ACKNOWLEDGEMENTS

The District of Columbia (District) experienced a severe storm from June 24-26, 2006 which caused extensive flooding within the Federal Triangle area, resulting in millions of dollars in damage. Several Federal and District agencies formed a Federal Triangle Stormwater Drainage Study Working Group to identify measures to reduce the risk and impact of flooding in the future. The Working Group held a series of meetings that investigated the existing sewer system in relation to the Federal Triangle, identified the storm frequencies and durations to be modeled and analyzed, identified interior rainfall and the Potomac River as causes of flooding, identified and evaluated alternatives to reduce the frequency of flooding, and developed a plan for further investigations to finalize a flood control strategy based upon the findings of the Study.

Greeley and Hansen would like to thank the members of the Working Group for their hard work, commitment, and assistance with the preparation of this Study. The Working Group includes:

- General Services Administration (GSA)
- District of Columbia Office of Planning (DCOP)
- District of Columbia Department of the Environment (DDOE)
- District of Columbia Homeland Security and Emergency Management Agency (DC HS&EMA)
- District of Columbia Water and Sewer Authority (DC Water)
- Federal Emergency Management Administration (FEMA)
- National Archives and Records Administration (NARA)
- National Capital Planning Commission (NCPC)
- National Gallery of Art (NGA)
- National Park Service (NPS)
- Smithsonian Institution (SI)
- U.S. Department of Justice (US DOJ)
- U.S. Environmental Protection Agency (US EPA)
- Washington Metropolitan Area Transit Authority (WMATA)

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DC WATER
Washington D.C.

Federal Triangle Stormwater Drainage Study

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Greeley and Hansen LLC
July 2011

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EXECUTIVE SUMMARY

The District of Columbia (District) experienced more than a 200-year storm event from June 24-26, 2006 which overwhelmed the sewer system and caused interior flooding within the Federal Triangle area. Following this severe storm event, several Federal and District agencies (partner agencies) convened a Flood Forum to identify steps that stakeholders can pursue to reduce the risks of flooding in the Monumental Core. Among the recommendations of the Flood Forum is the evaluation of the existing sewer capacity in the Federal Triangle, which several of the Flood Forum participants jointly funded through a Memorandum of Understanding executed on September 30, 2009.

The partner agencies that supported this Study are:

- General Services Administration (GSA)
- District of Columbia Office of Planning (DCOP)
- District of Columbia Department of the Environment (DDOE)
- District of Columbia Homeland Security and Emergency Management Agency (DC HS&EMA)
- District of Columbia Water and Sewer Authority (DC Water)
- Federal Emergency Management Administration (FEMA)
- National Archives and Records Administration (NARA)
- National Capital Planning Commission (NCPC)
- National Gallery of Art (NGA)
- National Park Service (NPS)
- Smithsonian Institution (SI)
- U.S. Department of Justice (US DOJ)
- U.S. Environmental Protection Agency (US EPA)
- Washington Metropolitan Area Transit Authority (WMATA)

DC Water conducted this Study through their consultant, Greeley and Hansen. A Working Group consisting of staff from the partner agencies provided the consultant guidance on the appropriate design frequency storms to use for the modeling, facilitated access to the Federal Triangle for the spot elevation surveys, and augmented the analysis of flood mitigation solutions. The partner agencies have committed to continue to work together after this Study is completed to determine the viability of implementing flood mitigation alternatives analyzed and recommended in this Study.

PURPOSE AND SCOPE OF STUDY

The purpose of this Study is to understand how the existing sewer system performed during the 2006 Flood and identify and evaluate potential improvements to the sewer system to reduce the risk of flooding due to interior rains in the Federal Triangle area. Flood protection measures to address interior drainage will complement the current public investments in the 17th Street Levee Project, which is intended to provide protection against river flooding of the Monumental Core, including the Federal Triangle,

Specifically, the scope of this Study was to:

- Determine the capacity of the existing sewer system in the Federal Triangle area.
- Predict the ponding level in the Federal Triangle for storms that exceed the capacity of the sewer system.
- Assess the impact of interior rains on flooding in the Federal Triangle separate from river flooding
- Assess the impact and combined probability of concurrent river floods and interior rain events on flooding in the Federal Triangle.
- Identify alternatives to improve the existing sewer system to provide protection from interior rains for a variety of different storm return frequencies.

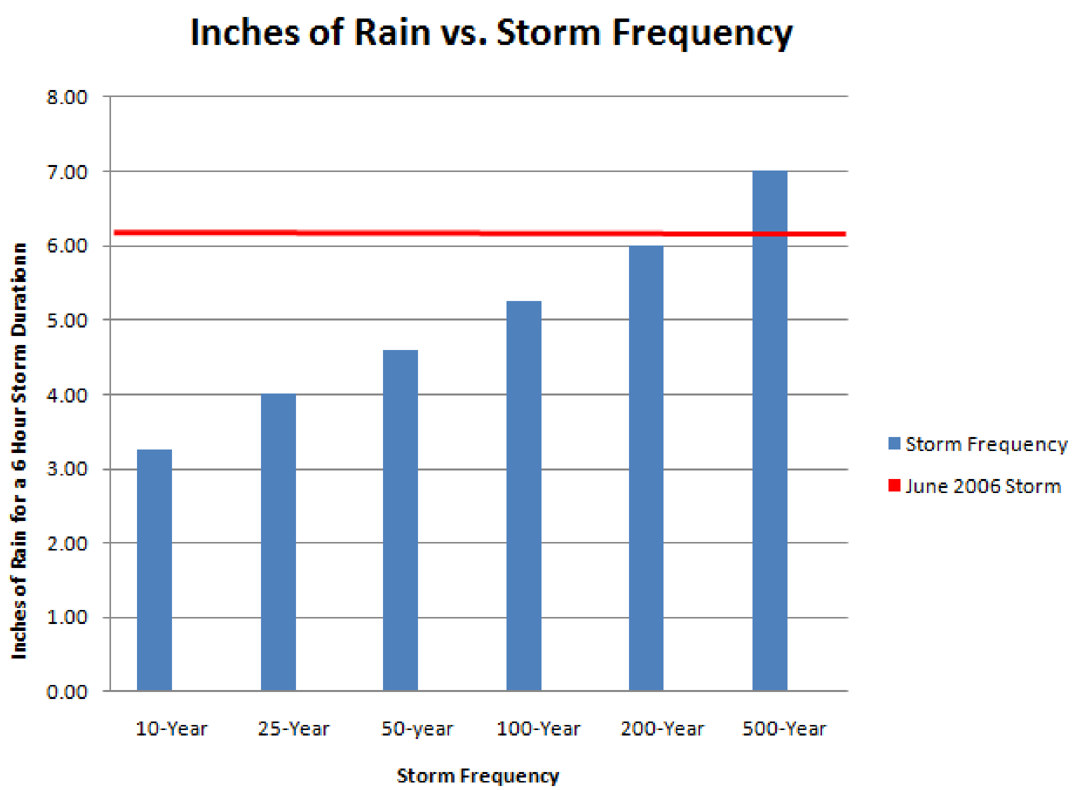
- Identify alternatives to monitor rain and or the sewer system, to provide an early warning of when flooding may occur in the Federal Triangle area.
- Evaluate the alternatives in terms of cost, benefits, and practicality for implementation.

This study did not evaluate flood proofing or “armoring” of Federal Triangle buildings since this is outside of the core mission of DC Water. The “armoring” of buildings may be a viable solution to mitigate the impact of flooding on buildings in the Federal Triangle area and should be investigated by the partner agencies as part of a separate study.

