F I N A L

Task 6: Germantown Stormwater Flood Risk Reduction Study

Alternative Evaluation and Recommended Outcome Report

Prepared for

City of Philadelphia Water Department

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Executive Summary

The Germantown Alternative Evaluation and Recommended Outcome (AERO) report evaluates selected storm flood risk reduction alternatives and CSO reduction benefits for the Germantown watershed in northwest Philadelphia. Significant basement and surface flooding risk exists throughout the watershed. These risks are related to a combination of factors that include buried historic streams, watershed development, and unique "bowl-shaped" topography. Consequences of these risks include an estimated $8.72 million of annual damages, including both structural and vehicular damages. The AERO develops selected alternatives identified in the Alternative Identification Memorandum II (AIM 2), and documents feasibility, constructability challenges, and flood risk reduction benefits for each alternative. It also presents high-level planning recommendations for moving forward (CH2M, 2019d).

At the start of the project, the project team co-authored the following mission statement to communicate the overall mission of the Germantown Storm Flood Relief (SFR) study:

> *The mission of the Philadelphia Water Department (PWD) and CH2M team is to determine the optimum and sustainable combination of structural and non-structural control measures to mitigate the effects of flooding in the Germantown neighborhood while also reducing combined sewer overflows (CSOs). The system of improvements must be affordable, supported by the Germantown Community, and capable of timely design and construction.*

Previous reports have documented:

- The monetary and non-monetary criteria established for the Germantown SFR project and how those criteria were used to guide the evaluation of potential system improvements
- Technical evaluations of the drainage system's performance characteristics and the causes of surface flooding
- The extent, depth, and duration of surface flooding associated with the baseline condition and proposed improvements as determined by the two-dimensional U.S. Environmental Protection Agency Stormwater Management Model
- Design components, conceptual costs, and benefits associated with 1,600 improvement alternatives

The AERO builds upon previous analysis and studies of flood reduction strategies in Germantown, as shown on Figure ES-1.

Alternative Development

Range of Technologies Considered

Alternative development began with the investigation of a range of specific stormwater management technologies, including those with which PWD has previous experience, such as the storage tank at Venice Island and tunneling technologies. A one-dimensional (1D) hydraulic model was used with an optimization engine to evaluate the effectiveness of over 1,600 unique alternatives formed from combinations of these technologies. The optimization engine provided an extensive hydraulic screening of both the alternatives and the individual technologies themselves. Scoring was based on basement flood risk reduction, surface flood risk reduction, and CSO benefits. Cost, residual risk, and feasibility were also considered. Figure ES-2 shows the specific technologies analyzed. These alternatives were summarized in the AIM 2 document.

This AERO report develops the high-performing select alternatives from the optimization process: the Storage Tank Alternative and the Tunnel Alternative. The following subsections contain further development details for each alternative. Figure ES-3 shows the engineering evaluation process.

