City of Alexandria, Virginia
Waterfront Implementation

Technical Memorandum 3
STORM SEWER COLLECTION SYSTEM UPGRADES

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COMMONWEALTH OF VIRGINIA
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Abbreviations

Carollo	Carollo Engineers
CASSCA	City of Alexandria Storm Sewer Capacity Analysis
City	City of Alexandria
COA	City of Alexandria
HGL	hydraulic grade line
IDF	intensity-duration-frequency
in/hr	inches per hour
mgd	million gallons per day
MSWMP	Master Storm Water Management Plan
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NVRC	Northern Virginia Regional Commission
NWS	National Weather Service
PS	pump station
TAPS	Thompsons Alley Pump Station
T&ES	City of Alexandria Department of Transportation & Environmental Services
Tc	time of concentration
VDEQ	Virginia Department of Environmental Quality
WFI	Waterfront Implementation
XPSWMM	Dynamic hydraulic and hydrologic modelling software (not an acronym)

Technical Memorandum 3

STORM SEWER COLLECTION SYSTEM UPGRADES

1.1 Purpose

The City of Alexandria (COA) currently experiences localized street flooding within the Waterfront Implementation Project (Project) core area. One of the flooding sources is caused by rainfall and the limited capacity of the existing storm sewer collection system. Street flooding affects businesses and residents and reduces mobility.

Carollo evaluated the proposed storm sewer collection system improvements from the Baseline Project to identify opportunities to maximize the collection and attenuation of stormwater runoff during the design storm, as defined in TM1 *Design Storm Selection for Hydrologic and Hydraulic Modeling*, to the maximum extent practicable. These stormwater infrastructure investments support the project goal to mitigate flooding within the core area.

This memorandum describes the following steps taken to support storm sewer collection system improvements:

- Summarizes the baseline project methodology and preliminary design, including design criteria and system components and configuration.
- Describes opportunities and verified results for further improvement to the proposed stormwater infrastructure design.
- Recommends additional upgrades to improve the effectiveness of the collection system.

1.2 Baseline Project Storm Sewer Collection System

1.2.1 Definition

The 2018 *Master Storm Water Management Plan* (MSWMP) analyzed various alternatives for upgrading the storm sewer collection system to mitigate street flooding within the WFI core area. From the 2018 report, the recommended alternative, Alternative 3B, proposed placing new inlets, upsizing the pipes within the core area, and routing the sewers through two distinctive drainage areas, each discharging into a proposed pump station: one at the Waterfront Park (PS1) and another located at the east end of Thompsons Alley (PS2). This alternative constitutes the storm sewer collection system baseline project.[1]

The proposed baseline project upgrades were sized to mitigate flooding caused by storms up to and including the 10-year storm event. In the 2018 MSWMP, the Rational Method was used for facility sizing by applying an assumed 5-minute time of concentration. The 2018 MSWMP study then relied upon the City's intensity-duration-frequency (IDF) curves to select the design storm intensity for all stormwater runoff, hydraulic grade line (HGL), and sizing computations. The stormwater facilities (sewers and pump stations) were sized using a 10-year 5-minute rainfall intensity of 9 inches per hour. Table 1 summarizes the baseline project storm sewer system key design elements.

[1] Refer to TM6 *Pump Stations Capacity and Sizing* for pump station-related discussion. This technical memorandum distinctly focuses on stormwater conveyance capacity including inlets and piping.

Table 1 Baseline Project Storm Sewer Collection System Components

Description	Value
Waterfront Park PS1 drainage area (acres)	27.5
Waterfront Park PS1 drainage area runoff flow (cfs)	198
Thompsons Alley PS2 drainage area (acres)	18.4
Thompsons Alley PS2 drainage area runoff flow (cfs)	132.5
Proposed New Storm Sewers	5,400 linear feet 12 – 60-inch diameter
Remaining Existing Storm Sewers	Duke Street Outfall Cameron Street Bypass

1.2.2 Evaluation

Carollo evaluated the baseline project to identify phasing, innovative solutions, and value engineering modifications that will allow the project to accomplish its goals cost-effectively. The following factors and options were reviewed:

- Modeling the hydraulic system to verify the baseline project effects on street flooding.
- Further increasing the size of the storm sewer pipes within the core area.
- Adding manholes and inlets to increase capture of runoff water.
- Re-routing the storm sewers to reduce the number of drainage areas and pump stations to one.
- Raising the proposed pipes to maximize addition of underground detention chambers at Waterfront and Founders parks.