ASSESSMENT OF JUNE 24-26, 2006 RAIN EVENT

Flooding in the Federal Triangle area can be caused by river flooding, by intense interior rainfall, or by a combination of the two. Using a carefully calibrated model, which is discussed in greater detail in the main body of this report, this Study found that:

- The intensity and duration of the June 2006 rain event, which was found to exceed a 200-year frequency storm, overwhelmed the capacity of the sewer system. None of the existing sewers were designed to handle storms of this magnitude; even the newer systems are typically designed for a 15-year storm event only. An assessment of the existing sewer system during the June 2006 storm demonstrated that the Main and O Street Pumping Stations operated as intended, except for one pump at the Main Pumping Station (that had been taken off-line for scheduled maintenance). Investigations of the existing sewer system also showed that there was no evidence of a power failure or equipment failure. While the Constitution Avenue Storm Sewer siphons at the B Street/New Jersey Sewer contained some siltation, these conditions did not significantly exacerbate flooding in the Federal Triangle. The chart below shows the rainfall intensity associated with various storm events in the DC region, shown as blue bars, and where the June 2006 flood falls, exceeding a 200-year frequency storm.

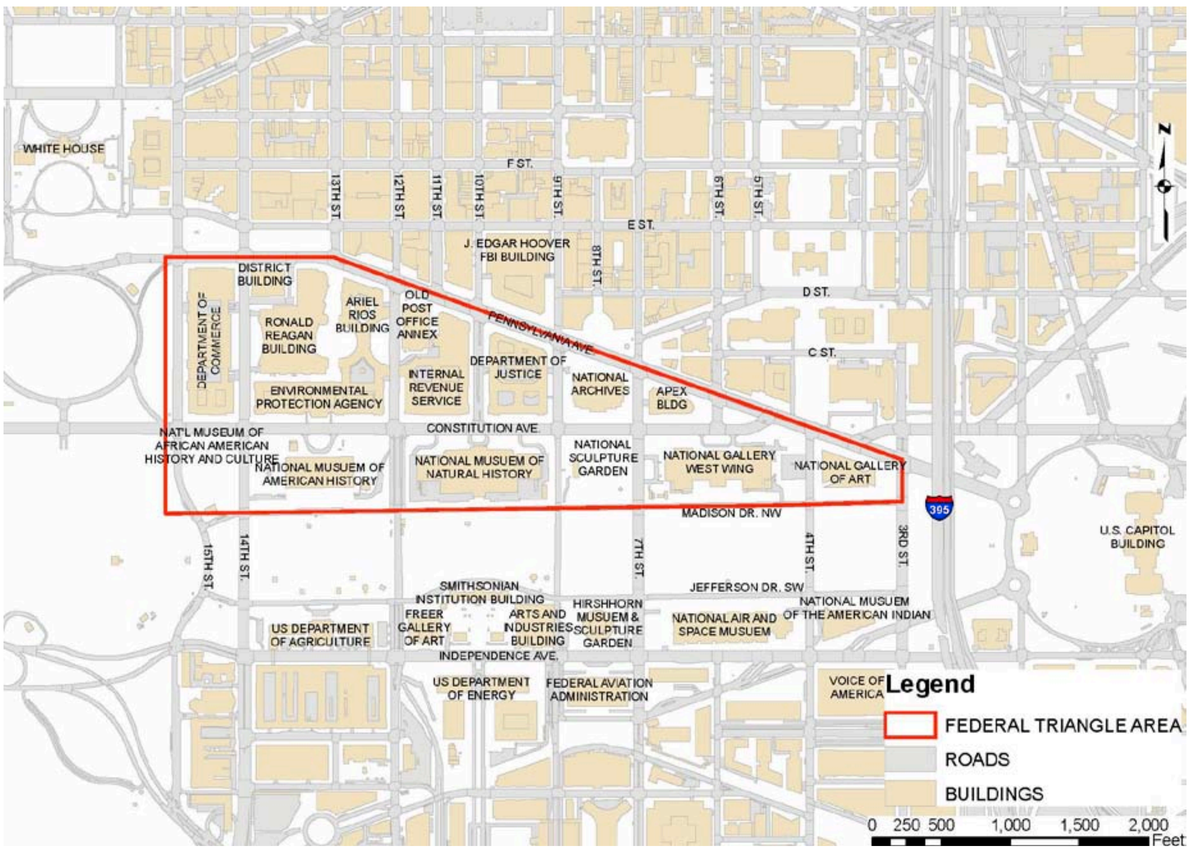


- The Federal Triangle is the lowest point of a large, predominantly impervious drainage area of the District, so excess stormwater from the upland areas flowed down to the Federal Triangle, and further exacerbated the flooding.
- The Federal Triangle is very flat so water on the surface does not easily flow into catch basins. This causes ponding even during small rain events.
- River flooding did not contribute to the flooding during this storm event.