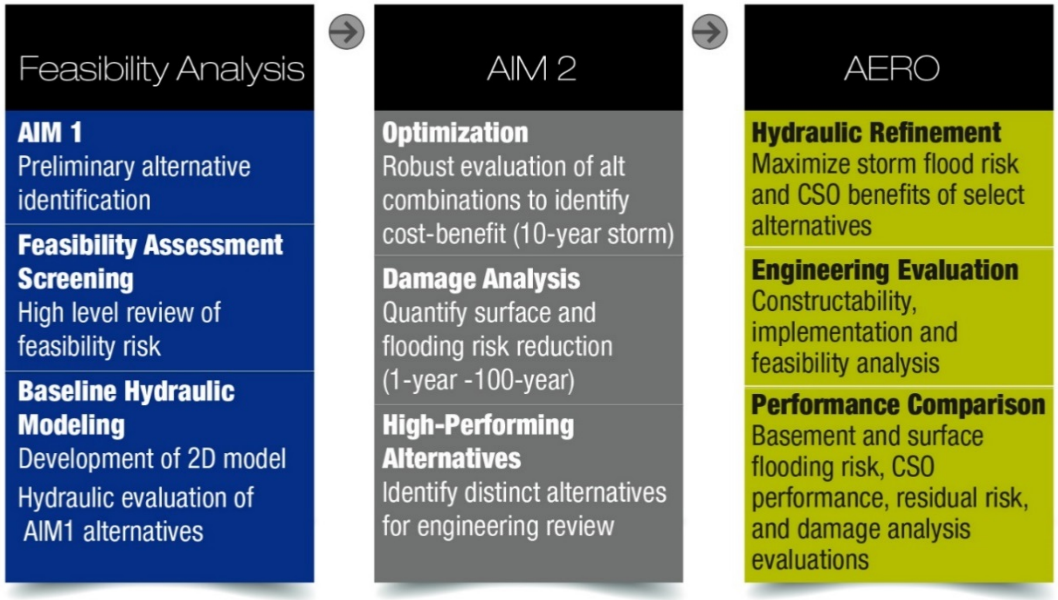

Figure ES-1. Study Overview

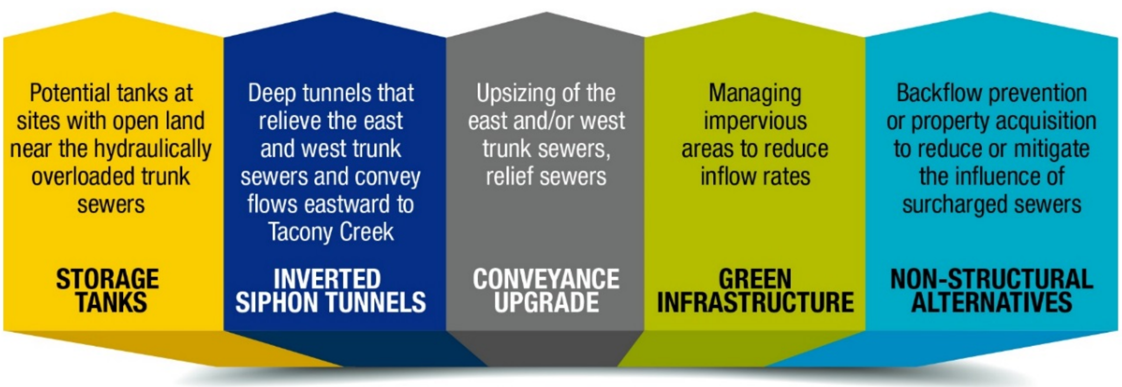

Figure ES-2. Alternative Technologies

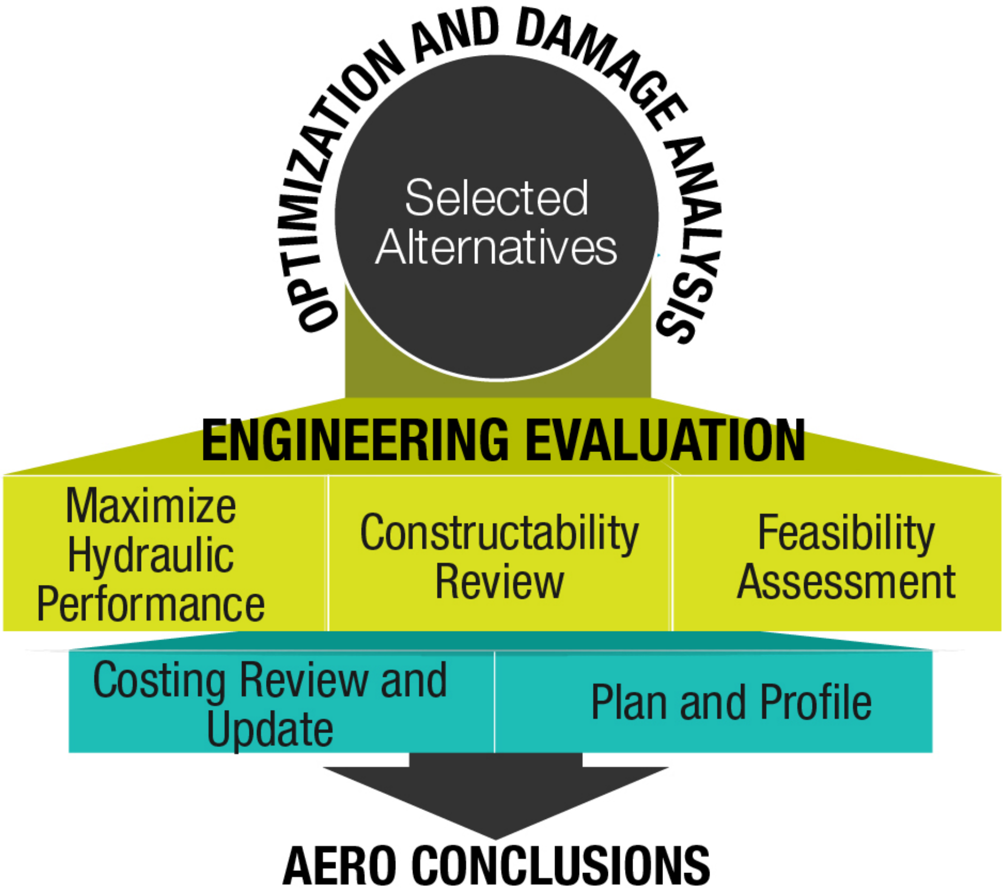

Figure ES-3. Engineering Evaluation Process

Storage Tank Alternative

The Storage Tank Alternative consists of six storage tanks configured for optimal flood mitigation and includes two sewer upsize projects. Chambers, weirs, and conduits were sized to optimize flood mitigation. An iterative process was used to maximize the flood storage potential and reduce the peak storm event flow in the existing system to a minimum. Each tank was designed to ensure that a significant surface flood reduction impact is yielded by each tank location.

The Storage Tank Alternative includes:

- Sedgwick Storage Tank: A 3.1 million gallon (MG) tank located within the Southeastern Pennsylvania Transportation Authority Sedgwick train station property.[1]
- Finley Storage Tank: A 11.8 MG tank located within the Finley Recreation Center.
- Cliveden Storage Tank: A 10.9 MG tank located within Cliveden Park.
- Awbury Storage Tank: A 21.2 MG tank located on the property of the Martin Luther King, Jr. High School.
- Lonnie Young Storage Tank: A 15.7 MG tank located within the Lonnie Young Recreation Center property.

[1] The feasibility of constructing a tank at this site was found to be difficult, making it an unlikely candidate for implementation.

- Waterview Storage Tank: A 12.1 MG tank located within the Waterview Recreation Center Property.
- Belfield Avenue Sewer Upsize: 1,200 linear feet (LF) of sewer upsize to a 12-foot by 15-foot rectangular sewer located along Belfield Avenue between East Church Lane and East Penn Street. 1,600 LF of sewer upsize to a 13-foot by 21.5-foot rectangular sewer located along Belfield Avenue between East Penn Street and Wister Street. Sedgwick Street Sewer Upsize: 141 LF of sewer upsize to a 6-foot diameter sewer located along East Mount Pleasant Avenue near the proposed Sedgwick Storage Tank.

Figure ES-4 provides an overview of the Storage Tank Alternative.

Tunnel Alternative

This alternative includes a deep 60-MG storage tunnel. The tunnel design evaluated for this report is based on the design that was prepared for PWD by Mott MacDonald (MM, 2018) with additional trunk sewer improvements (“upsizes”) identified by PWD. The Mott MacDonald team developed the design to meet PWD’s objectives for CSO capture. The alignment provides for up to 60 MG of CSO storage for wet weather events. For this report, the Mott MacDonald design with the additional PWD-identified improvements is known as the Tunnel Alternative.

