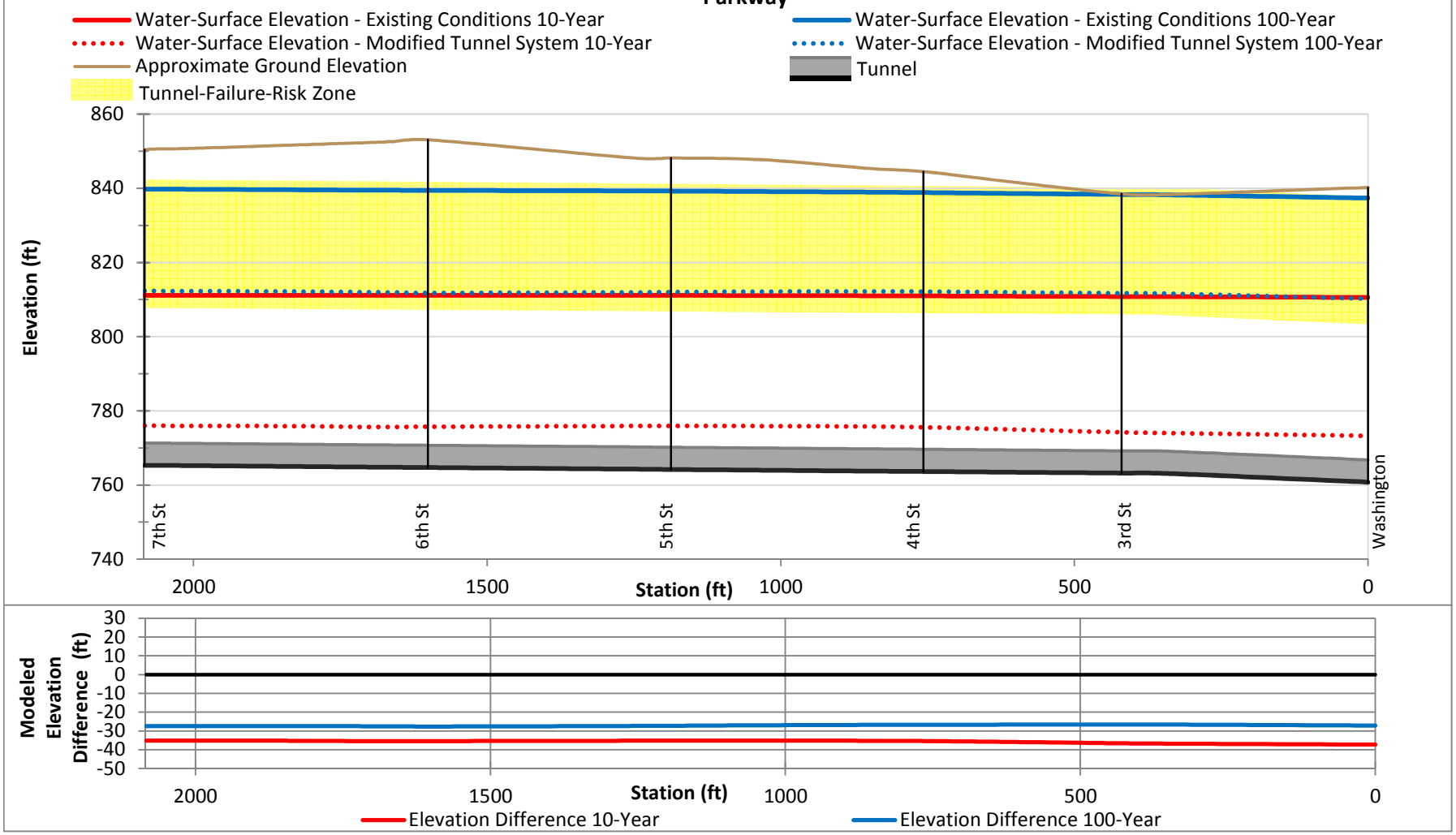
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Marquette Avenue - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



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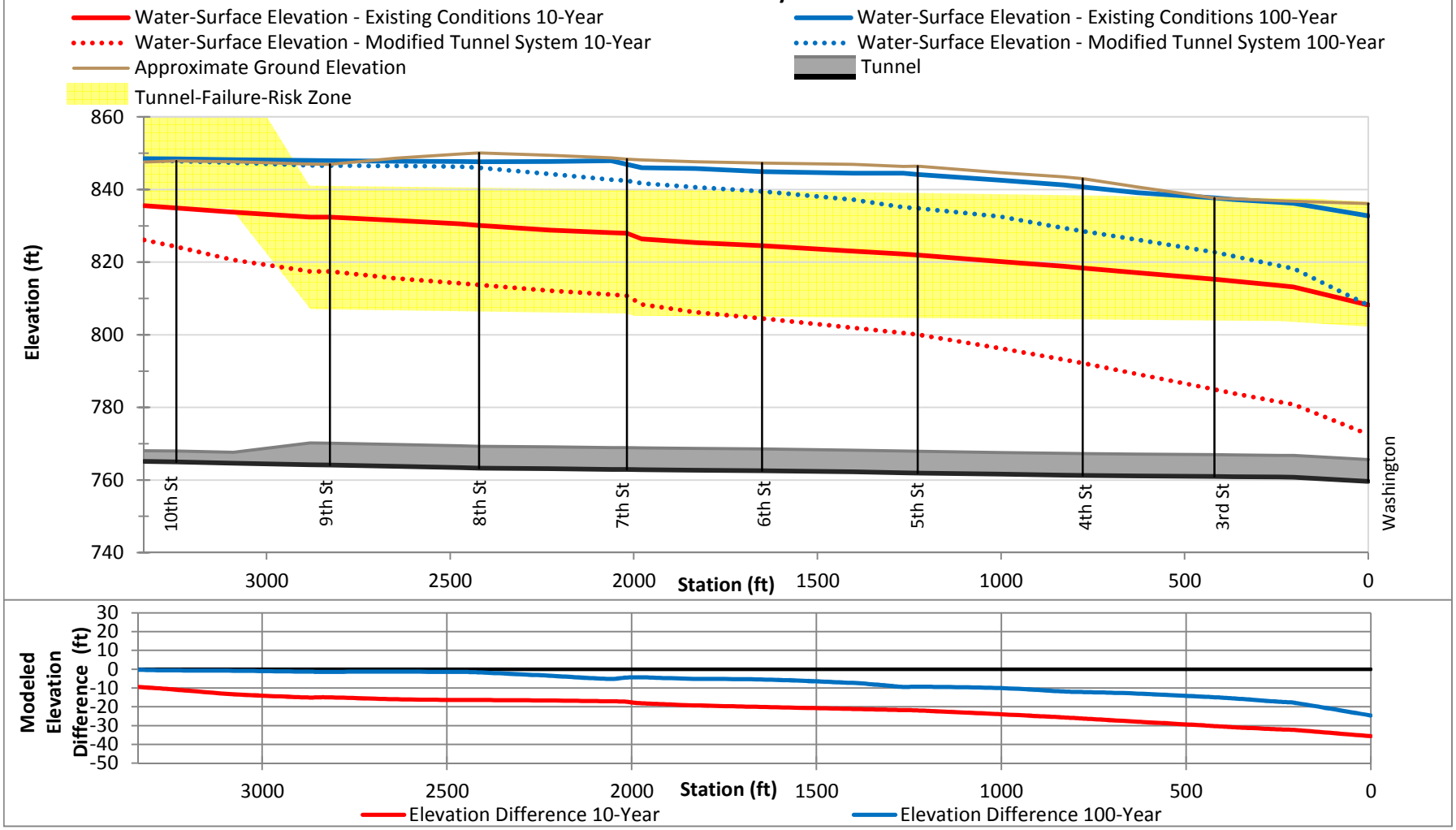
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Second Avenue S. - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



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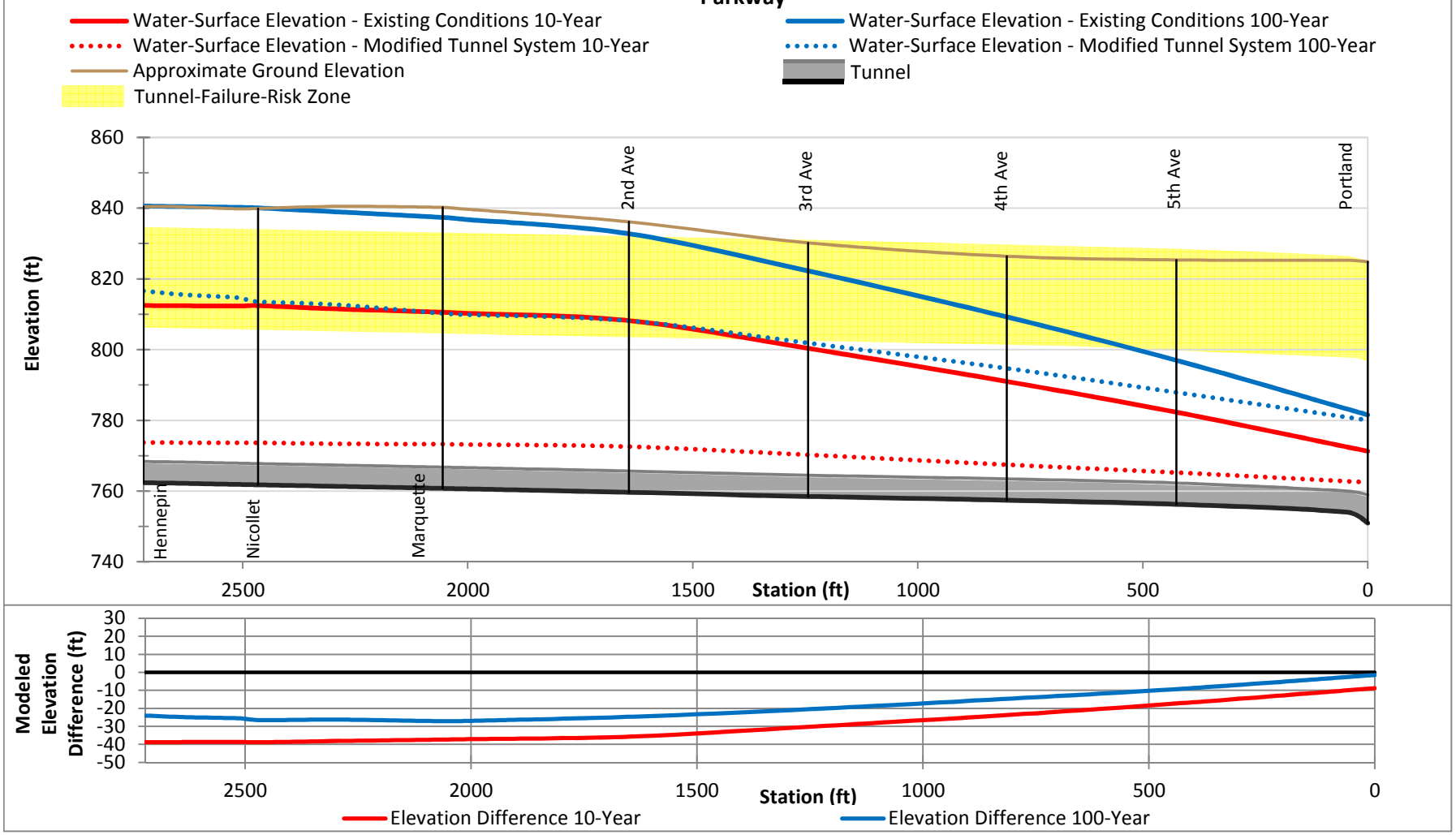
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



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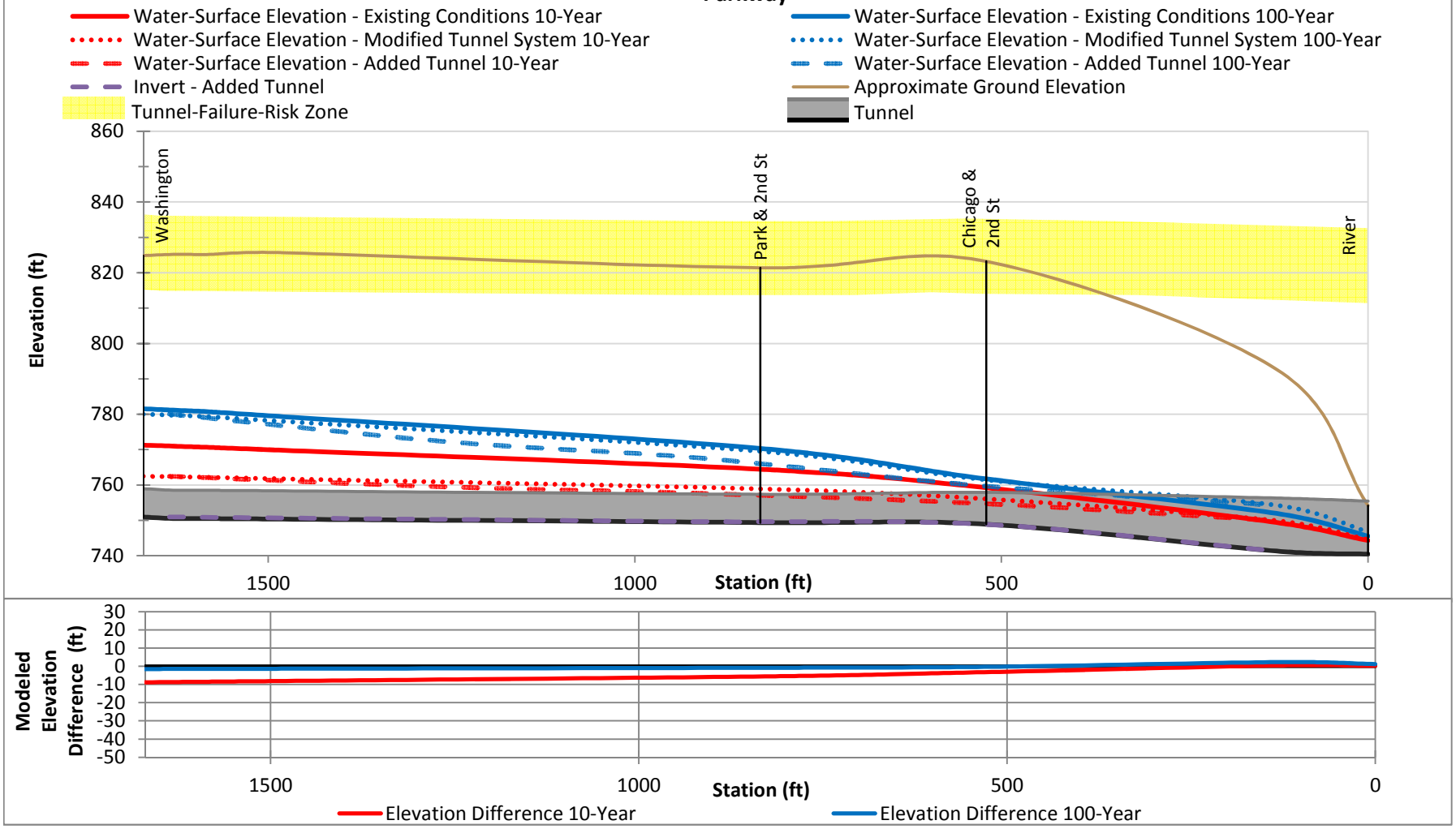
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Portland Avenue - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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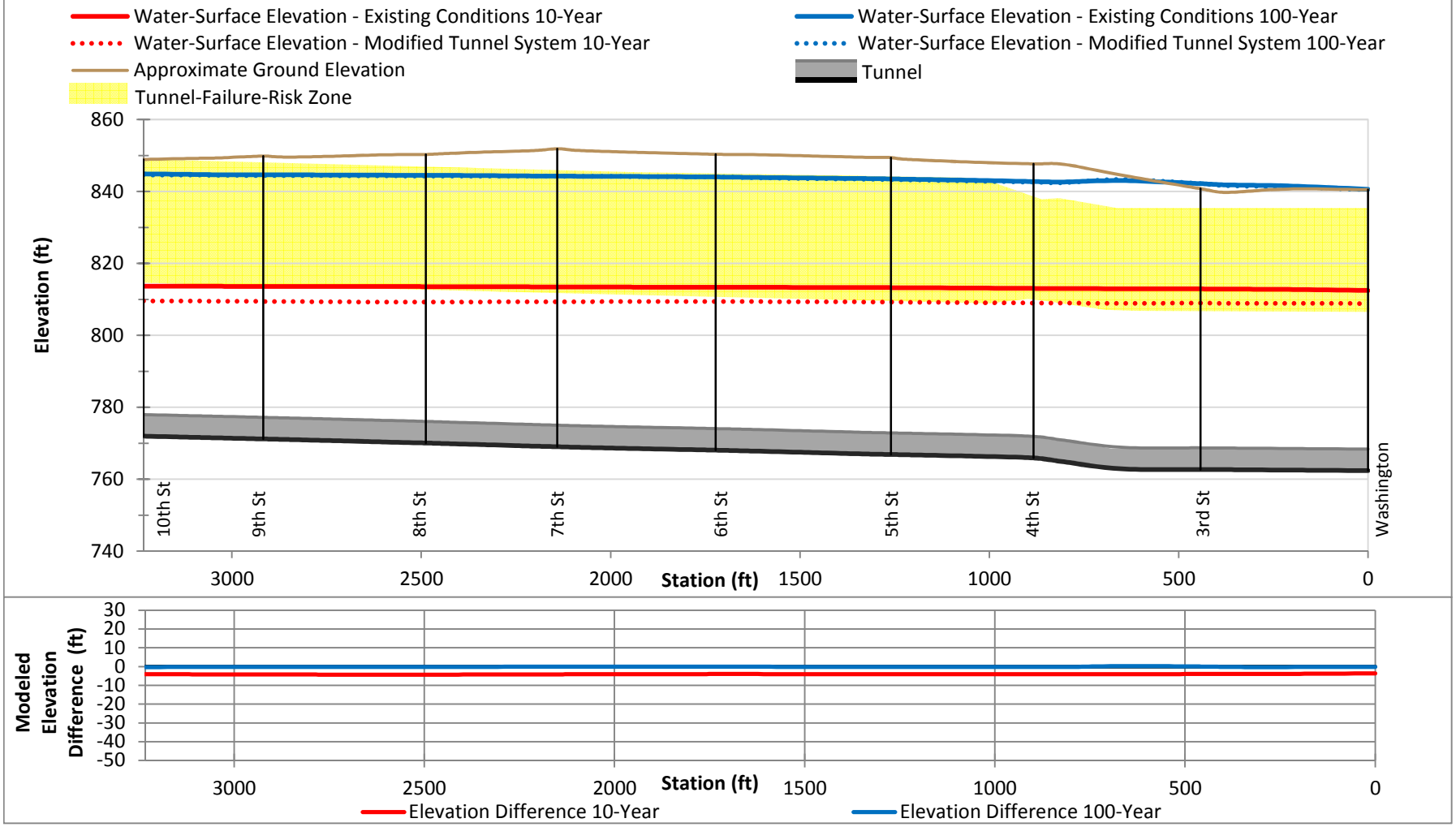
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 2a

Oversize Tunnel on Second Avenue S.



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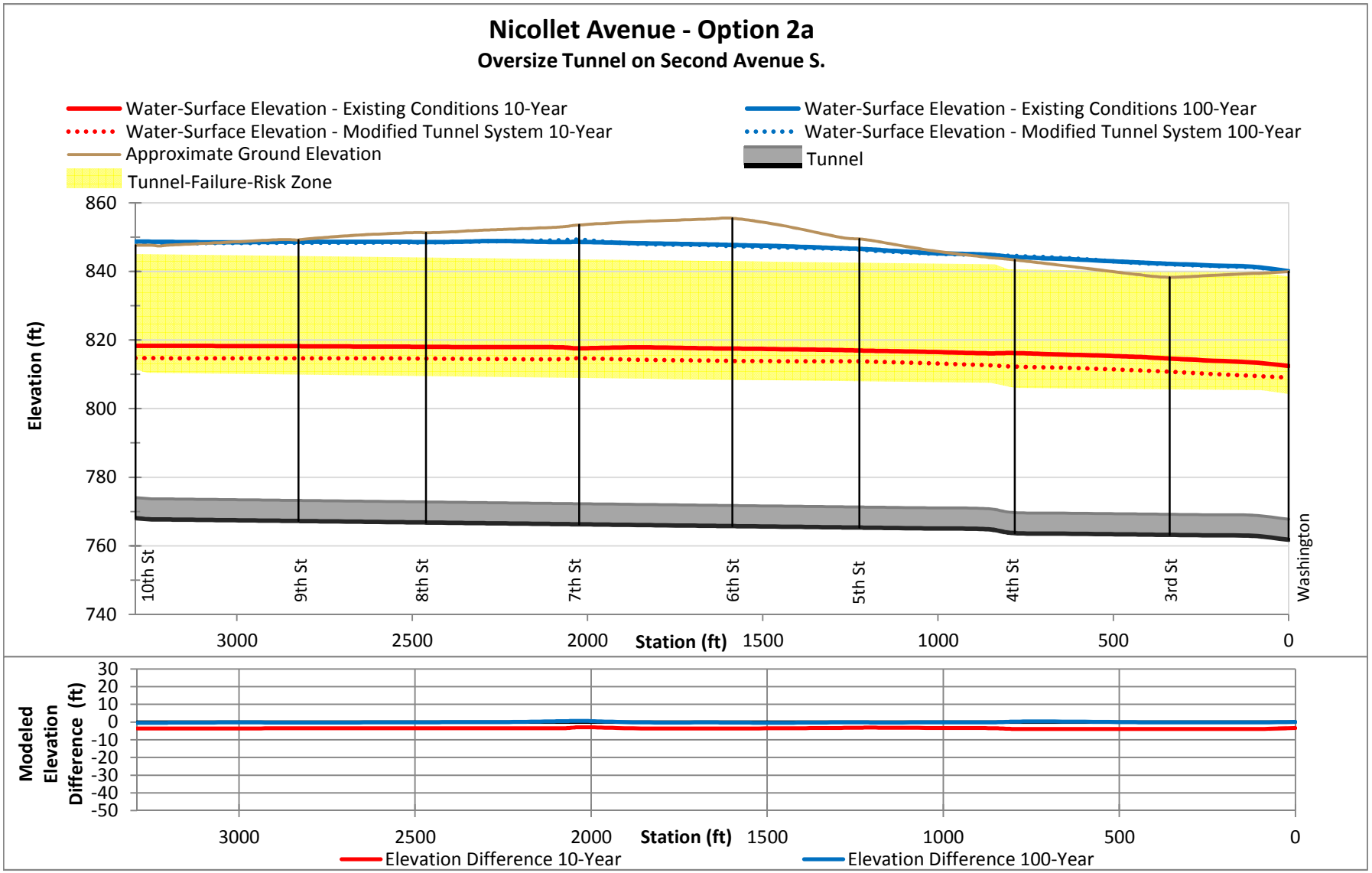

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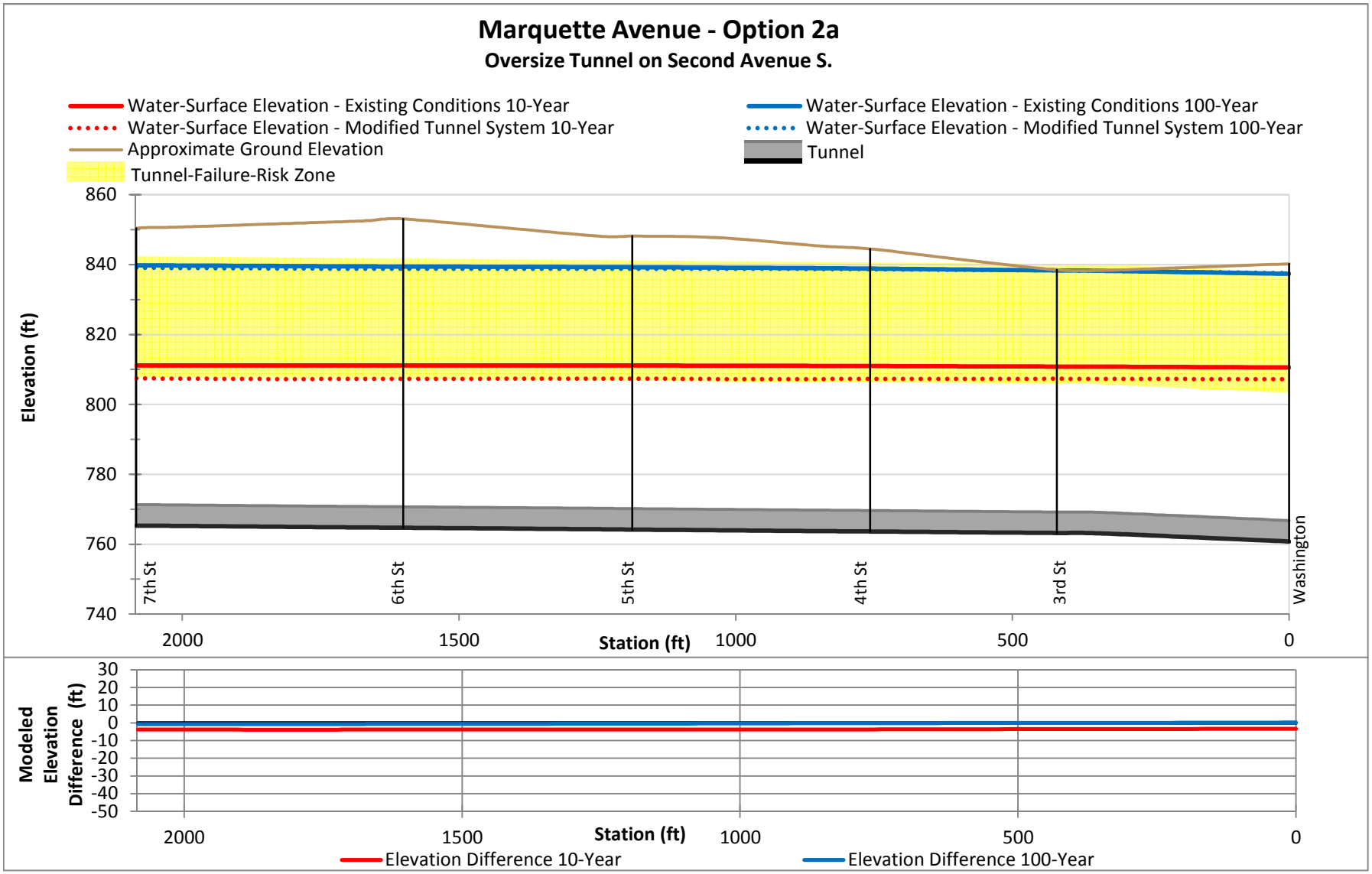

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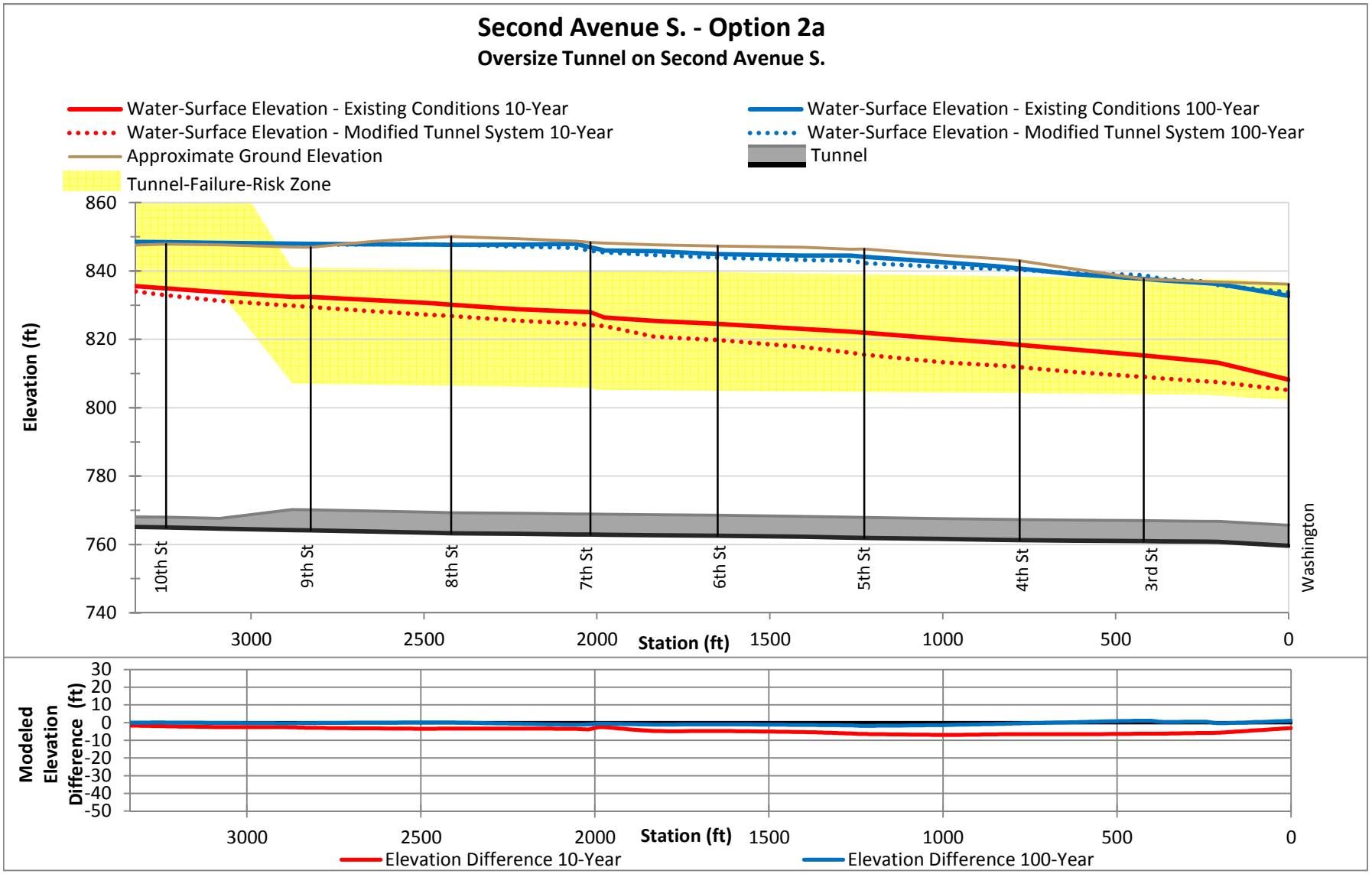

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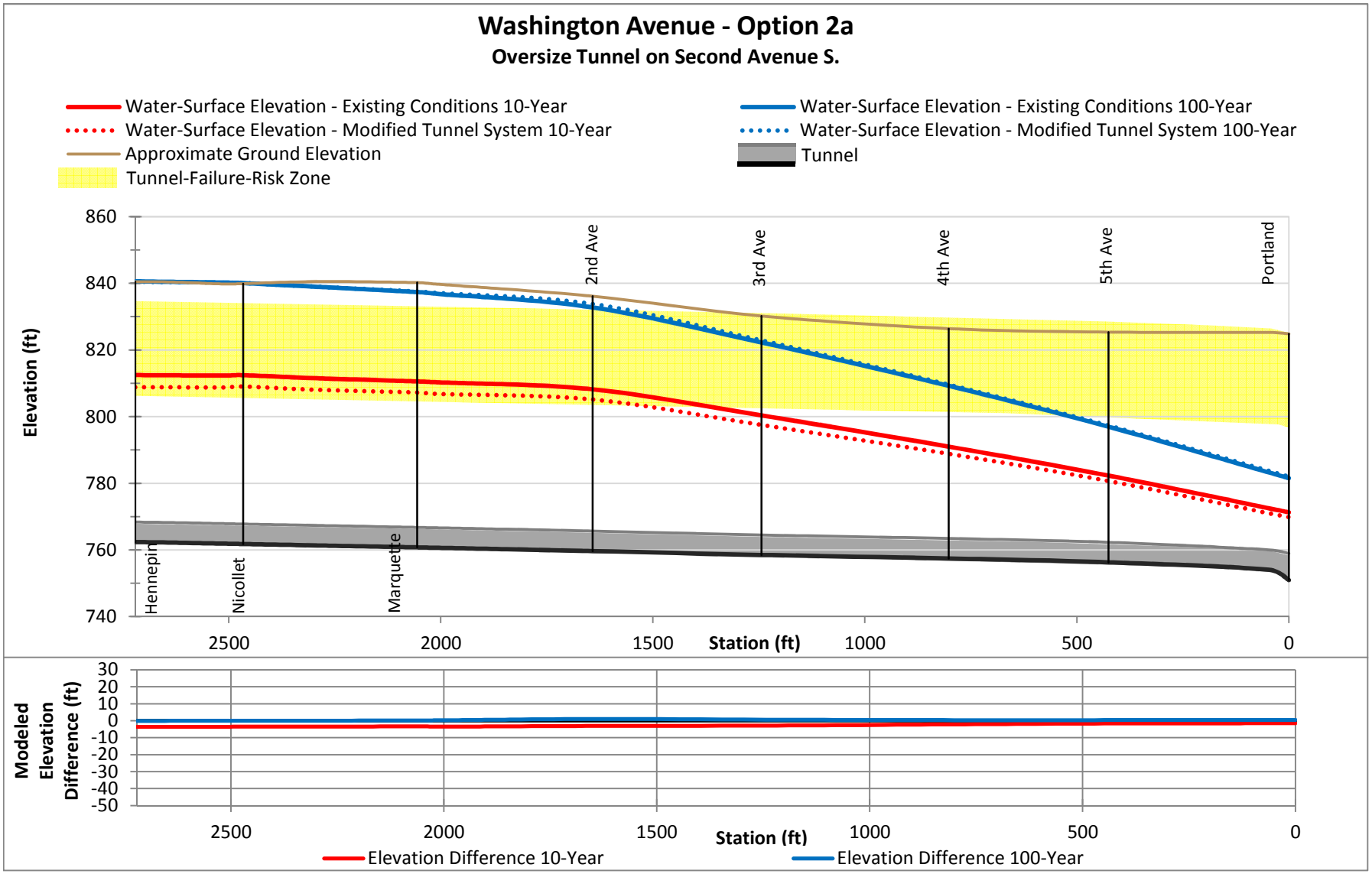