BACKGROUND

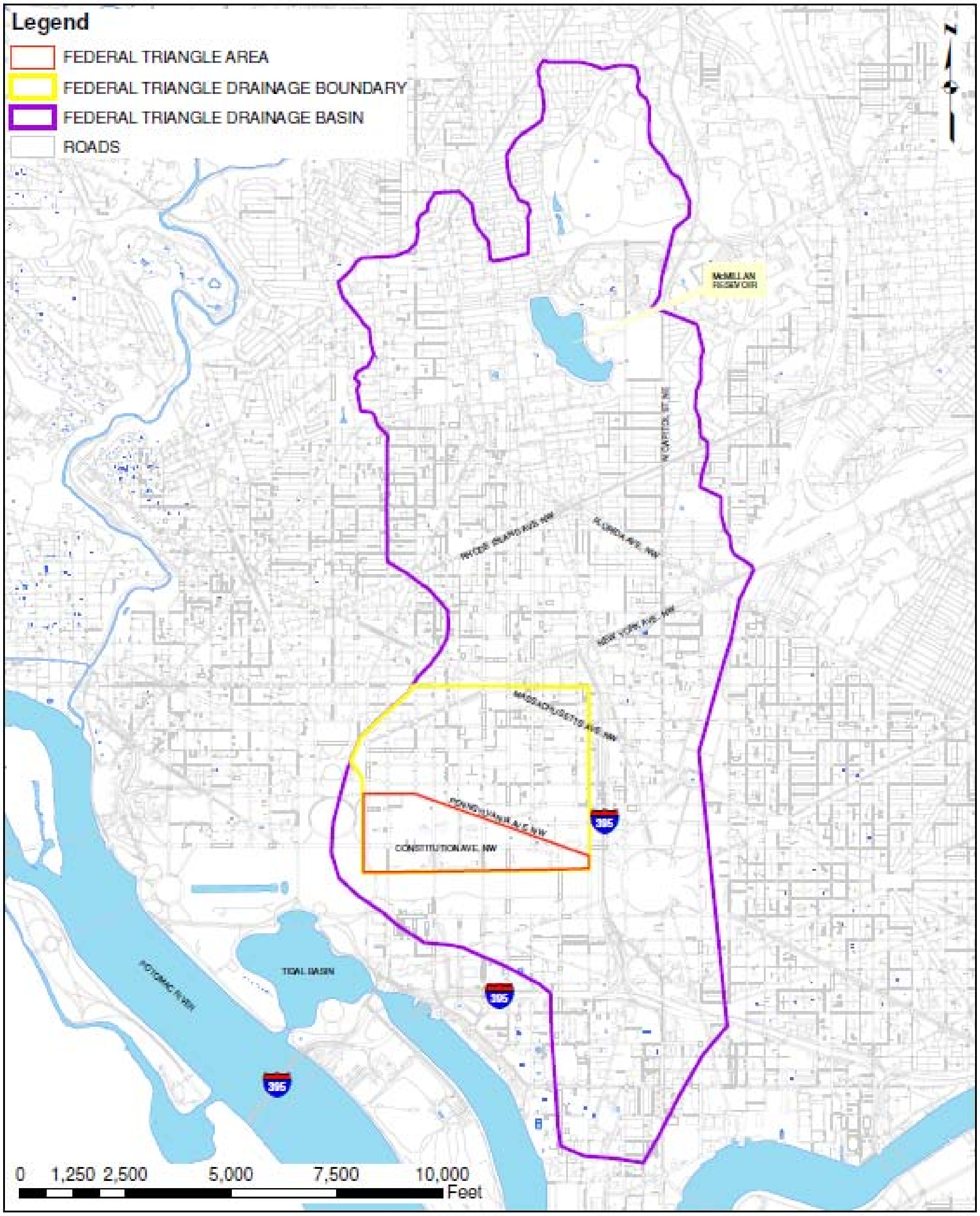
Study Area

The Federal Triangle study area is in the northwest quadrant of the District and is bounded by 15th St NW to the west, Madison Dr. NW to the South, 3rd St. NW to the east, and Pennsylvania Ave. NW to the north and northeast. The Federal Triangle area is the home of many prominent buildings owned by the Federal government. The figure below shows the location of the Federal Triangle in relation to other notable civic buildings such as the White House and the U.S. Capitol Building.



Federal Triangle Drainage Area

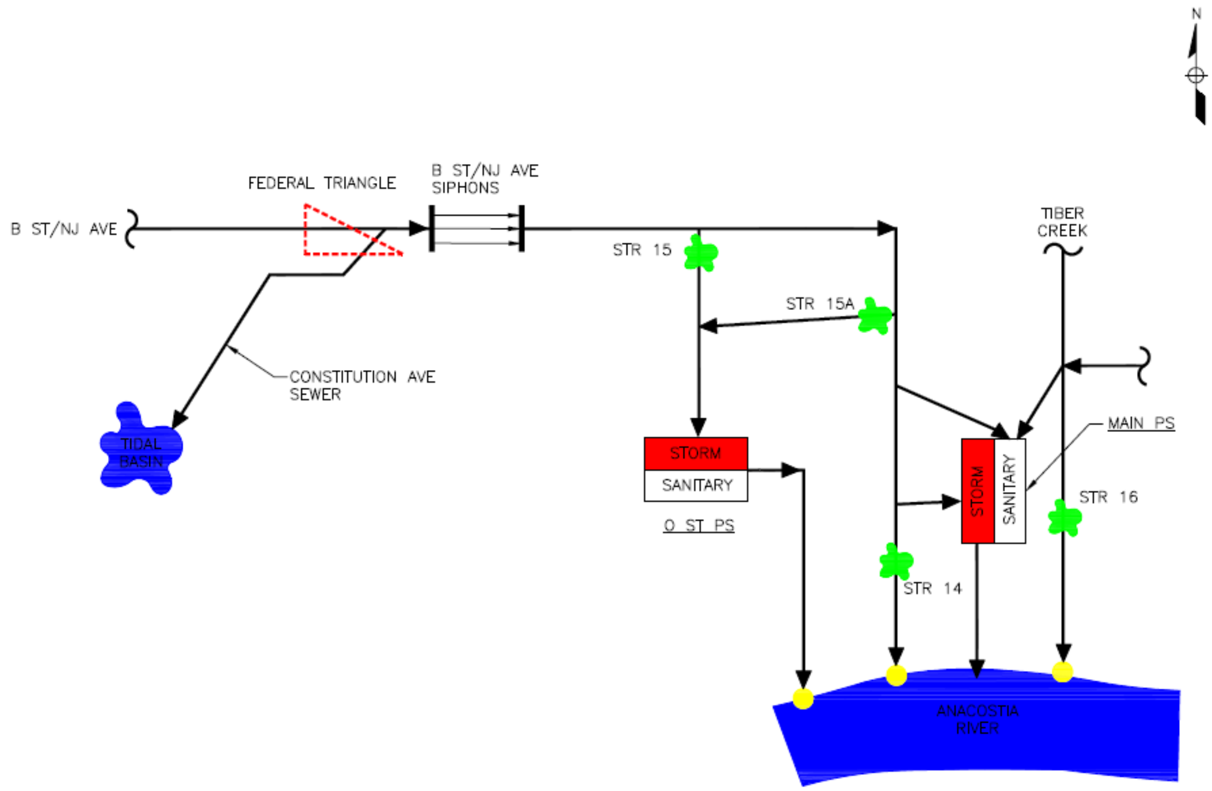
The Federal Triangle, because it is the lowest point for a large area of the District, is impacted by stormwater runoff from a larger drainage area beyond the streets and blocks adjacent to it. This drainage area, as shown on the map below, is 5.83 square miles (3,732 acres) and 24 times the size of the Federal Triangle. When it rains, the sewer system in the higher elevations conveys stormwater by gravity to the Federal Triangle sewers. Furthermore, when stormwater runoff can no longer be handled by the sewers in the higher ground, delineated by the yellow rectangular area in the figure below, the excess stormwater flows overland to and accumulates in the Federal Triangle area. Hence, the sewer system in the Federal Triangle, while similarly sized with those in the higher elevations of the drainage area, is expected to handle not only stormwater directly collected from the Federal Triangle, but also stormwater volumes multiple times greater in magnitude coming from other parts of the drainage area.



In the figure above, the purple line represents the topographic boundary of the Federal Triangle drainage basin. The yellow line represents the area that was determined by modeling that will flow overland to the Federal Triangle when storm events exceed the capacity of the existing sewer system.

Existing Sewer System
The study area is served by the District's combined sewer system and a single storm sewer. Combined sewers are typical in older cities and a combined sewer carries both sewage and runoff from storms. Modern practice is to build separate sewers for sewage and storm water and no new combined sewers have been built in the District since the early 1900's.

The Federal Triangle has two major sewers that convey rainfall away from the Federal Triangle. The B Street/New Jersey Avenue Sewer conveys flows by gravity to the Main and O Street Pumping Stations, which in turn pump flow to the District's Advanced Wastewater Treatment Plant at Blue Plains (Blue Plains) for treatment. Flows in excess of the conveyance and treatment capacity are pumped directly to the Anacostia River. Additionally, rainfall in the Federal Triangle may be conveyed by gravity to the Tidal Basin via the Constitution Avenue Storm Sewer. The Constitution Avenue Storm Sewer has an irregular profile since it was put into service using existing sewers that were originally designed for other purposes. This fact coupled with the low grade elevation in the Federal Triangle compared to the river elevation and obstructions from other utilities significantly minimizes the capacity of the Constitution Avenue Storm Sewer to convey rainfall to the Tidal Basin by gravity. The major sewers and pumping stations are shown in the figure below.



MODELING USED FOR THIS STUDY
In order to understand how the sewer system performed during the 2006 Flood and to evaluate alternatives to mitigate flooding, a detailed computer model of the terrain and the sewer system was developed. This model was then calibrated using information available about the flooding in the Federal Triangle in June of 2006. It was then used to predict ponding levels and volumes of flow that would occur in the Federal Triangle area for various storm frequencies and with various flood control alternatives. This Study employed new spot elevation data to establish a higher level of accuracy in depicting the existing or baseline conditions for the modeling.

The Working Group provided direction in the development of the model, which involved three main steps:

a. collecting accurate data to enter into the model;
b. determining the storm frequencies that are most relevant to model; and
c. selecting the acceptable risk tolerance for flooding on the street.

For the June 2006 flood event, the Working Group assisted the consultant in collecting field observations data which were used to calibrate the model, a necessary step to ensure that the model is set up to correctly simulate existing conditions. The Working Group also assisted the consultant in the field survey which produced refined topography data that was entered into the model to help attain more accurate flood prediction results.