1.2.3 Hydraulic Modeling Verification

1.2.3.1 Model "Hot Spot" Approach for Analysis

Carollo used XPSWMM to model the existing conditions and the baseline project to determine the extent to which the baseline project may control or mitigate street flooding. As discussed in the memorandum *Design Storm Selection for Hydrologic and Hydraulic Modeling*, Carollo ran the existing conditions and the baseline project for the City's 10-year storm IDF with a rainfall intensity of 9 inches per hour for a 2-hour storm duration. In addition to these rainfall parameters, the Potomac River levels were used to estimate boundary conditions to determine the effect of the river on the stormwater conveyance system during storm events. The high tide elevation of 3.6 feet, relative to the 1988 North American Vertical Datum (NAVD88), was used to analyze the occurrence of street flooding, given that at this elevation all the storm sewer discharge outfalls to the river are in a submerged condition.

The model results predicted localized street flooding with the existing storm sewer collection system and the baseline-defined upgrades near select manholes and inlets within the core area. The localized street flooding assessment was performed by comparing the maximum HGL to the approximate ground surface elevation. At locations in which the model predicted the peak HGL to exceed the ground surface, on-street flooding was predicted to occur. This approach combined with other modeling tools identified several model nodes at King Street between Union and Strand with high frequency of flooding due to tidal back-up and storm conveyance capacity issues; these locations are also known as "hot spots".

Figure 1 illustrates a typical street flood location in XPSWMM and Figure 2 depicts the selected "hot spots".

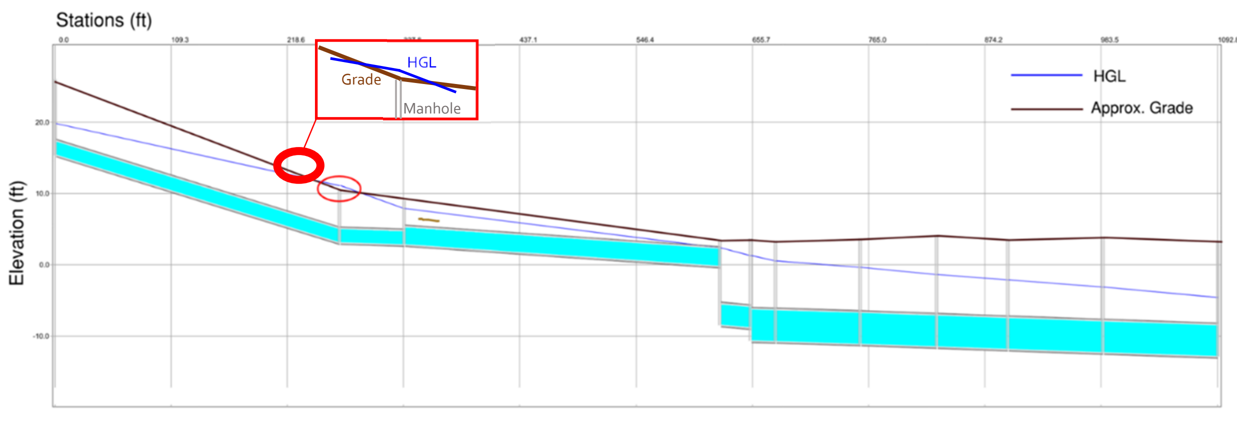

Figure 1 Example of a Storm Sewer Street Flooding Location in XPSWMM

Figure 2 Selected "Hot Spots" for Flooding Assessment

1.2.3.2 Resultant Flooding Under Design Storm Rainfall Conditions

Under design storm conditions, the model predicted localized street flooding with existing and baseline (proposed) stormwater infrastructure. Model results showed that the baseline project can reduce rainfall-induced street flooding at several locations from up to 3 feet deep for a period of close to two hours under existing conditions, down to 8 inches in less than one hour. Figure 3 depicts the street flood locations and depths projected for the design storm, for the existing conditions and baseline project. Note that the baseline project includes the Core Area Grading Plan developed by Olin as part of the *Master Utility Plan* as well as the implications of maintaining the existing Cameron Street bypass storm drain adjacent to the Torpedo Factory.