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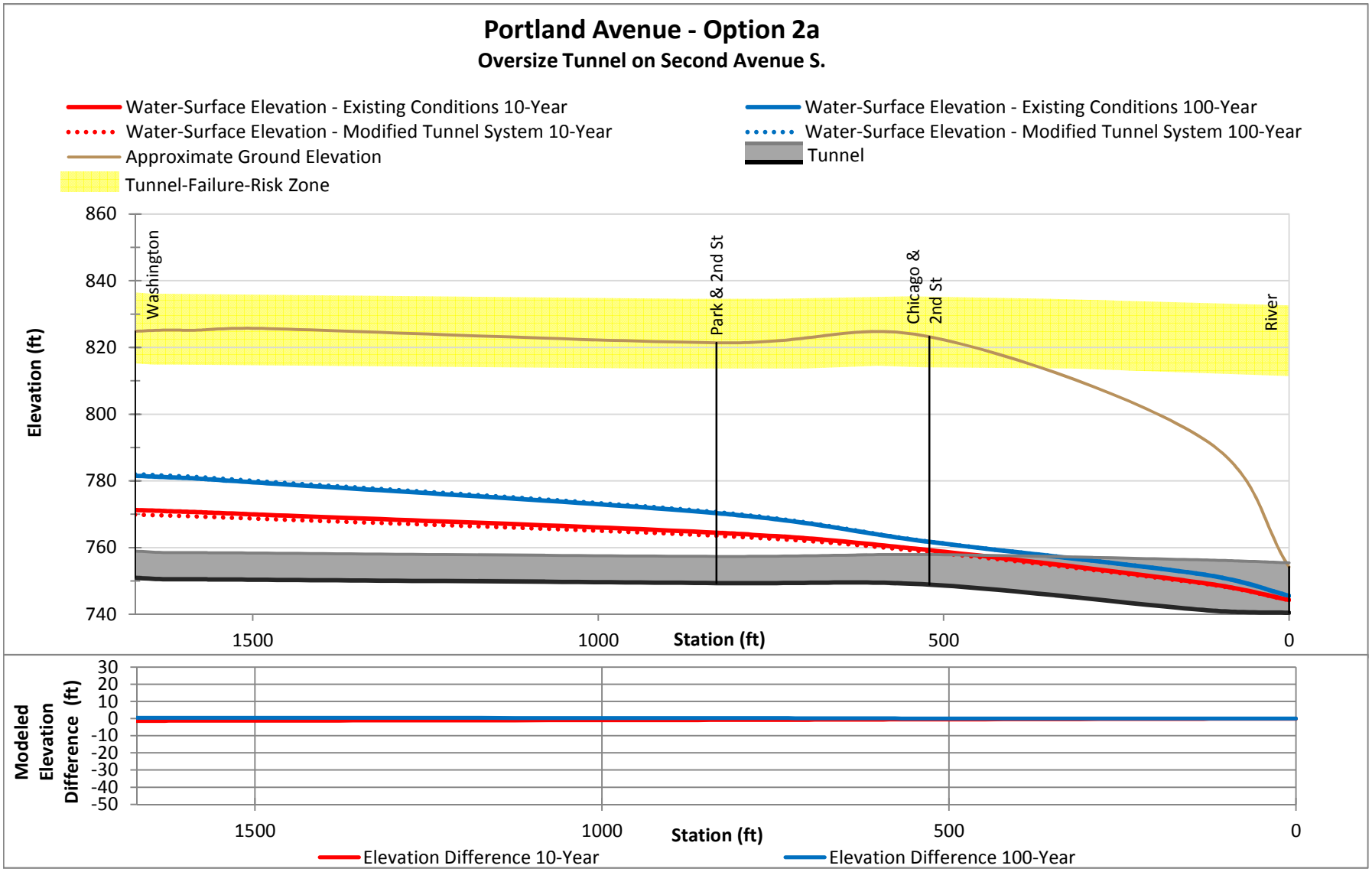

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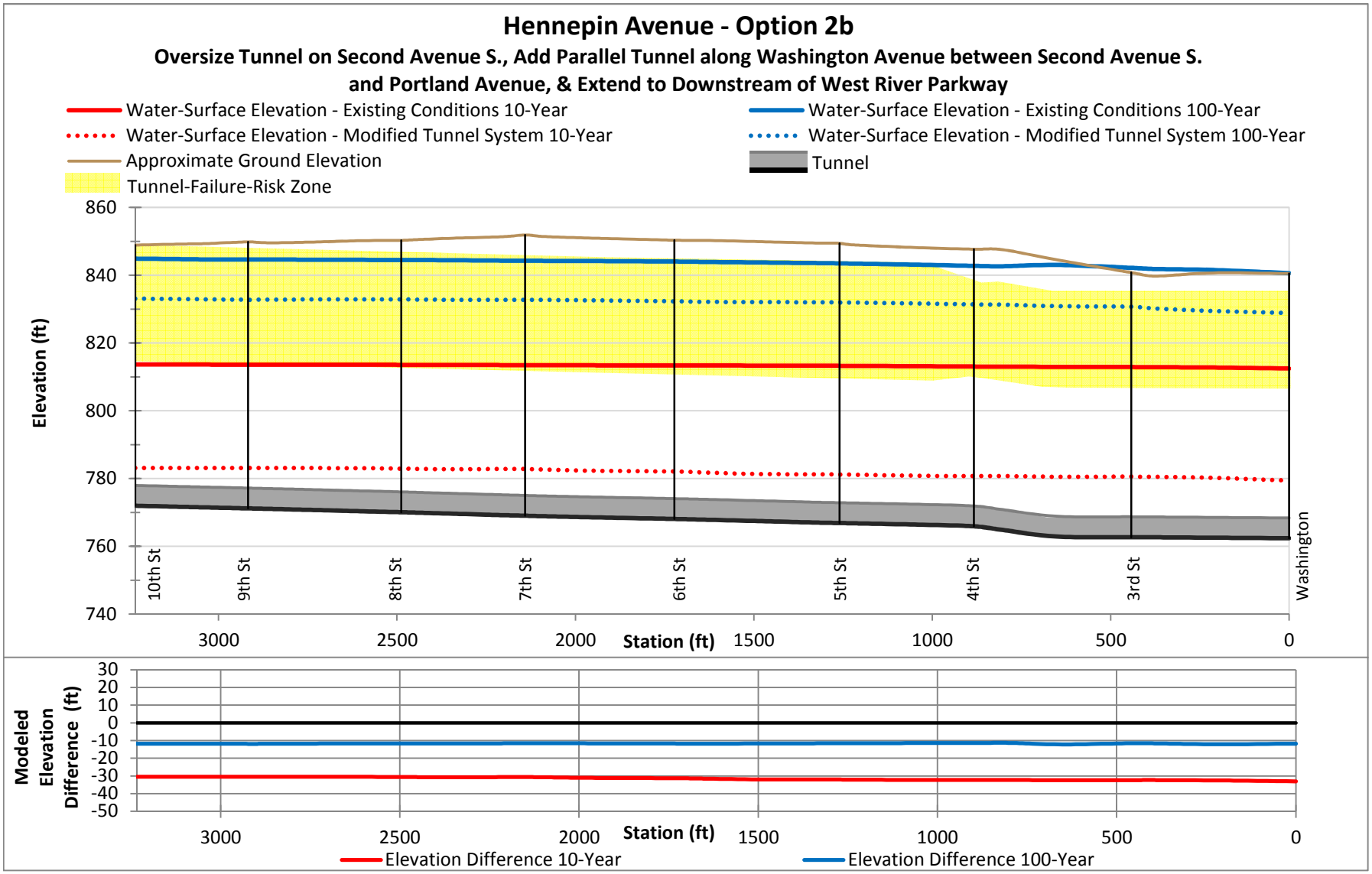

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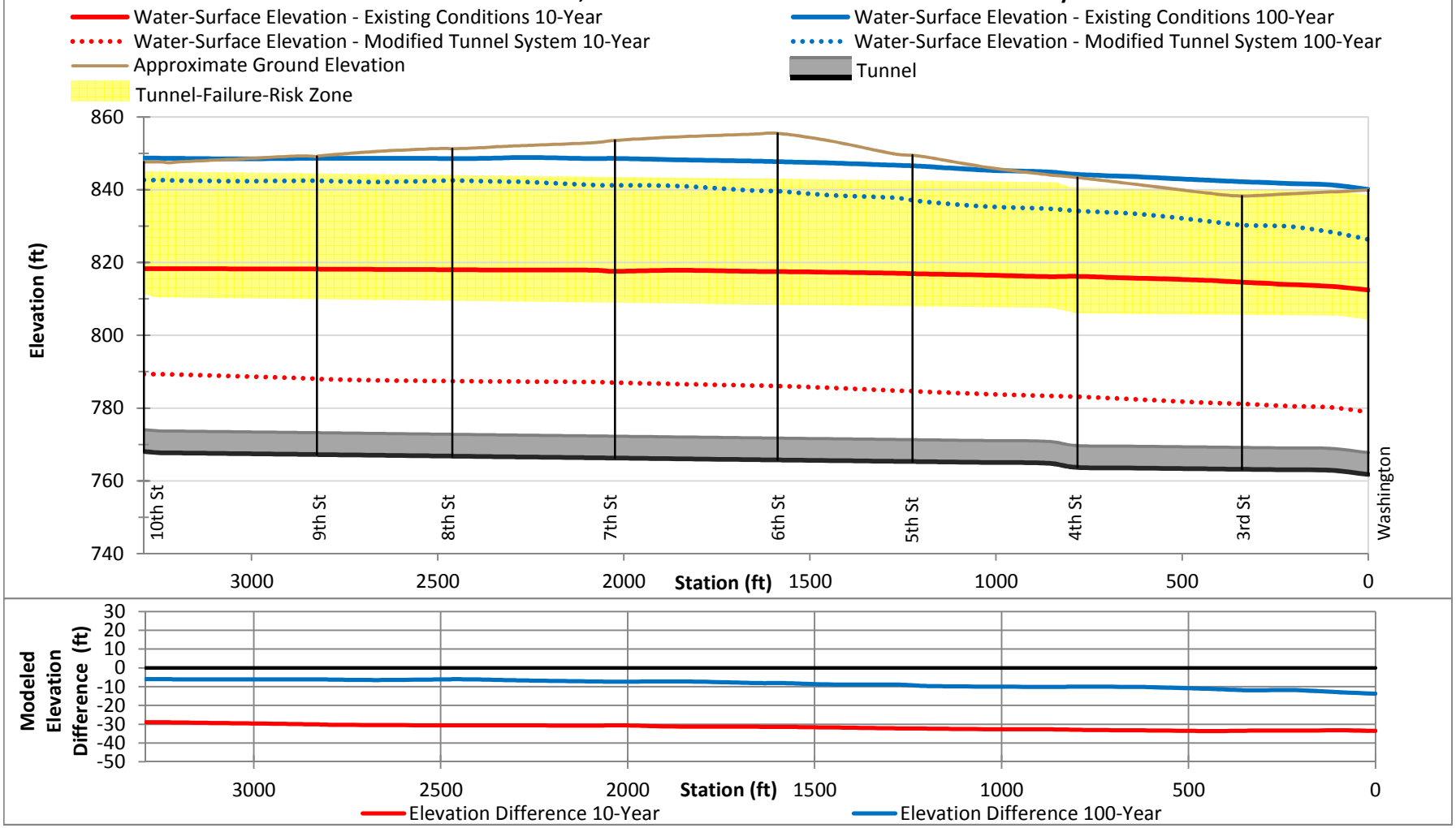
Nicollet Avenue - Option 2b

Oversize Tunnel on Second Avenue S., Add Parallel Tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & Extend to Downstream of West River Parkway



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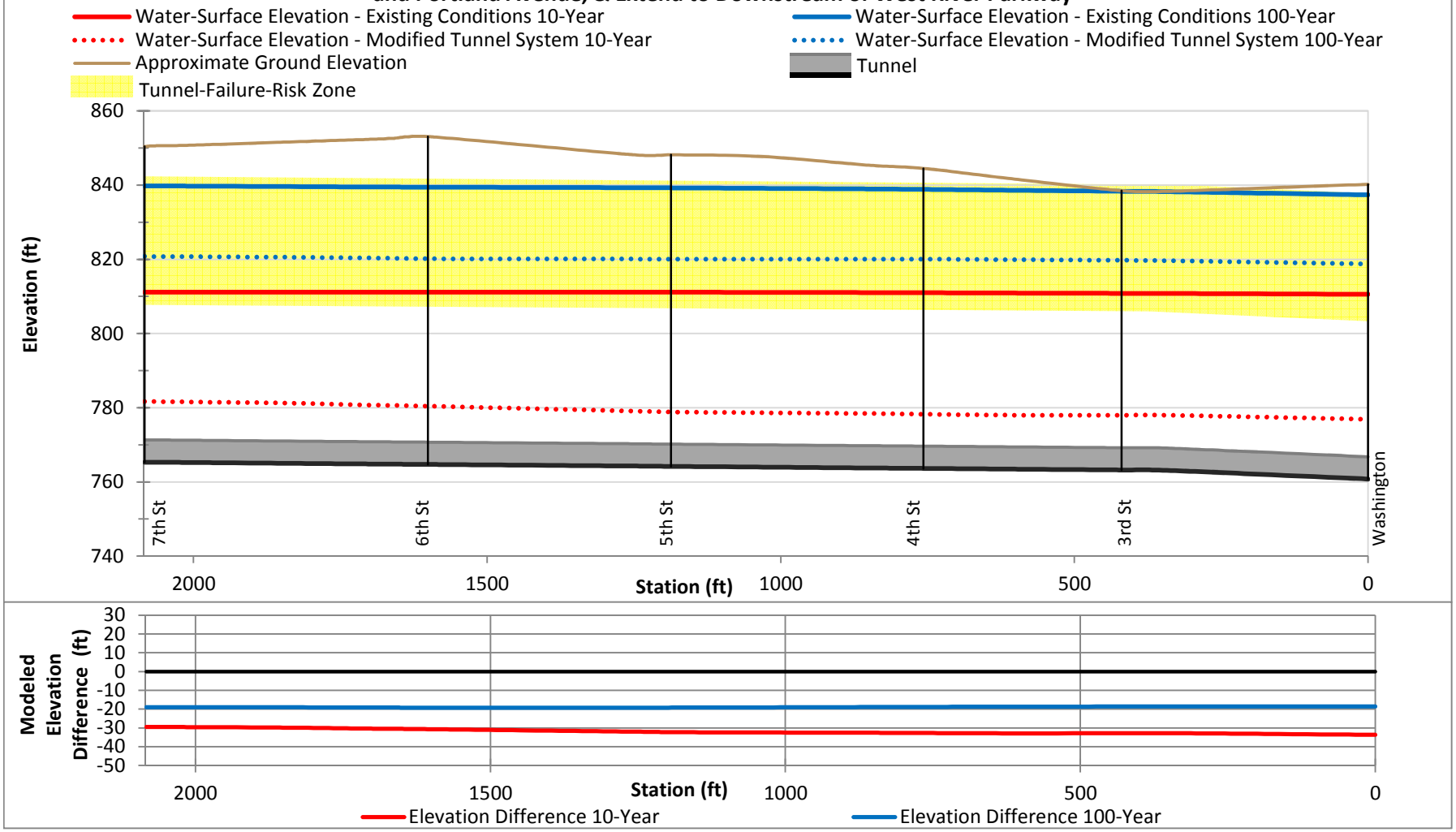
Marquette Avenue - Option 2b

Oversize Tunnel on Second Avenue S., Add Parallel Tunnel along Washington Avenue between Second Avenue S. and Portland Avenue, & Extend to Downstream of West River Parkway



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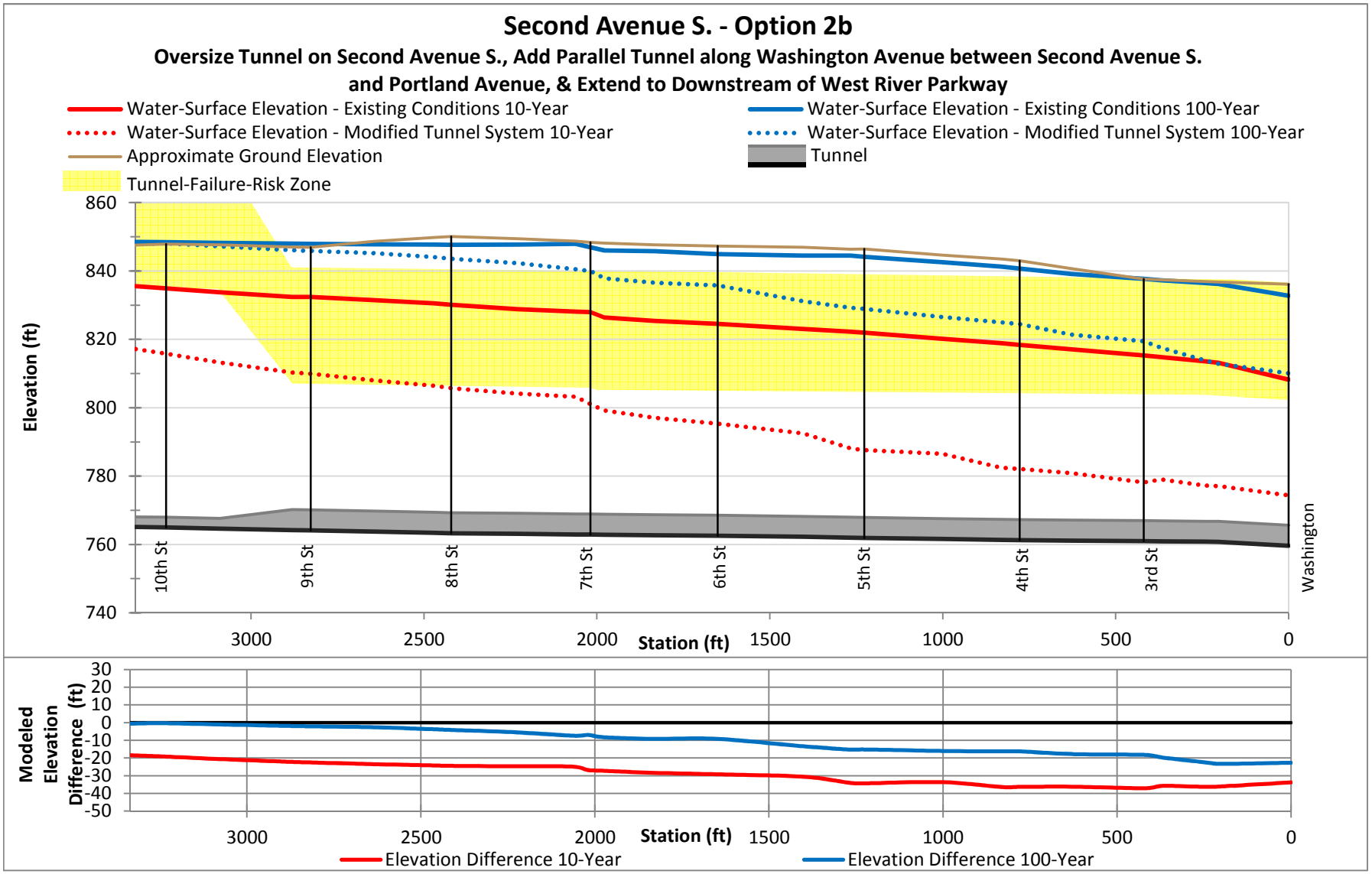

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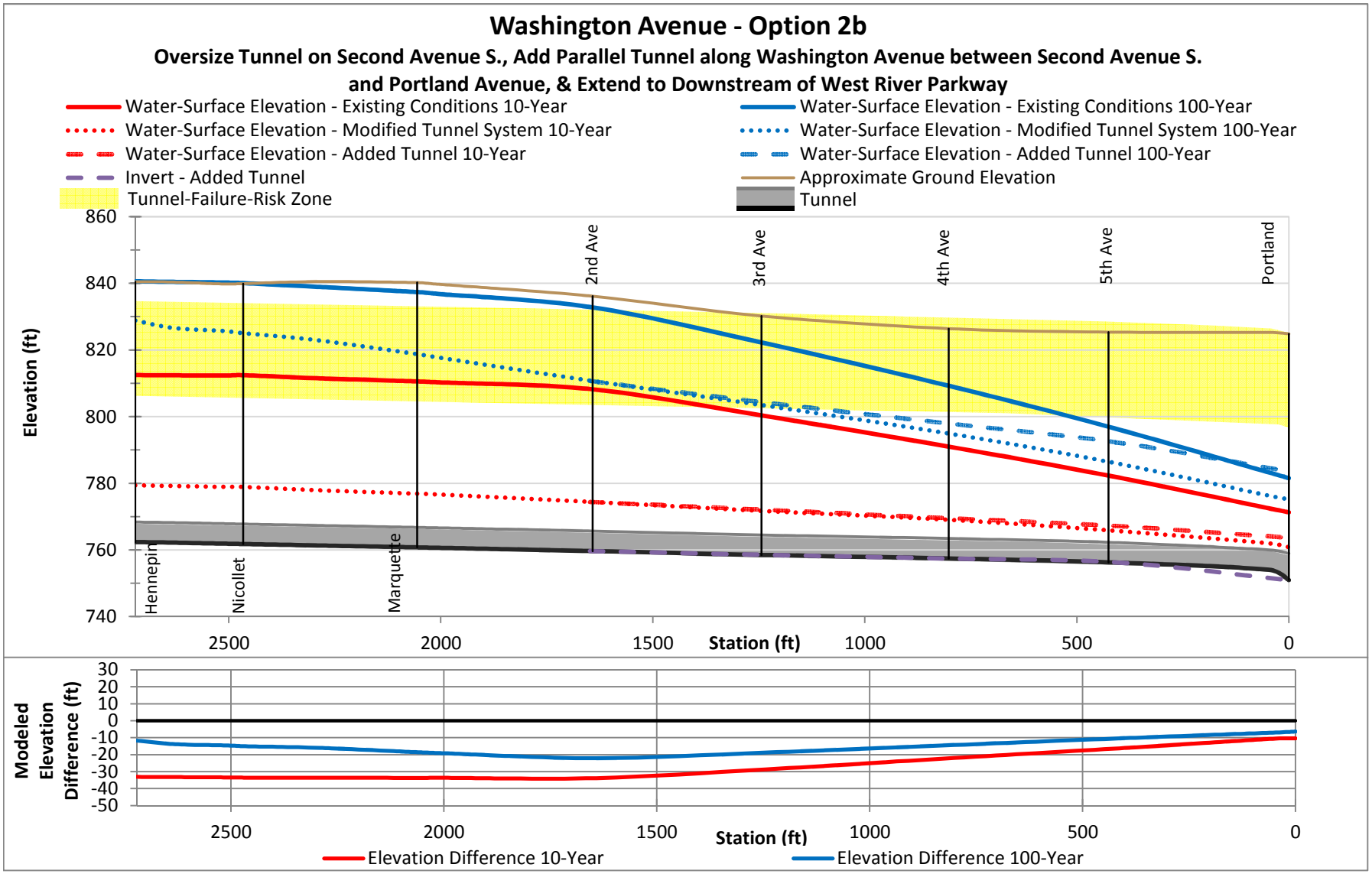
* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).

* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.

* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

*The water-surface elevation profile is based on the maximum elevation during the design event(s).



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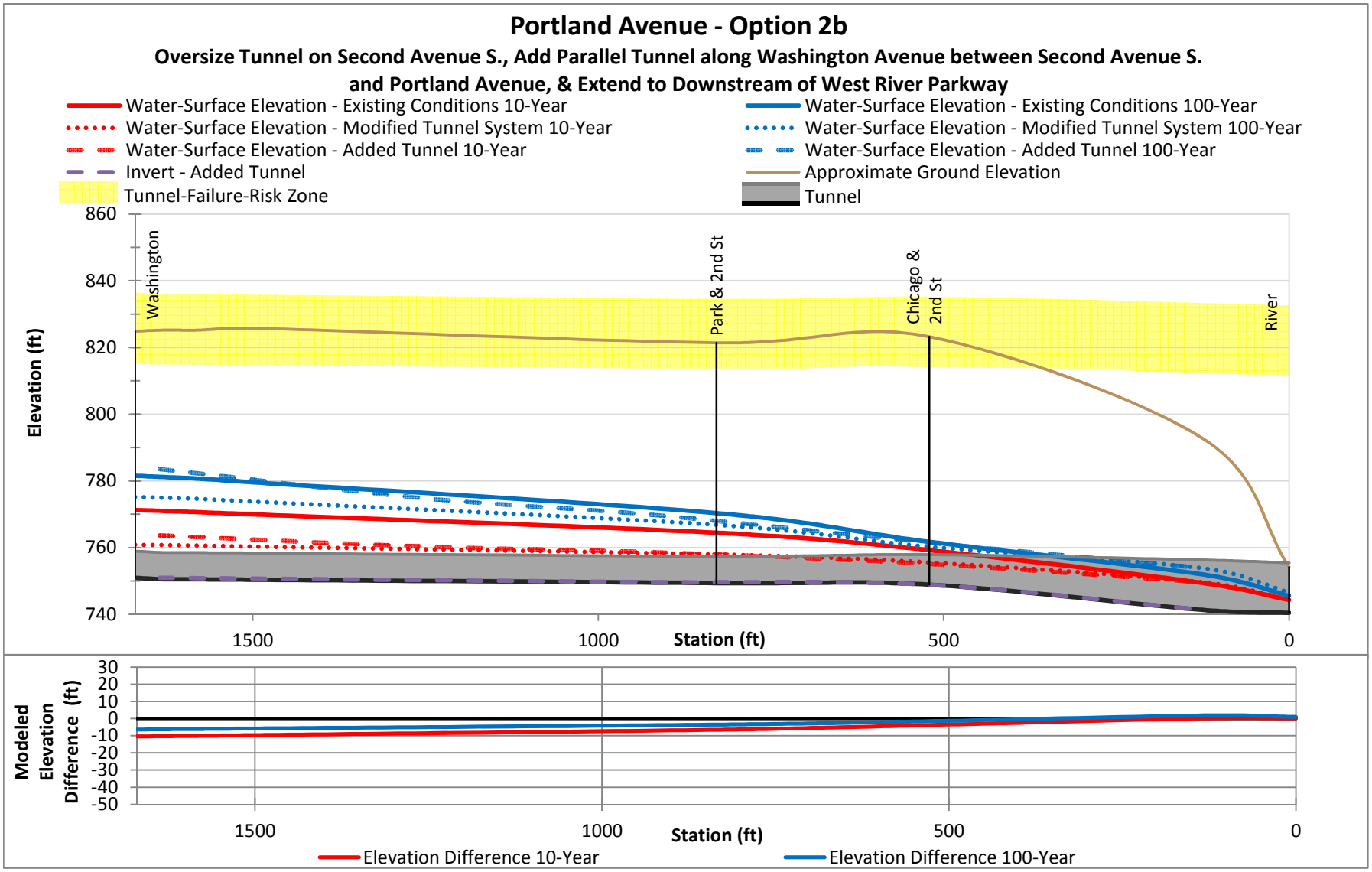

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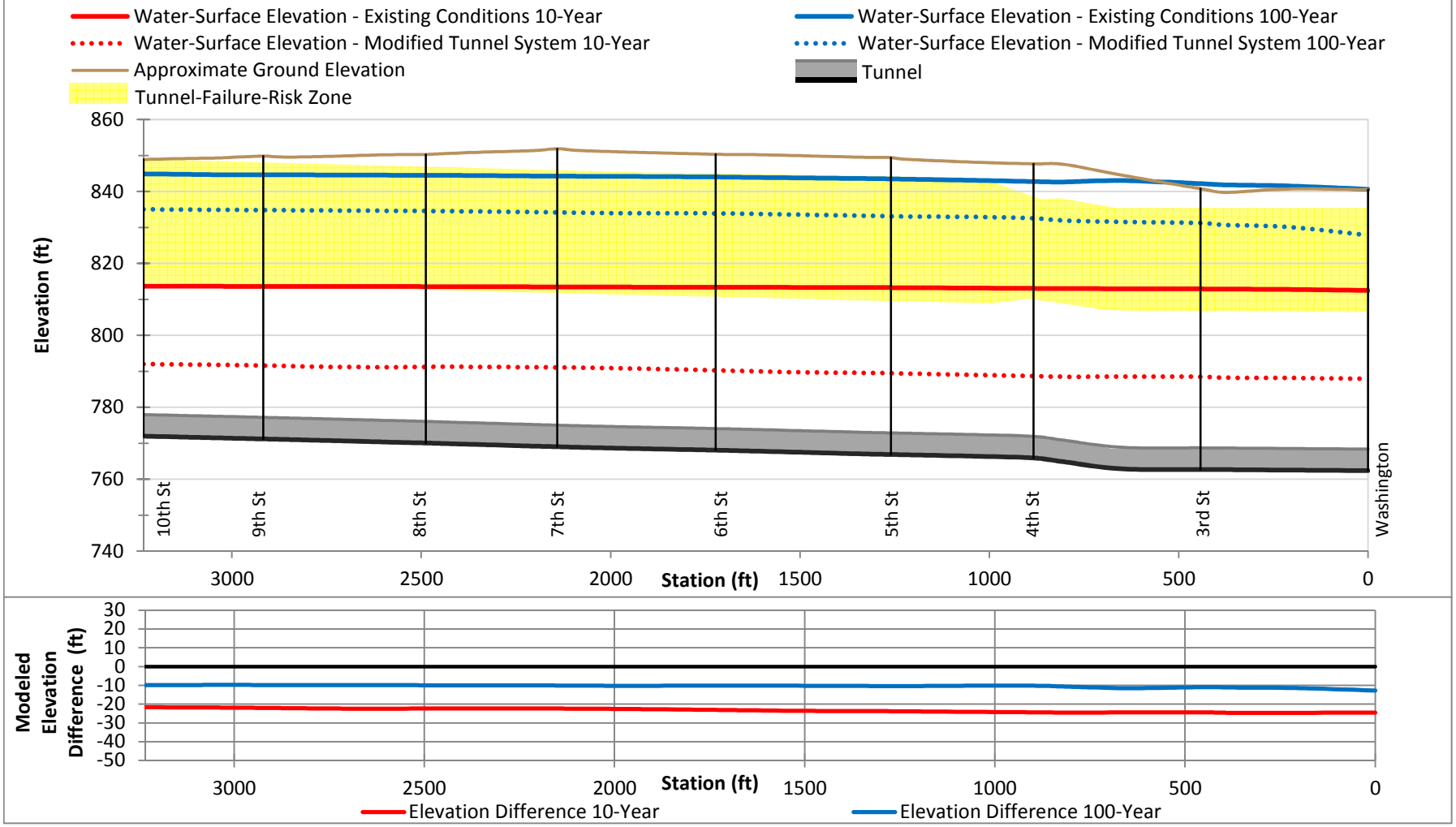
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue



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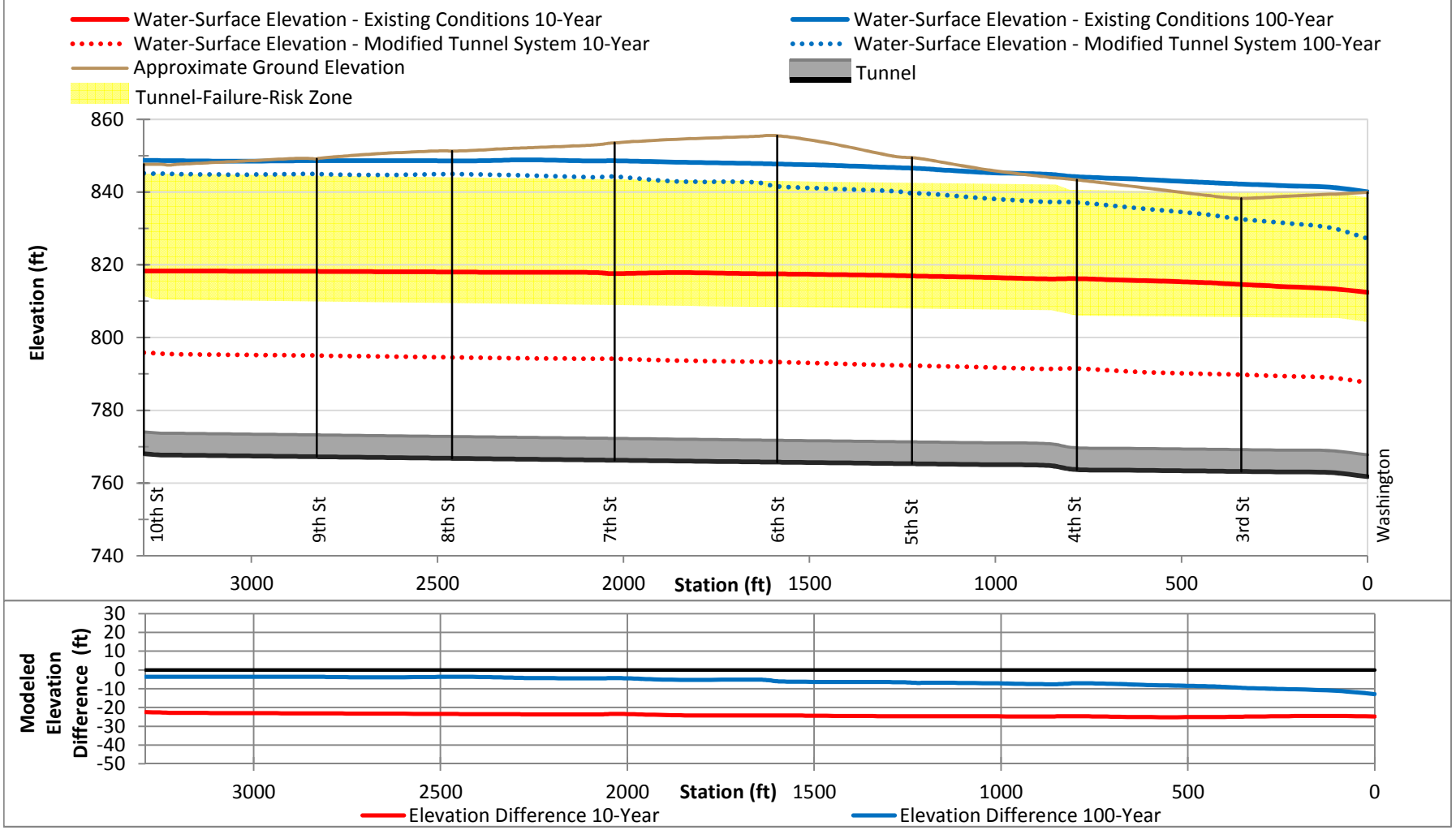
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Nicollet Avenue - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue



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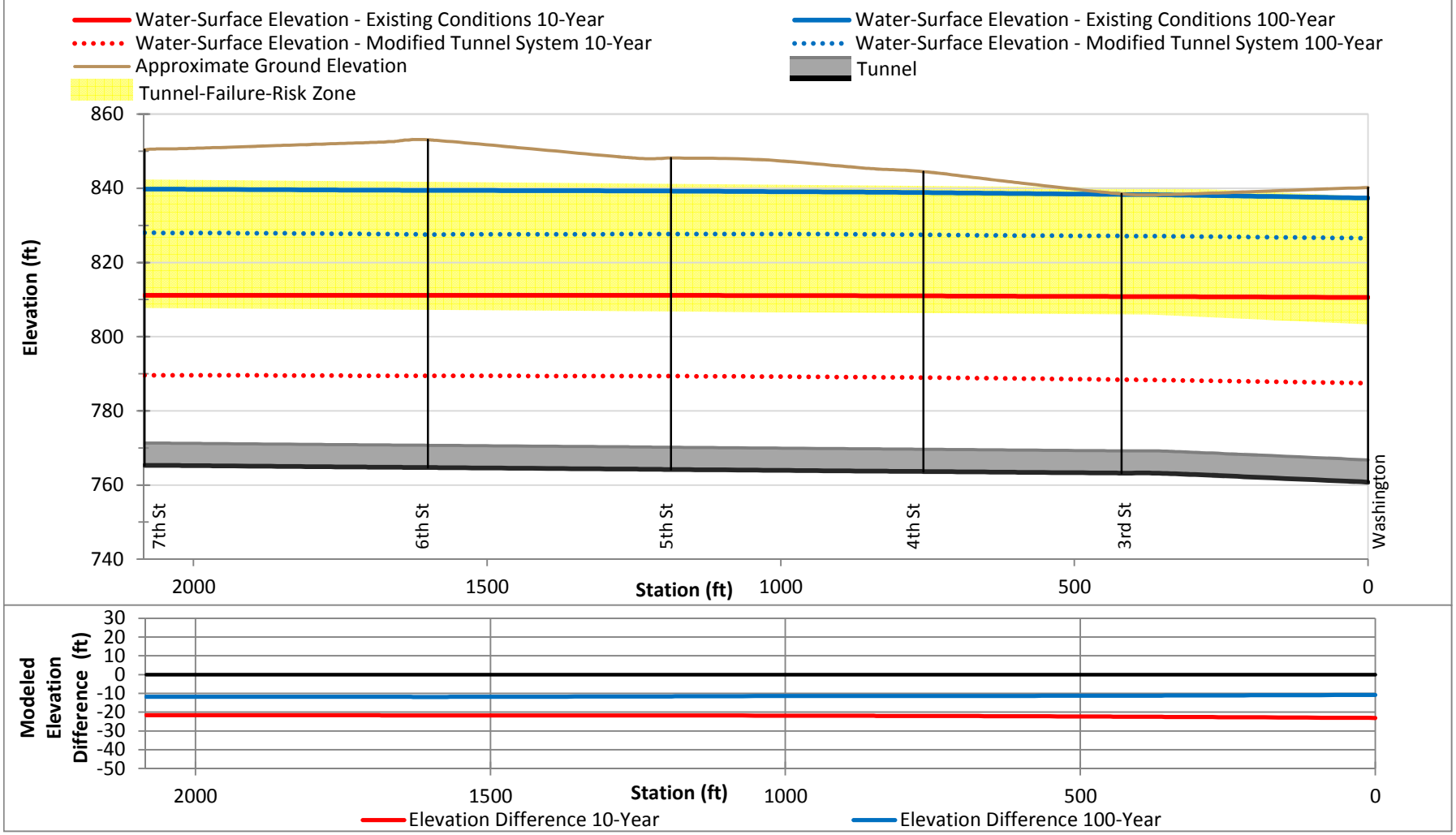
Marquette Avenue - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue



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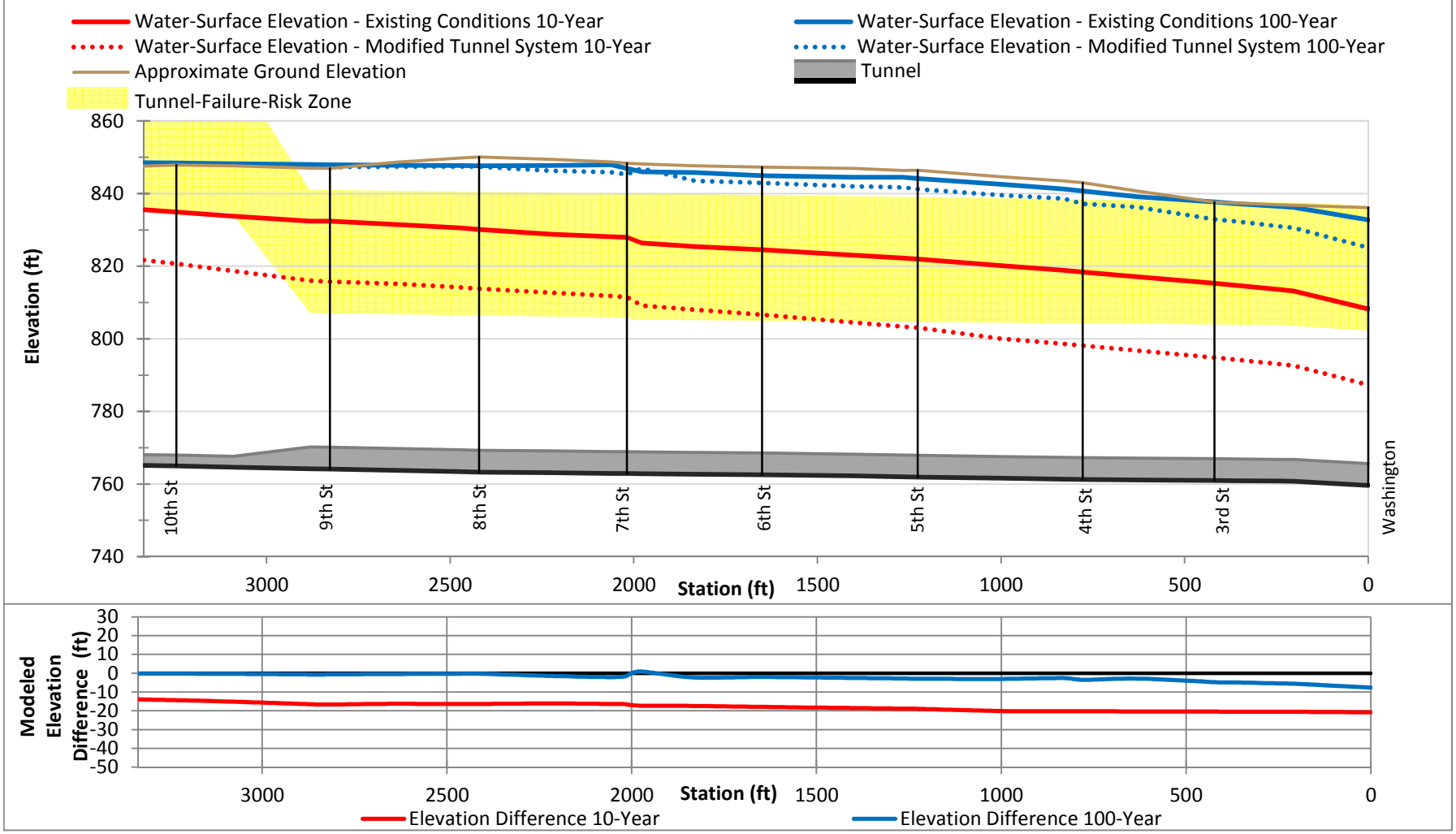
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Second Avenue S. - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue



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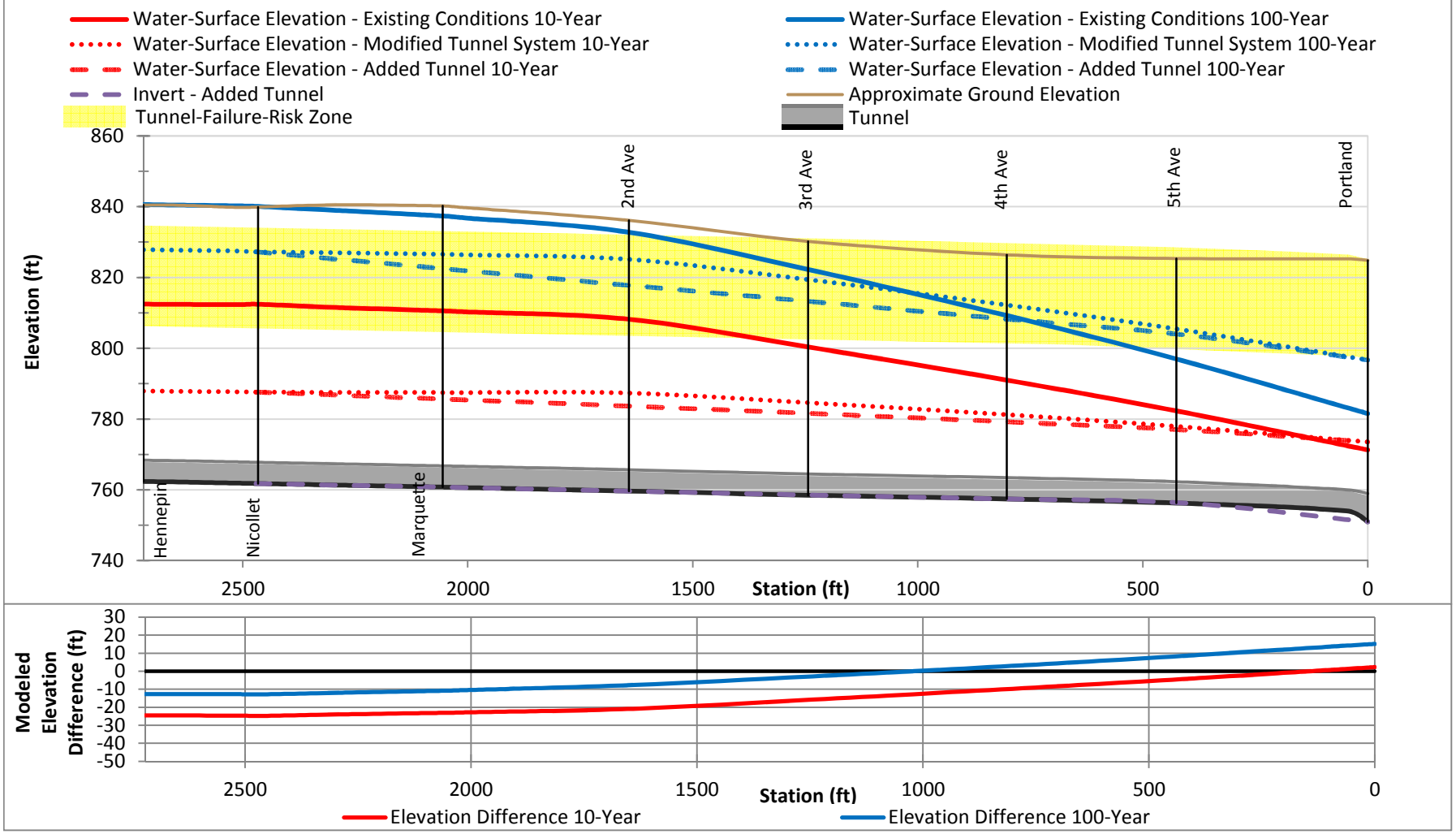
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue



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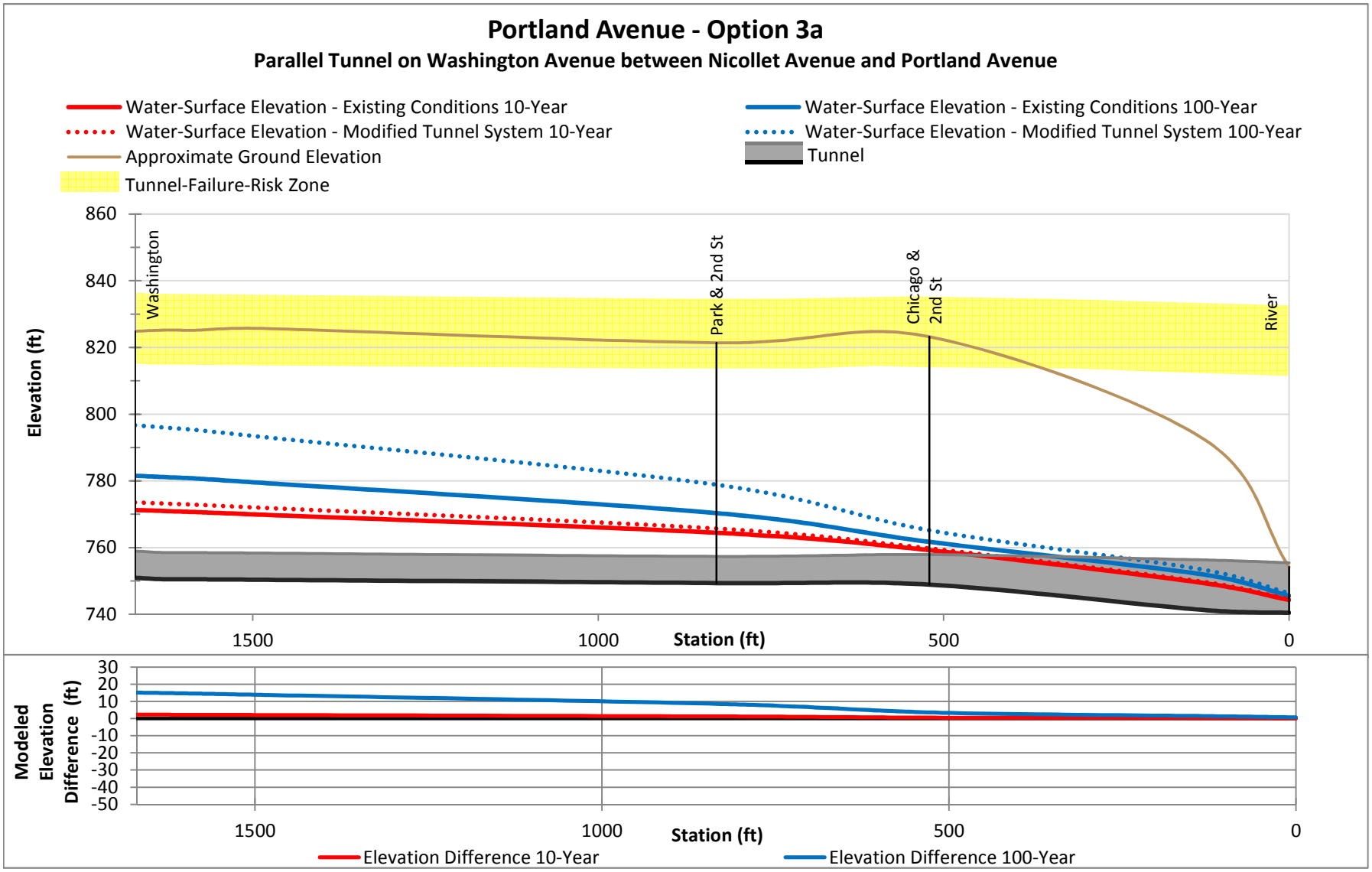

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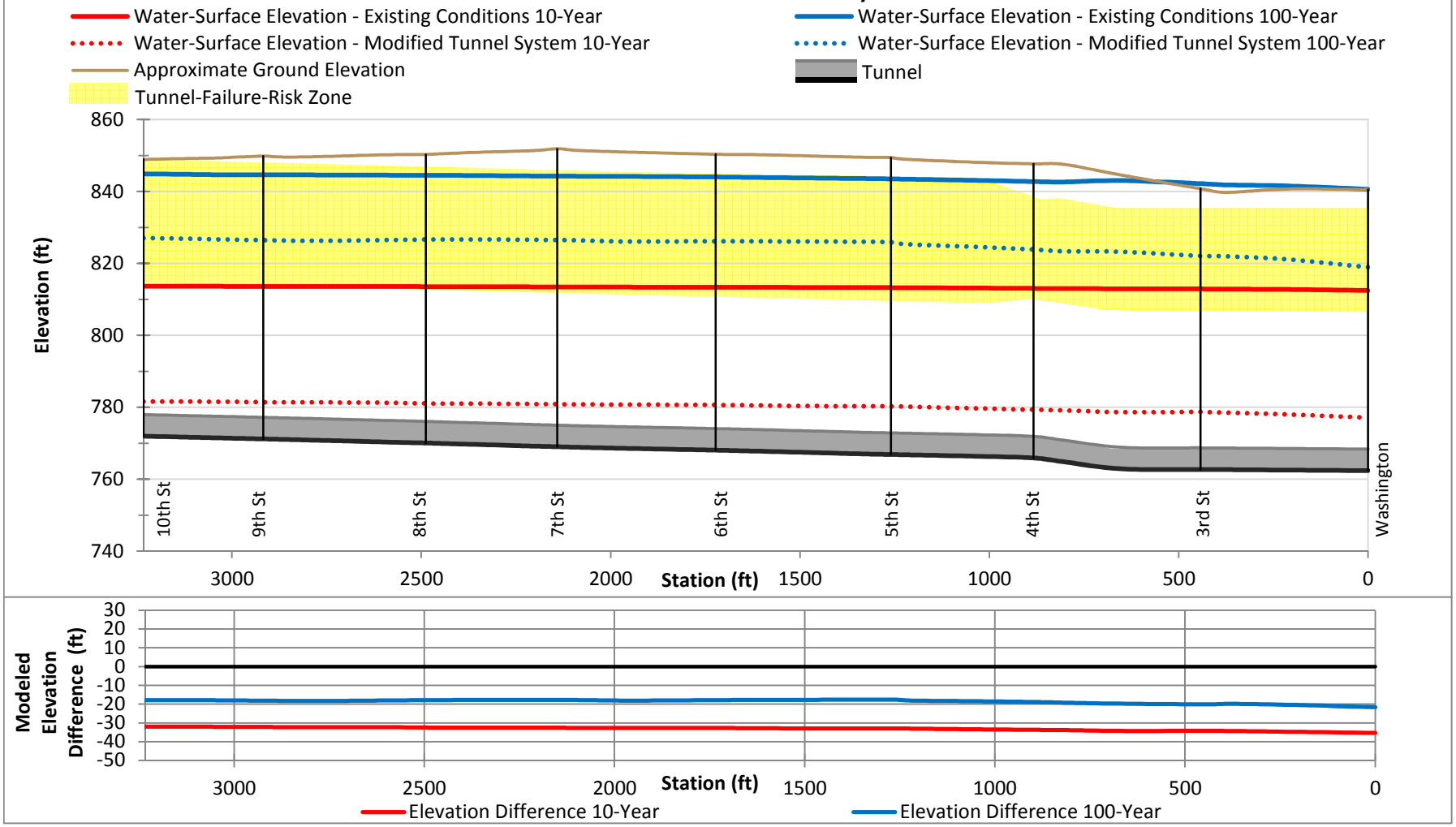
Hennepin Avenue - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



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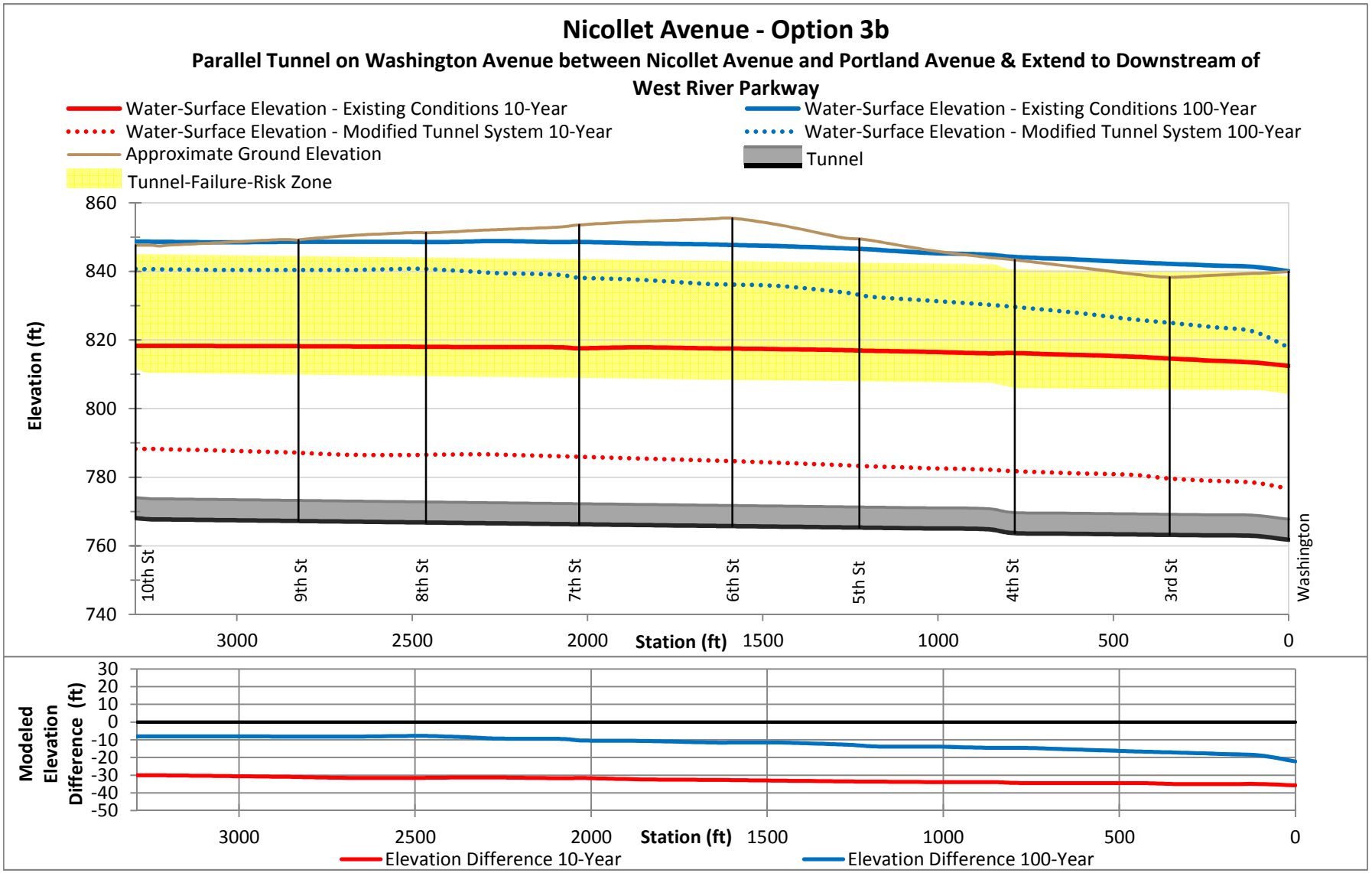

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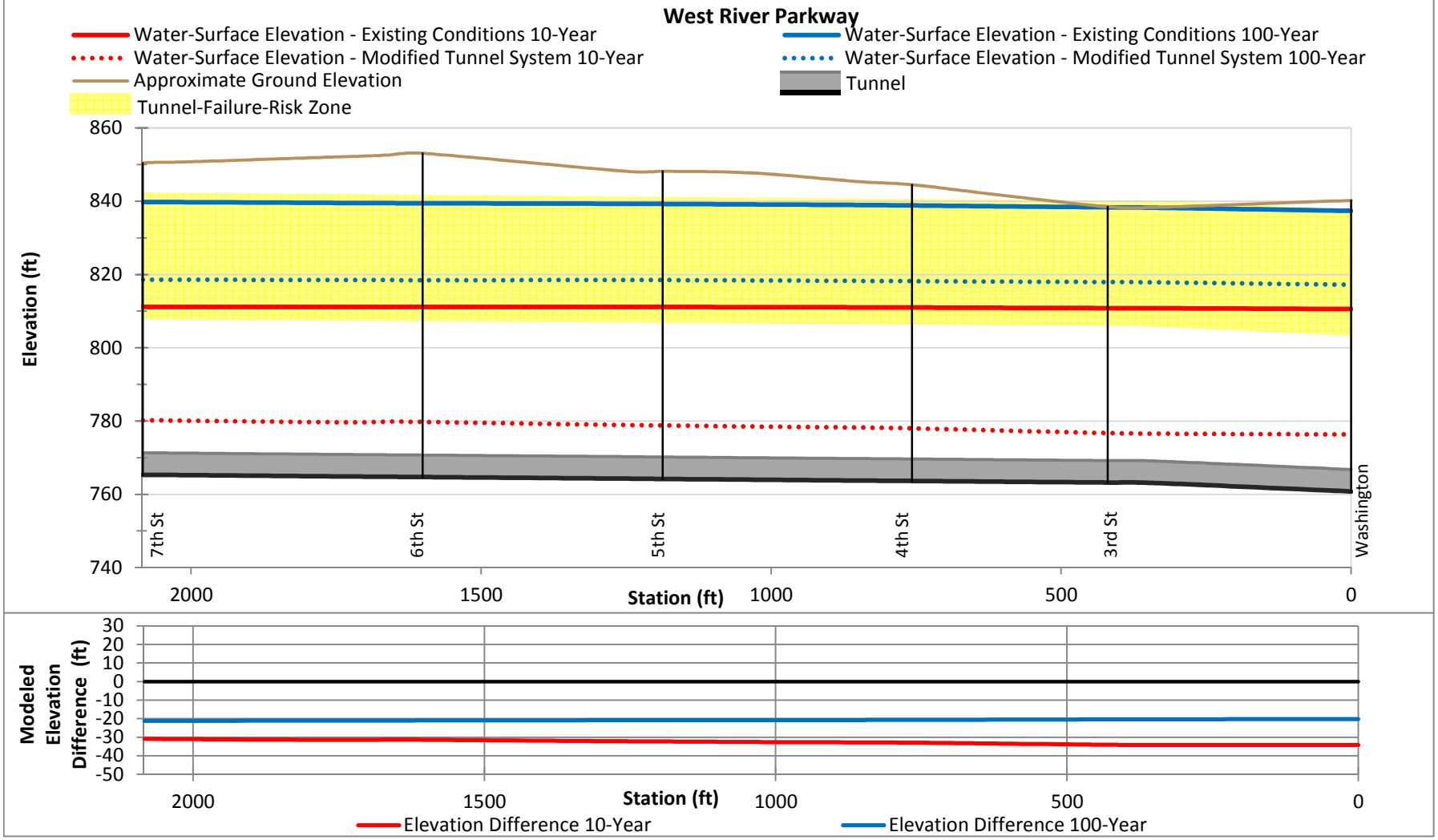
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Marquette Avenue - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



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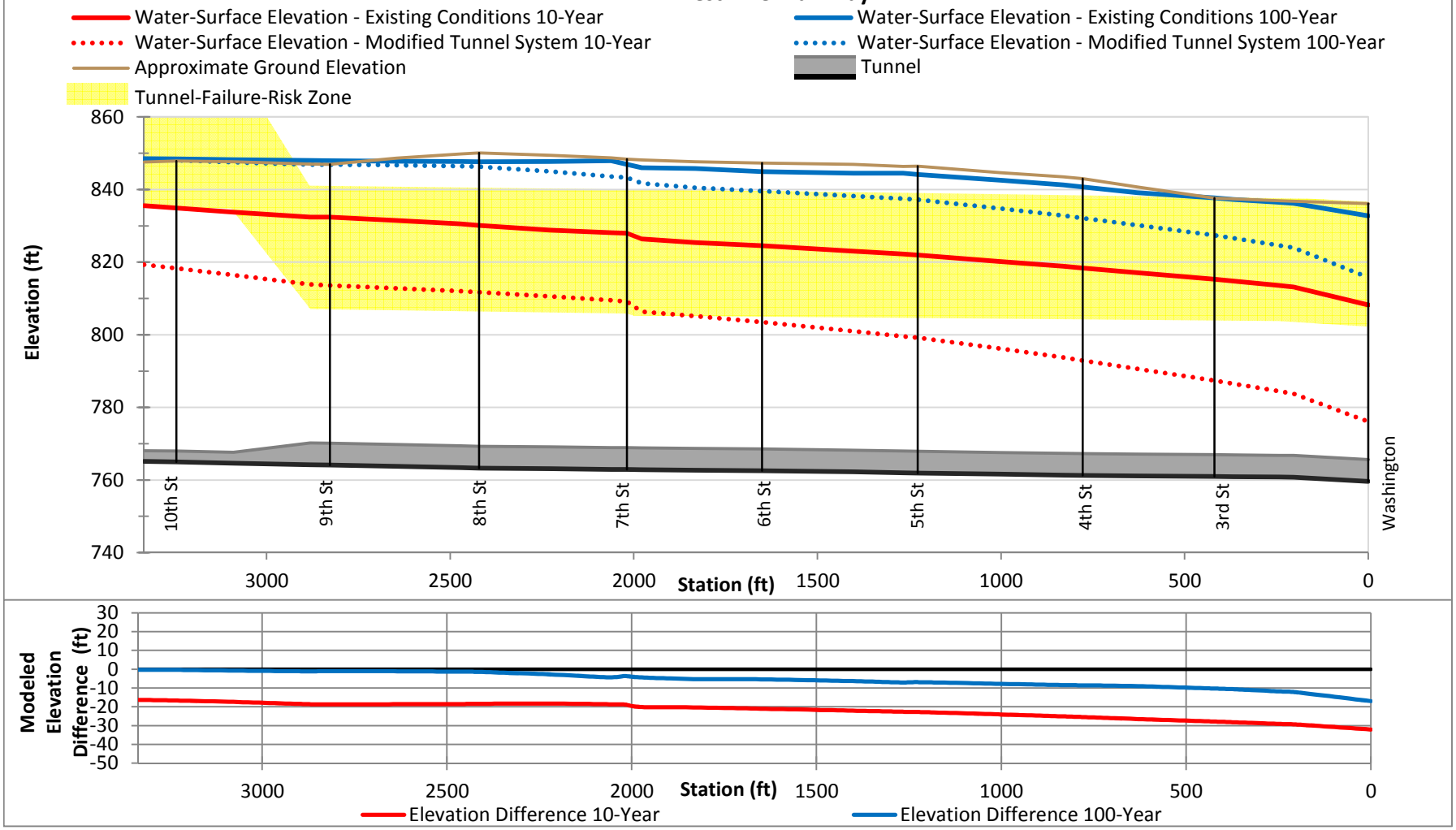
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Second Avenue S. - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