The particular model used in this Study built upon the GIS-based model already being used by DC Water for its capital planning activities. Surface and subsurface pipe models of the combined and sanitary sewer systems were developed to evaluate how flooding occurs in the Federal Triangle. The surface model analyzed the overland surface flow in the Federal Triangle. The subsurface pipe model analyzed the capacity of the sewer system. The subsurface pipe model in the Federal Triangle area includes over 2,200 interceptor and trunk sewers, sanitary sewers, and pipe segments. Next, the Working Group worked with the consultants to select the size and frequency of storms (i.e. Design Storm) to use for the modeling, which are the following:

BASELINE PONDING PREDICTIONS

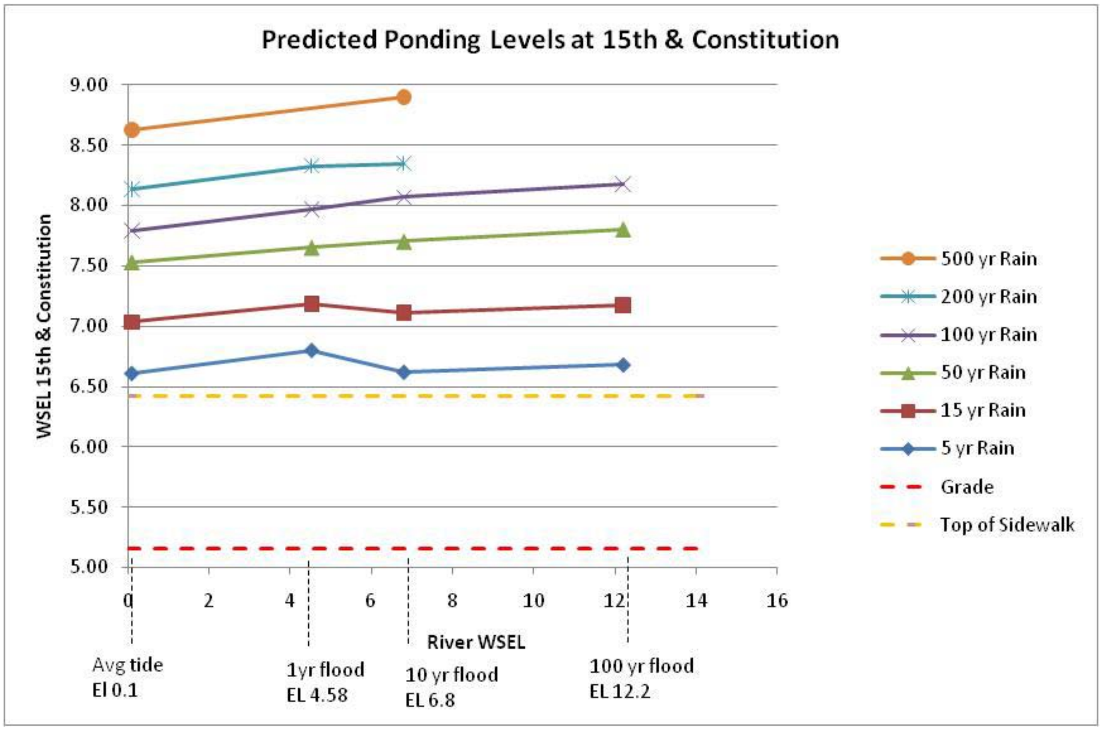
Storm Design Return Frequency Analyzed

The Working Group determined that the 100 Year storm should be analyzed since it is the FEMA standard by which the National Flood Insurance Program Flood Insurance Rate Maps (NFIP FIRM) maps are developed. The Group also agreed that storms one size smaller and one size larger should be analyzed to give a range of data. The 50 Year storm was chosen as one size smaller storm. The 200 Year storm was selected as one size larger storm. Additionally, the 200-Year storm was selected to account for the potential effects that global warming may have upon the ecosystem and to recognize that more severe storms are becoming more prevalent around the country. Finally, the 15 Year storm was also selected because it is the design storm that DC Water uses to construct new sewer facilities.

Acceptable Ponding Level

This Working Group also looked at what were acceptable levels of stormwater ponding within the District. Due to the low elevation and flat profile of the Federal Triangle area, some amount of stormwater ponding must occur simply for the stormwater to flow at ground level to the inlet catch basins. Discussions with the Working Group have determined that at 15th and Constitution Ave. NW, the low point of the Federal Triangle, the critical elevations are:

- Grade El. 5.16
- Top of the curb El. 5.28
- Top of the sidewalk El. 6.42



The above diagram shows the predicted ponding elevations in the Federal Triangle for different storm frequencies and river elevations. The Working Group decided that ponding up to the top of the sidewalk is an acceptable level of risk to assume for the purpose of this Study.

Equipped with the predicted ponding levels data, the consultants were now able to calculate the volume of water for each Design Storm and design the various alternatives to accommodate the predicted volume of water. Using the model, each alternative can then be tested in its ability to handle various volumes of stormwater. The model also helped define the scale and test the effectiveness of each alternative.

ALTERNATIVES EVALUATION

The Working Group developed a preliminary list of potential strategies to prevent flooding within the Federal Triangle. These potential strategies are:

Strategy	No.	Description
Warning System	A	Early Warning Systems
Reduce floodwaters entering Federal Triangle	B	Low Impact Development (green practices)
	C	Storage Upstream of Federal Triangle
Convey floodwaters out of Federal Triangle or store them	D	Use GSA Condensate Line
	E	Storage Beneath National Mall
	F	Pumping Station Serving National Mall
	G	Tunnel to Main & O Pumping Stations
	I	Maximize use of sewer system
	J	Gravity sewer to Tidal Basin
Protect properties from flood waters	H	Flood-proof buildings

Through a series of meetings with the Working Group, Alternative I was rejected because the existing sewer systems were not designed to handle large scale storms and changing operational parameters would not measurably reduce flooding risk. Alternative J was rejected, because the grade elevation of the Federal Triangle is too low relative to the Potomac River and Tidal Basin for a new gravity sewer to function reliably. Alternative H, Flood Proofing of Structures within the Federal Triangle is a viable solution but is not within the scope of this Study. Consequently, seven (7) alternatives were identified as potential projects that may prevent flooding in the Federal Triangle area and warranted further investigation. These alternatives are:

- Alternative A – Early Warning Systems
- Alternative B – Low Impact Development Strategies (Green Infrastructure)
- Alternative C – Storage Upstream of Federal Triangle Area
- Alternative D – Utilize GSA Condensate Line
- Alternative E – Storage Beneath the National Mall
- Alternative F – New Pumping Station Serving the National Mall
- Alternative G – New Tunnel to the Existing O Street Pumping Station

Alternatives A through G were evaluated in terms of cost, benefits, and other technical factors. A brief description of each alternative and a table comparing the advantages and disadvantages of each strategy follows.