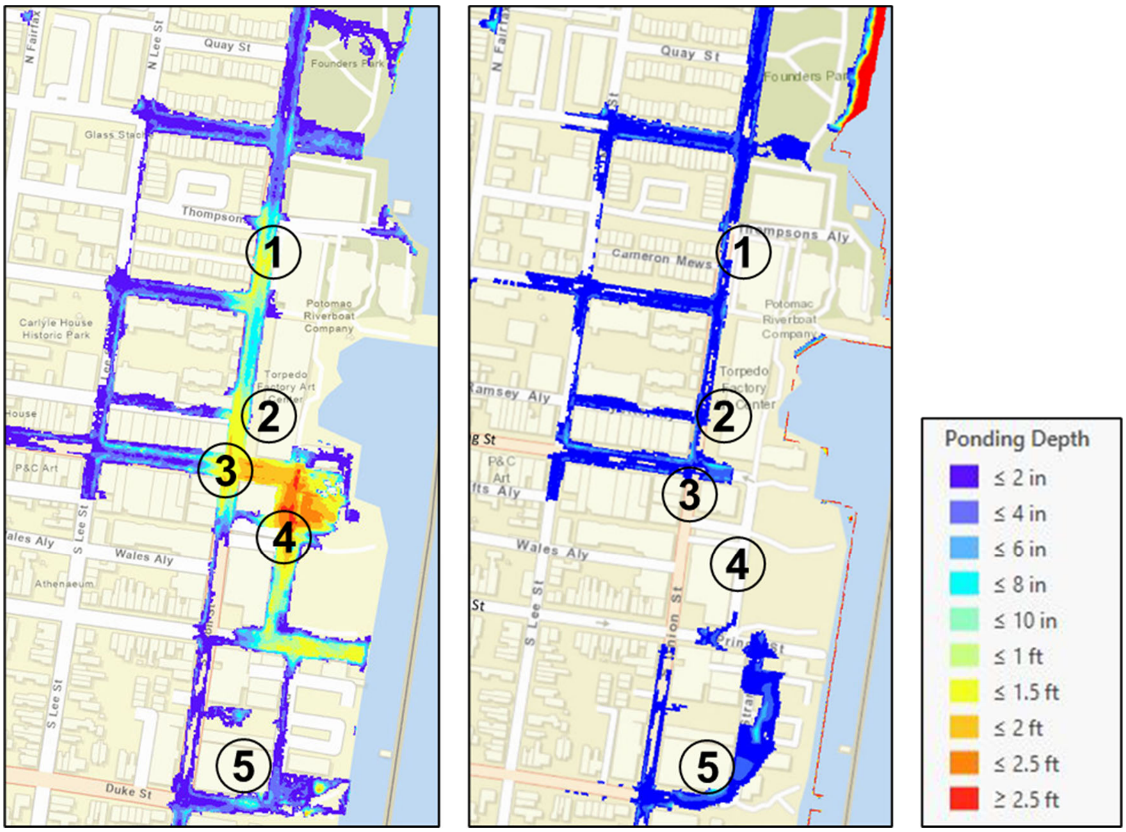

Figure 3 Design Storm Projected Street Flooding for Existing Conditions (Left) and Baseline Project (Right)

Carollo analyzed the core area and compared the extent of flooding for the existing stormwater infrastructure and the baseline improvements under design storm conditions. Specific areas of concern per Figure 3 are described below in Table 2.