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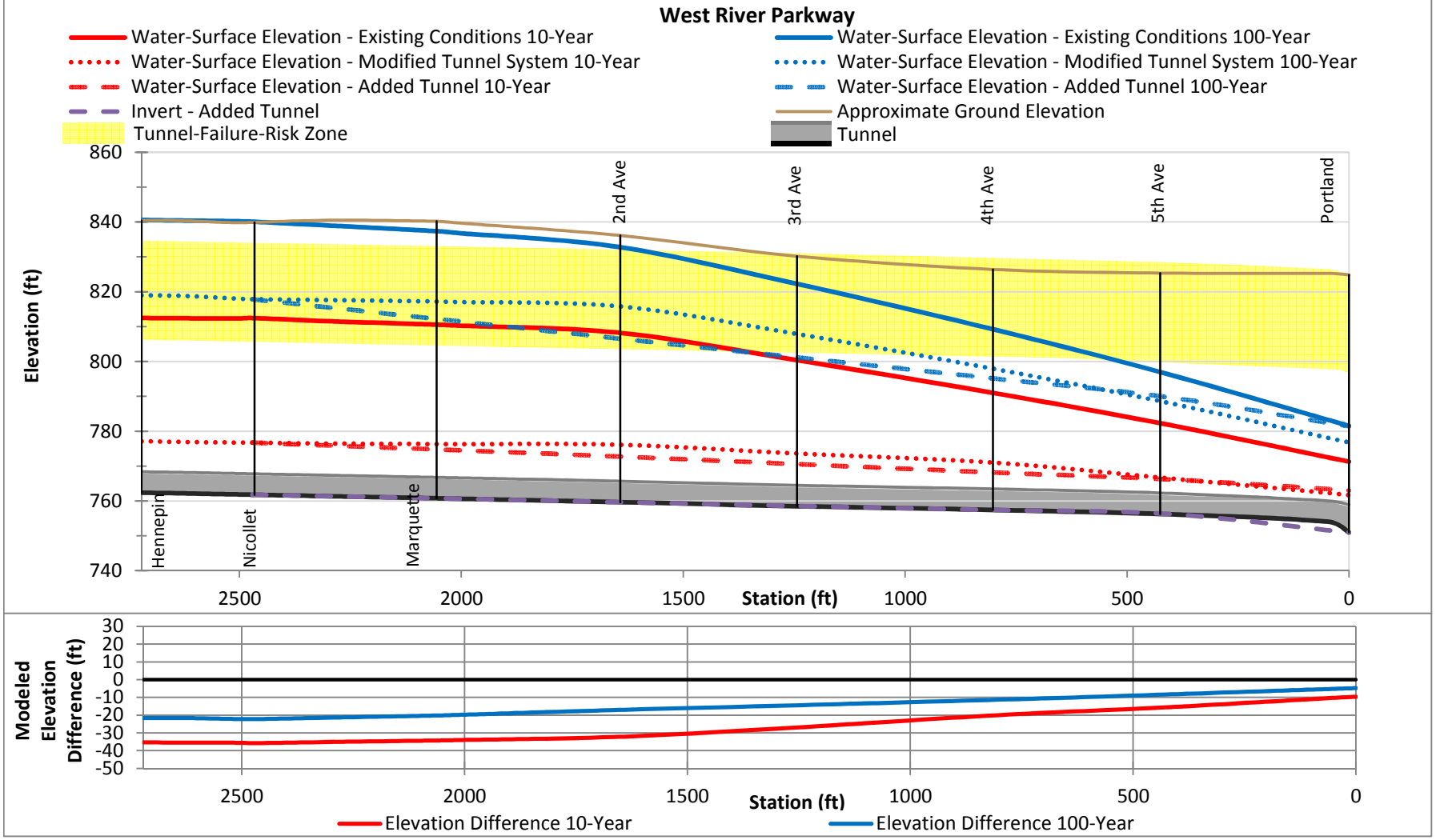
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



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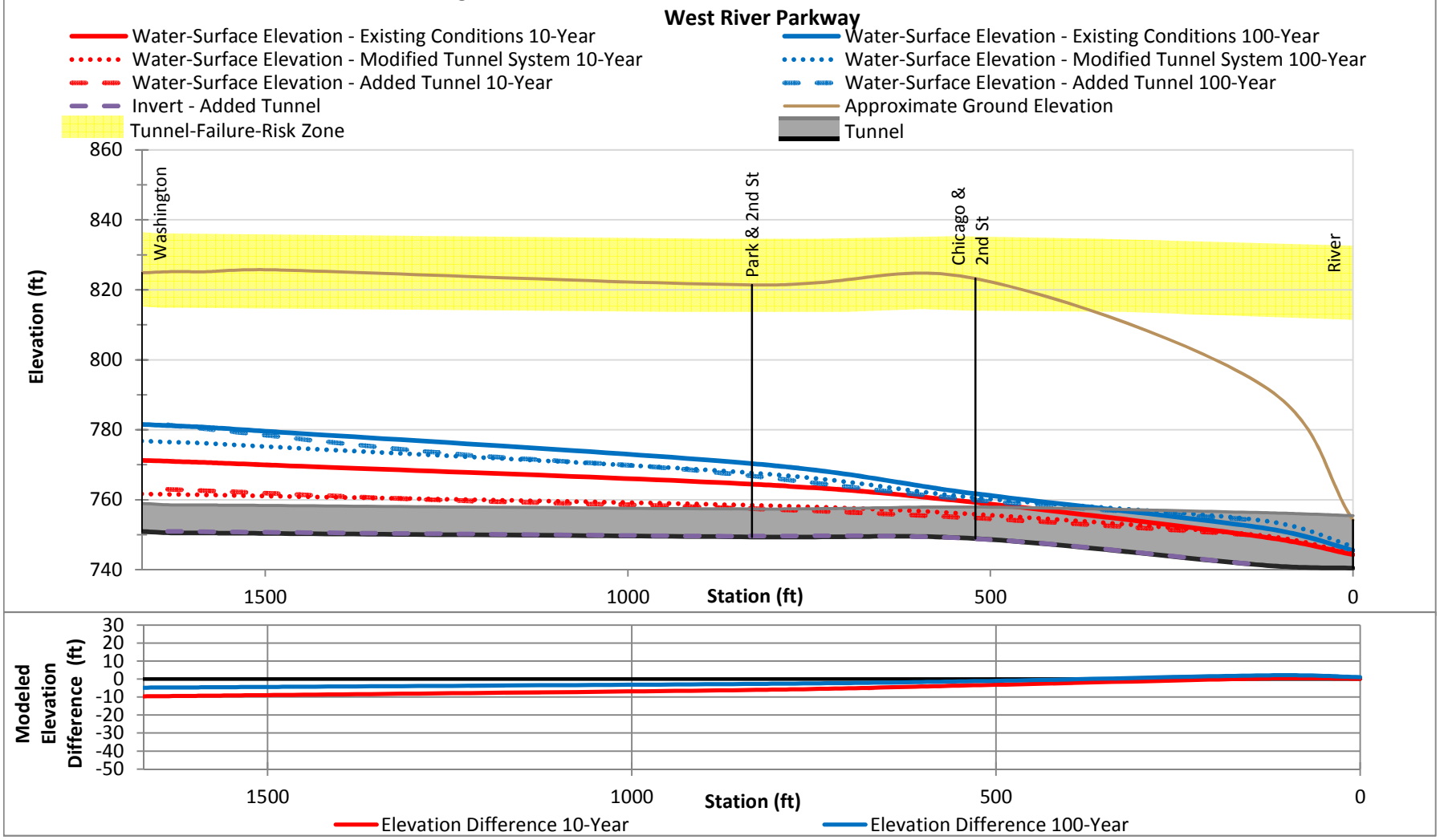
Portland Avenue - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway



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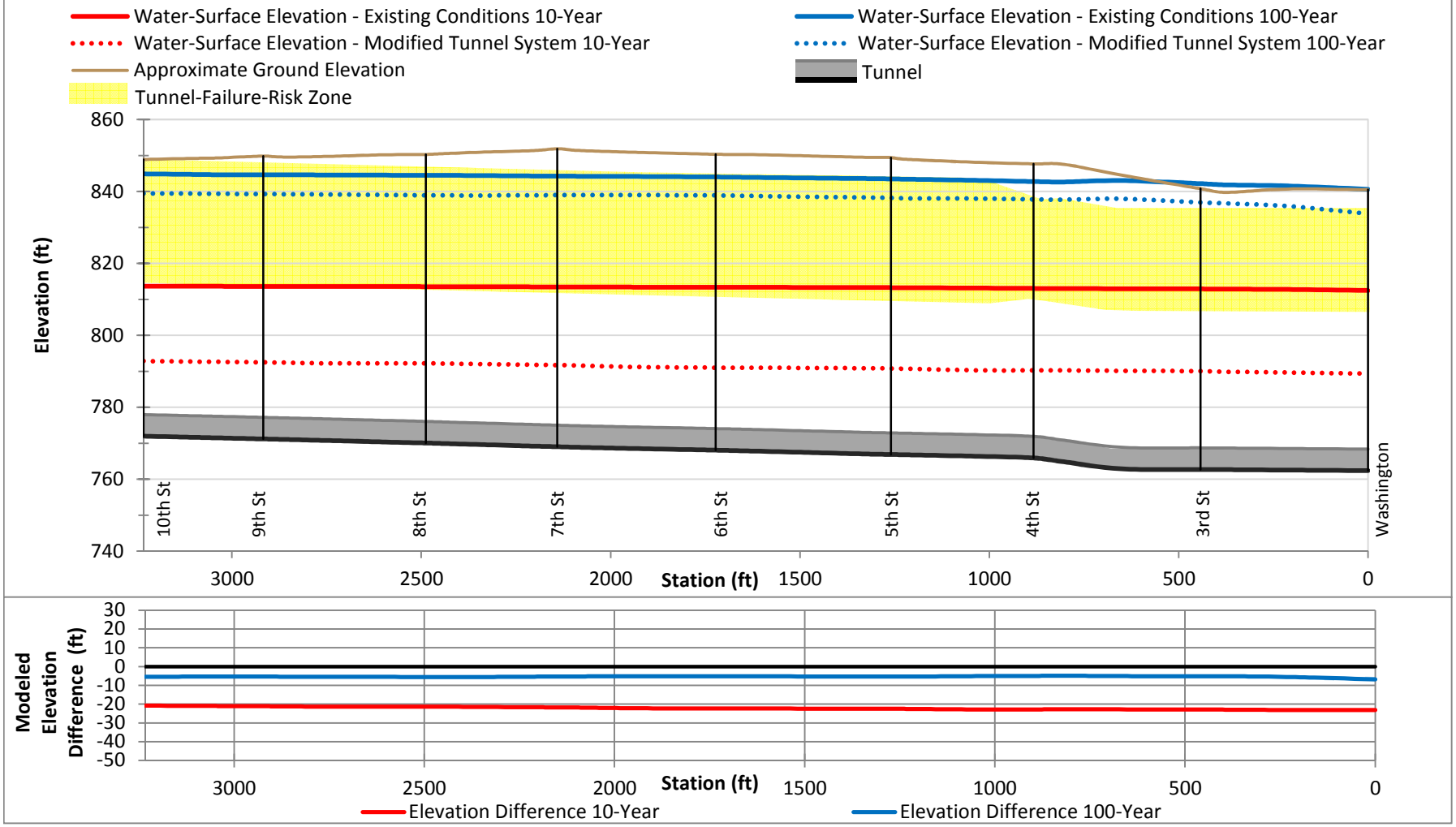
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 4a

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue



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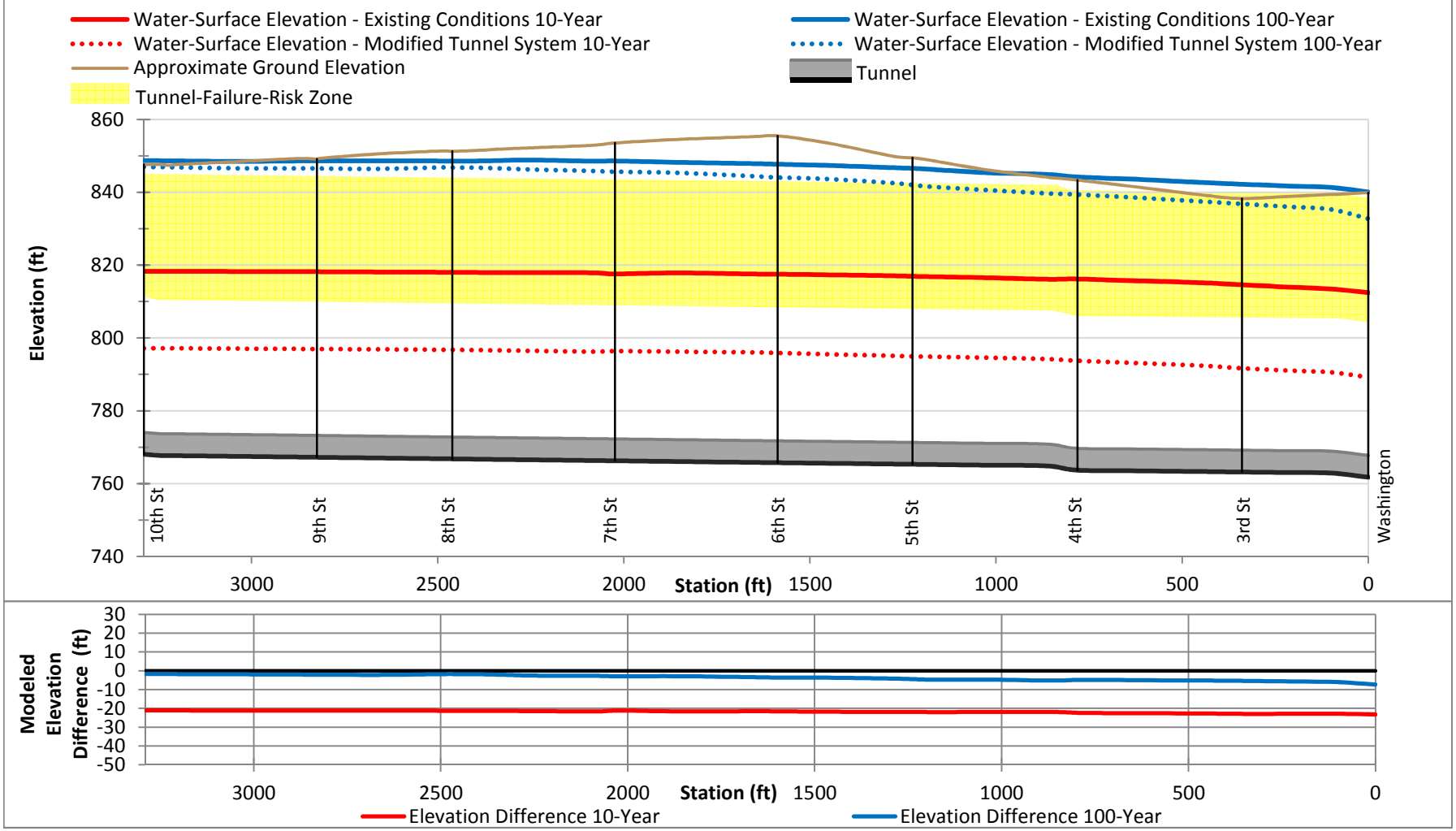
Nicollet Avenue - Option 4a

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue



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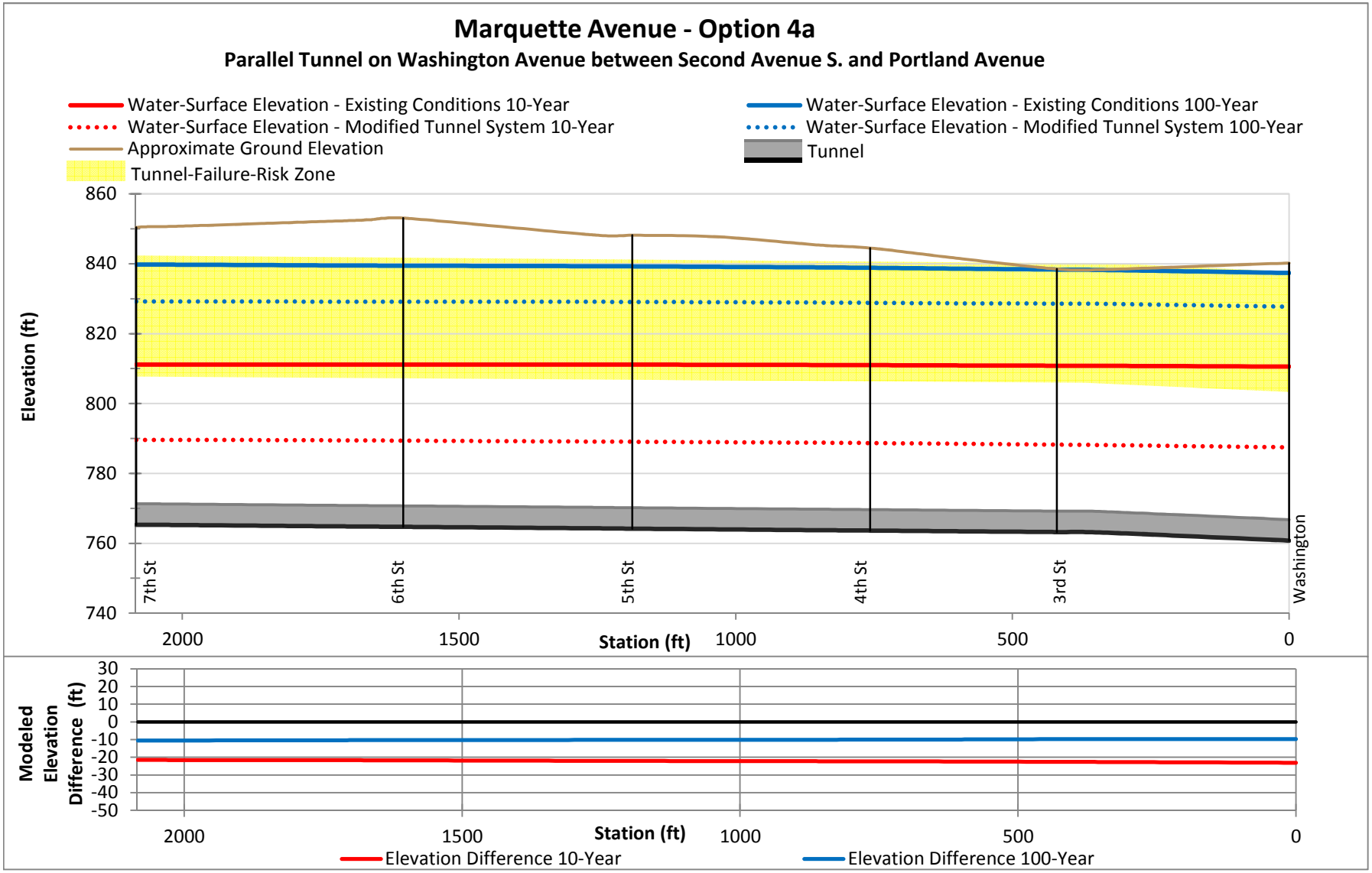

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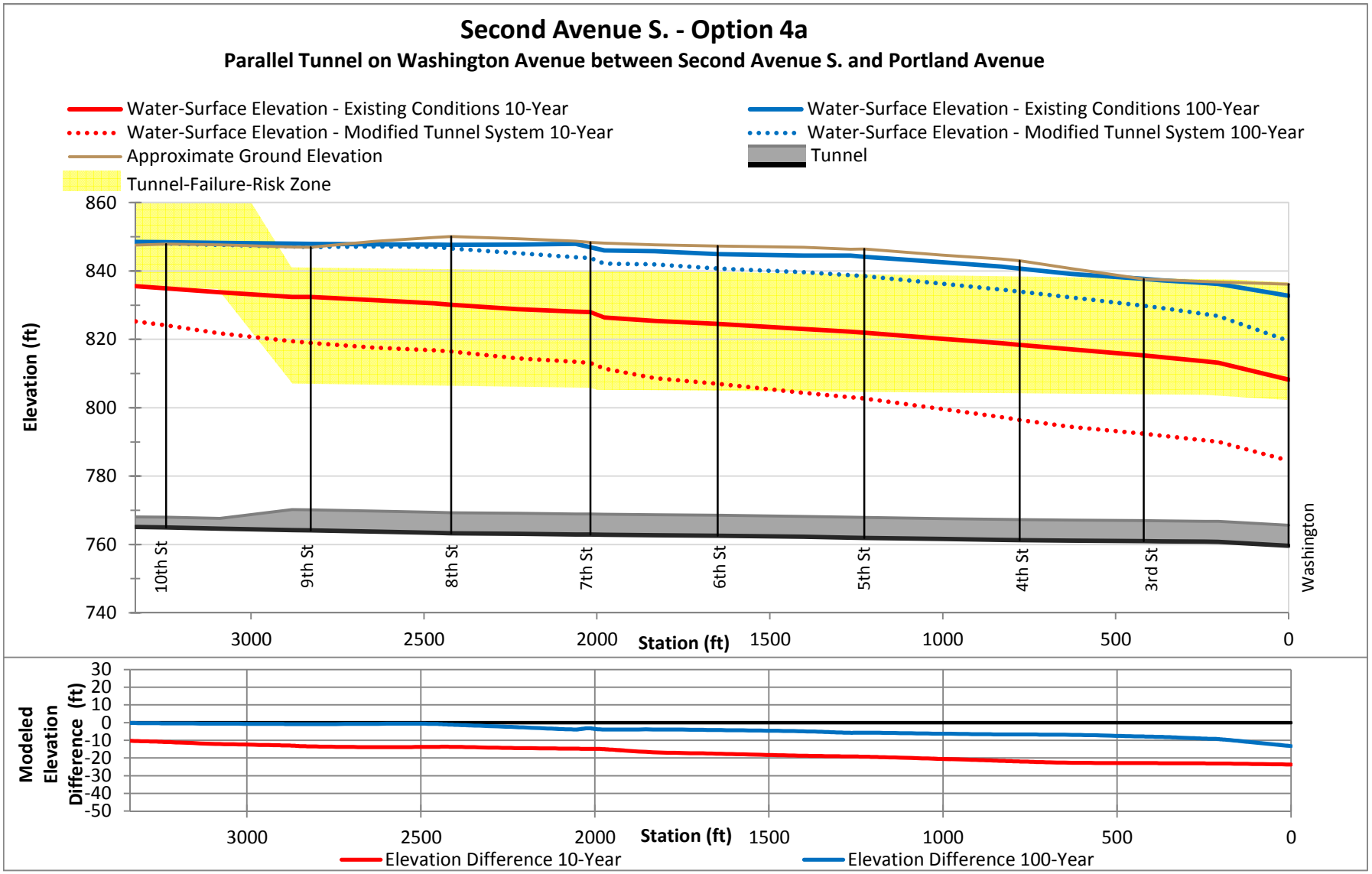

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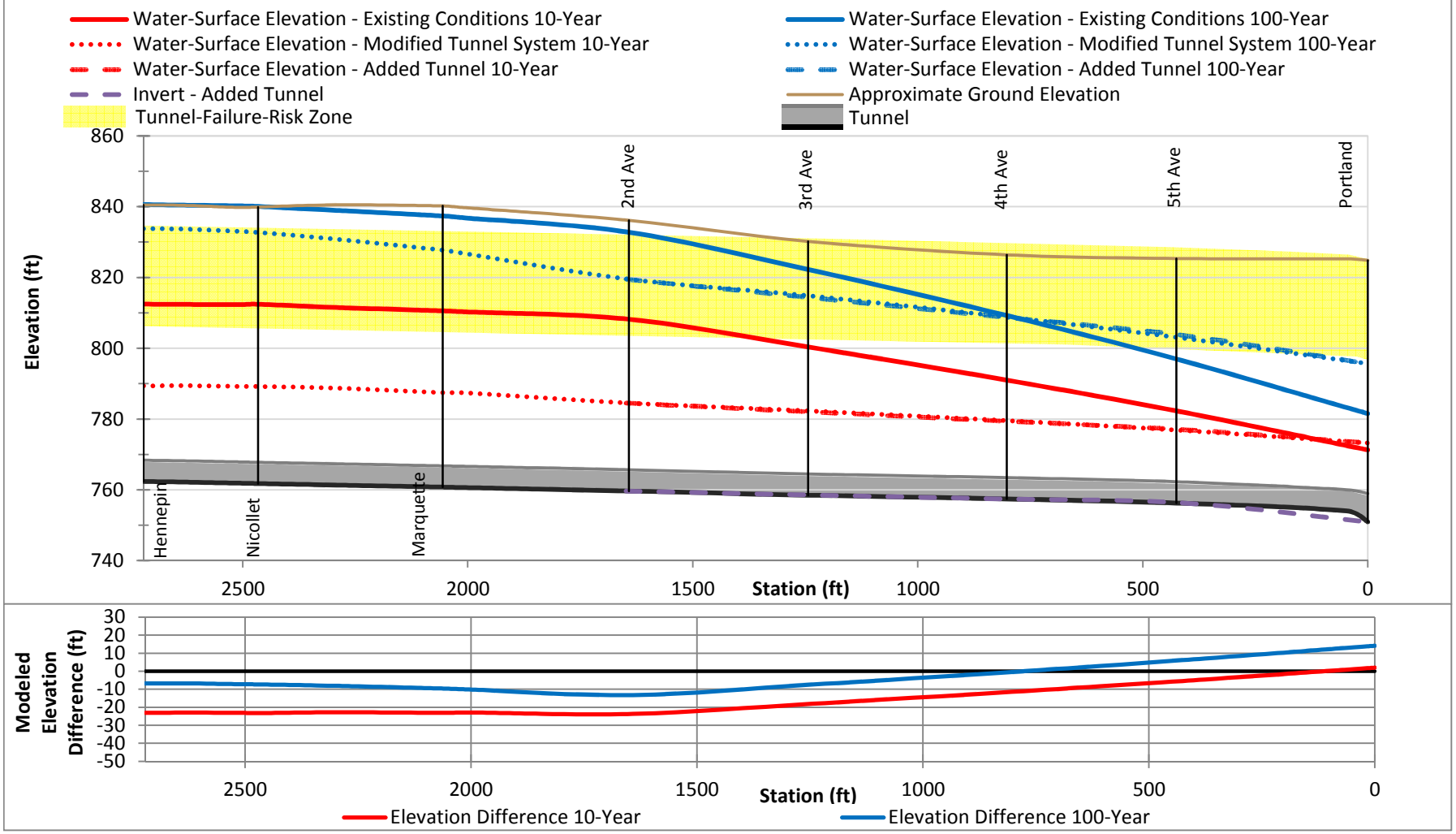
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 4a

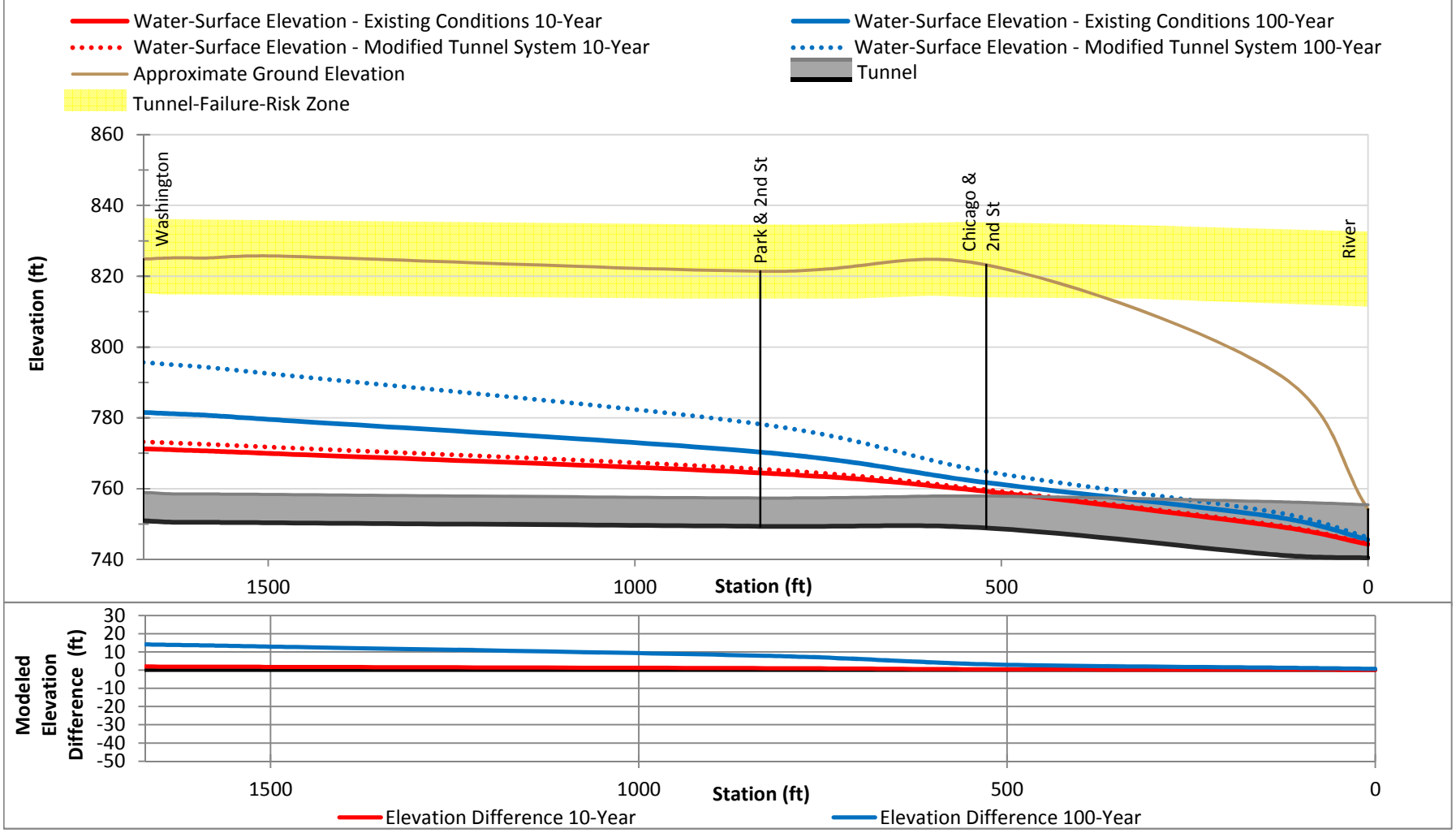
Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
* The tunnel liner is assumed to be concrete for all tunnel sections. The concrete is assumed to have a compressive strength of 3,000 psi with a resulting modulus of rupture of 411 psi, per the design code (ACI 318 Eq. 9-10). A 0.6 safety factor was applied per the design code (ACI 318 section 9.3.5).
* The Tunnel-Failure-Risk Zone assumes a circular tunnel shape. The assumed circular shape was estimated to reflect a cross-sectional area equivalent to the typical tunnel section shown on the tunnel profile drawings provided by the City.
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Portland Avenue - Option 4a