The Tunnel Alternative includes:

- Olney Tunnel: Approximately 27,500 LF (5.2 miles) of a 20-foot diameter tunnel extending along Chew Avenue from the intersection of Chew Avenue and Washington Lane to its outfall at Tacony Creek.
- Washington Collector System: Approximately 4,400 LF of collector extending along Washington Lane from Mansfield Avenue to Chew Avenue. The system includes two diversions located at either end of the system, the Washington East and Washington West diversions, and one drop shaft located within the Awbury Arboretum. The collector is 10 feet in diameter east of the drop shaft, and 12 feet in diameter west of the drop shaft.
- Church Lane Collector System: Approximately 4,900 LF of collector extending along Church Lane from 21st Street to Belfield Avenue. The system includes two diversions located at either end of the system, Church Lane East and Church Lane West, and one drop shaft located at the intersection of Church Lane and Chew Avenue. The collector is 10 feet in diameter east of the drop shaft, and 13 feet in diameter west of the drop shaft.
- Belfield Avenue Sewer Upsize – North: Approximately 1,700 LF of sewer upsize to a 11.5-foot by 8-foot rectangular sewer located along Belfield Avenue between Vernon Road and East Upsal Street.
- Belfield Avenue Sewer Upsize – South: Approximately 1,450 LF of sewer upsize to a 11.5-foot by 8.0-foot rectangular sewer located along Belfield Avenue between East Johnson Street and Washington Lane.
- 21st Street Sewer Upsize: Approximately 1,850 LF of sewer upsize to a 6.0-foot-diameter sewer located along 21st Street from Stenton Avenue to West Godfrey Avenue.
- McCallum Street Sewer Upsize: Approximately 1,050 LF of sewer upsize to a 6.0-foot-diameter sewer located along McCallum Street from West Tulpehocken Street to Germantown Avenue.
- Mansfield Avenue Sewer Upsize – North: Approximately 800 LF of sewer upsize to a 6.5-foot x 9.0-foot rectangular sewer along Mansfield Avenue from Phil Ellena Street to Upsal Street.
- Mansfield Avenue Sewer Upsize – South: Approximately 1,850 LF of sewer upsize to a 7.5-foot x 10.5-foot rectangular sewer along Mansfield Avenue from Upsal Street to Washington Lane.

Figure ES-5 presents an overview of the Tunnel Alternative.