<u>Alternative A – Early Warning Systems</u>
Early warning systems can vary greatly in complexity and warning accuracy, from a region wide system consisting of hundreds of weather stations and weather radar measurements, to simpler systems consisting of a handful of sensors located at areas that are known to be prone to flooding to provide advance warning of flooding events. These systems usually consist of a system of monitoring stations

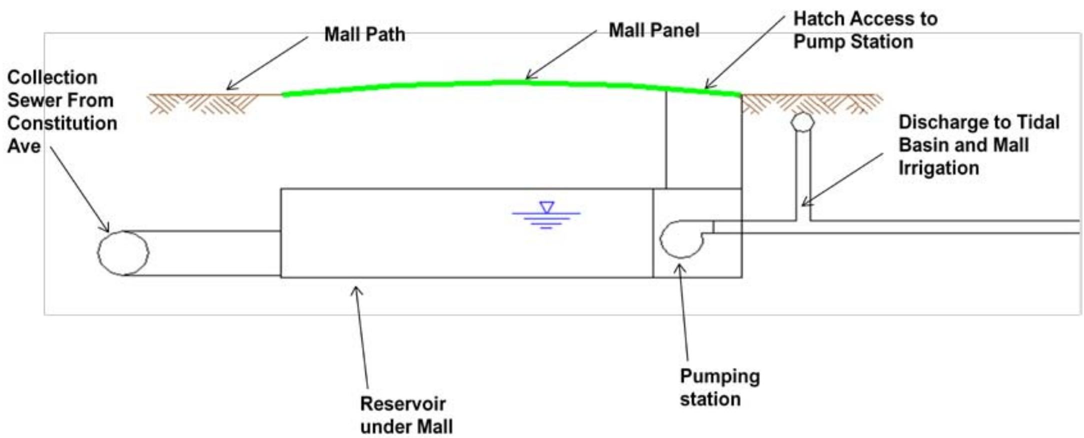
that transmit weather data to a central control center, where the data is compiled with other weather measurements such as radar rainfall information. At these control centers the risk of flooding for the area in question is assessed and if necessary a flood warning is issued to the area.

Alternative B – Low Impact Development Strategies (Green Infrastructure)
Low Impact Development (LID) strategies, also known as Green Infrastructure, are design approaches to recreate predevelopment hydrological conditions at a new development or redevelopment site. LID strategies use many different techniques to reduce the amount of impervious cover and to maximize the hydrologic capacity of the developed landscape. Typical LID strategies include engineered structures like green roofs, bioretention, vegetated swales, permeable pavement, rain barrels and cisterns, as well as natural practices like planting trees and native landscaping.

Alternative C – Storage Upstream of Federal Triangle Area
Alternative C looks at opportunities to prevent excess rainfall upstream in the drainage area from flowing down to the Federal Triangle. The Federal Triangle drainage area is 24 times larger than the size of the Federal Triangle itself and the existing sewers in the Federal Triangle are designed to convey only the stormwater in the vicinity of the Federal Triangle. If the rainfall is captured upstream of the Federal Triangle in underground collection basins, the excess storm water would not contribute to flooding in the Federal Triangle. Upstream Storage can be classified in two ways, consolidated storage and distributed storage. Consolidated storage would be centralized locations that stormwater is conveyed to and stored. Examples of consolidated storage would be cisterns or storage basins beneath parking lots or vacant land or tunnels located beneath roads. Distributed storage would involve installing rainfall storage across the entire area that would otherwise drain to the Federal Triangle. The distributed (or decentralized) storage would be the equivalent of implementing LID technologies within public rights-of-way across this area.

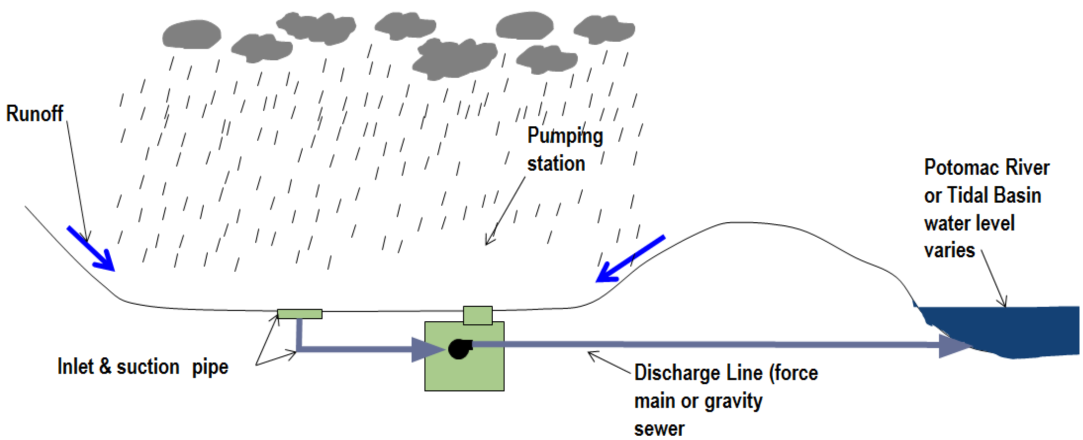
Alternative D – Utilize GSA Condensate Line
Alternative D looks at re-using an abandoned 48-inch gravity GSA Condensate Line to convey stormwater out of the Federal Triangle. This condensate line was formerly used to bring water from the Tidal Basin to the Federal Triangle buildings to be used for cooling purposes, such as condensing steam. In the course of this Study, the Smithsonian Institution informed the Working Group that a section of the condensate line that crosses the future site of the National Museum of African-American History will need to be demolished to make way for the museum. For this reason, reusing the condensate line is no longer an option; however, Greeley and Hansen has completed its evaluation of the viability of this alternative and this analysis is included in the body of the report. Greeley and Hansen concludes that this is not a viable alternative because the condensate line would be able to handle only a very small portion of the volume of water that needs to be removed and it is prone to siltation from the Tidal Basin.

Alternative E – Storage Beneath the National Mall
Construction of storage basins beneath the National Mall to capture and convey storm water away from the Federal Triangle could serve as flood protection for the Federal Triangle, while also providing a source of non-potable water to irrigate the National Mall. As part of this solution, a pumping station would also be constructed to pump the captured storm water out of the storage basins into a new sewer line that connects to the Mall's sprinkler system. The pumping station will also allow excess water to be pumped away from the Federal Triangle, into the Tidal Basin, should back-to-back storms necessitate this. The National Mall is an area used frequently for large public events and gatherings so any new construction would strive to minimize the disturbance to the National Mall. The pump station could be located primarily below grade; however, there will have to be an entrance for personnel and access hatches for equipment maintenance located at or above grade. A typical conceptual cross section of a storage basin and pumping station beneath the National Mall is shown in the figure below.



Alternative F – New Pumping Station Serving the National Mall

To alleviate flooding in the Federal Triangle a new collection sewer could be constructed adjacent to the National Mall to capture and convey rainfall to a new Pumping Station serving the National Mall (See diagram below). The new Pumping Station would pump collected rainfall to the Tidal Basin. To achieve this, a new Pumping Station would have to be located on or adjacent to the National Mall. The Pumping Station could be located primarily below grade; however, there will have to be an entrance for personnel and access hatches for equipment maintenance located at or above grade. The figure below shows a cross section of a new below grade Pumping Station servicing the National Mall. The actual location of the new pumping station will require a more detailed analysis than this study can offer and consultation with various public stakeholders of the National Mall.



Alternative G – New Tunnel to the Existing Main and O Street Pumping Stations

Alternative G looks at how new facilities constructed to provide flood protection to the Federal Triangle area can be combined with facilities being constructed across the District to provide Combined Sewer Overflows (CSO) control can operate together to achieve an integrated District wide solution. Presently the B Street/New Jersey Avenue sewer, which serves the Federal Triangle, conveys collected rainfall to the Main and O Street Pumping Stations. The B Street/New Jersey Avenue sewer does not have sufficient capacity to convey rainfall from large storm events away from the Federal Triangle. On the other hand, the Main and O Street Pumping Stations have pumping capacity that isn't utilized during large storms because the stormwater cannot get to the pumping stations quickly enough. Constructing a new Federal Triangle tunnel to capture and convey rainfall from the Federal Triangle directly to the Main and O Street Pumping Stations would make use of the pumping capacity of the facilities and provide an increased level of flood protection for the Federal Triangle. The actual location and alignment of the new tunnel requires a more detailed analysis than what this study can offer.