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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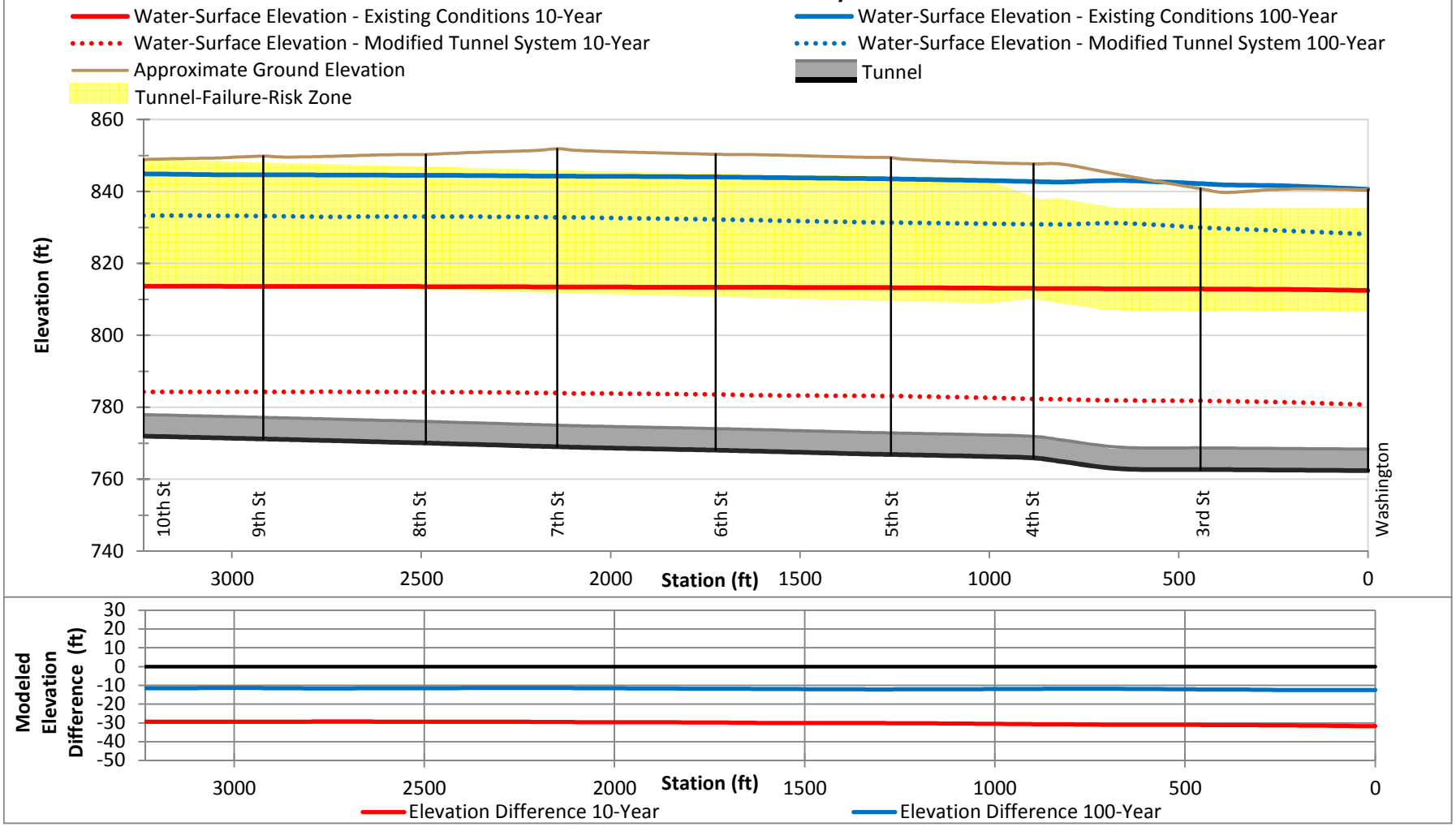
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
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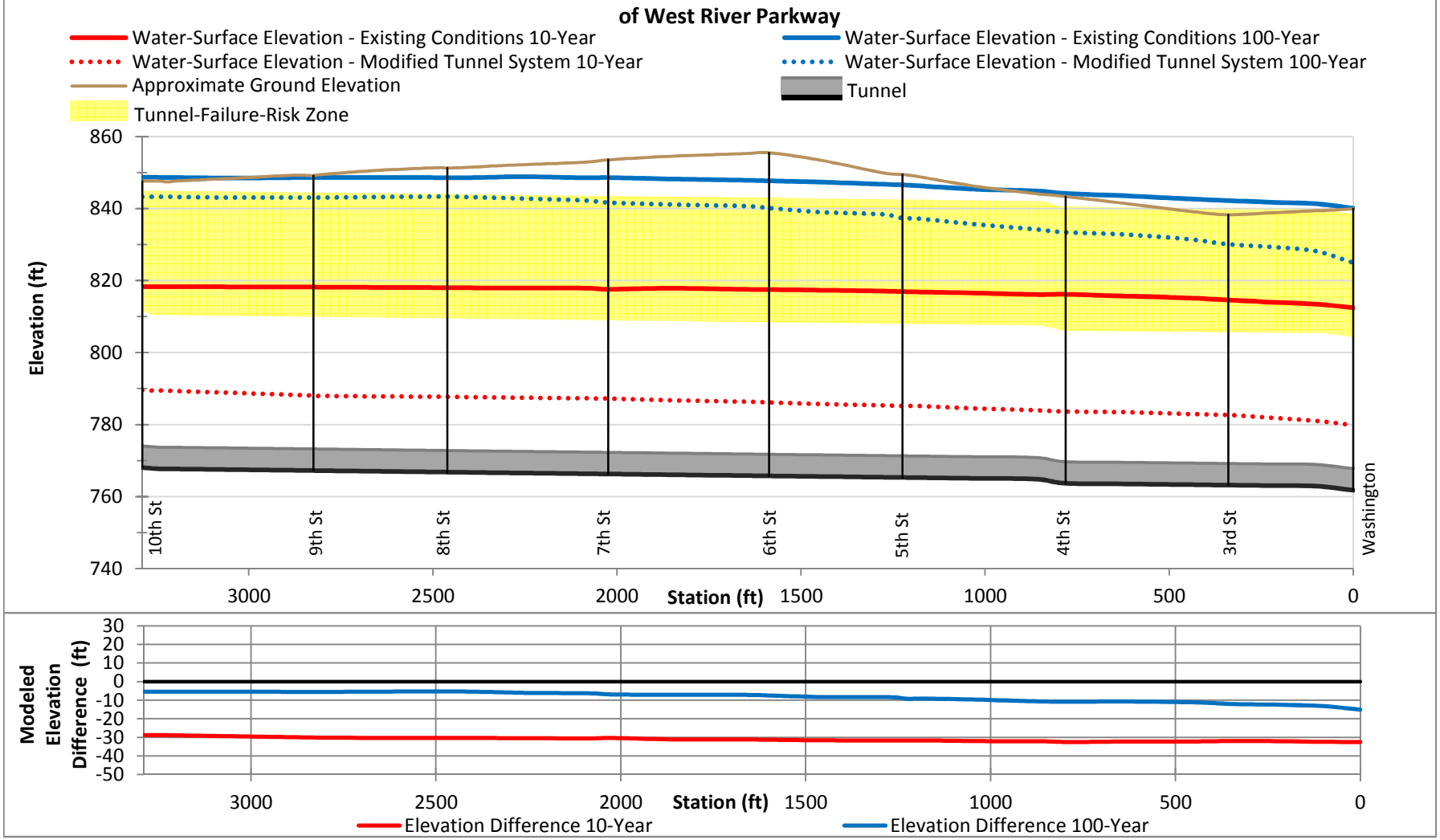
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Nicollet Avenue - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
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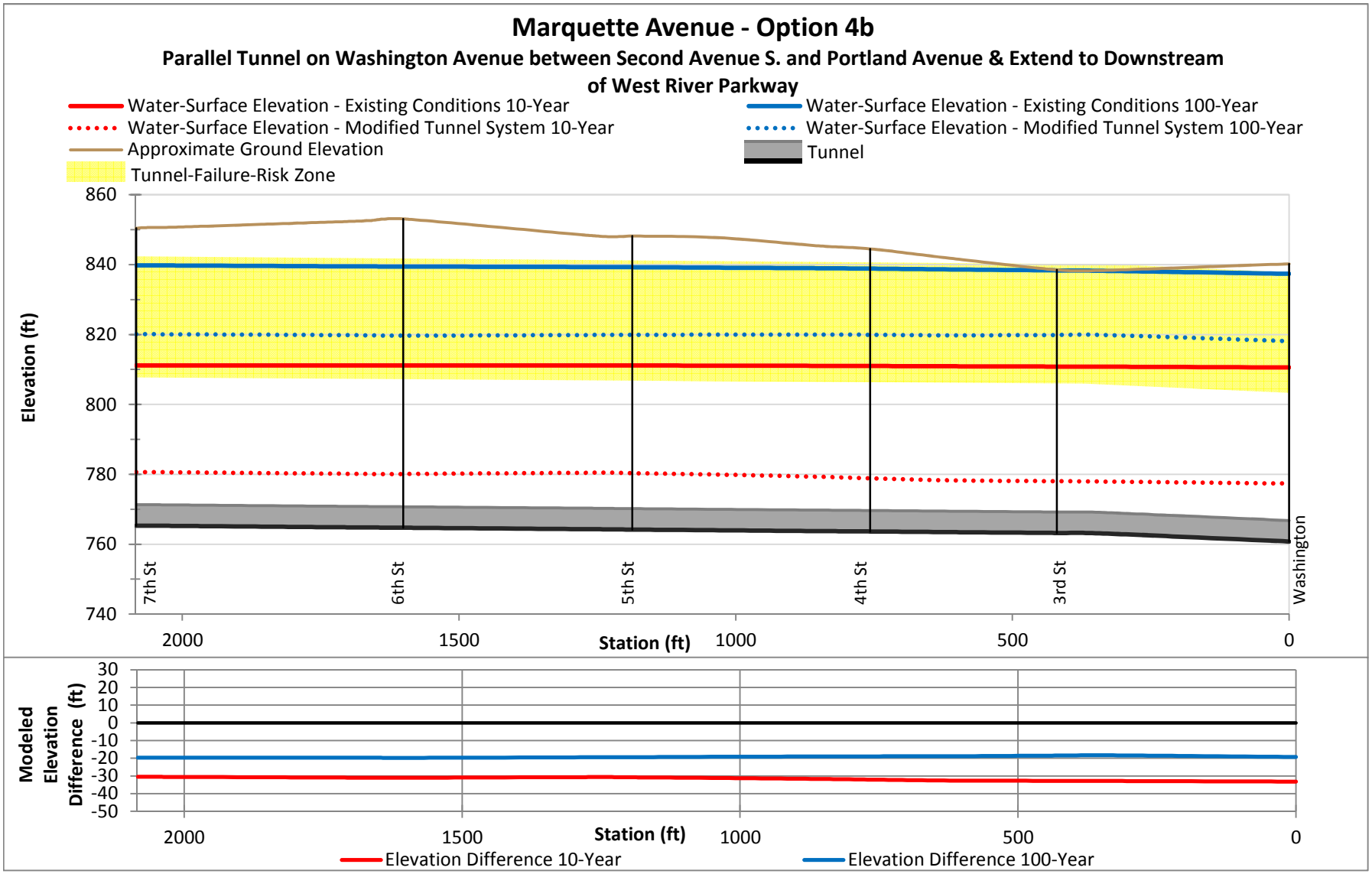
*The water-surface elevation profile is based on the maximum elevation during the design event(s).



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.

* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.

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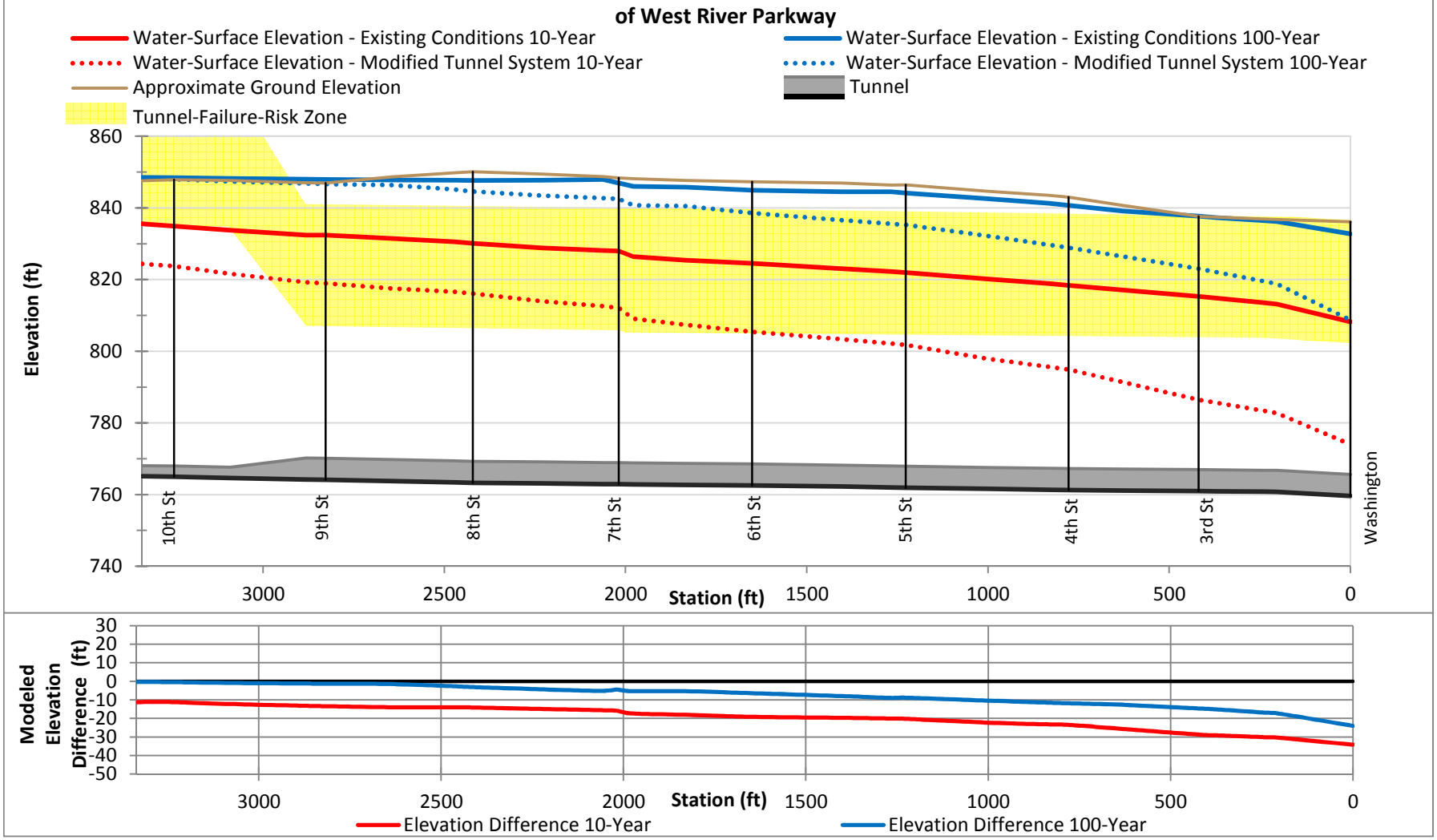
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).

*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Second Avenue S. - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
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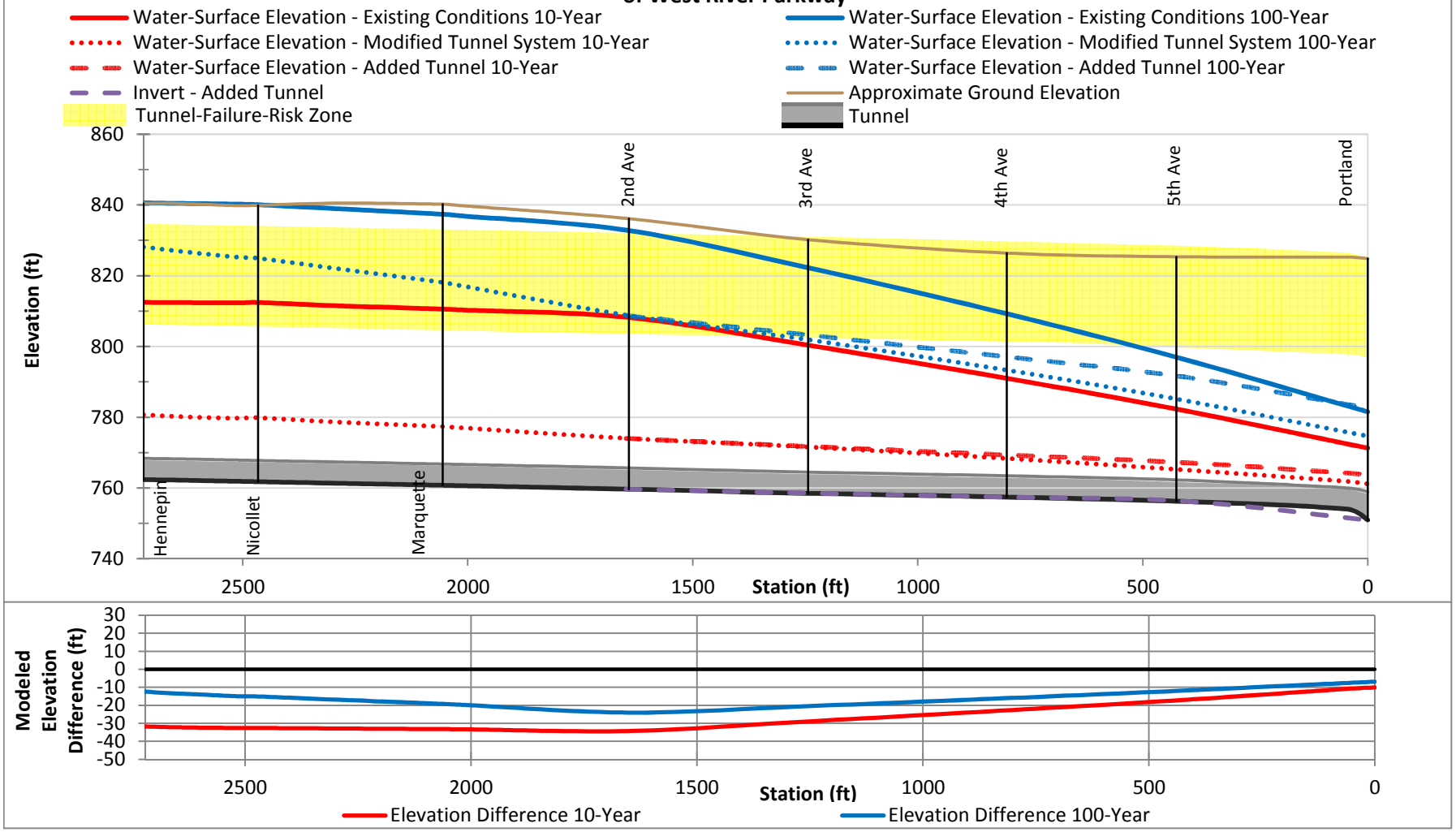
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



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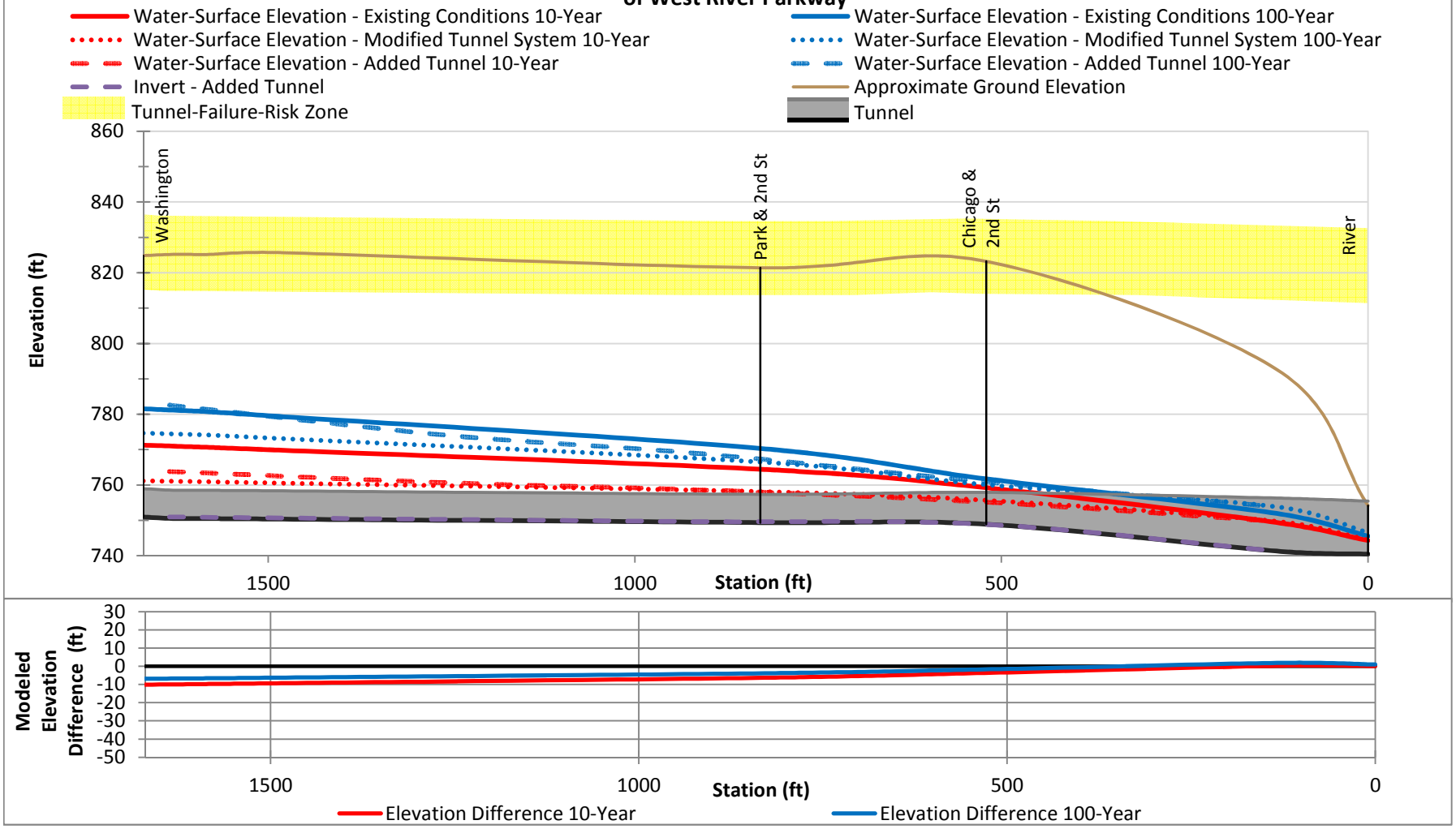
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Portland Avenue - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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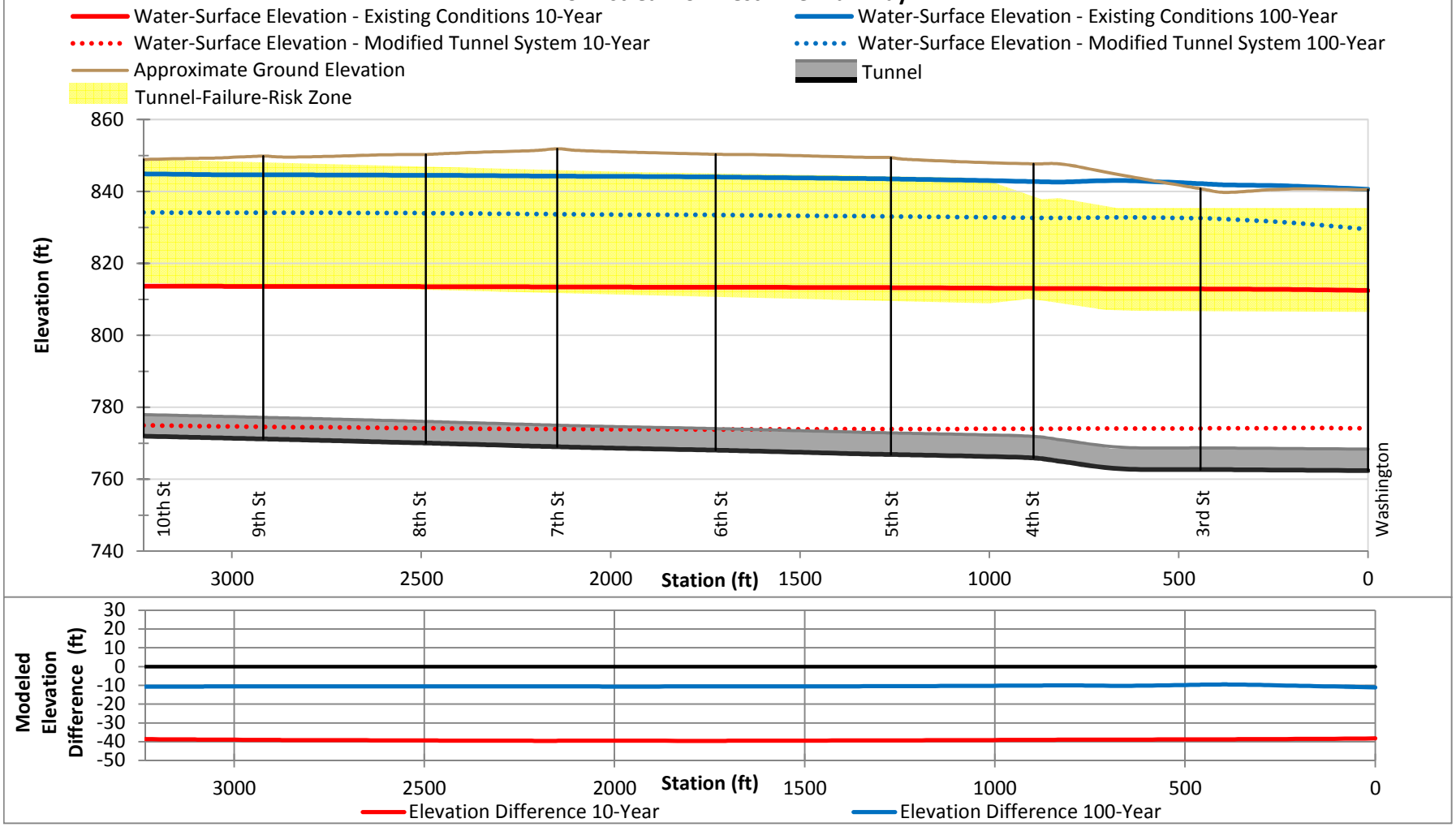
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Hennepin Avenue - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
* The upper and lower bounds for the Tunnel Failure Risk Zone were estimated assuming the tunnel liner thickness is ± 2 inches from what is shown on the tunnel profile drawings provided by the City.
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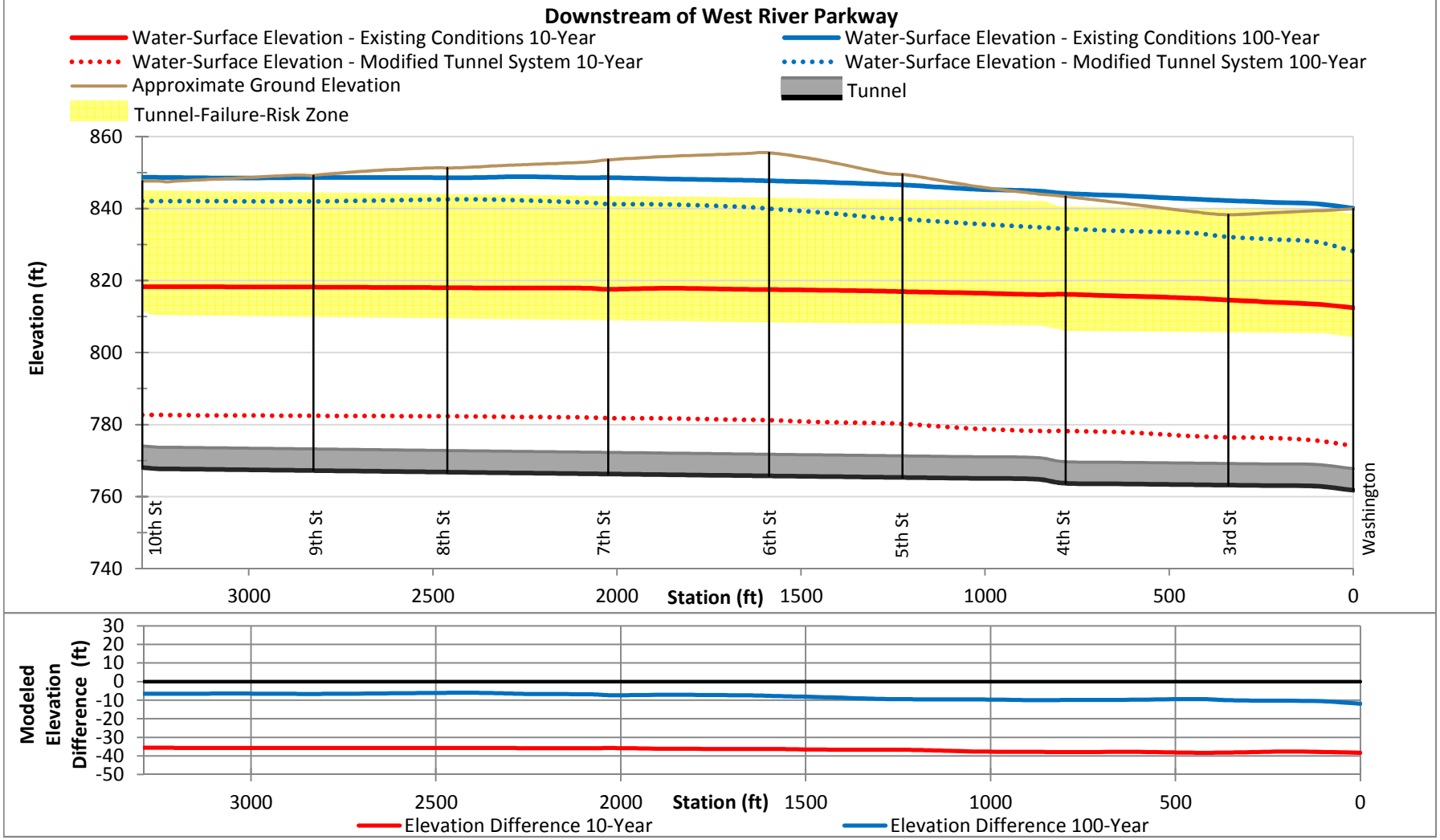
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Nicollet Avenue - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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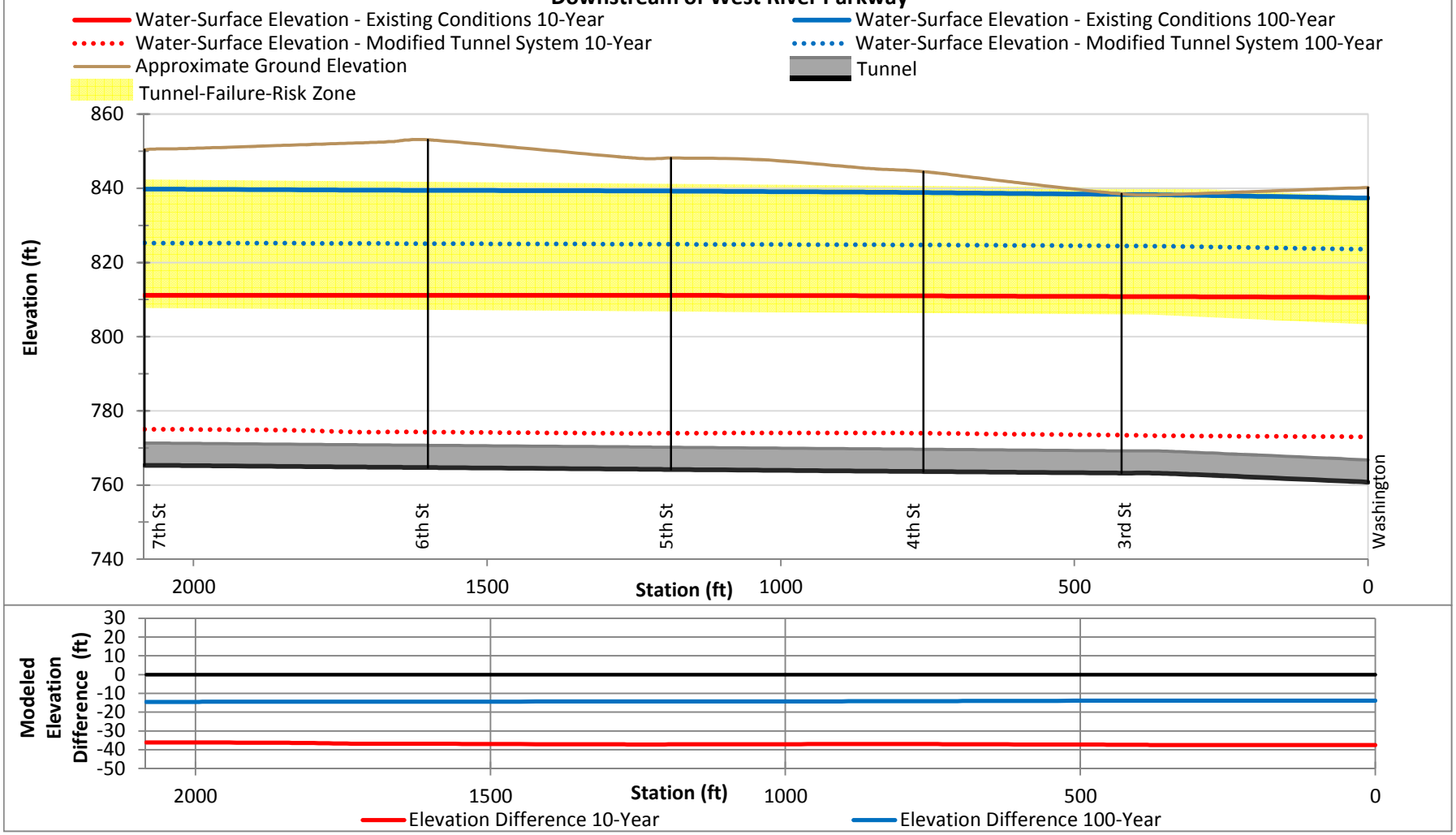
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Marquette Avenue - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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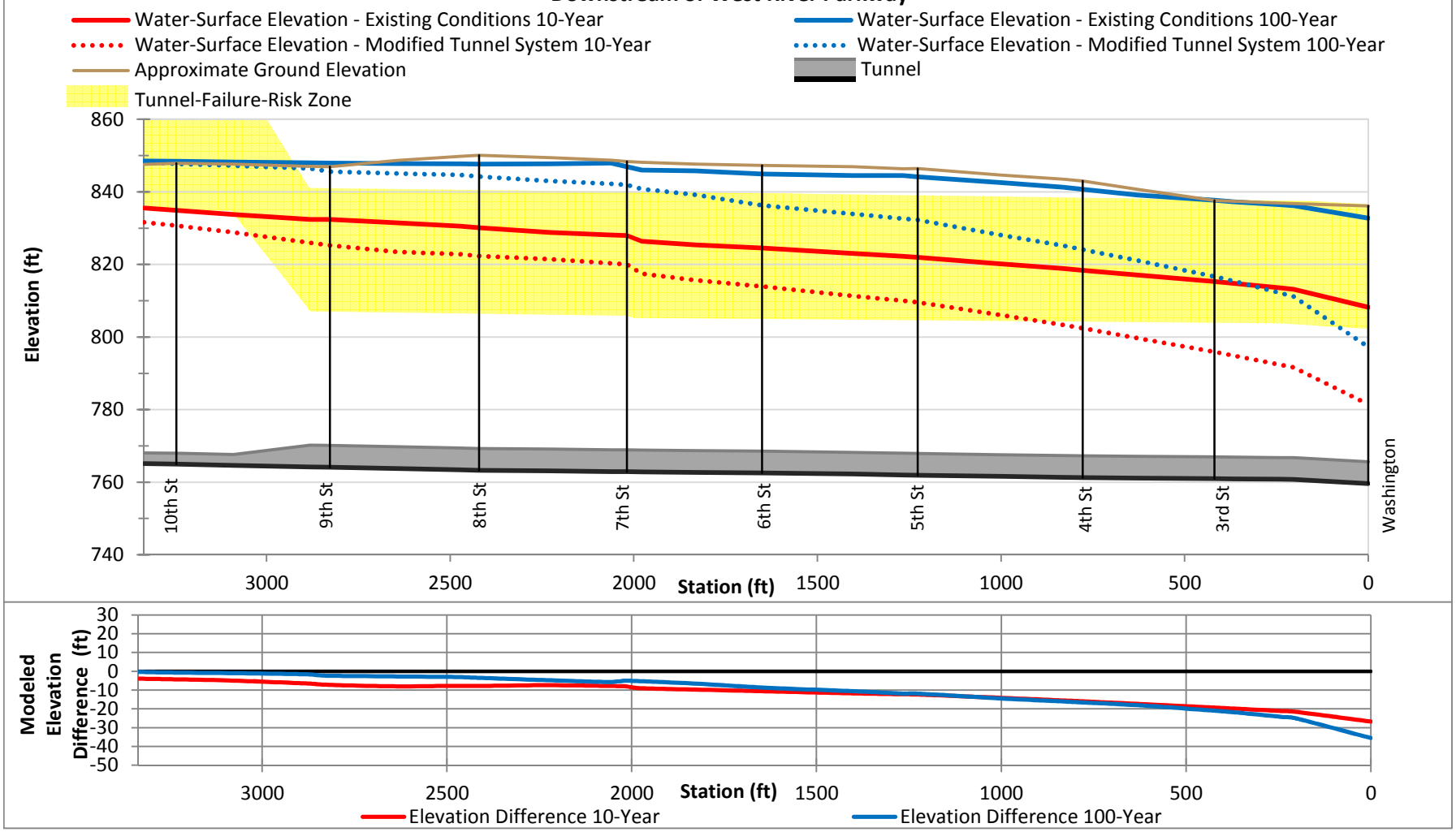
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Second Avenue S. - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