Table 2 Existing and Improved Infrastructure Performance during the Design Storm

Location	Existing Stormwater Infrastructure	Baseline Improvements
Location 1: Union Street between Cameron and Queen Street	Floodwaters reach El. +6ft causing over a foot of water on the sidewalks and up to six inches of flooding in the parking garage. The residential homes along Union Street are protected regardless of stormwater infrastructure improvements because the stairs and finished floors are a few feet above grade.	There is still some residual flooding in this area mostly caused by upstream storm sewer capacity issues. Excess runoff will travel downstream to the core area. This results in floodwaters reaching an elevation less than +5ft and up to three inches of water on the sidewalk. Flooding in the parking garage is reduced to only a few inches and all homes remain protected.
Location 2: Union Street between Cameron and King Street	The Torpedo Factory loading dock is vulnerable to up to eight inches of flooding. The Residences at the Torpedo Factory, including the front entrance door and parking garage, may experience up to one foot of flooding. The Torpedo Factory entrance along Union Street and other office buildings and shops between Cameron and King Street are protected due to stairs leading up to an elevated finished floor	Flooding would be eliminated at The Residences at the Torpedo Factory as well as at the loading dock. A few inches of flooding would remain below the curb line along Union.
Location 3: Union Street and King Street Intersection	The intersection may experience up to two feet of ponding. The 100 North Union Street apartments, located at the northeast corner of The Lucky Knot building, have an at-grade entrance that may experience up to 9 inches of flooding. Mia's Italian Kitchen can expect up to 1.5 feet of flooding due to the presence of a doorway at grade with the sidewalk. The Fitzgerald Warehouse, including Starbucks and Apartments 102 and 104, would experience between 1 and 1.5 feet of flooding. The 102 North Union Street entrance is especially vulnerable because the entrance is a half-foot-step below grade	The intersection may have up to three inches of residual flooding, again mostly caused by upstream storm sewer capacity issues. However, the Fitzgerald Warehouse, Mia's Italian Kitchen, and all other buildings at this intersection are protected.
Location 4: Strand Street between King and Prince Street	This intersection is predicted to have the greatest extent of ponding. For instance, the Mai Thai restaurant could experience up to 1.5 feet of flooding. King Street Square could experience over 2.5 feet of water. The parking garage located at the Prince Street and Strand Street intersection would flood with up to a foot of water.	The intersection may have some residual flooding causing up to five inches of flooding in the Mai Thai restaurant. Flooding on King Street Square is reduced to a couple of inches at most. Flooding along Strand Street between King and Prince, including the parking garage, is eliminated.
Location 5: Strand Street between Duke and Prince Street	Prince Street could flood up to El. +4.5 feet causing up to a foot of flooding in Big Wheel Bikes and half a foot in Misha's Coffee. Along Strand Street, the water elevation stays below the curb line, thus protecting Chadwick's.	Big Wheel Bikes and Misha's Coffee are protected against any flooding.

1.2.3.3 Resultant Flooding Under Historical Rainfall Events

In addition to modeling the design storm, Carollo evaluated historical storms that have caused significant flooding within the core area. This effort demonstrated how the baseline project investments would mitigate flooding under known storm events. We reviewed available historical rainfall data between the years 1948 and 2019 collected at the National Weather Service (NWS) station at Ronald Reagan Airport. The rainfall data in year 2013, with 44.24 inches of total annual rainfall accumulation and 107 recorded storm events, was selected as the typical year from the data set; the year 2018, with over 66 inches of total annual rainfall, was identified as the wettest year on record.

On July 12th, 2018, the City experienced a 25-year storm with 2.75 inches recorded in 1 hour, followed by a 10-year 12-hour storm event on July 21. Given this, the model was run for the existing conditions and project baseline infrastructure under the 2018 rainfall conditions. The model predicted six flooding events in the project core area under the existing conditions and indicated that under the 2018 rainfall conditions, including the July storm events, the baseline project substantially reduce street flooding. Figure 4 depicts the resultant maximum ponding condition for the existing and baseline project conditions over the year which occurred on July 17th, 2018.