This Study considered two variations for a new Federal Triangle Tunnel:

Alternative G1 Description
Alternative G1 provides flood protection for the Federal Triangle area as a standalone solution. Collected rainfall will flow by gravity from the Federal Triangle via the new Federal Triangle Tunnel to Main and O Street Pumping Stations. After the rain has subsided and the Blue Plains Tunnel has been emptied, a gate will be opened and liquid in the Federal Triangle Tunnel will drain by gravity to the Blue Plains WWTP. If liquid levels become too high in the Federal Triangle Tunnel before it may be drained into the Blue Plains Tunnel, the O Street Pumping Station pumps will turn on and pump the water out to the river.

Alternative G2 Description
Alternative G2 combines new facilities providing flood protection to the Federal Triangle area with facilities being constructed to provide CSO control to achieve an integrated District-wide solution. Alternative G2 would operate the same as Alternative G1; however, the new Federal Triangle Tunnel could be extended to connect to the Potomac CSO Tunnel for additional CSO control within the District. By connecting the Potomac CSO Tunnel to the Main and O Street Pumping Stations, a new Pumping Station for the Potomac CSO Tunnel would not have to be built.

The table below lists the flood prevention alternatives being analyzed, each alternatives advantage, each alternatives disadvantage, additional considerations, and conclusion if the alternative will be further evaluated or not.

ALTERNATIVE	ADVANTAGES	DISADVANTAGES	ADDITIONAL CONSIDERATIONS	CONCLUSION
Low Impact Development (Capturing rainwater through green infrastructure)	• Implementation of LID technologies is beneficial for small storms • Reduces volume of water reaching the sewer system • Can reduce the size of capital facilities-amount depends on scale of LID • Recreates hydrological conditions of original environment	• LID alone will not adequately prevent flooding in the Federal Triangle • Difficult to implement wholesale LID technologies in built-out city • Long-term operation and maintenance (i.e. reliability) needs to be addressed	• Has ancillary benefits: aesthetics, reduced heat island effect • Institutional issues need to be addressed to facilitate implementation (i.e. private property issues)	LID technologies are not a standalone solution to flooding in the Federal Triangle area, but can augment or improve other flood control measures.

ALTERNATIVE	ADVANTAGES	DISADVANTAGES	ADDITIONAL CONSIDERATIONS	CONCLUSION
Storage Upstream of Federal Triangle: Consolidated Storage or Distributed (multiple LIDs)	• Distributed storage will be located in the right-of-way, minimizing private properties that may need to be acquired	• Will not capture the runoff in the immediate Federal Triangle area • Will not address the problems of surcharged sewers • Land acquisition cost for the consolidated storage option is cost prohibitive, since the drainage area is in the downtown area • Multiple upstream storage facilities will be needed to intercept flows from many locations in the drainage area. • Construction of facilities in multiple street and rights-of-way would be disruptive to traffic, business operations, street parking and location of existing utility lines	• Long term operation and maintenance of LIDs will depend on individual property owners • Additional survey will be needed to ensure that these can be accommodated with all the existing utilities and sewer infrastructure under the rights-of-way	Storage upstream of the Federal Triangle is not considered a practical solution to preventing flooding in the Federal Triangle.
Utilize the 48-inch gravity GSA condensate line that runs along Constitution Avenue from 7th Street to the Tidal Basin		• The GSA condensate line slopes by gravity in the wrong direction so it cannot effectively flush flood water out of the Federal Triangle • The condensate line storm conveyance capacity is significantly limited because its elevation is below the average tidal elevation • The condensate line is undersized for volumes of rainfall that would have to be conveyed to prevent flooding • The condensate line is prone to siltation		The condensate line is no longer an option since a section of the line has to be abandoned as part of construction of the Smithsonian National Museum of African American History. The limitations of the GSA condensate line make this alternative not viable for flood prevention in the Federal Triangle area.

ALTERNATIVE	ADVANTAGES	DISADVANTAGES	ADDITIONAL CONSIDERATIONS	CONCLUSION
Storage Beneath the National Mall	• Captures large volumes of water that would otherwise Tidal Basin • Stormwater can be used for irrigation of the National Mall by NPS. Rain from smaller storm events falling into the Federal Triangle does not have to get into the Tidal Basin or conveyed to the Main and O St. Pumping Stations	• Construction will cause significant disruption to major events annually held on the National Mall • NPS does not issue easements, only 10-year renegotiable rights-of-way permits. The significant investments for a storage facility underneath the Mall would be placed at risk by the lack of easements after permits expire • Construction of facilities in multiple street and rights-of-way would be disruptive to traffic, business operations, street parking and location of existing utility lines	• A pumping station is also required to pump the water up to the Mall or to the sewer system • In addition to the storage areas under the Mall, a new collection sewer will need to be constructed adjacent to the National Mall to capture and convey the rainfall to the storage basins.	Storage beneath the National Mall is a viable option for preventing flooding in the Federal Triangle
New Pumping Station Serving the National Mall (to be located underground with access hatches and vents carefully located so as to preserve the Mall's visual quality)	• Pumping station will operate at any River elevation • System does not have complex operating parameters • Pumping station is independent of outside system influence	• Construction will be a major disruption to a highly sensitive area • Need to operate, maintain, and upgrade Pumping Station over time	• Will need to address ownership issues. • There are limited location options for a pumping station under the Mall due to the complex system of underground utility and transportation infrastructure and the protected viewsheds above ground. • If NPS does not assume ownership of the pumping station, the feasibility of this alternative will depend on having some legal instrument such as an easement or MOU with NPS that will allow the long-term operation of the pumping station under the Mall.	A new pumping station servicing the National Mall is a viable option for preventing flooding in the Federal Triangle

ALTERNATIVE	ADVANTAGES	DISADVANTAGES	ADDITIONAL CONSIDERATIONS	CONCLUSION
New Tunnel to the Main and O Street Pumping Station	• Maximizes the use of existing sewer facilities • Does not require the construction of a pumping station on or near the National Mall. • Boring tunnels will minimize disruption to the surface streets or properties.	• Tunneling through a soil/rock interface will add to the complexity and cost of tunneling. • The tunnel alignment will go under private and government properties with high level of security requirements. Requesting property owners to share information about their buildings will be difficult due to security issues. This information is required in order to design the tunnels. • Difficult to find construction staging sites in a built-out city like DC		A new tunnel to the O Street Pumping Station is a viable option for preventing flooding in the Federal Triangle
New Tunnel to the Main and O Street Pumping Stations connected to the Potomac CSO Tunnel	• Eliminates the need for the Potomac CSO Tunnel Dewatering Pumping Station • Simplifies overall CSO Program operation • Maximizes the use of existing sewer facilities • Does not require the construction of a pumping station on or near the National Mall.	• Tunneling through a soil/rock interface will add to the complexity and cost of tunneling. • Difficult to find construction staging sites in a built-out city like DC • The tunnel alignment will go under private and government properties with high level of security requirements. Requesting property owners to share information about their buildings will be difficult due to security issues. This information is required in order to design the tunnels.		A new tunnel to the O Street Pumping Station is a viable option for preventing flooding in the Federal Triangle

COST COMPARISON OF ALTERNATIVES

Other criteria used to assist the Working Group and the consultants in evaluating the feasibility of the alternatives is the order-of-magnitude capital, as well as operations and maintenance costs. At this conceptual stage of alternative analysis, detailed facility layouts have not been prepared, thus the tables below represent “concept level” cost estimates.