* Tunnel-Failure-Risk Zone is estimated based on the pressure to cause fracturing. Other failure modes are possible, but were not evaluated as part of this analysis. Other types of failure modes should be considered during the next phase of evaluating potential tunnel modifications.
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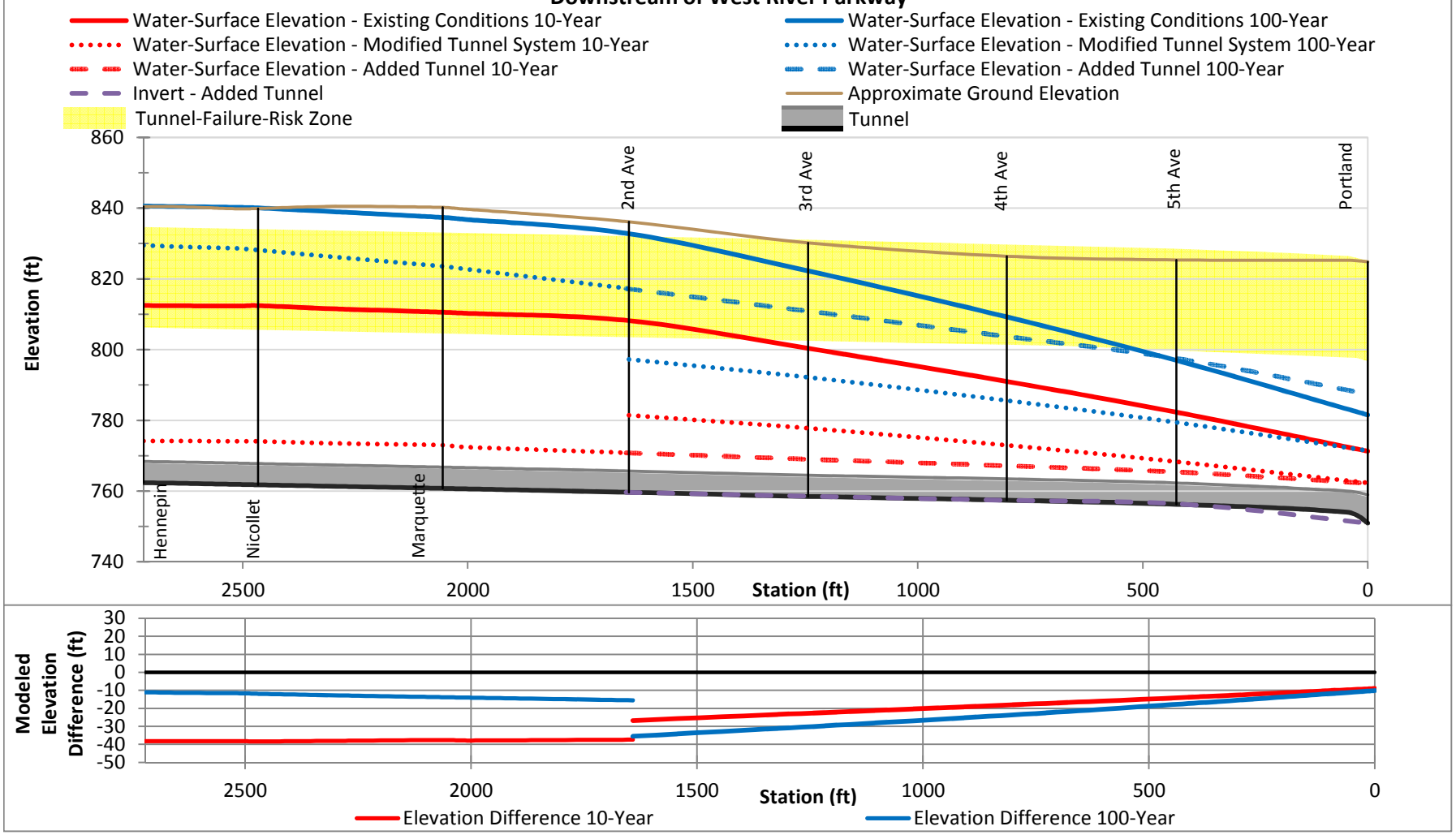
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Washington Avenue - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



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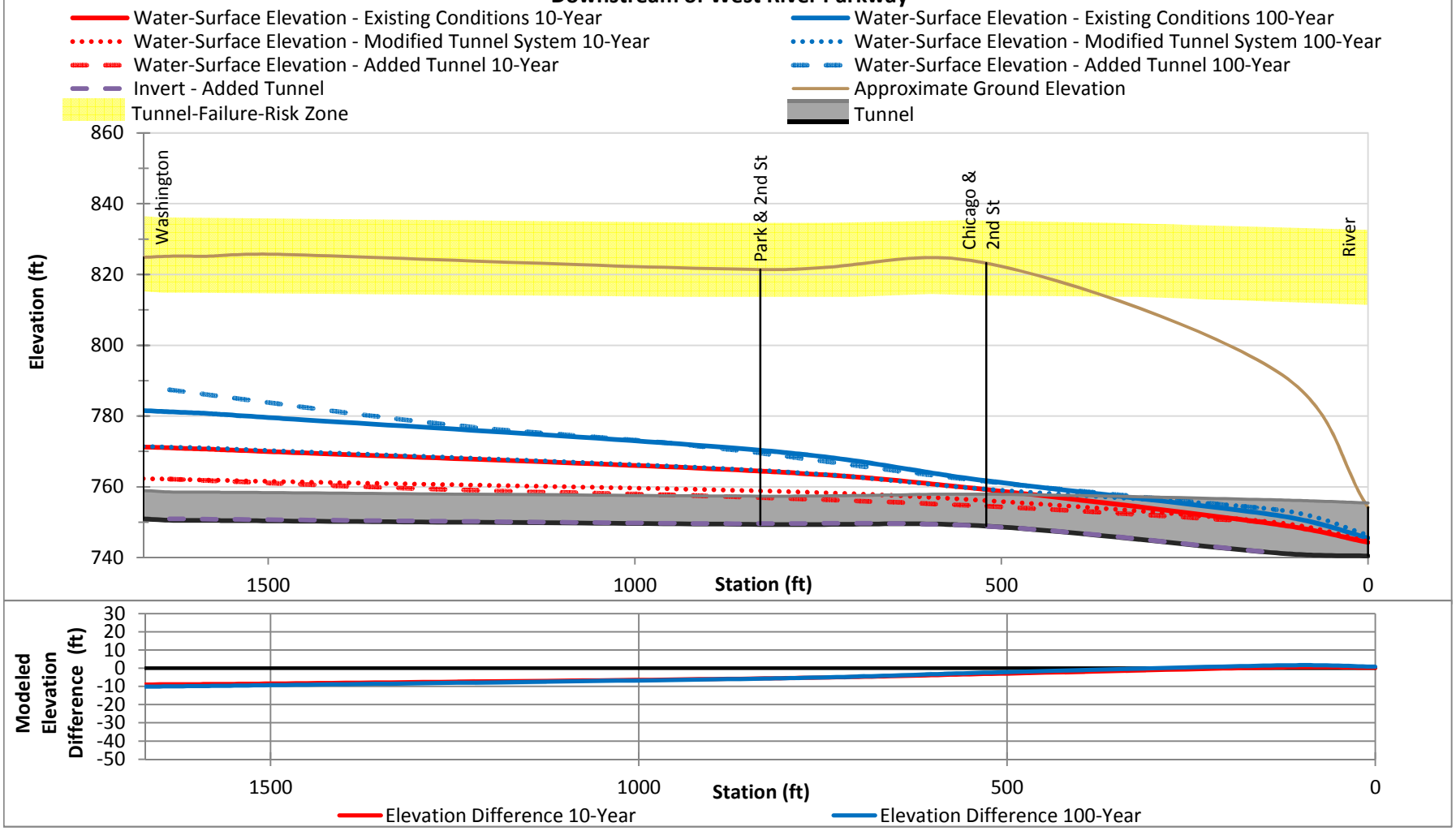
* The Tunnel-Failure-Risk Zone was calculated assuming the tunnel liner is not in contact with the native soil/bedrock (i.e., void space exists along the entire profile and surrounding the entire tunnel cross section).
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Portland Avenue - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue S. and Portland Avenue & Extend to Downstream of West River Parkway



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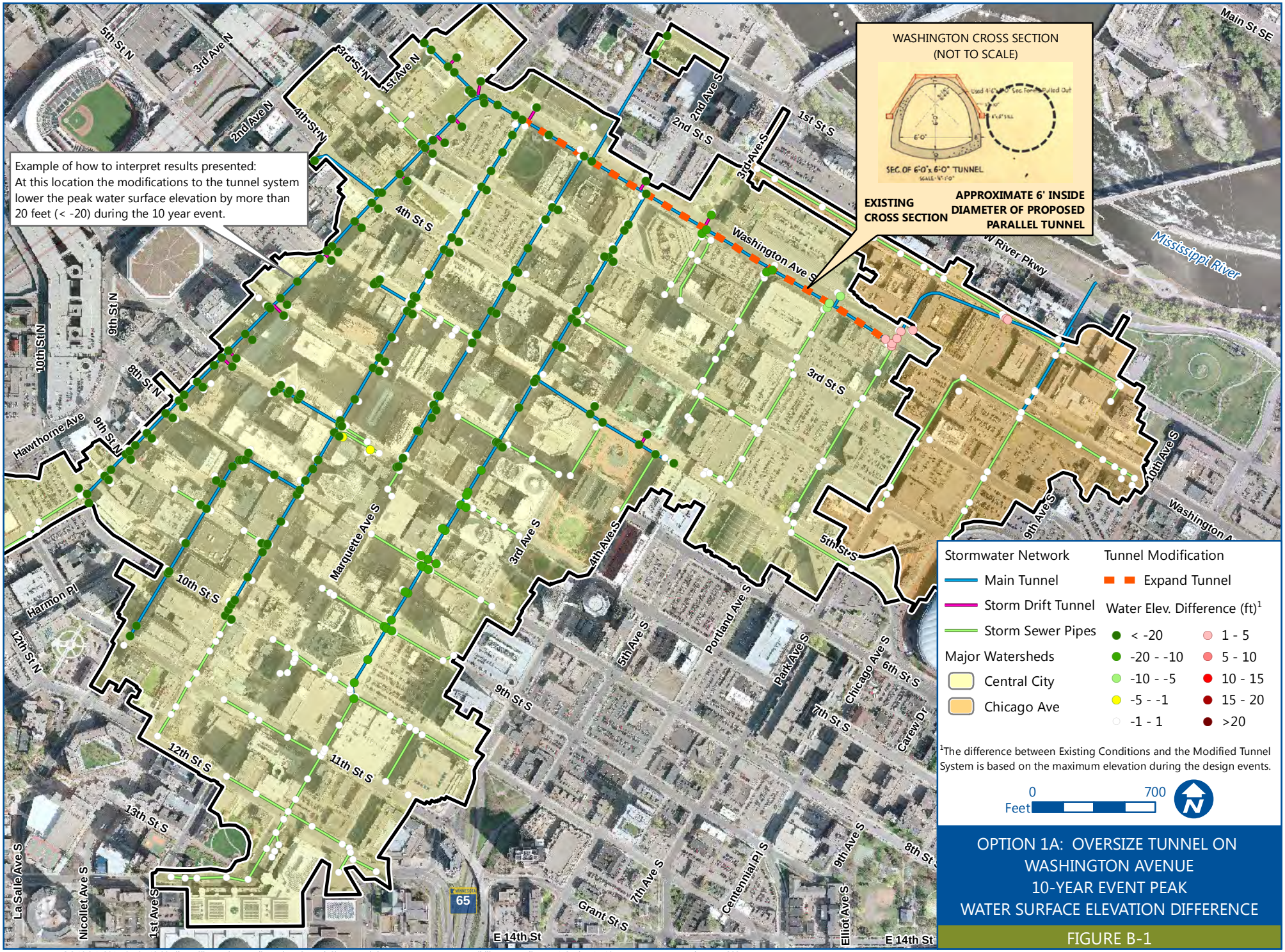
*The water-surface elevation profile is based on the maximum elevation during the design event(s).

Appendix B

Reduction in Peak Water Surface Elevation for Each Pressure-Mitigation Option

Reduction in Peak Water Surface Elevation for Each Pressure-Mitigation Option

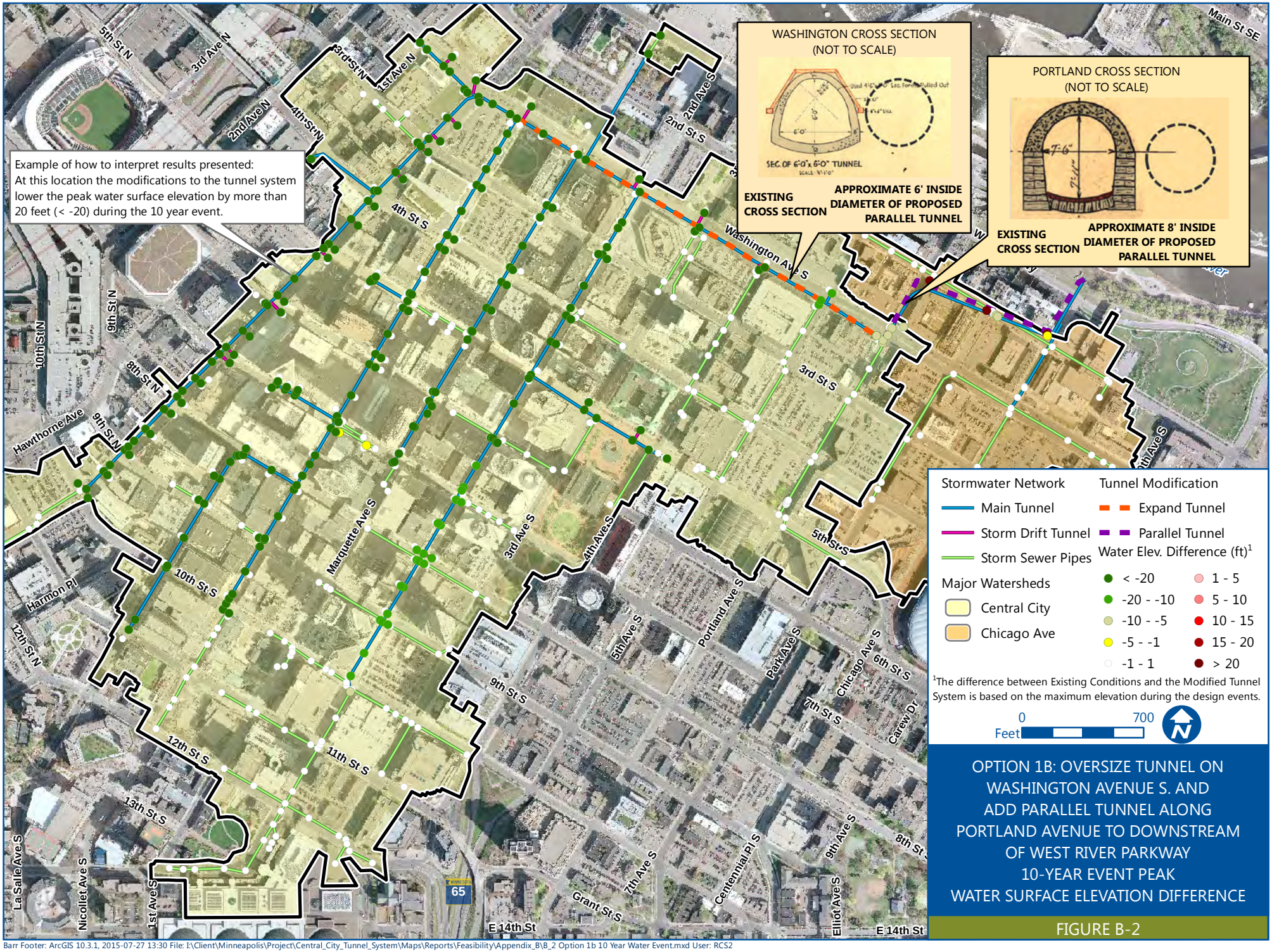
10-year, 24-hour Storm Event Results



OPTION 1A: OVERSIZE TUNNEL ON WASHINGTON AVENUE
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-1

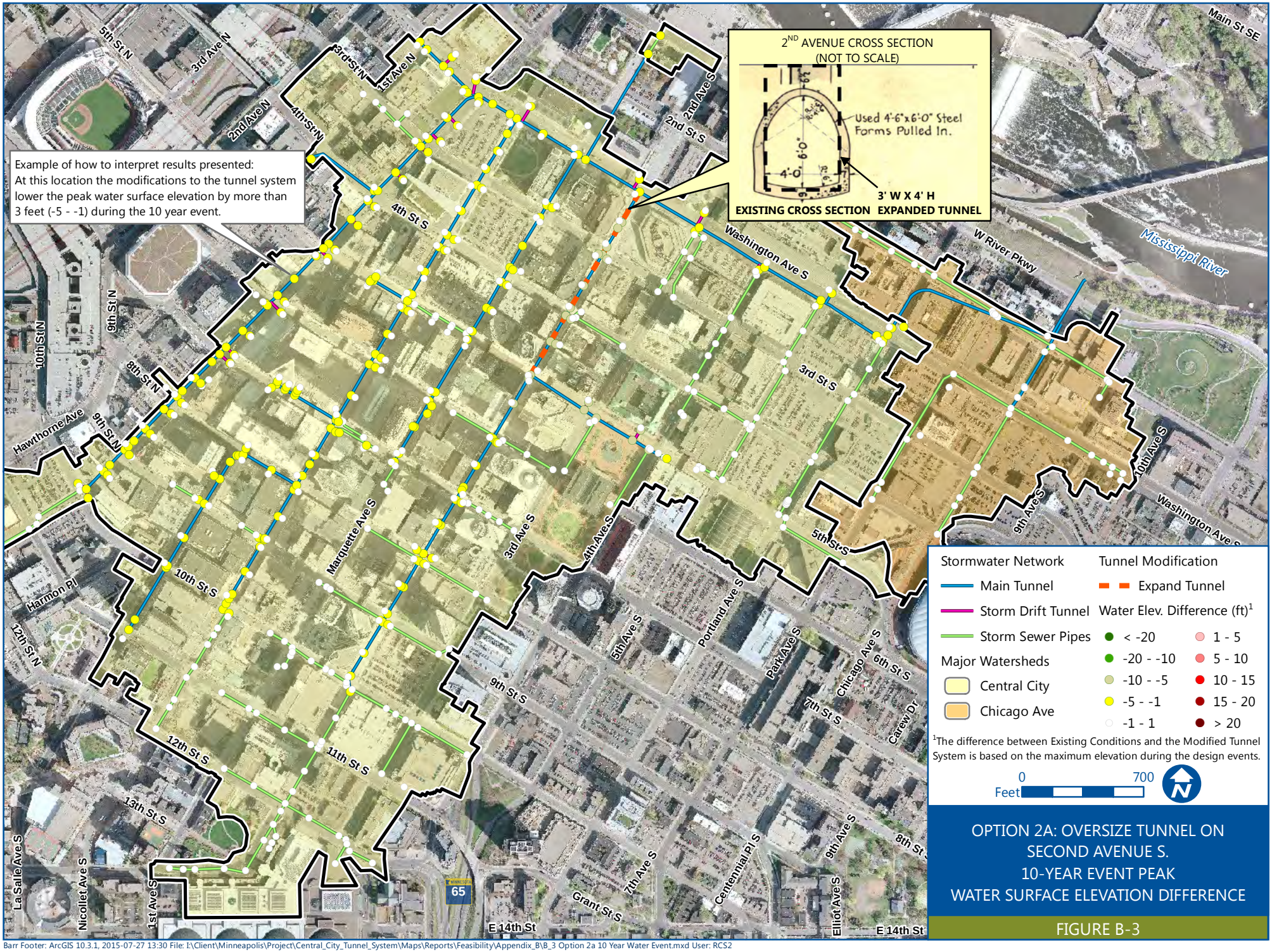
Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:29 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_1 Option 1a 10 Year Water Event.mxd User: RCS2



OPTION 1B: OVERSIZE TUNNEL ON WASHINGTON AVENUE S. AND ADD PARALLEL TUNNEL ALONG PORTLAND AVENUE TO DOWNSTREAM OF WEST RIVER PARKWAY
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-2

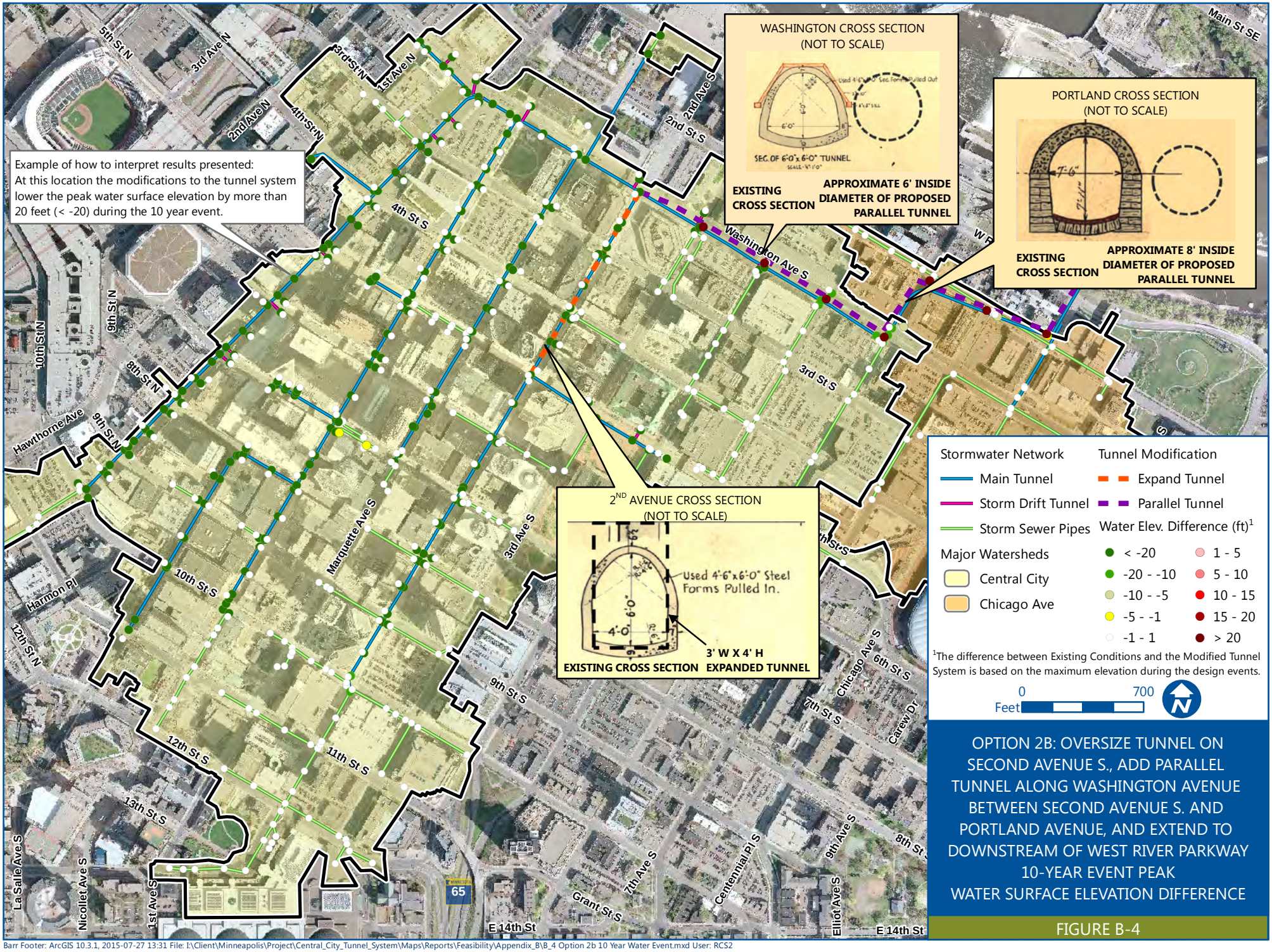
Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:30 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_2 Option 1b 10 Year Water Event.mxd User: RCS2



OPTION 2A: OVERSIZE TUNNEL ON SECOND AVENUE S.
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

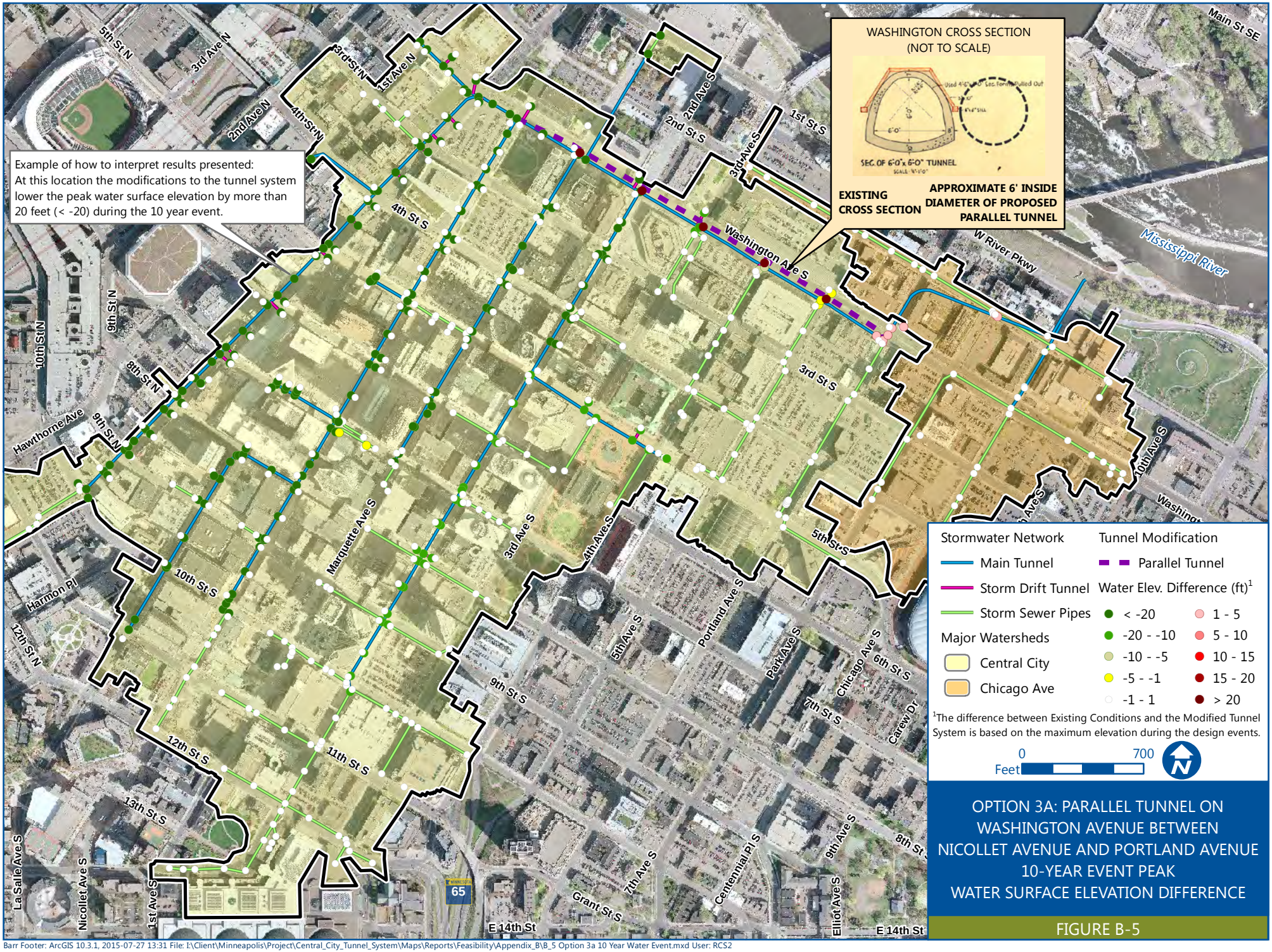
FIGURE B-3

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:30 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_3 Option 2a 10 Year Water Event.mxd User: RCS2



OPTION 2B: OVERSIZE TUNNEL ON SECOND AVENUE S., ADD PARALLEL TUNNEL ALONG WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