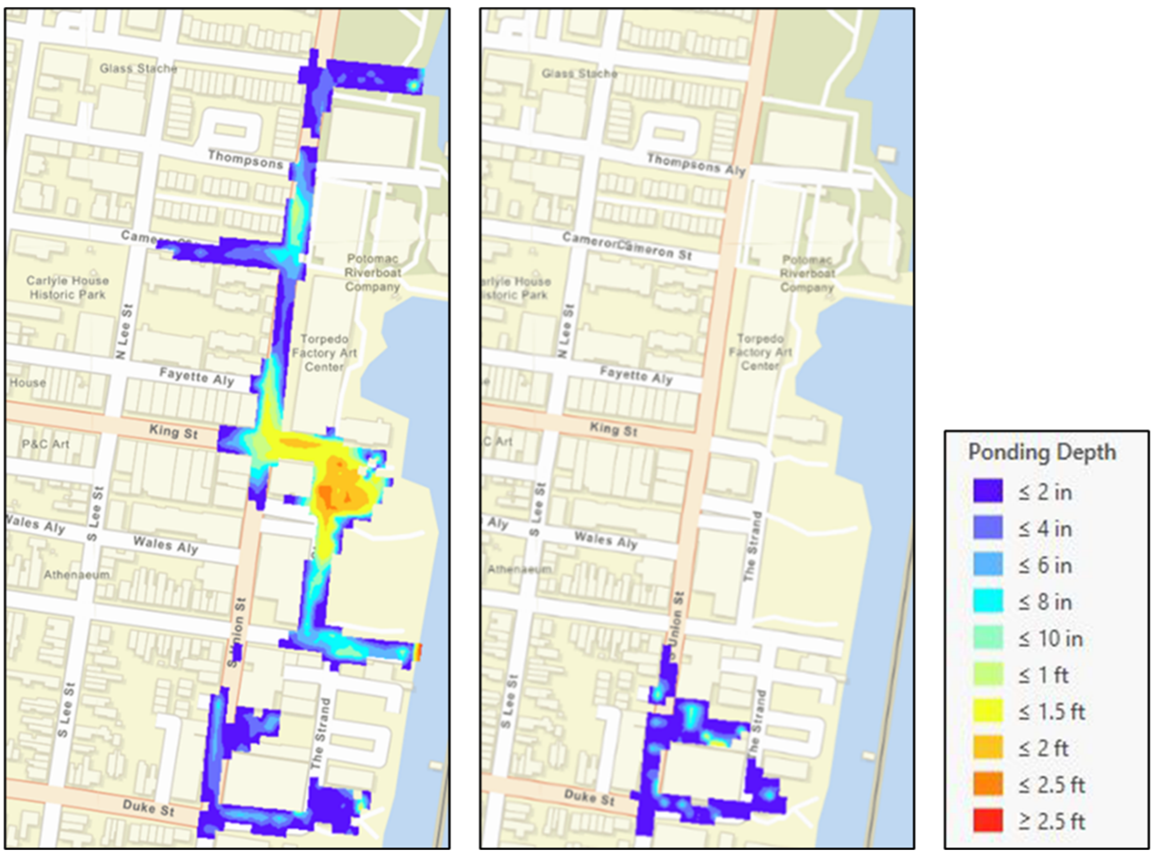

Figure 4 Year 2018 Projected Street Flooding for Existing Conditions (Left) and Baseline Project (Right)

The results in Figure 4 indicate that King Street between Union and Strand Street, and along Strand Street are the most vulnerable to flooding. For instance, the July 2018 storm resulted in about 3 feet of flooding for 2 hours at the intersection of King and Union Streets and 1 foot of flooding along Union Street between Cameron and Queen for 2 hours (Figure 4). These model results are in general agreement with previous reports and online reports of the July 2018 flooding events, validating the model predictions. Figure 5 depicts street flooding at the King Street and Strand Street intersection, comparable to the model results illustrated in the left side of Figure 4 for the existing conditions. Ultimately by incorporating the baseline stormwater infrastructure all street flooding is eliminated (at the low-lying manholes depicted in Figure 2) under these storm conditions.

However, Figure 4 (on the right side) does not eliminate flooding entirely; rather the result illustrates an opportunity for further storm sewer improvements along Duke Street. To alleviate the 2 to 8 inches of ponding between Union and Strand, Carollo recommends upsizing the storm sewer in this location.

Figure 5 July 21, 2018 Flooding at the King Street and Strand Street Intersection (source: Washington Post, July 24, 2018)

1.2.3.4 Revisions to Collection System from XPSWMM Efforts

In conclusion, Carollo's hydraulic modeling verification found that the baseline project is projected to significantly reduce street flooding under the design storm conditions and largely eliminate street flooding under storm conditions like those from year 2018 as well as the design storm. It was also concluded from the model results that the existing storm sewer system west of the core area has very limited capacity and cannot convey flows associated with a 1-year storm. While it may be advantageous to increase the stormwater pipe sizes and add manholes, curb inlets, and catch basins west of the core area, the pump station design would need to be larger. Such improvements would effectively capture and convey water faster to the pump stations, thus increasing the peak hydrograph to point higher than the baseline pump station rated capacity and result in more flooding in the core area.

Therefore, to limit the implications on pump station sizing, the following enhancements are recommended to increase stormwater capacity, conveyance, and control:

- Upsizing the storm sewer along Duke Street between the waterfront and S. Union Street, from 18 inches to up to 36 inches in diameter, to reduce ponding at that location.
- Adding streetscape green infrastructure infiltration practices west of Union Street to reduce stormwater runoff towards the core area and adding underground detention chambers at the Waterfront and Founders Parks. These solutions are discussed in TM4 *Parkspace and Streetscape Attenuation Solutions*.
- Using backflow preventers at the existing outfalls to prevent sewer backups caused by storm surge and tidal changes in the Potomac River. This solution is discussed in TM5 *Interim Tidal Back-Up Solutions.*
- Raising the proposed pipes to maximize addition of underground detention chambers at Waterfront and Founders parks. The use of underground detention chambers is discussed in TM4.