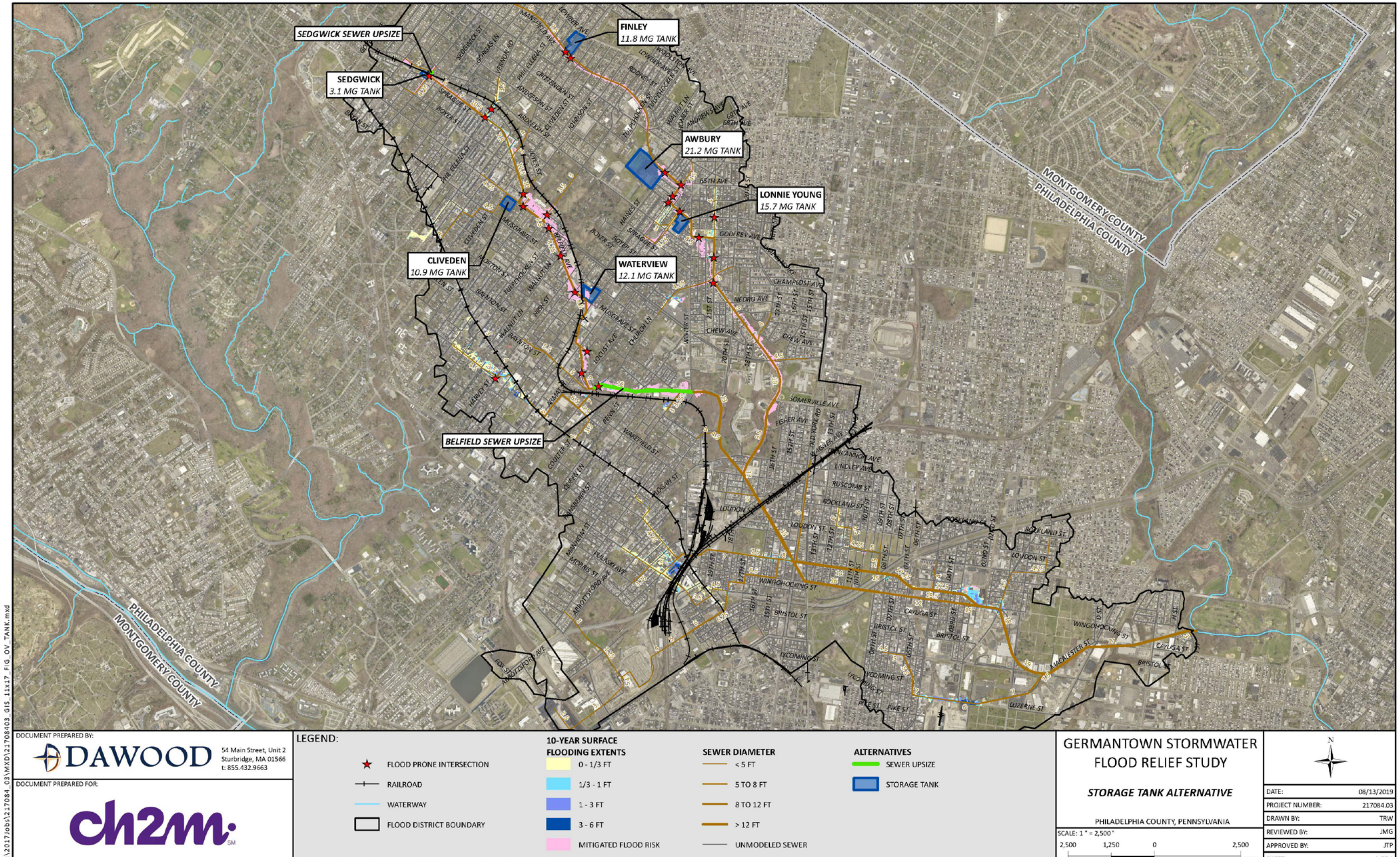

Figure ES-4. Storage Tank Alternative Overview

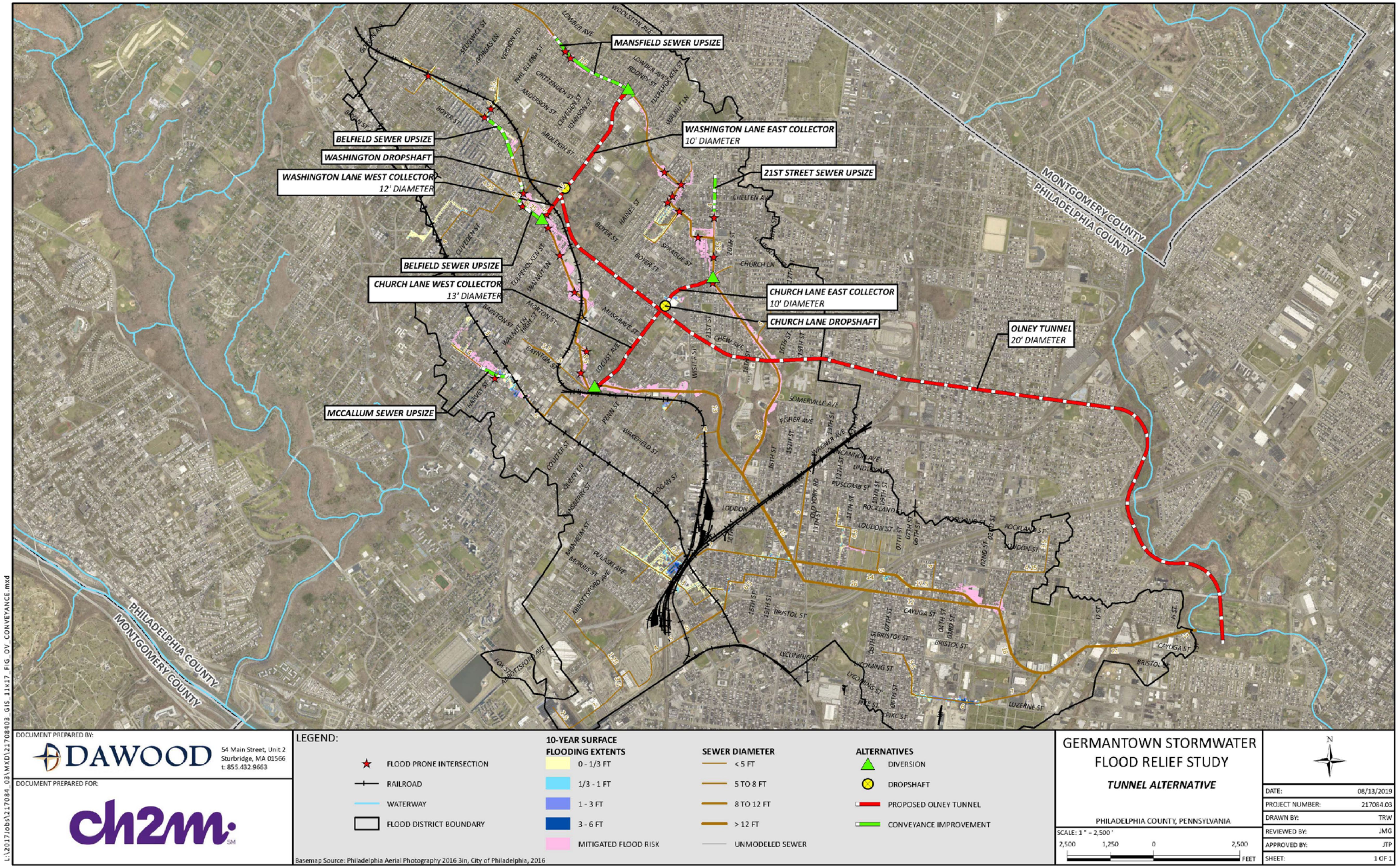

Figure ES-5. Tunnel Alternative Overview

Alternative Analysis

Benefits, costs, and constructability were evaluated for each alternative. The following subsections contain conclusions from these analyses.

Storm Events Analyzed

The 10-year, 24-hour synthetic storm event was used as the design event in this study. Six additional synthetic recurrence interval (RI) events (1-, 2-, 5-, 25-, 50-, and 100-year, 24-hour) were analyzed to demonstrate potential flood mitigation over a range of storm intensities and precipitation totals. Five historic storm events were also evaluated for existing conditions and each alternative to provide historic context for the synthetic RI and design events. A design and historic event characterization summary is provided in Table ES-1. Additional rainfall information is provided in Section 1.4.2 and in Appendix H.

Table ES-1. Storm Event Summary

Storm Event	Approximate Duration (hours)	Peak Intensity (inches/hour)	Total Max Rainfall (inches)	Recurrence Interval Storm Characterization
Synthetic Design Storm Event	24	2.05	4.80	10-yr, 24-hr
8/1/2004	4	3.7	4.49	10-yr, 24-hr
9/28/2004	24	3.6	7.79	100-yr, 24-hr
8/2/2009	8	2	3.69	5-yr, 24-hr
8/27/2011 (Hurricane Irene)	26	1.74	6.75	5-yr, 24-hr
9/5/2011 (Tropical Storm Lee)	80	2.9	10.44	25-yr, 24-hr

Benefits and Performance Comparison

Flood risk reduction and damage risk reduction benefits were quantified for each alternative. Similar to previous reports, a primary metric used to determine performance was comparing the flooding depths at twenty-four key flood-prone intersections (FPIs) identified by PWD with the depths at these intersections in the baseline model. FPI locations are show in Figure ES-6 below. The maximum flooding depth counts at these intersections during the 10-year, 24-hour design storm event for Baseline, Storage Tank Alternative, and Tunnel Alternative conditions are shown in Table ES-2.

Flood damage risk was analyzed using an approach consistent with FEMA's depth-damage curve methodology (FEMA, 2015). In this approach, assessed property market values were used on an individual structure basis, and were compared against depth-damage curves for structures, depth-damage curves for contents, content-to-structure value ratios, and the modeled flood depth at the structure to estimate damage values for each structure. Damages were calculated in a similar manner for vehicles. An annualized damage value was calculated based on a range of seven storm events for each alternative using these individual structural and vehicular damage estimates. Flood damage risk reduction is quantified in Tables ES-3 and ES-4.