Capital Costs: Comparison of Alternatives ($ Millions)

No.	Alternative	Storm Design Return Frequency		
		50-yr	100-yr	200-yr
B[(1)]	Low Impact Development	$135	$135	$135
E	Storage Beneath National Mall	$325	$400	$455
F	Pumping Station Serving National Mall	$240	$360	$400
G1	Tunnel from O St. to Fed Triangle – Stop at Fed Triangle	$405	$405	$470
G2[(4)]	Tunnel from O St. to Fed Triangle – Connect to Potomac	$480	$480	$545

(1) Alternative B is not a viable alternative on its own, supplements other alternatives
(2) Costs are in Year 2010 dollars, ENR Construction Cost Index = 8805
(3) In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be “Concept Level” estimates with an accuracy of +50%/-30%
(4) Capital costs for Alternative G2 may be reduced through a partnership with DC Water as this alternative also addresses their needs. A detailed cost analysis can be found in the main body of this report.

The table above is a summary of capital costs in millions of dollars, for the alternatives identified above sized for various design storms. It shows that there is no difference in capital costs for the Low Impact Development (LID) alternative because these types of facilities are limited in their ability to mitigate design storm frequencies in the ranges that this Stormwater Study considered. The Tunnel from Main and O Street to the Federal Triangle alternative shows that there is no cost savings for constructing a tunnel to mitigate a 50-year storm versus a 100-year storm. For a detailed explanation of the contingencies included in the cost estimate, please read the main body of the report.

Net Present Worth of Operation and Maintenance Costs:

Comparison of Alternatives ($ Thousands/Year)

No.	Alternative	Storm Design Return Frequency		
		50-yr	100-yr	200-yr
B[(1)]	Low Impact Development	$845	$845	$845
E	Storage Beneath National Mall	$2,535	$3,099	$3,512
F	Pumping Station Serving National Mall	$1,427	$2,103	$2,329
G1	Tunnel from O St. to Fed Triangle – Stop at Fed Triangle	$798	$798	$920
G2	Tunnel from O St. to Fed Triangle – Connect to Potomac	$939	$939	$1,061

(1) Alternative B is not a viable alternative on its own, supplements other alternatives
(2) Costs are in Year 2010 dollars, ENR Construction Cost Index = 8805
(3) In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be “Concept Level” estimates with an accuracy of +50%/-30%

The table above is a summary of operation and maintenance costs in thousands of dollars, for the alternatives identified above sized for various design storms. The operation and maintenance costs are present worth costs calculated over a lifetime of 20 years, a 6.5% interest rate, and 3% inflation rate.

FINDINGS

The major findings of this study with respect to the capabilities of the existing sewer system, magnitude of the June 2006 storm, impacts of different storm frequencies on ponding within the Federal Triangle area, and alternatives to prevent flooding within the Federal Triangle area are:

- The June 24-26, 2006 rain event exceeded a 200-year return frequency storm. The volume of water from this storm exceeded the capacity of the sewer system in the Federal Triangle area, which is designed for a 5 to 15 year storm, and is typical of the capacity of sewers in other parts of the District.

- The Federal Triangle is at the bottom of a topographic bowl, with the land sloping upward in all directions. This condition exacerbated the flooding in June 2006 because stormwater runoff from the drainage area, which is 24 times the size of the Federal Triangle, flowed down to the Federal Triangle within a 6-hour period and overwhelmed the sewers.

- During the June 24-26, 2006 storm event, the Constitution Avenue Storm Sewer and one of the inverted siphons on the B Street /New Jersey Avenue sewer was partially obstructed with silt and debris. Modeling indicated that these conditions did not significantly affect flooding during the June 2006 flood. If the sewers had been clean, the ponding depth in the Federal Triangle would have been about 4" lower than observed ponding levels during the June 2006 storm. The magnitude of the storm far exceeded the design capacity of the sewer system.

- The Federal Triangle is at a low elevation compared to the Potomac River, making it difficult and sometimes impossible to drain runoff to the river by gravity. This also makes the area susceptible to flooding due to high river levels. While the modeling used in this Study considered the combined effects of river and interior drainage flooding simultaneously occurring in the vicinity of the Federal Triangle, the consultant found that the Potomac River was not at flood stage during the June 2006 flood.

- Since the Federal Triangle is a topographic low point, it is important to note that any alternative for flood control could be overwhelmed if a sufficiently large storm occurs. No structural solution will be able to completely eliminate the risk of flooding.

- The 17th Street Levee Project currently under construction in the National Mall will provide a higher degree of protection for the Monumental Core of Washington from river flooding. However, it does not mitigate flooding due to rainfall occurring inside the protected zone. Thus, The DC Flood Insurance Rate Map, which will be revised to reflect the effect of the levee in reducing the flood areas of the Monumental Core, will still show the Federal Triangle area in the 100-Year floodplain.

- Alternative A, Early Warning System, and Alternative D, Use of GSA Condensate Line, as standalone solutions, are ineffective in mitigating the effects of flooding in the Federal Triangle due to the incompatibility between their inherent purposes and the goals of the Working Group for protecting the Federal Triangle from a flood event. Most early warning systems are used to predict river flooding and assumes a slower rising flood that allows emergency management personnel enough time to prepare for it; however, the Study found that the Federal Triangle is susceptible to interior drainage flooding due to systemic and topographic conditions.

- Alternative B – LID Strategies and Alternative C – Storage Upstream of the Federal Triangle Area, cannot prevent flooding as standalone solutions. It is possible to use one of these alternatives along with another flood prevention alternative in a layered approach to flood prevention. The layered approach could potentially realize benefits from each alternative to help reduce the magnitude and costs of the alternatives. For example, constructing Alternative B –

LID strategies could help reduce the magnitude and costs of Alternative G2 - Construct new Tunnel from O Street Pumping Station to Federal Triangle (Connect to Potomac CSO Tunnel).

- The following alternatives were found to be viable engineered or structural solutions for handling floods due to storms of various frequencies in the Federal Triangle:
  - Alternative E, Storage beneath the National Mall;
  - Alternative F, Pumping Station serving the National Mall; and
  - Alternative G, Sewer Tunnel connected to the Main and O Street Pumping Stations

  The actual location of these facilities will require a more detailed analysis than this Study intended to evaluate, and consultation with various public stakeholders will be necessary to further evaluate the feasibility of each. Other political, aesthetic, and logistical considerations will also need to be addressed by the Working Group and other stakeholders.

- Because the capital cost of the engineered alternatives is large, it is recommended that a study be conducted to assess the practicality and cost associated with flood proofing buildings. The results of the flood proofing study could then be compared to the results of this study to develop the most cost effective and practicable solution.

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Section 1 INTRODUCTION

From June 24, 2006 through June 26, 2006, intense rainfall inundated the District of Columbia (District) with approximately 14-inches of rainfall. Based on a six hour duration rainfall, the storm had a return frequency of more than 200 years (200-year storm). The extensive flooding that occurred during the June 2006 storm event caused severe property damage at key Federal buildings in the Federal Triangle area of the District. Additionally, two Washington Metropolitan Area Transit Authority (Metro) stations were flooded and the 9^{th} and 12^{th} Streets NW tunnels were inaccessible for several hours.

Following this severe storm event, several Federal and District agencies (partner agencies) convened a Flood Forum to identify steps that stakeholders can pursue to mitigate flooding and reduce the risks of flooding in the monumental core. Among the recommendations of the Flood Forum is the evaluation of the existing sewer capacity in the Federal Triangle, which several of the Flood Forum participants jointly funded through a Memorandum of Understanding on September 30, 2009.