1.2.4 Revisions to Storm Sewer Layout

Carollo reviewed the layout and depth of the baseline project storm sewer to optimize the size and depth of the storm sewer pipes to maximize infrastructure investment. One option reviewed was re-routing southward the storm sewers along Union Street between King Street and Queen Street to reduce the number of pump stations to one at the Waterfront Park. As described in the *Design Optimization Report,* this option was deemed not feasible due to cost and operational risks, as well as due to the significant increase in required pump capacity at Waterfront Park (Carollo 2021). Given the topography of the area sloping towards the southeast corner of the core area, the other potential layout revisions to the baseline project storm sewers were deemed not hydraulically feasible.

The following optimizations depicted in Figure 6 are identified to further increase stormwater capture in the core area:

- Connecting the Cameron Street Bypass storm sewer to the TAPS local storm sewer along North Union Street. The Cameron Street Bypass is located at the east end of Cameron Street, crossing the boardwalk north of the Torpedo Factory and discharges into the river. The baseline project does not address this system, and modeling indicates some potential for surface flooding during the design storm (Figure 3). The predicted surface flooding could cause up to three inches of flooding in the Torpedo Factory. The Steelite International Washington, D.C. Showroom and Experience Center and other surrounding restaurants are protected due to the elevated first floor entrances. The surface flooding is predicted to travel due west towards Union Street as well as east down the Marina boardwalk and into the Potomac. The model indicates that re-routing this system towards North Union Street to the TAPS would eliminate flooding and surcharge from this system at Union Street and at the boardwalk.
- Collecting drainage on the lower boardwalk across the Chart House restaurant if flood protection up to 6 feet NAVD88 elevation, is implemented at this location.