Each alternative carries the potential for CSO volume reduction, and each alternative reduces annual flooding damages by over 60 percent, with an 81 percent reduction by the Tunnel Alternative.

Table ES-2. Flood-Prone Intersection Count

Flood-Prone Intersection Count	Baseline Conditions	Storage Tank	Tunnel
Surface Flooding	24	10	6
Surface Flooding > 1/3 foot Depth	23	8	6
Surface Flooding > 1 foot Depth	22	3	1
Surface Flooding > 2 feet Depth	11	2	1

Table ES-3. Alternative Performance Comparison[1]

Performance Metric	Baseline Conditions	Storage Tank Alternative	Tunnel Alternative
Surface Flood Risk Reduction	22 of 24 FPIs experience flooding above 1 foot depth	Flood risk mitigated below 1 foot depth at 21 of 24 FPIs	Flood risk mitigated below 1 foot depth at 23 of 24 FPIs
Basement Flood Risk Reduction	2,270 basements at risk	1013 basements at risk	801 basements at risk
Annual CSO Reduction	N/A	60 MG	650 MG

1 Surface and Basement Flood Risk Reduction values given are for the 10-year, 24-hour design storm event.
2 Annual CSO reductions are based on the Typical Year Rainfall as defined in PWD's CSO Long-Term Control Plan.

Table ES-4. Alternative Damage Analysis Comparison[1]

Performance Metric	Baseline Conditions	Storage Tank Alternative	Tunnel Alternative
Annual Estimated Buildings Damages (Alt Only)	$7.14 million	$2.92 million	$1.50 million
Annual Estimated Vehicular Damages (Alt Only)	$1.58 million	$320,000	$170,000
Total[3] Annual Estimated Damages (Alt Only)	$8.72 million	$3.24 million	$1.66 million
Total[3] Annual Estimated Damages (Alternative + Backflow[2])	$4.79 million	$2.09 million	$1.20 million
Cost of Backflow Prevention[2]	$20.56 million	$9.25 million	$7.80 million

1 Damages were calculated using the market value of the structure.
2 The installation of backflow prevention technology to individual structures under baseline and alternative conditions provides additional protection to those particular structures from combined sewer basement backup flooding.
3 "Total" damage values refer to damage values that sum building and vehicular damage values.

High-risk surface flooding is defined as design event surface flooding with a key 10-year, 24-hour design storm event FPI depth greater than two feet. As shown in Table ES-2, each of the alternatives presented in this report mitigate high-risk surface flooding at over 90 percent of the key FPIs, and the Tunnel Alternative mitigates high-risk surface flooding at 23 of the 24 key FPIs. Key results for historic events are provided in Table ES-5.

Table ES-5. Historic Event Results Summary

Historic Storm Event	FPIs with High-Risk Surface Flooding			At-Risk Basements		
	Baseline	**Storage**	**Tunnel**	**Baseline**	**Storage**	**Tunnel**
8/1/2004	12	3	1	2759	1290	929
9/28/2004	12	7	1	2749	1634	903
8/2/2009	6	1	0	1096	244	214
8/27/2011	0	0	0	93	21	3
9/5/2011	12	6	1	2313	1133	576