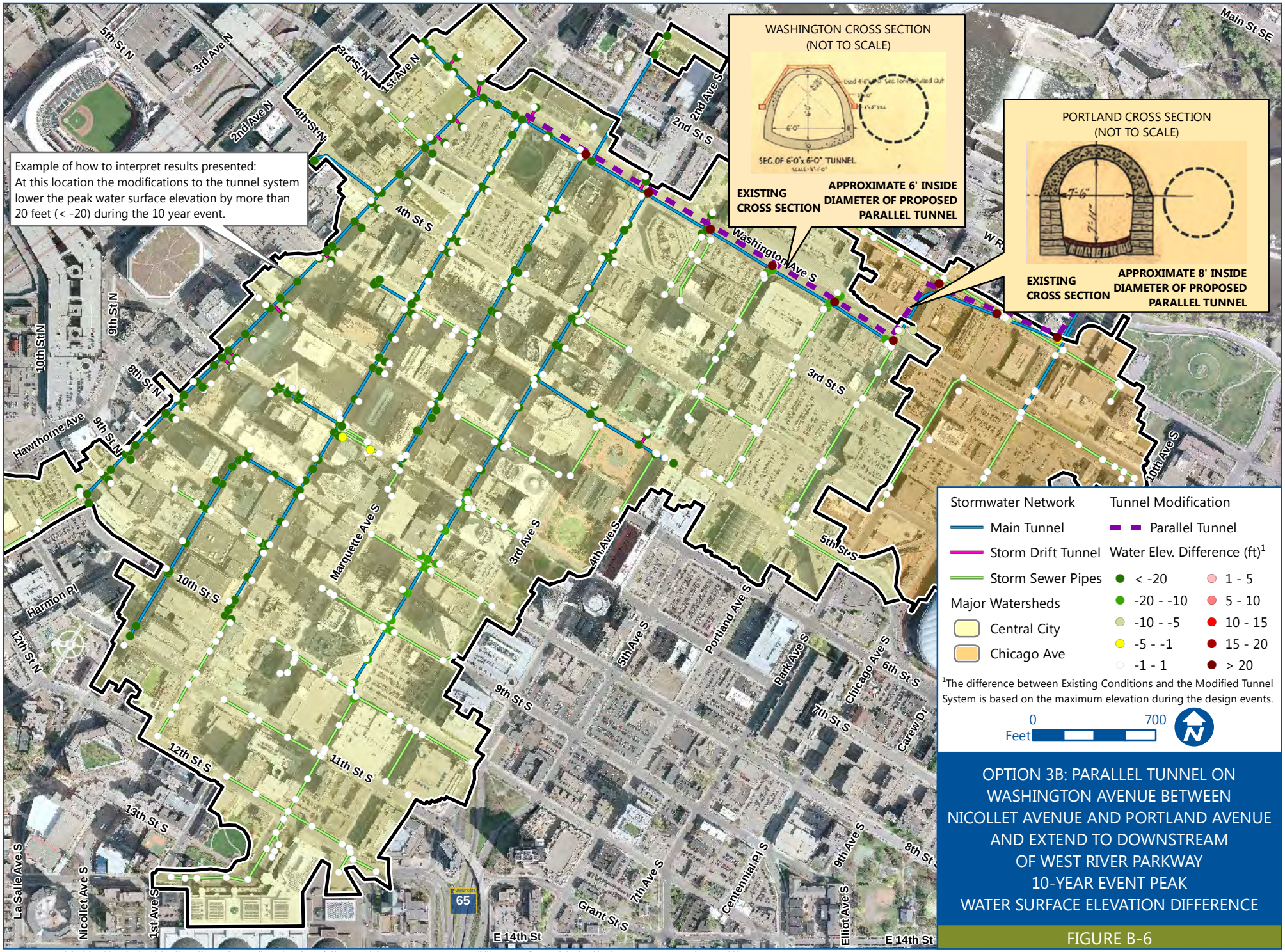
FIGURE B-4



OPTION 3A: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN NICOLLET AVENUE AND PORTLAND AVENUE
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

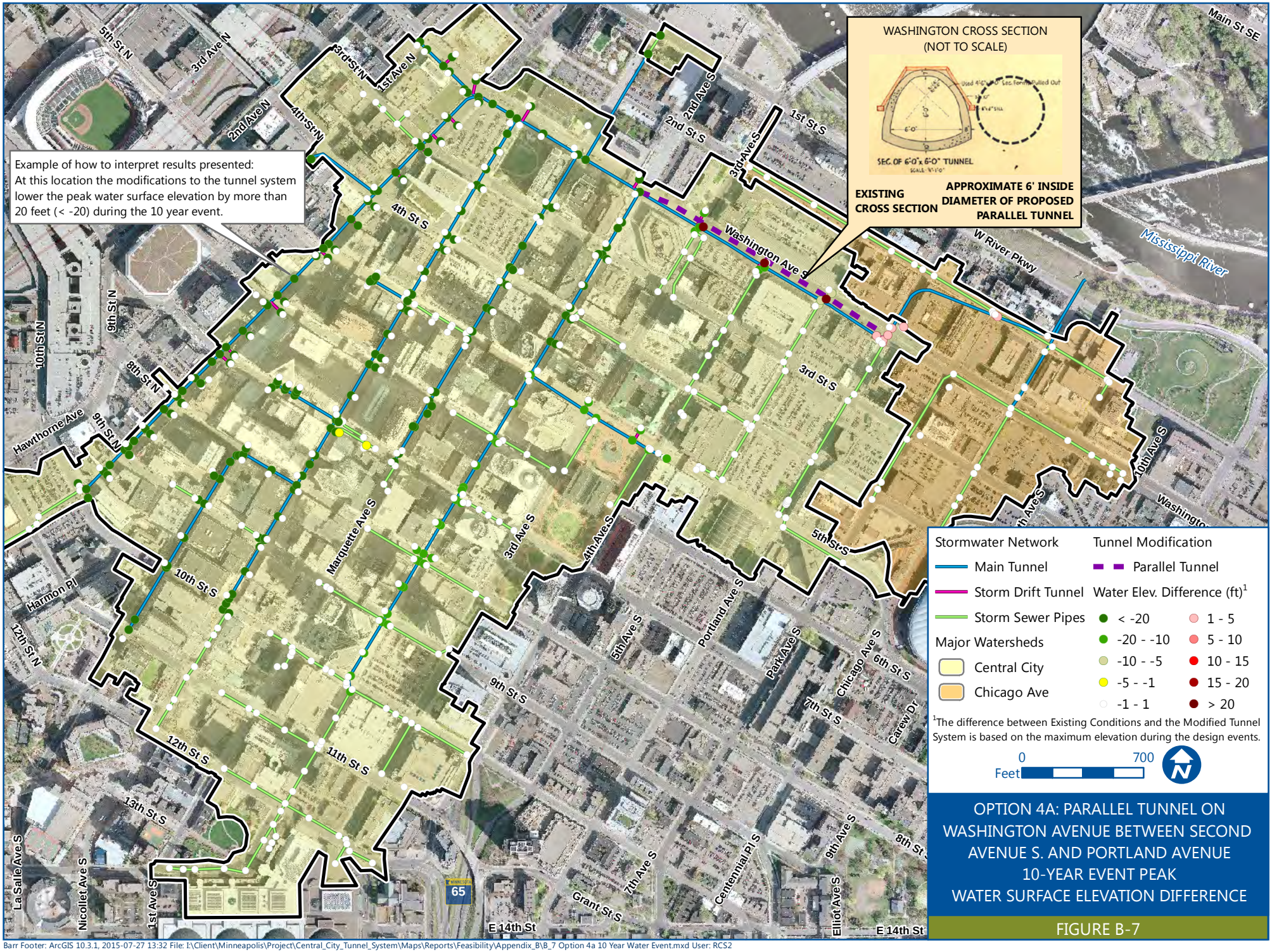
FIGURE B-5

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:31 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_5 Option 3a 10 Year Water Event.mxd User: RCS2



OPTION 3B: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN NICOLLET AVENUE AND PORTLAND AVENUE AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

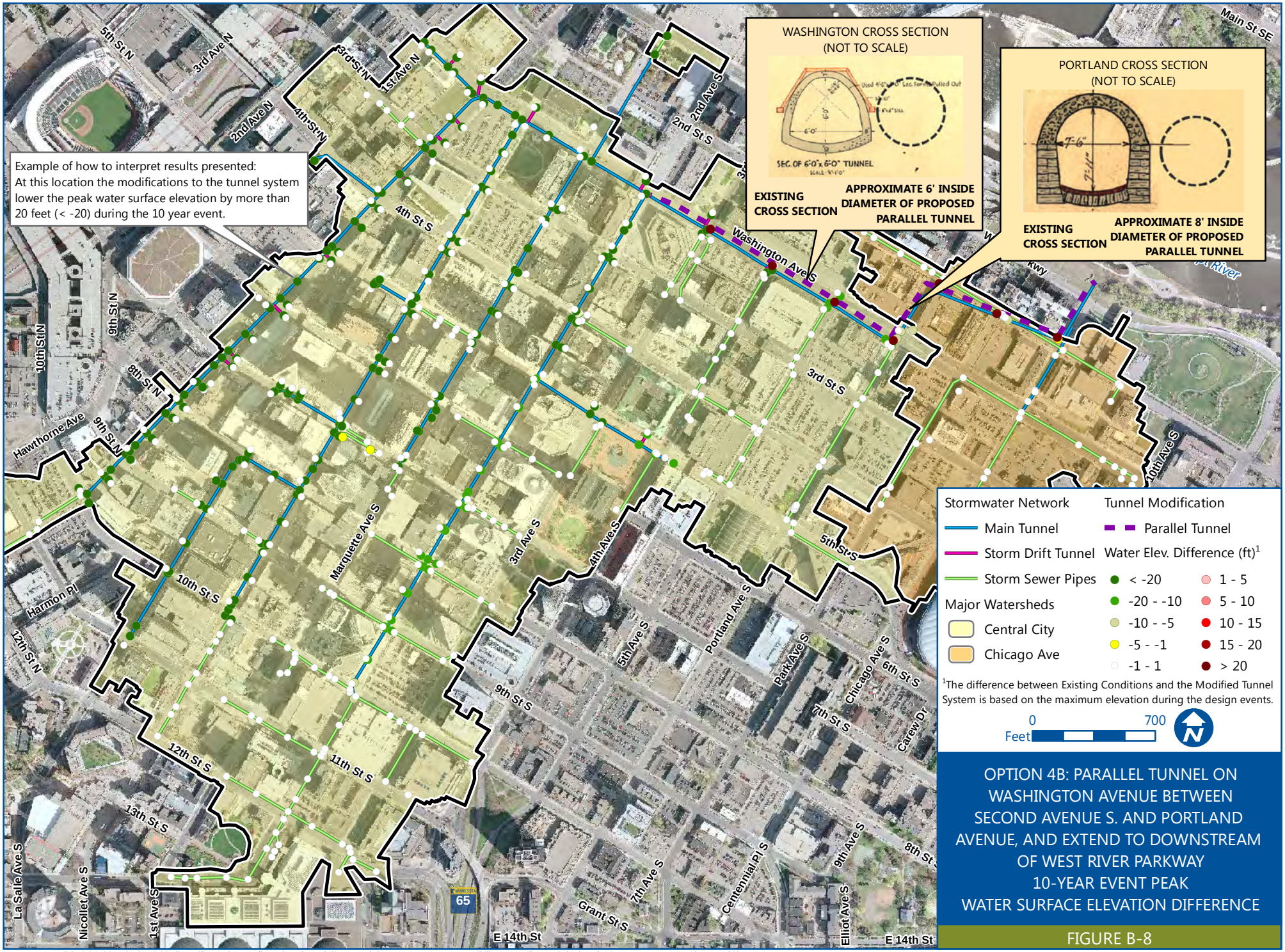
FIGURE B-6



OPTION 4A: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE 10-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

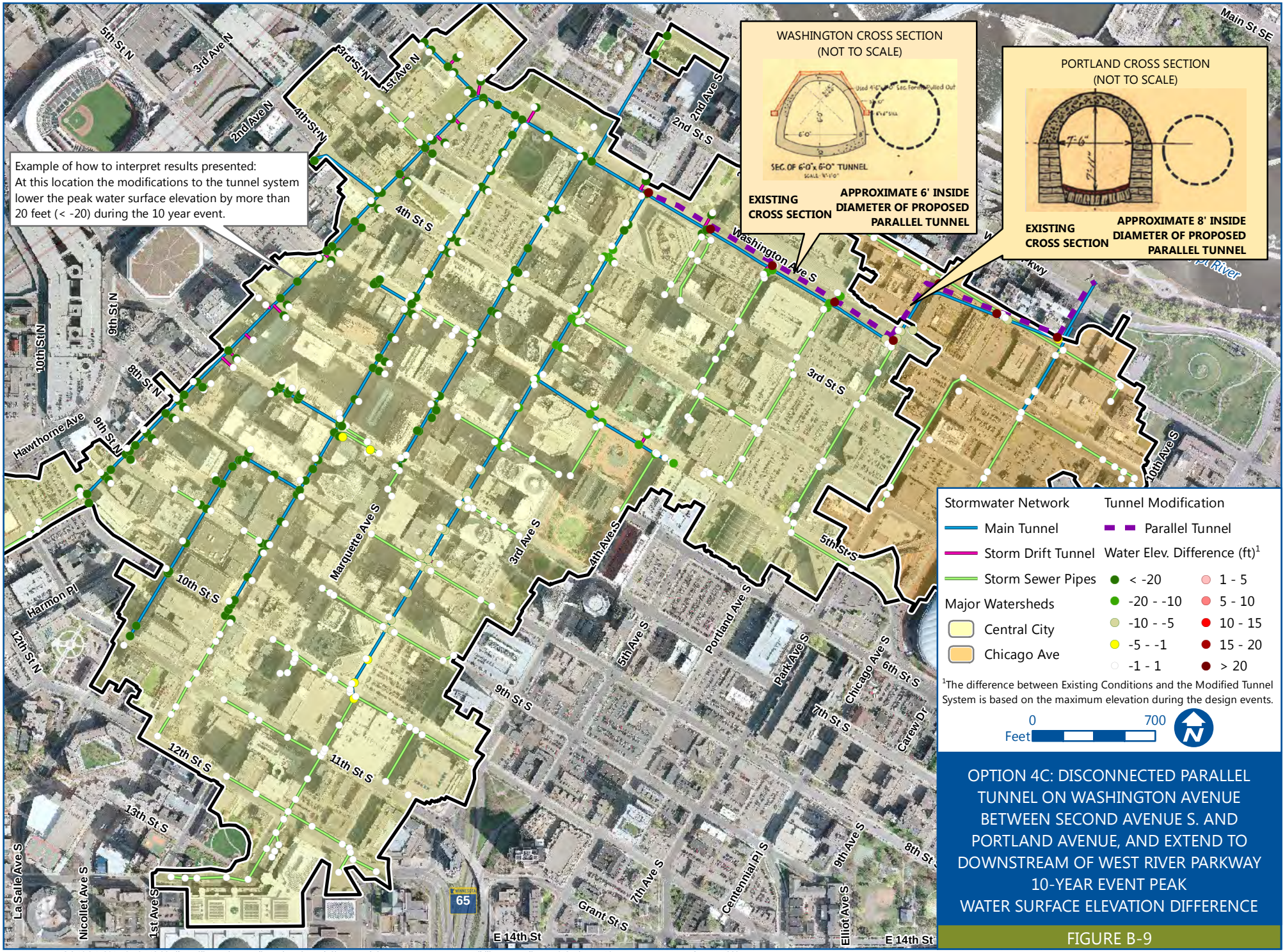
FIGURE B-7

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:32 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_7 Option 4a 10 Year Water Event.mxd User: RCS2



OPTION 4B: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-8

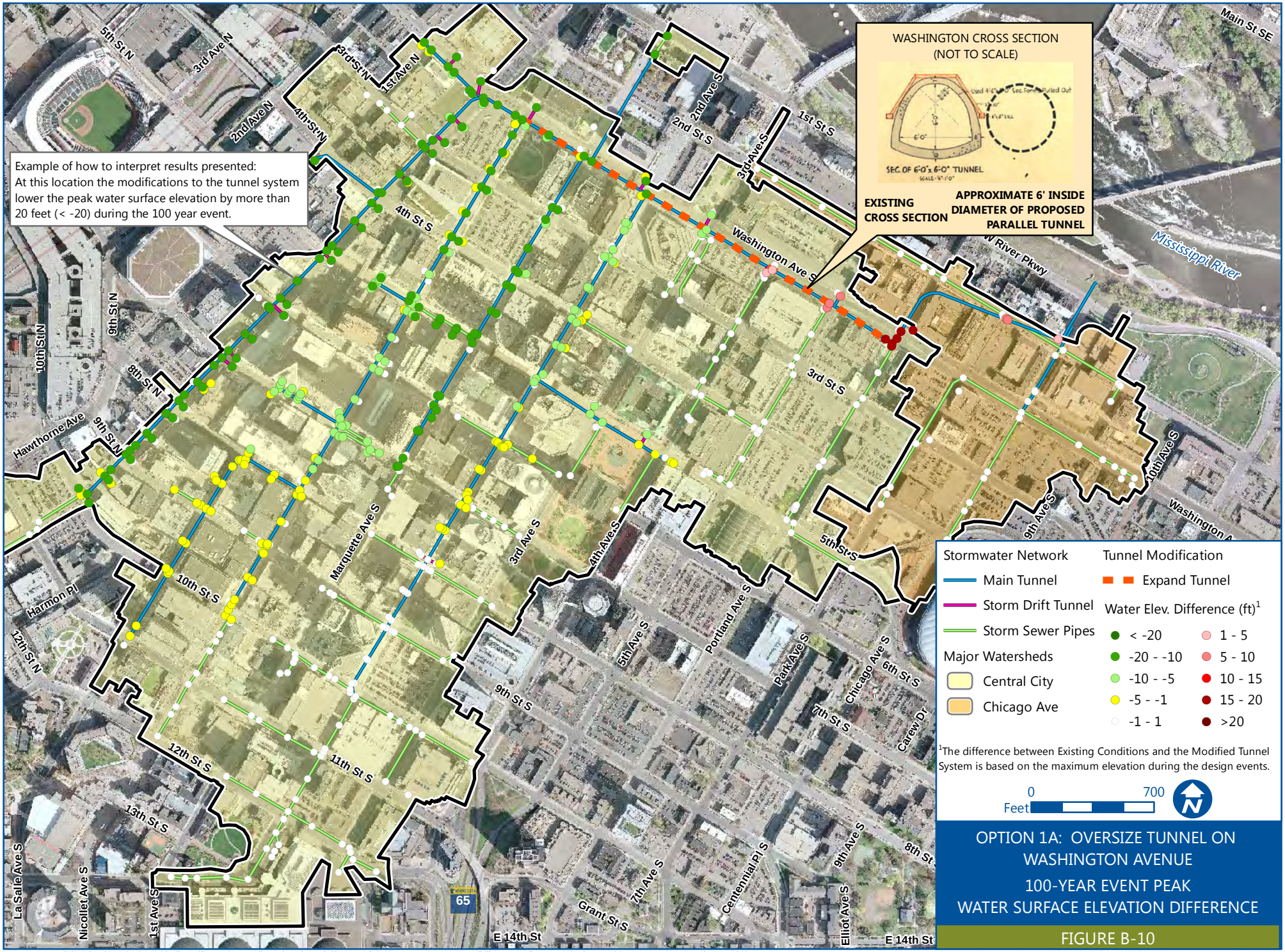


OPTION 4C: DISCONNECTED PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY
10-YEAR EVENT PEAK
WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-9

Reduction in Peak Water Surface Elevation for Each Pressure-Mitigation Option

100-year, 24-hour Storm Event Results

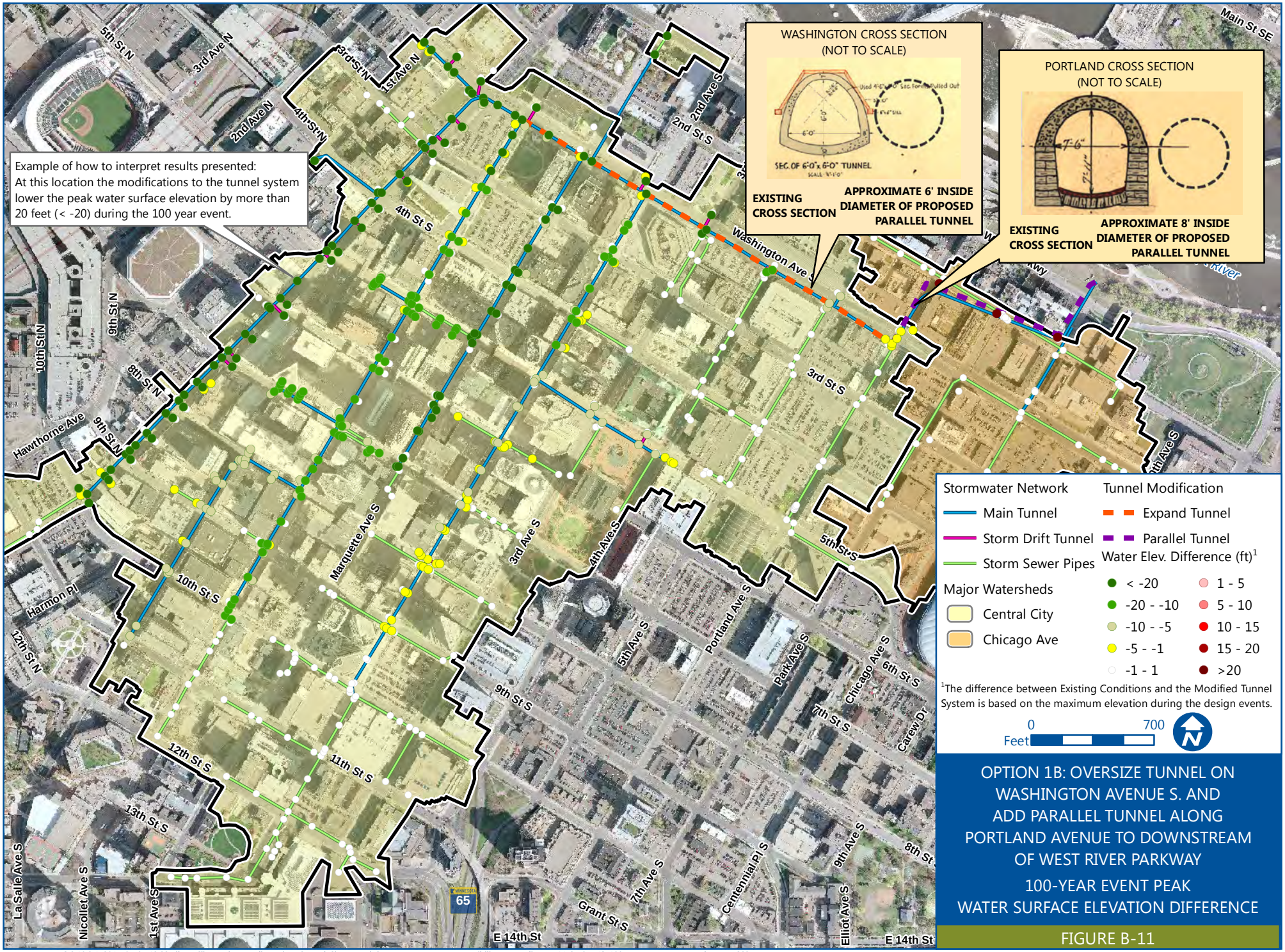


OPTION 1A: OVERSIZE TUNNEL ON WASHINGTON AVENUE

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-10

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:33 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_10 Option 1a 100 Year Water Event.mxd User: RCS2

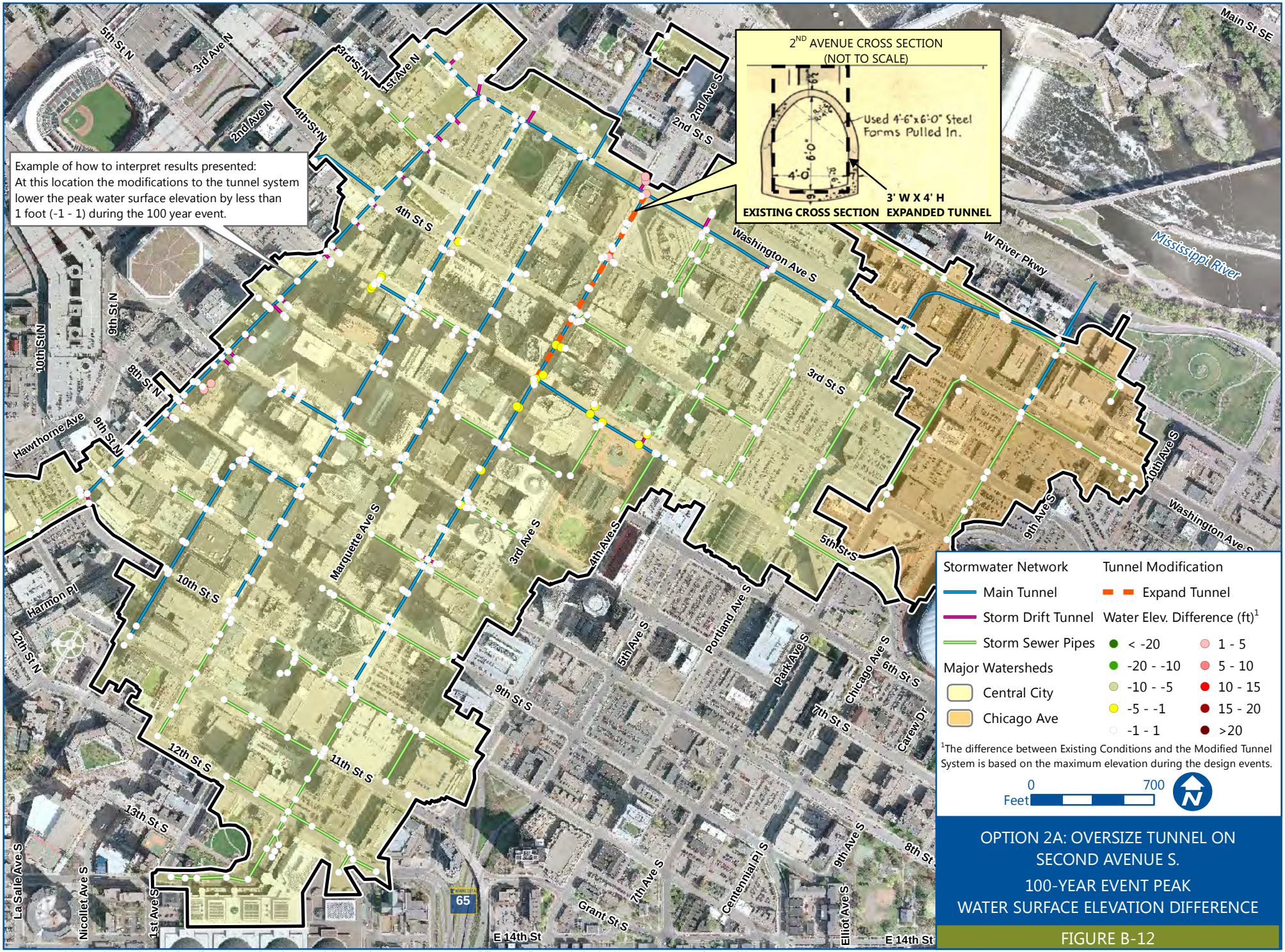


OPTION 1B: OVERSIZE TUNNEL ON WASHINGTON AVENUE S. AND ADD PARALLEL TUNNEL ALONG PORTLAND AVENUE TO DOWNSTREAM OF WEST RIVER PARKWAY

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-11

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:33 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_11 Option 1b 100 Year Water Event.mxd User: RCS2

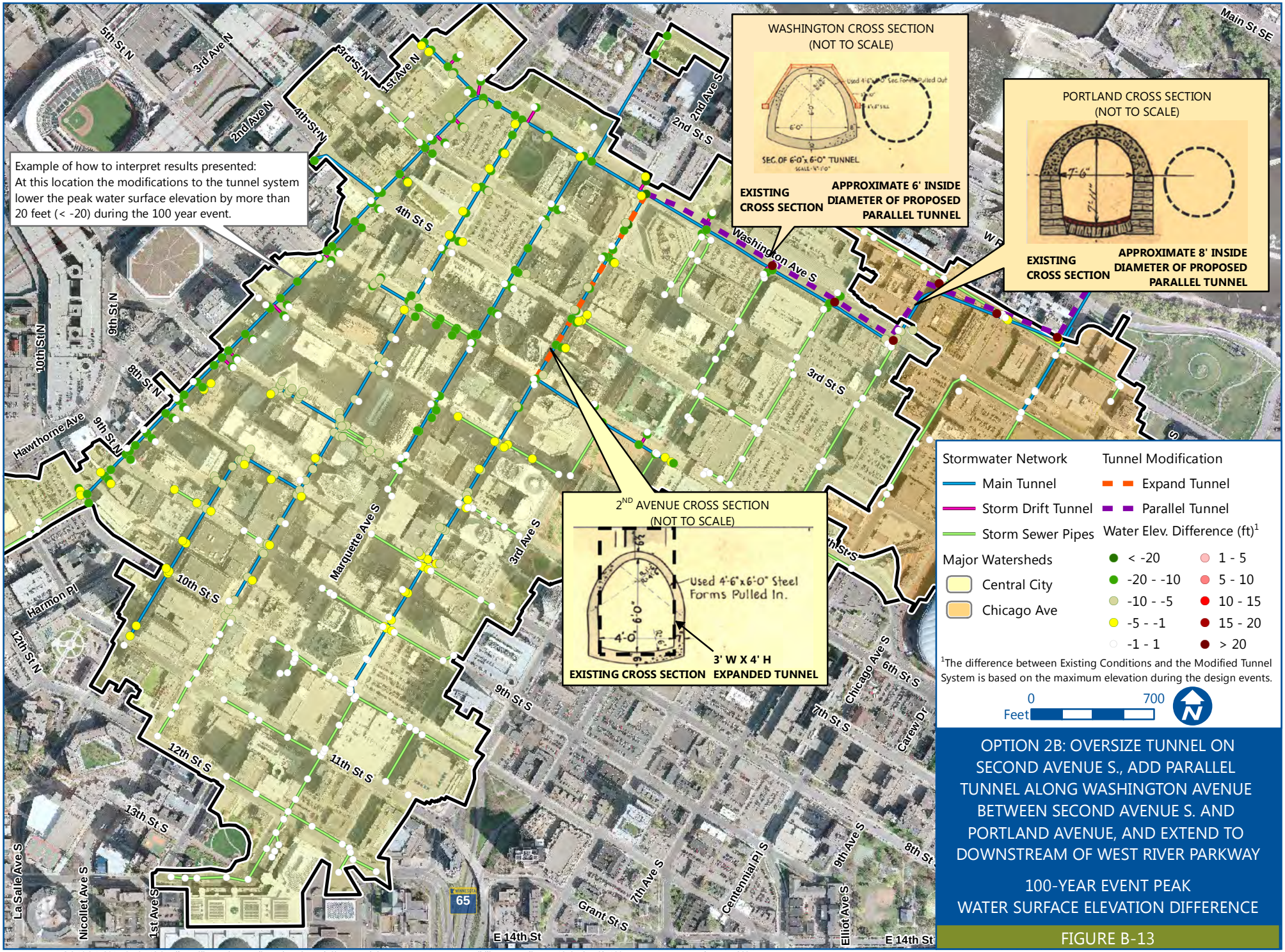


OPTION 2A: OVERSIZE TUNNEL ON SECOND AVENUE S.