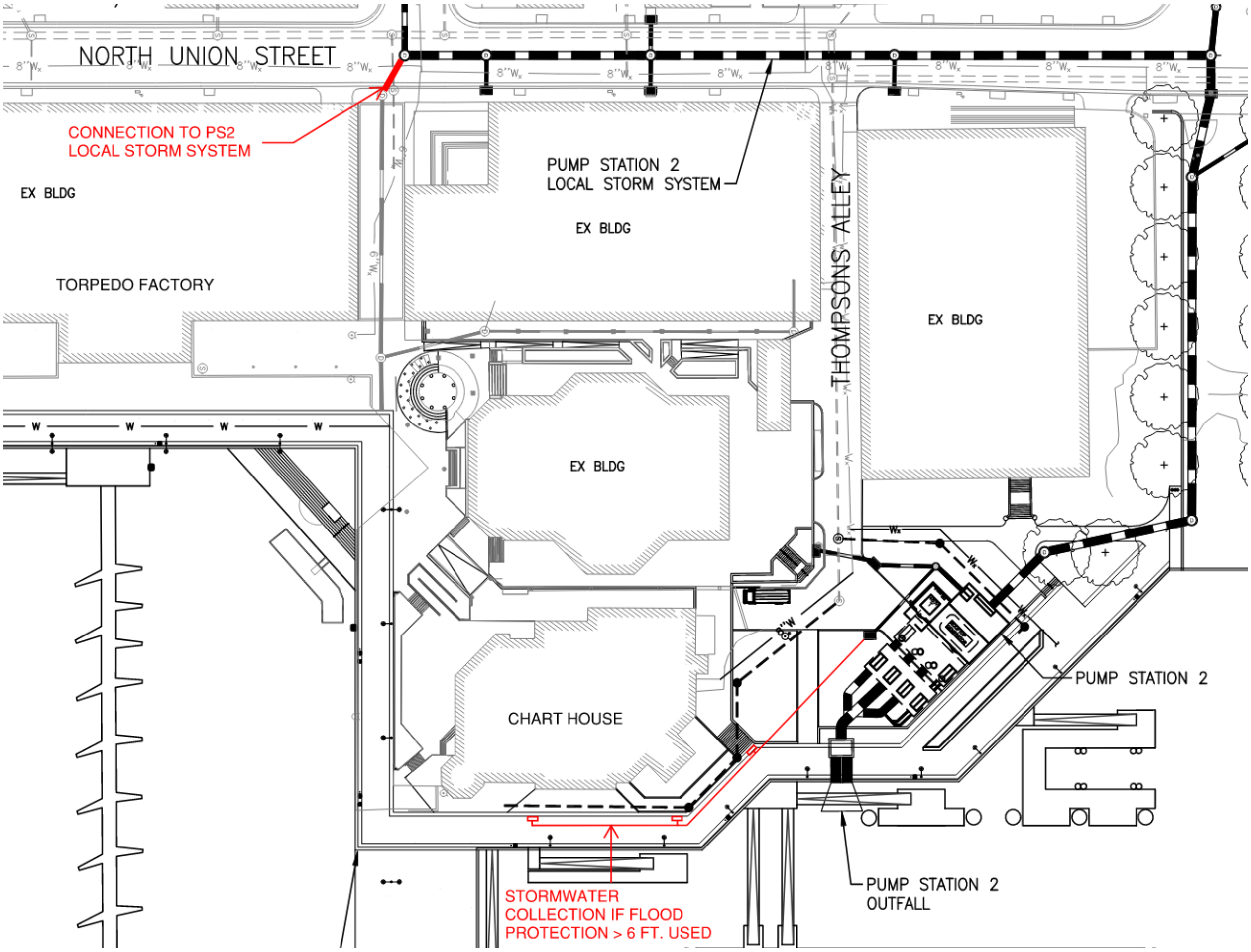

Figure 6 Cameron Street Bypass Connection and Chart House Stormwater Collection to PS2

1.2.5 Revisions to Storm Sewer Depth

Carollo determined that the baseline project storm sewer depths within the core area could be raised to allow for the installation of underground stormwater detention chambers at the Waterfront Park and Founders Park. Installation of underground detention chambers under the parks is anticipated to decrease the required capacity of the baseline project pump stations and is further discussed in the *Parkspace and Attenuation Solutions* and the *Pump Stations Capacity and Sizing* memoranda.

A cursory review of the baseline project storm sewer layout and the existing utilities in the area for potential conflicts determined that several pipe segments totaling approximately 1,700 linear feet (LF) could be raised an average of approximately 6 feet. This reduction in depth across the system would reduce the excavation and backfilling required for replacement of the storm sewers proposed by the baseline project, and the underground detention chambers proposed by Carollo, by approximately 400 cubic yards. Figure 7 depicts in yellow the storm sewer pipe segments that could potentially be raised, pending confirmation from future survey that no utility conflicts impact the proposed depths.