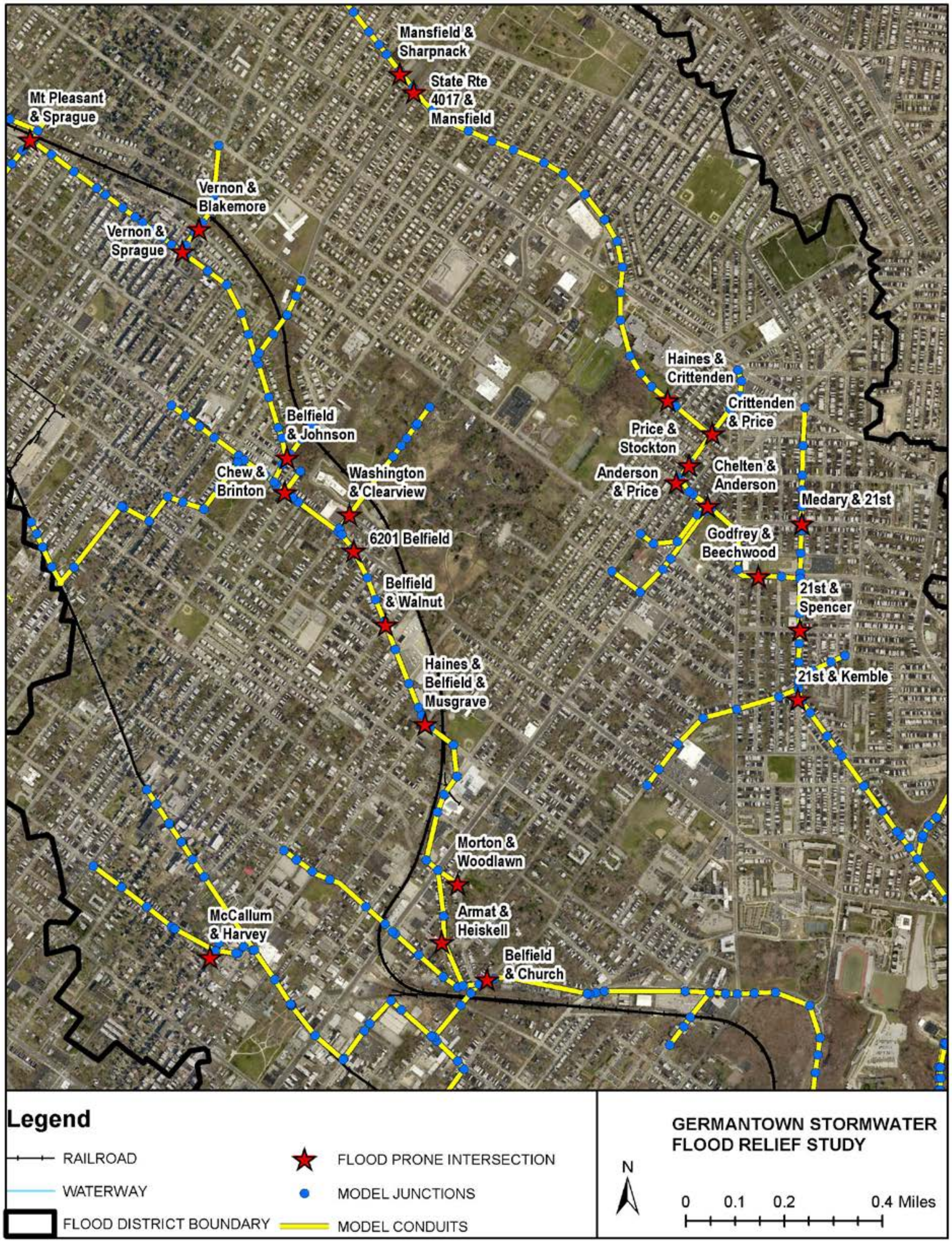

Figure ES-6. Flood-Prone Intersection Locations

Construction Costs

A Class 4 construction cost estimate was developed by the CH2M project team for the Storage Tank Alternative. A Class 4 construction cost estimate was developed by PWD and Mott MacDonald for the Tunnel Alternative. The Class 4 estimates for both alternatives are included in Appendix G. Figure ES-7 demonstrates the construction cost estimate accuracy ranges for the cost estimates (-30 percent to +50 percent). Table ES-6 shows the cost estimates for the Storage Tank and Tunnel Alternatives.

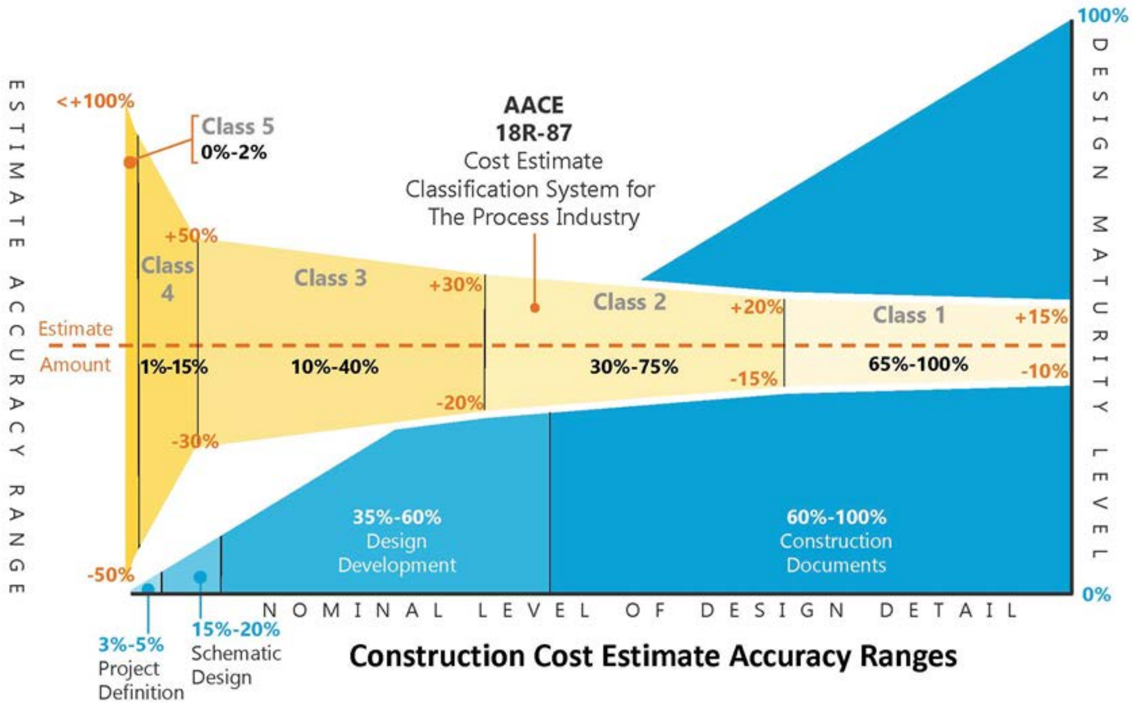

Figure ES-7. Construction Cost Estimate Types

Table ES-6. Planning Level Construction Cost Estimates

Alternative	Cost Estimate (-30% to +50%)	Notes
Storage Tank Alternative	$585 million ($410 million-$878 million)	Class 4 Construction Cost Estimate developed by CH2M
Tunnel Alternative	$384 million ($269 million-$577 million)	Class 4 Construction Cost Estimate developed by PWD and Mott MacDonald (MM, 2018)[1]

[1] Cost estimates for sewer system improvements were developed by PWD; Olney tunnel and Church and Washington collector system cost estimates were developed by Mott MacDonald.

Although each of the alternatives provides significant benefits to reducing surface flooding, the Tunnel Alternative was shown to provide the largest reduction in flood-prone intersection and basement flooding. Figure ES-8 graphically depicts alternative performance as determined in this study as a function of Class IV cost estimate ranges.