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-12

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:33 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_12 Option 2a 100 Year Water Event.mxd User: RCS2

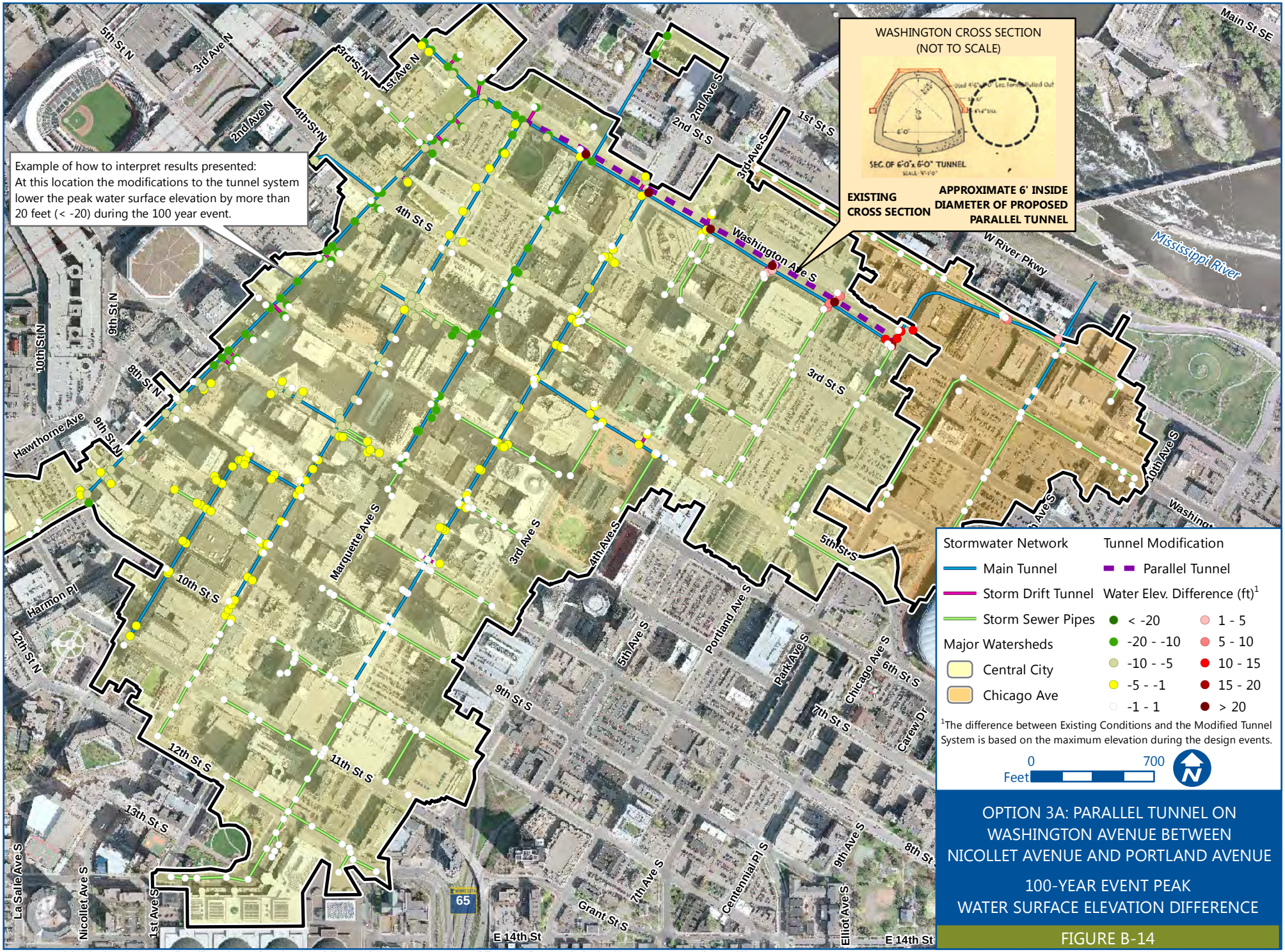


OPTION 2B: OVERSIZE TUNNEL ON SECOND AVENUE S., ADD PARALLEL TUNNEL ALONG WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-13

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:34 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_13 Option 2b 100 Year Water Event.mxd User: RCS2

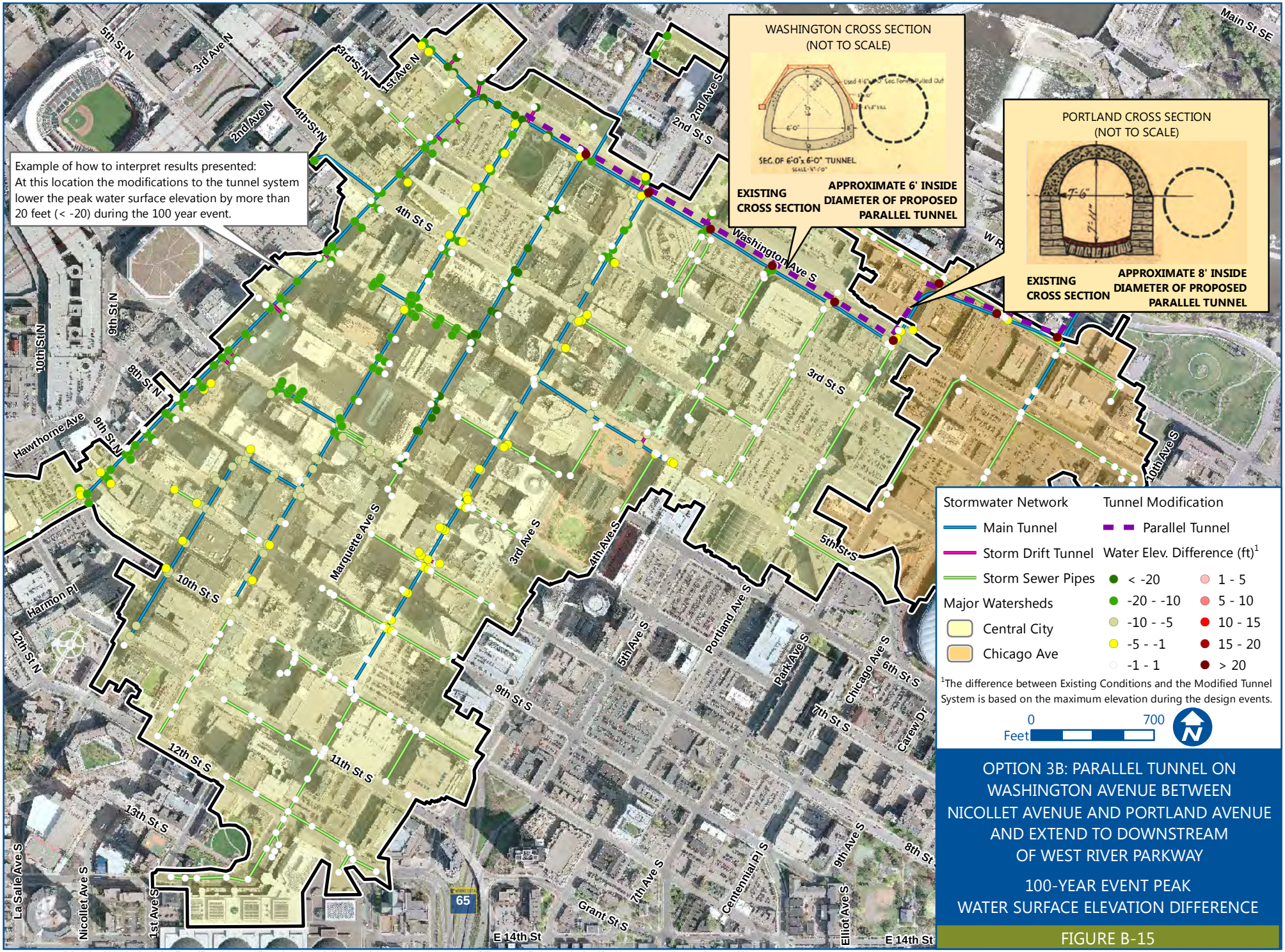


OPTION 3A: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN NICOLLET AVENUE AND PORTLAND AVENUE

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-14

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:34 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_14 Option 3a 100 Year Water Event.mxd User: RCS2

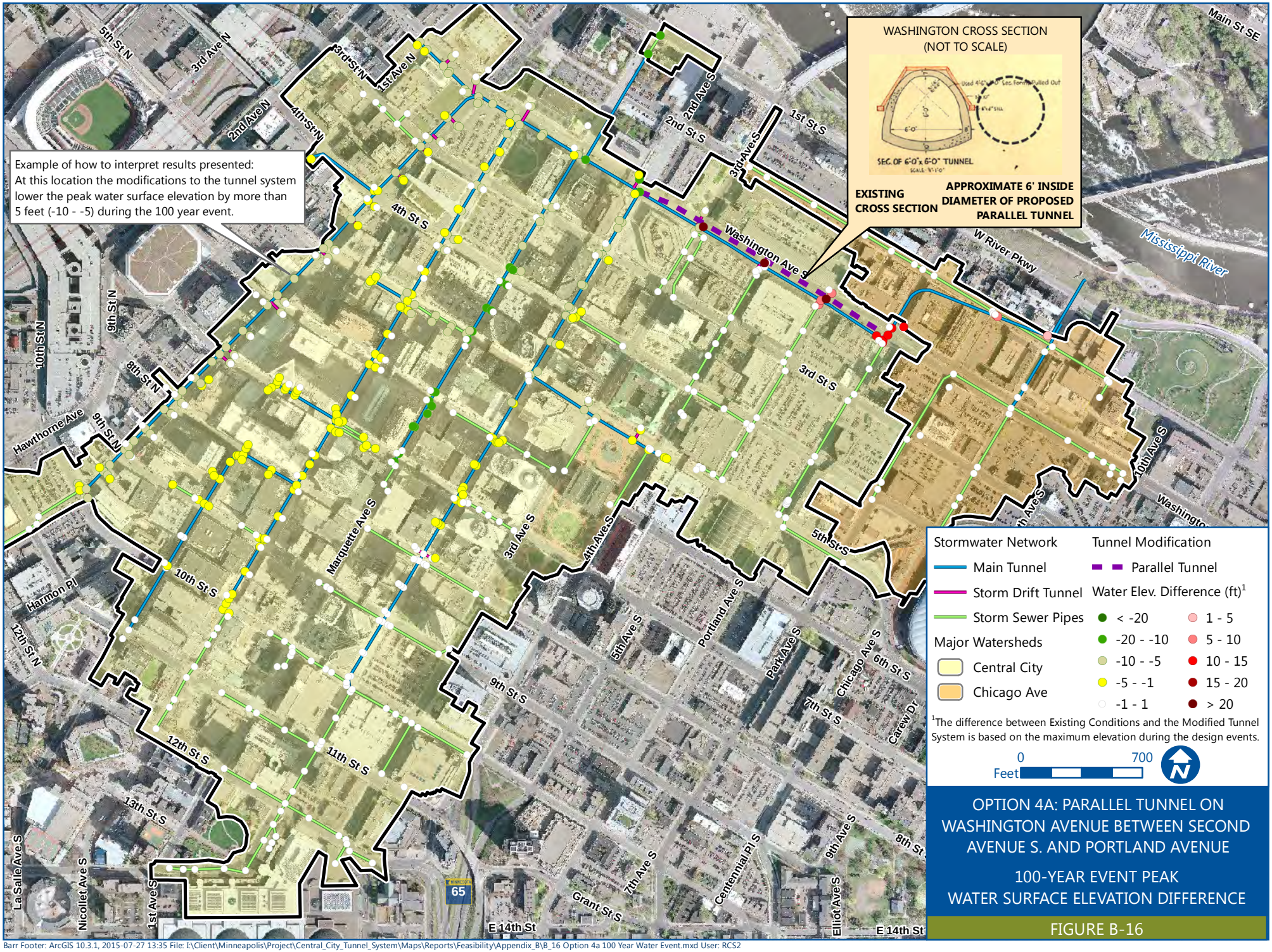


OPTION 3B: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN NICOLLET AVENUE AND PORTLAND AVENUE AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-15

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:34 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_15 Option 3b 100 Year Water Event.mxd User: RCS2

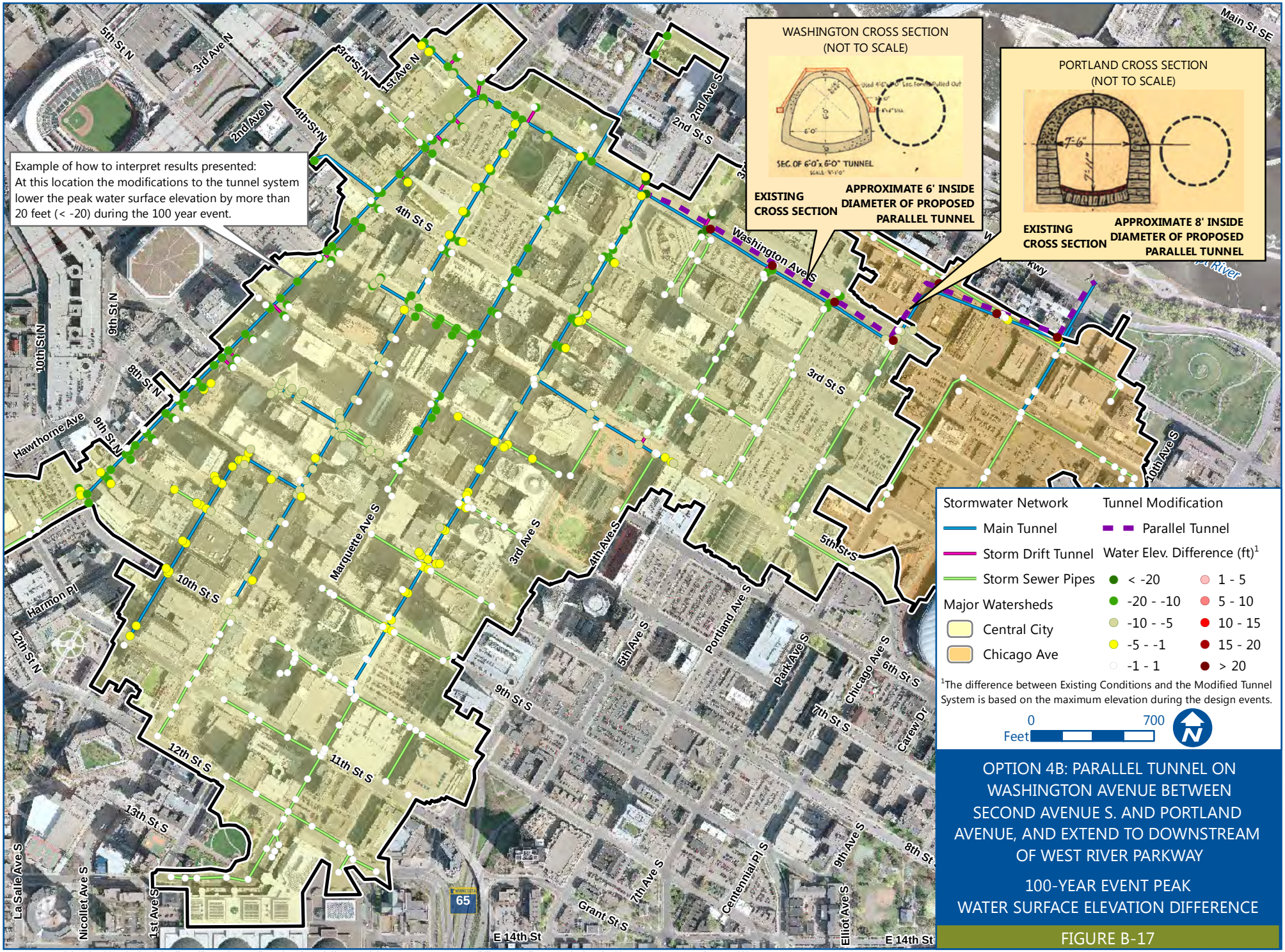


OPTION 4A: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-16

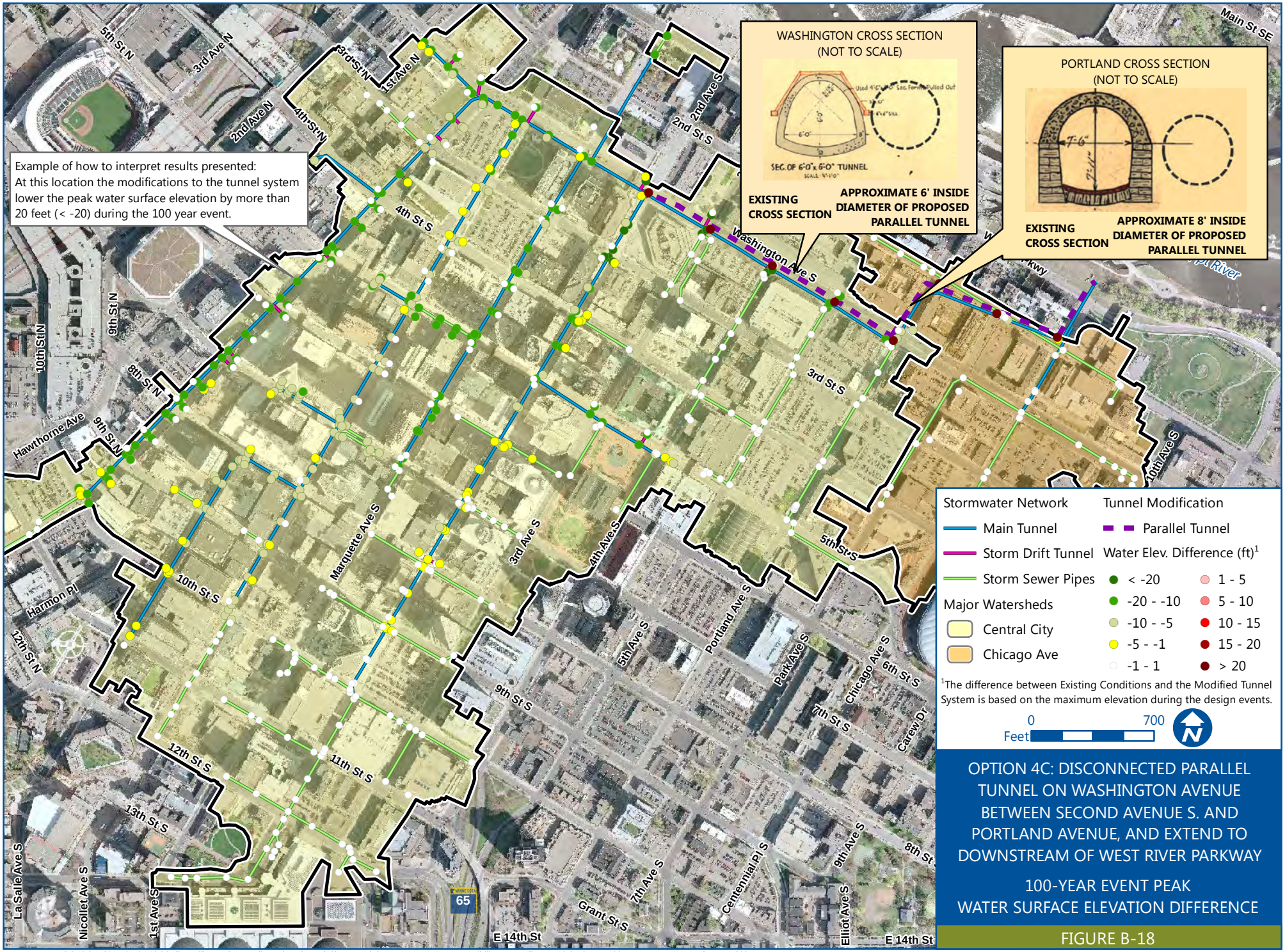
Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:35 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_16 Option 4a 100 Year Water Event.mxd User: RCS2



OPTION 4B: PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-17



OPTION 4C: DISCONNECTED PARALLEL TUNNEL ON WASHINGTON AVENUE BETWEEN SECOND AVENUE S. AND PORTLAND AVENUE, AND EXTEND TO DOWNSTREAM OF WEST RIVER PARKWAY

100-YEAR EVENT PEAK WATER SURFACE ELEVATION DIFFERENCE

FIGURE B-18

Barr Footer: ArcGIS 10.3.1, 2015-07-27 13:36 File: I:\Client\Minneapolis\Project\Central_City_Tunnel_System\Maps\Reports\Feasibility\Appendix_B\B_18 Option 4c 100 Year Water Event.mxd User: RCS2

Appendix C

Engineer's Opinion of Probable Construction Cost for Pressure-Mitigation Options

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 1a

Oversize Tunnel on Washington Avenue

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$537,000	$537,000	see category description
B	STAGING AREA	EACH	3	$50,000	$150,000	see category description
C	EROSION CONTROL	EACH	6	$10,000	$60,000	see category description
D	CONTROL OF WATER	EACH	6	$100,000	$600,000	see category description
E	REMOVAL OF EXISTIING CONCRETE TUNNEL	LN FT	2466	$568	$1,401,000	see category description
F	8 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	2466	$2,272	$5,603,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	2	$350,000	$700,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	5	$60,000	$300,000	see category description
I	BACKFILL GROUTING VOIDS	LN FT	2960	$186	$551,000	see category description
J	CROSS CONNECTIONS	EACH	5	$75,000	$375,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$200,000	$200,000	see category description
M	TRAFFIC CONTROL	EACH	10	$25,000	$250,000	see category description
	SUBTOTAL				$11,277,000	1,2,3,4,5,6
	CONSTRUCTION CONTINGENCY (30%)				$3,383,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$2,255,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$3,383,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$20,298,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$17,300,000**	1,2,3,4,5,6
		50%			**$30,500,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[E] Cost to demo existing 6 foot concrete tunnel and remove materials, approx. 0.6 cy/ft

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[I] Cost from Hiawatha tunnel repairs for Ln. Ft. of tunnel grouting

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 1b

Oversize Tunnel on Washington Avenue & Add Parallel Tunnel along Portland Avenue to Downstream of West River Parkway

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$779,450	$779,000	see category description
B	STAGING AREA	EACH	4	$50,000	$200,000	see category description
C	EROSION CONTROL	EACH	7	$10,000	$70,000	see category description
D	CONTROL OF WATER	EACH	10	$100,000	$1,000,000	see category description
E	REMOVAL OF EXISTIING CONCRETE TUNNEL	LN FT	2466	$568	$1,401,000	see category description
F	8 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	2466	$2,272	$5,603,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	1510	$1,860	$2,809,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	2	$350,000	$700,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	8	$60,000	$480,000	see category description
I	BACKFILL GROUTING VOIDS	LN FT	2960	$186	$551,000	see category description
J	CROSS CONNECTIONS	EACH	7	$75,000	$525,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
N	REBUILD OUTLET STRUCTURE	EACH	1	$750,000	$750,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$350,000	$350,000	see category description
M	TRAFFIC CONTROL	EACH	10	$25,000	$250,000	see category description
	SUBTOTAL				$16,368,000	1,2,3,4,5,6
	CONSTRUCTION CONTINGENCY (30%)				$4,910,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$3,274,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$4,910,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$29,462,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$25,100,000**	1,2,3,4,5,6
		50%			**$44,200,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[E] Cost to demo existing 6 foot concrete tunnel and remove materials, approx. 0.6 cy/ft

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[I] Cost from Hiawatha tunnel repairs for Ln. Ft. of tunnel grouting

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[N] Estimated cost to connect two existing old twin tunnel chamber

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 2a

Oversize Tunnel on Second Avenue South

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$227,200	$227,000	see category description
B	STAGING AREA	EACH	2	$50,000	$100,000	see category description
C	EROSION CONTROL	EACH	5	$10,000	$50,000	see category description
D	CONTROL OF WATER	EACH	4	$100,000	$400,000	see category description
Q	REMOVE TOP OF EXISTIING CONC. TUNNEL	LN FT	1277	$337	$430,000	see category description
R	REBUILD TOP OF TUNNEL USING EXT. VOID	LN FT	1277	$1,372	$1,752,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	1	$350,000	$350,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	2	$60,000	$120,000	see category description
I	BACKFILL GROUTING VOIDS	LN FT	1034	$186	$192,000	see category description
J	CROSS CONNECTIONS	EACH	4	$75,000	$300,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$150,000	$150,000	see category description
M	TRAFFIC CONTROL	EACH	6	$25,000	$150,000	see category description
	SUBTOTAL				$4,771,000	1,2,3,4,5,6
	CONSTRUCTION CONTINGENCY (30%)				$1,431,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$954,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$1,431,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$8,587,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$7,300,000**	1,2,3,4,5,6
		50%			**$12,900,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[I] Cost from Hiawatha tunnel repairs for Ln. Ft. of tunnel grouting

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[Q] Cost to remove top section of tunnel. (2/3 cost of removing 6 foot tunnel)

[R] Cost to replace top section of existing tunnel expanding in void area. (2/3 cost of 7 foot tunnel)

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 2b

Oversize Tunnel on Second Avenue South, Add Parallel Tunnel along Washington Avenue between Second Avenue South and Portland Avenue, & Extend to Downstream of West River Parkway

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$637,100	$637,000	see category description
B	STAGING AREA	EACH	3	$50,000	$150,000	see category description
C	EROSION CONTROL	EACH	7	$10,000	$70,000	see category description
D	CONTROL OF WATER	EACH	6	$100,000	$600,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	3152	$1,860	$5,863,000	see category description
Q	REMOVE TOP OF EXISTIING CONC. TUNNEL	LN FT	1277	$337	$430,000	see category description
R	REBUILD TOP OF TUNNEL USING EXT. VOID	LN FT	1277	$1,372	$1,752,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	1	$350,000	$350,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	8	$60,000	$480,000	see category description
I	BACKFILL GROUTING VOIDS	LN FT	1034	$186	$192,000	see category description
J	DRIFT TUNNEL CROSS CONNECTIONS	EACH	10	$75,000	$750,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
P	BULKHEAD EXISTING TUNNEL	LS	1	$5,000	$5,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
N	REBUILD OUTET STRUCTURE	EACH	1	$750,000	$750,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$250,000	$250,000	see category description
M	TRAFFIC CONTROL	EACH	8	$25,000	$200,000	see category description
	SUBTOTAL				$13,379,000	1,2,3,4,5,6
	CONSTRUCTION CONTINGENCY (30%)				$4,014,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$2,676,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$4,014,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$24,083,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$20,500,000**	1,2,3,4,5,6
		50%			**$36,200,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[I] Cost from Hiawatha tunnel repairs for Ln. Ft. of tunnel grouting

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[N] Estimated cost to connect two existing old twin tunnel chamber

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

[P] Cost for installing substantial bulkhead in existing tunnel including reinforcement tie-in's, forming, and casting bulkhead.

[Q] Cost to remove top section of tunnel. (2/3 cost of removing 6 foot tunnel)

[R] Cost to replace top section of existing tunnel expanding in void area. (2/3 cost of 7 foot tunnel)

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 3a

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$406,100	$406,000	see category description
B	STAGING AREA	EACH	3	$50,000	$150,000	see category description
C	EROSION CONTROL	EACH	6	$10,000	$60,000	see category description
D	CONTROL OF WATER	EACH	6	$100,000	$600,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	2466	$1,860	$4,587,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	2	$350,000	$700,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	5	$60,000	$300,000	see category description
J	CROSS CONNECTIONS	EACH	5	$75,000	$375,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$200,000	$200,000	see category description
M	TRAFFIC CONTROL	EACH	10	$25,000	$250,000	see category description
	SUBTOTAL				$8,528,000	see category description
	CONSTRUCTION CONTINGENCY (30%)				$2,558,000	see category description
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$1,706,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$2,558,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$15,350,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$13,100,000**	1,2,3,4,5,6
		50%			**$23,100,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST
PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00
OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 3b

Parallel Tunnel on Washington Avenue between Nicollet Avenue and Portland Avenue & Extend to Downstream of West River Parkway

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$616,000	$616,000	see category description
B	STAGING AREA	EACH	5	$50,000	$250,000	see category description
C	EROSION CONTROL	EACH	7	$10,000	$70,000	see category description
D	CONTROL OF WATER	EACH	10	$100,000	$1,000,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	3976	$1,860	$7,395,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	1	$350,000	$350,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	8	$60,000	$480,000	see category description
J	CROSS CONNECTIONS	EACH	7	$75,000	$525,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
N	REBUILD OUTLET STRUCTURE	EACH	1	$750,000	$750,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$350,000	$350,000	see category description
M	TRAFFIC CONTROL	EACH	10	$25,000	$250,000	see category description
	SUBTOTAL				$12,936,000	see category description
	CONSTRUCTION CONTINGENCY (30%)				$3,881,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$2,587,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$3,881,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$23,285,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$19,800,000**	1,2,3,4,5,6
		50%			**$35,000,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[N] Estimated cost to connect two existing old twin tunnel chamber

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST
PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00
OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 4a

Parallel Tunnel on Washington Avenue between Second Avenue South and Portland Avenue

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$299,200	$299,000	see category description
B	STAGING AREA	EACH	2	$50,000	$100,000	see category description
C	EROSION CONTROL	EACH	5	$10,000	$50,000	see category description
D	CONTROL OF WATER	EACH	4	$100,000	$400,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	1642	$1,860	$3,054,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	2	$350,000	$700,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	3	$60,000	$180,000	see category description
J	CROSS CONNECTIONS	EACH	3	$75,000	$225,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$175,000	$175,000	see category description
M	TRAFFIC CONTROL	EACH	8	$25,000	$200,000	see category description
	SUBTOTAL				$6,283,000	see category description
	CONSTRUCTION CONTINGENCY (30%)				$1,885,000	see category description
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$1,257,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$1,885,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$11,310,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$9,700,000**	1,2,3,4,5,6
		50%			**$17,000,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST
PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00
OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 4b

Parallel Tunnel on Washington Avenue between Second Avenue South and Portland Avenue & Extend to Downstream of West River Parkway

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$497,150	$497,000	see category description
B	STAGING AREA	EACH	3	$50,000	$150,000	see category description
C	EROSION CONTROL	EACH	7	$10,000	$70,000	see category description
D	CONTROL OF WATER	EACH	6	$100,000	$600,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	3152	$1,860	$5,863,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	1	$350,000	$350,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	6	$60,000	$360,000	see category description
J	CROSS CONNECTIONS	EACH	6	$75,000	$450,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
N	REBUILD OUTLET STRUCTURE	EACH	1	$750,000	$750,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$250,000	$250,000	see category description
M	TRAFFIC CONTROL	EACH	8	$25,000	$200,000	see category description
	SUBTOTAL				$10,440,000	see category description
	CONSTRUCTION CONTINGENCY (30%)				$3,132,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$2,088,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$3,132,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$18,792,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$16,000,000**	1,2,3,4,5,6
		50%			**$28,200,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[N] Estimated cost to connect two existing old twin tunnel chamber

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

PREPARED BY: BARR ENGINEERING COMPANY

CENTRAL CITY TUNNEL SYSTEM FEASIBILITY STUDY
ENGINEER'S OPINION OF PROBABLE CONSTRUCTION COST

PROJECT: Central City Tunnel System Pressure Mitigation Options
LOCATION: City of Minneapolis, MN
PROJECT #: 23/27-1397.00

OPINION OF COST - SUMMARY

Engineer's Opinion of Probable Construction Cost - Option 4c

Disconnected Parallel Tunnel on Washington Avenue between Second Avenue South and Portland Avenue & Extend to Downstream of West River Parkway

Cat. No.	ITEM DESCRIPTION	UNIT	ESTIMATED QUANTITY	UNIT COST	ITEM COST	NOTES
A	MOBILIZATION/DEMOBILIZATION	L S	1	$497,400	$497,000	see category description
B	STAGING AREA	EACH	3	$50,000	$150,000	see category description
C	EROSION CONTROL	EACH	7	$10,000	$70,000	see category description
D	CONTROL OF WATER	EACH	6	$100,000	$600,000	see category description
F	6 FOOT MONOLITHIC CONCRETE TUNNEL	LN FT	3152	$1,860	$5,863,000	see category description
G	120" DIA. SHAFT HOLE/ACCESS	EACH	1	$350,000	$350,000	see category description
H	24" DIA. DRILL HOLE/ACCESS	EACH	6	$60,000	$360,000	see category description
J	DRIFT TUNNEL CROSS CONNECTIONS	EACH	6	$75,000	$450,000	see category description
O	CONNECTION CHAMBER WITH EXISTING TUN.	L S	1	$350,000	$350,000	see category description
P	BULKHEAD EXISTING TUNNEL	LS	1	$5,000	$5,000	see category description
K	SPECIAL CHAMBERS	EACH	1	$550,000	$550,000	see category description
N	REBUILD OUTLET STRUCTURE	EACH	1	$750,000	$750,000	see category description
L	MISC. SURFACE REMOVAL & REPLACEMENT	LS	1	$250,000	$250,000	see category description
M	TRAFFIC CONTROL	EACH	8	$25,000	$200,000	see category description
	SUBTOTAL				$10,445,000	1,2,3,4,5,6
	CONSTRUCTION CONTINGENCY (30%)				$3,134,000	1,2,3,4,5,6
	ENGINEERING/CONSTRUCTION OBSERVATION (20%)				$2,089,000	1,2,3,4,5,6
	PROJECT CONTINGENCY (30%)				$3,134,000	1,2,3,4,5,6
	ESTIMATED TOTAL CONSTRUCTION COST				$18,802,000	1,2,3,4,5,6
	ESTIMATED ACCURACY RANGE	**-15%**			**$16,000,000**	1,2,3,4,5,6
		50%			**$28,300,000**	1,2,3,4,5,6

Notes

[1] Limited design work completed (10 - 15%). Opinions of cost represent relative comparision of mitigation options evaluated.

[2] Quantities based on design work completed.

[3] Unit prices based on information available at this time. See category descriptions for additional details.

[4] No soil boring or field investigation information available.

[5] This feasibility-level (Class 4, 10-15% design completion per ASTM E 2516-06 and USACE EI 01D010 (9/1/97)) cost estimate is based on feasibility-level designs, alignments, quantities and unit prices. Costs will change with further design. Time value-of-money escalation costs are not included. A construction schedule is not available at this time. Contingency is an allowance for the net sum of costs that will be in the Final Total Project Cost at the time of the completion of design, but are not included at this level of project definition. The estimated accuracy range for the Total Project Cost as the project is defined is -15% to +50%. The accuracy range is based on professional judgement considering the level of design completed, the complexity of the project and the uncertainties in the project as scoped. The contingency and the accuracy range are not intended to include costs for future scope changes that are not part of the project as currently scoped or costs for risk contingency. Operation and Maintenance costs are not included.

[6] Estimated costs are to construct this option. The estimated costs do not include permittings, operations and maintenance, or additional tasks following construction.

[7] Estimated costs do not include repairs of existing tunnel sections adjacent to new parallel tunnel that would likely be required to maintain the existing tunnel.

[A] 5% of construction cost

[B] Costs to set up and remove staging area, safety chain link fencing, field office, equipment storage, tunnel access, materials shipping

[C] $10,000 Per block, Maintenance for 1 yr

[D] $100,000 Per Block Dewatering Wells or bypass piping

[F] 2000 City cost for construction of sand rock concrete tunnel times 1.6 (ENR) increase to 2015 costs

[G] 2000 City cost for construction of concrete drop shaft times 1.6 (ENR) increase to 2015 costs

[H] Estimate for drilling 24" diameter shaft for Lilydale Project 2015 of $600 a foot from Trout Drilling. Use each drill hole at approximate 100 L.F. deep.

[J] $75,000 Per Intersection. Cost for connecting/routing existing drift tunnels from drill hole to new tunnel and repairing old drifts.

[K] Cost to mine out area for connecting chamber to old North MPLS sewer overflow/discharge tunnel and any backdraft odor controls/venting or flow control or diversions.

[L] Cost to remove and replace curb and gutter, pavement, concrete sidewalk around access points, shafts, drill holes, etc.

[M] $25,000 an intersection and advanced warning signage/detours

[N] Estimated cost to connect two existing old twin tunnel chamber

[O] Cost to mine out area to make connection with the existing tunnel and construct curved transition section to divert flow into new parallel tunnel system

[P] Cost for installing substantial bulkhead in existing tunnel including reinforcement tie-in's, forming, and casting bulkhead.