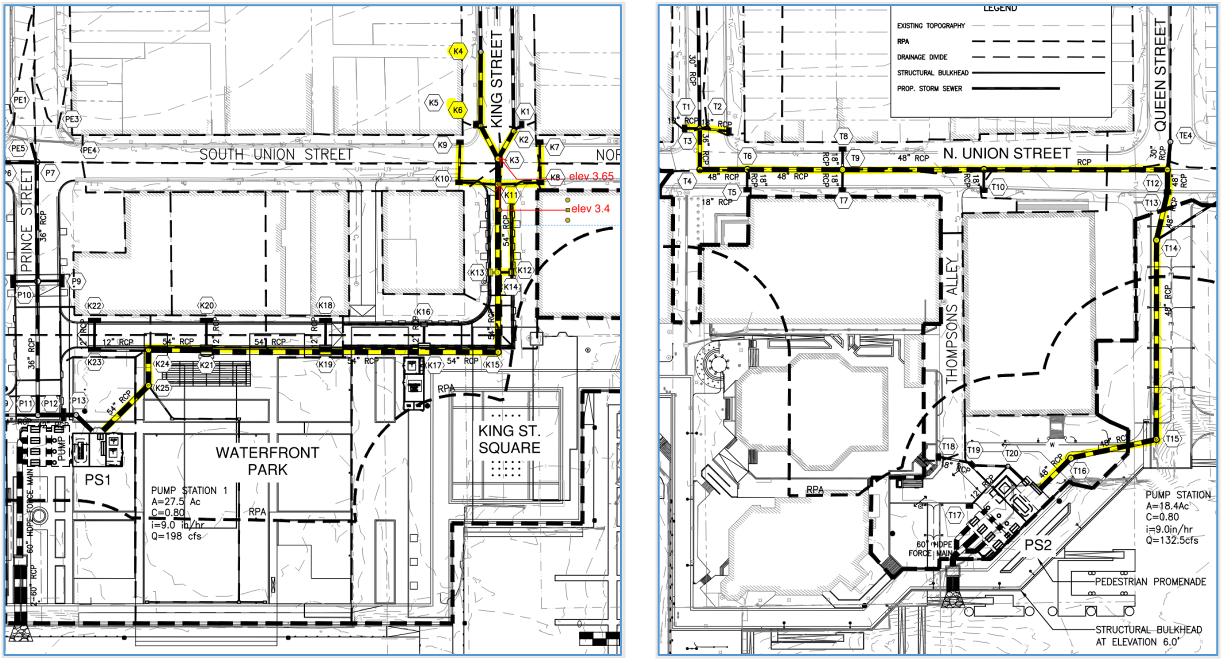

Figure 7 PS1 Storm Sewer (Left) and PS2 Storm Sewer (Right) Revised Depths

1.3 Conclusions and Recommendations

Carollo concluded from the results of the hydraulic model of the existing and baseline project storm sewer collection system, **that the existing system does not have sufficient hydraulic capacity to handle the design storm** and to mitigate historical storms known to cause street flooding in recent years. The **baseline project improvements are projected to reduce street flooding** from up to 3 feet of depth to less than 8 inches for the design storm and to largely eliminate street flooding for historical storms like the July 2018 storms (which recorded up to a 25-year storm with 2.75 inches in 1 hour). However, as previously discussed, the 8 inches of flooding under design storm conditions still leaves a parking garage along Union Street as well as the Mai Thai restaurant vulnerable such that further storm sewer improvements are warranted. **These revisions are recommended (in part) to eliminate building flooding within the core area such that any residual street flooding is contained within the curb line of the streets to maintain sidewalk mobility.**

In development of various project alternatives, Carollo recommends evaluating and/or incorporating the following elements as compared to the baseline project:

- Evaluate the use of streetscape green infrastructure infiltration practices west of Union Street to reduce stormwater runoff to the core area.
- Evaluate the use of underground stormwater detention chambers and their effect on the reduction of the pump station sizes and on stormwater quality, including nutrient removal.
- Upsize the storm sewer along Duke Street between the waterfront and S. Union Street, from 18 inches to up to 36 inches in diameter, to reduce non-tidal ponding at that location.
- Add an overflow pipe connection from the Cameron Street Bypass to the storm sewer on North Union Street, to direct overflow to PS2.
- Collect drainage across the Chart House restaurant if protection up to 6 feet NAVD88 is considered for implementation.

- Raise the proposed storm sewers as follows:
  - From PS1 to Strand Street.
  - Along Strand Street between Prince and King Streets.
  - Along King Street from Strand Street to just west of S. and N. Union Street.
  - Along N. Union Street between Cameron and Queen Streets.
  - Along Queen Street from North Union Street to PS2.

The development and evaluation of alternatives to be completed in the next step, including the stormwater collection system recommendations listed above, shall also include the flood protection elements recommended by other memoranda, including but not limited to:

- Streetscape infiltration practices and underground stormwater detention chambers.
- Backflow prevention at the stormwater outfalls to the Potomac River.
- Protection from tidal flooding and modifications to the bulkhead along the waterfront.
- Optimized size of the stormwater pump stations.

A utility and topographic survey, geotechnical investigation, and hydraulic modeling of the design alternatives will be necessary to complete the evaluation of design alternatives from which a conceptual design can be formulated.

1.4 References

City of Alexandria IDF Curves:

1. "IDF Curves for the City of Alexandria," https://www.alexandriava.gov/uploadedFiles/tes/IDFCurvesCityofAlexandria.pdf; found in the "Design and Construction Standards," 1989, City of Alexandria. https://www.alexandriava.gov/uploadedFiles/tes/info/Manual_%20Design%20and%20Construction%20Standards%201989.pdf

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2. "Comparison of Alexandria's Storm Design Criteria to Neighboring Jurisdictions," May 1, 2009, CH2M Hill.
3. "City of Alexandria Storm Sewer Capacity Analysis Summary Report" (CASSCA), February 2016, CH2M Hill. https://www.alexandriava.gov/uploadedFiles/tes/Stormwater/CASSCA%20Final%20Summary%20Report.pdf
4. "Stormwater Capacity Analysis for Potomac River, City of Alexandria, Virginia," February 2016, CH2M Hill. https://www.alexandriava.gov/uploadedFiles/tes/Stormwater/SCA8PotomacRivercompressed.pdf
5. "Master Storm Water Management Plan," November 2018, Stantec.
6. "City of Alexandria Master Stormwater Management Plan – Concurrence Review Memo," November 16, 2018, AKRF.

Other Referenced Technical Documentation Prepared by Carollo Engineers:

7. "Design Storm Selection for Hydrologic and Hydraulic Modeling", February 18, 2022.
8. "Potomac River Flood Frequency Analysis", February 18, 2022, Carollo Engineers.
9. "Parkspace and Streetscape Attenuation Solutions," May 27, 2021, Carollo Engineers.
10. "Pump Stations Capacity and Sizing Project Memorandum," June 30, 2021, Carollo Engineers.
11. "Design Optimization Report", March 16, 2021, Carollo Engineers.