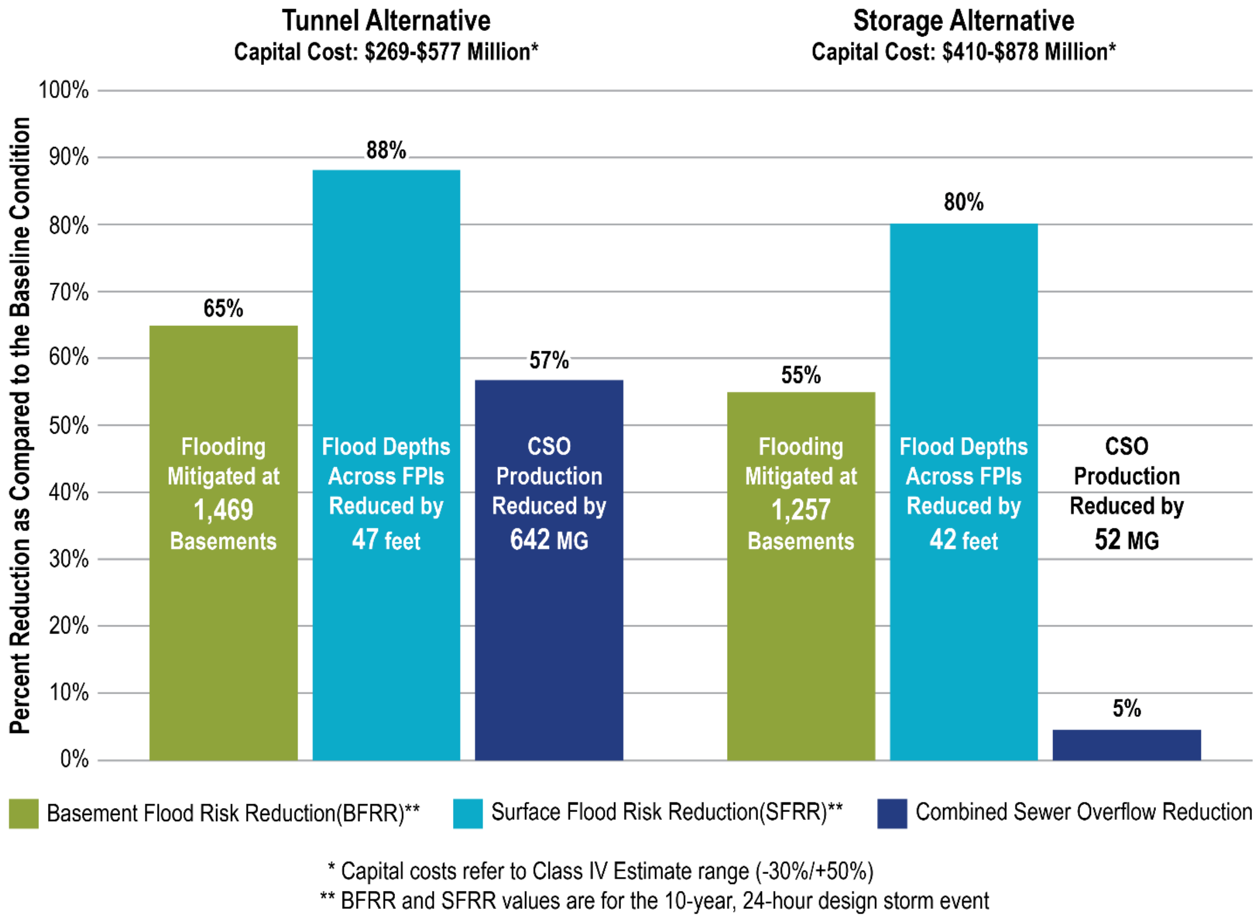

Figure ES-8. Alternative Cost/Benefit Summary.

Feasibility and Constructability

Planning level feasibility and constructability analyses were performed for each site in the Storage Tank Alternative, as well as for each diversion and drop shaft structure in the Tunnel Alternative. Feasibility and constructability issues were identified for each major component of each alternative. Although the identification and documentation of these issues is intended to support the PWD planning and alternative evaluation processes, in some cases, additional information or discussion may be needed to fully evaluate feasibility. This may include site-specific geotechnical data and/or integration with other programs effecting system behaviors.

Although the extent of the impacts varies for the construction sites inherent in each alternative, some key issues identified during this assessment included:

- Difficult access to the site for construction and/or operation and maintenance
- The need to acquire temporary and/or permanent easements in the ROW
- The potential for extensive rock excavation
- The potential for significant temporary disruption during construction
- The potential for prolonged community impacts related to operations and maintenance activities
- Proximity to major transportation sites

Tables ES-7 and ES-8 show the feasibility and constructability review for the Storage Tank and Tunnel Alternatives, respectively.

Table ES-7. Storage Tank Alternative Feasibility and Constructability Summary

Tank	Technical	Social/Political	Operations and Maintenance	Environmental	Construction Cost[2]
Sedgwick[3]	28’+ Rock Excavation; Near Commuter Rail	Closure of Commuter Rail Station	Easement Req’d – SEPTA Property; Tank O&M[1]	Environmental Impact Study Required	$34,560,000
Finley	23’+ Rock Excavation	Shutdown Outdoor RC Activities	Easement Required; Tank O&M[1]	Potential Tree Removal – EIS Required	$67,560,000
Cliveden	24’+ Rock Excavation; Extensive Piping	Park Access Severely Limited	Limited Impact; Tank O&M[1]	Mature Tree Removal	$84,330,000
Awbury	50’+ Feet Rock Excavation	Impact to School and Adj. Property	Limited Access to Site; Tank O&M[1]	Potential Tree Removal – EIS Required	$159,410,000
Lonnie Young	25’+ Rock Excavation	Temporary Shutdown of All Outdoor RC Activities	Easement Required; Tank O&M[1]	Potential Tree Removal – EIS Required	$88,230,000
Waterview	36’+ Rock Excavation; Near SEPTA Rail	Temporary RC Activities Baseball Fields Inaccessible	Easement Required; Tank O&M[1]	EIS Required	$98,030,000

Notes:
EIS = environmental impact study
RC = recreation center

[1] Operational and Maintenance Requirements: easement acquisition, confined space entry, traffic control required for access at diversion structure, maintenance of mechanical/electrical/odor control & ventilation components including tank drain pumps and flushing systems. Regular grit & debris removal required at tank following operation.

[2] Construction cost refers to Class IV estimate presented in Appendix G.

[3] The feasibility of constructing a tank at this site was found to be difficult, making it an unlikely candidate for implementation.

Table ES-8. Tunnel Alternative Feasibility and Constructability Summary

Structure	Technical	Social/Political	Operations and Maintenance	Environmental
Washington East Diversion	25'+ Rock Excavation	Impacts to State Rte, Bus Rte,& Local Businesses	Easement Required – Private Property	Limited Apparent Impact
Washington West Diversion	40'+ Excavation	Impacts to State Rte, Bus Rte,& Local Businesses	Easement Required – Private Property	Limited Apparent Impact
Washington Lane Drop Shaft	300'+ Rock Excavation	High Level of Resistance due to Historic Property & Community Center	Easement Required – Access to shaft will be challenging	Possible Adjacent Wetlands; Impacts to Organic Farm
Church East Diversion	30'+ Rock Excavation	Impacts to Local Residents	Limited Impact	Environmental Impact Study Required
Church West Diversion	30'+ Rock Excavation	Impacts to Local Residents & Businesses	Possible Easement Acquisition	Environmental Impact Study Required
Church Lane Drop Shaft	250+ Feet Deep Excavation	Impacts to State Rte, Bus Rte, & Local Businesses	Easement Required – Private Property	Limited Apparent Impact
Conveyance Improvements	8700' Sewer Upsize	Potential Impacts to State Rte, Bus Rte, and Local Businesses	Limited Impact	Limited Impact

Looking Forward

The alternatives were evaluated at the planning level stage in the AERO study. Results from this analysis show that each alternative reduces annual damages by over 60 percent from the existing conditions.

Significant design storm (10-year, 24-hour design storm event) flood mitigation at key FPIs involves significant feasibility and constructability concerns, as well as other factors. Careful consideration of these factors for each alternative must be compared against the flood mitigation and CSO reduction benefits presented in this report. Key considerations for moving forward are discussed below.

Alternative Performance: The Storage and Tunnel Alternatives presented in this report provide for both flood risk and CSO reduction benefits. The location and design of alternative diversion structures is critical to ensuring the flood risk and CSO reduction performance of both alternatives. The PCSWMM evaluation capabilities for complex hydraulic scenarios is limited, and therefore computational fluid dynamics (CFD) modeling will be required at each drop shaft and diversion location for future design efforts to gain a more complete understanding of hydraulic conditions. The results of future modeling should be used to confirm the hydraulic capacity of the diversions, collectors, and tunnel for a range of synthetic storm event scenarios. It is also anticipated that real-time control gates for either alternative would allow operational flexibility to maximize alternative performance for CSO reduction or flood mitigation as needed.

Hydraulic Structure Analysis: Drop shafts, diversions that maximize flood diversion volumes, tunnel collectors, and the tunnel itself experience significant peak flows and velocities that require an increased level of hydraulic analysis to fully evaluate performance. Laboratory studies and/or a computational fluid dynamics analysis of these elements is needed before further design to fully characterize system performance and maximize diversion volume.

Implementation: Although tunnel and storage alternatives can each be constructed as one large project, storage tanks can also be built in phases. While it is a potential possibility for conveyance system upsizes to be constructed separately from the tunnel, care should be taken to fully understand any negative downstream impacts from doing so prior to project planning and implementation. Phasing of the construction of storage tanks would reduce simultaneous construction impacts and spread the construction capital cost over a longer period of time. Conversely, although phasing is less advantageous for the tunnel, much of the tunnel construction occurs underground and causes less surface disruption during construction. Storage tanks tend to impact public recreation, mature trees, and rail facilities and may require environmental compliance, while tunnel drop shafts and diversion structures tend to impact state routes, private property, and business with more limited environmental impacts.

Cost Considerations: Class 4 construction cost estimates were developed by CH2M for the Storage Tank Alternative and are provided in Appendix G. The total construction cost of the storage alternative is estimated to be $585 million. This estimate is significantly impacted by assumptions related to geotechnical issues at each site as discussed below.

The cost estimate for the Tunnel Alternative was developed by PWD and Mott MacDonald, with an estimated total construction cost of $384 million. This estimate is also included in Appendix G. Class 4 estimates may vary +50% to -30% from a detailed cost of a specific alternative.

Operation and Maintenance Considerations: A tunnel system and a tank system have different maintenance and operational needs. Storage tanks have high operational and maintenance needs, and require individual attention after each storm event, including inspection, cleaning, regular maintenance, and flushing. Tanks also incorporate multiple pieces of equipment that require regular maintenance. Once constructed, the tunnel system can be maintained as a whole system and requires less maintenance overall than a network of storage tanks. It is anticipated that operating either the tank or tunnel system to be effective for both CSO capture and flood mitigation will require real-time controlled gates to allow flexibility to maximize the system for CSO reduction or flood mitigation as needed. These types of controls come with additional operation and maintenance requirements.

Geotechnical Investigations: Geotechnical understanding is important for both the tunnel and storage tank alternatives. Currently, limited geotechnical information is available at the specific storage tank and tunnel diversion locations. Cost estimating efforts for the storage tanks used available geotechnical information; however, more detailed, site-specific information is needed to fully understand site conditions and inform cost-estimating efforts. Geotechnical investigation will impact the constructability assessment, and project cost and schedule will be better defined with more site-specific information. Additionally, with more site-specific information, the storage tank shapes can be optimized to improve on constructability (such as evaluating circular tanks, reducing the footprint of the structure and minimizing requirements for support of excavation), which can reduce impacts on the vicinity of the construction site.

Regulatory Implications: Potential regulatory and downstream impacts from the tunnel overflow into Tacony Creek were not fully evaluated as part of this AERO study. The regulatory requirements related to creating a new outfall on Tacony Creek should be considered during the planning process. When moving forward with the alternatives, in particular the Tunnel Alternative, consideration of potential increased flood flows as they impact the flood levels and bank stabilization of Tacony Creek may be warranted.

Resiliency: PWD may wish to investigate the performance of the mitigation alternatives under climate-projected rainfall scenarios to allow for a resiliency evaluation.

Residual Risk Mitigation: The alternatives are effective for mitigating the 10-year, 24-hour design storm event flood risk at key intersections directly along the East and West branches of the existing Germantown sewer system. Alternatives studied in this document were refined to minimize residual risk within the east and west branch project area limits, while taking into consideration relative cost/benefit guidelines. The remaining residual risk is primarily caused by localized system inadequacies. The findings of this study can guide more detailed, localized studies to inform a complete strategy using green stormwater infrastructure, backflow prevention, localized conveyance designs, and property acquisition for addressing residual risk throughout the watershed.