The partner agencies that supported this Study are:

- General Services Administration (GSA)
- District of Columbia Office of Planning (DCOP)
- District of Columbia Department of the Environment (DDOE)
- District of Columbia Homeland Security and Emergency Management Agency (DC HS&EMA)
- District of Columbia Water and Sewer Authority (DC Water)
- Federal Emergency Management Administration (FEMA)
- National Archives and Records Administration (NARA)
- National Capital Planning Commission (NCPC)
- National Gallery of Art (NGA)
- National Park Service (NPS)
- Smithsonian Institution (SI)
- U.S. Department of Justice (US DOJ)
- U.S. Environmental Protection Agency (US EPA)
- Washington Metropolitan Area Transit Authority (WMATA)

DC Water conducted this Study through their consultant, Greeley and Hansen. A Working Group consisting of staff from the partner agencies provided the consultants guidance in the appropriate design frequency storms to use for the modeling, facilitated access to the Federal Triangle for the spot elevation surveys, and augmented the analysis of flood prevention solutions. The partner agencies have committed to continue to work together after this Study is completed to determine the viability of implementing flood prevention alternatives analyzed and recommended in this Study.

1.1 PURPOSE AND SCOPE OF STUDY

The purpose of this Study is to understand how the existing sewer system performed during the 2006 Flood and identify and evaluate potential improvements to the sewer system to reduce the risk of flooding due to interior rains in the Federal Triangle area. Flood protection measures to address interior drainage will complement the current public investments in the 17^{th} Street Levee Project, which is intended to provide protection against river flooding in the Monumental Core, including the Federal Triangle.

Specifically, scope of this Study was to:

- Determine the capacity of the existing sewer system in the Federal Triangle area.
- Predict the ponding level in the Federal Triangle for storms that exceed the capacity of the sewer system.

- Assess the impact of interior rains on flooding in the Federal Triangle separate from river flooding
- Assess the impact and combined probability of concurrent river floods and interior rain events on flooding in the Federal Triangle.
- Identify alternatives to improve the existing sewer system to provide protection from interior rains for a variety of different storm return frequencies.
- Identify alternatives to monitor rain and or the sewer system to provide an early warning of when flooding may occur in the Federal Triangle area.
- Evaluate the alternatives in terms of cost, benefits, and practicality for implementation.

This study did not evaluate flood proofing or "armoring" of Federal Triangle buildings since this is outside of the core mission of DC Water. The "armoring" of buildings may be a viable solution to mitigate the impact of flooding on buildings in the Federal Triangle area and should be investigated by the partner agencies as part of a separate study.

This report is divided into the following sections:

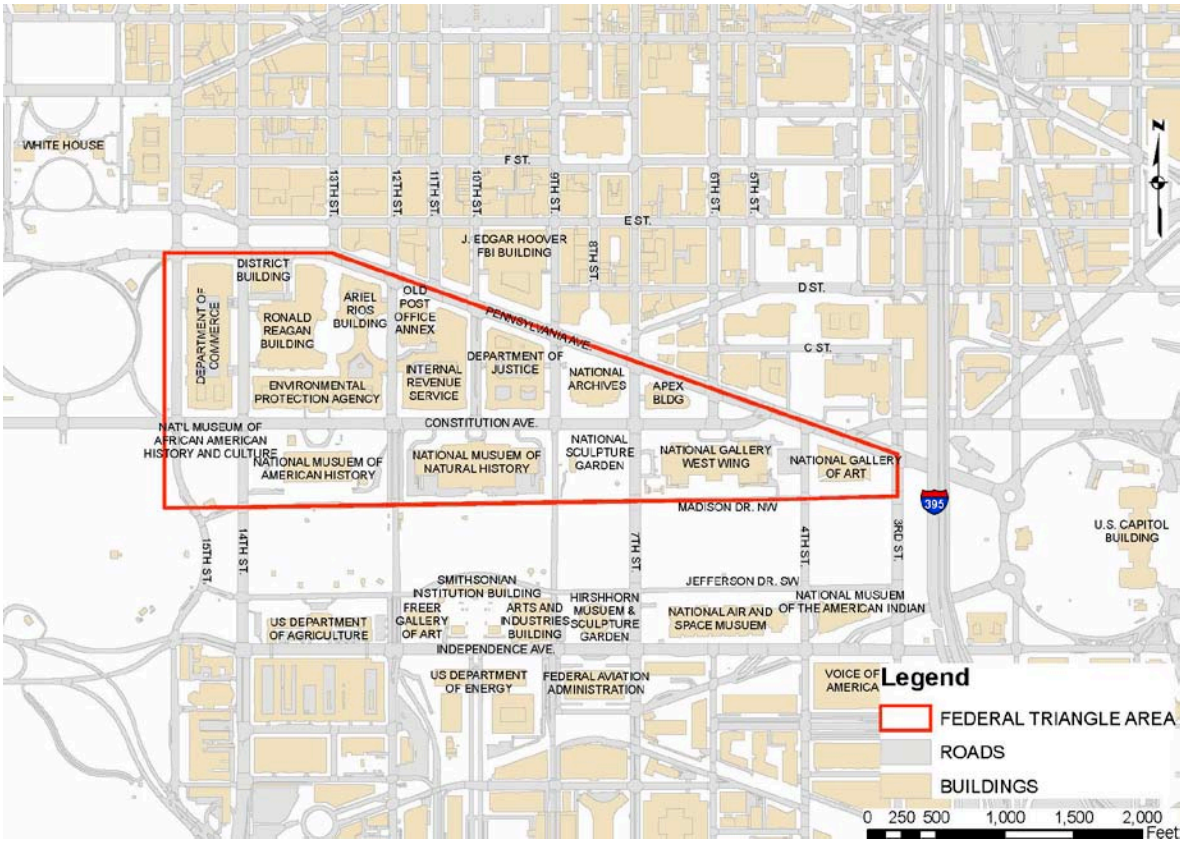
- Section 1 - Introduction
- Section 2 – Existing Conditions
- Section 3 – June 2006 Flood Event
- Section 4 – Model Development and Calibration
- Section 5 – Baseline Ponding Predictions
- Section 6 – Identification and Evaluation of Alternatives
- Section 7 – Findings

1.2 BACKGROUND

The Federal Triangle area is in the northwest quadrant of the District and is bounded by 15th St. NW to the west, Madison Dr. NW to the South, 3rd St. NW to the east, and Pennsylvania Ave. NW to the north and northeast. The Federal Triangle is the home of many prominent buildings owned by the Federal government. Figure 1-1 below shows the Federal Triangle in relation to other notable civic buildings such as the White House and the Capitol Building.

Figure 1-1

Federal Triangle Area



The Federal Triangle area is at the bottom of a topographic bowl. 15th St. NW and Constitution Avenue is the topographic low point of the Federal Triangle. The grade rises in all directions from this intersection. When the capacity of the existing sewer system is exceeded, runoff that cannot enter the existing sewer system will flow overland to an area of low elevation. The Federal Triangle area is in a low-lying area and is susceptible to a significant amount of ponding from runoff due to its low elevation.

The Federal Triangle area is located in the District's combined sewer area. Combined sewers are common in older cities. Combined sewers carry both sewage and runoff from storms. Modern practice is to build separate sewers for sewage and storm water and no new combined sewers have been built in the District since the early 1900's. Approximately 33% (12,478 ac) of the District has a combined sewer systems whereas 67% of the District uses a separate sanitary and storm water sewer system. DC Water operates both the combined and separate sewers in the District.

1.2.1 Previous Flooding Studies

Due to the damage caused by the June 2006 storm flooding, the General Services Administration (GSA) hired a consultant to study the problem. The GSA study was charged with determining what happened during the storm event and then to identify alternatives to mitigate risk of similar future flooding, and how to avoid catastrophic building failure if flooding were to occur again. The GSA Flood Mitigation and Prevention Study was completed in January 2007. The buildings within the Federal Triangle were resistant to the storm and flooding until the existing sewer system was overwhelmed and the stormwater began ponding on Constitution Avenue and overflowing onto the adjacent properties. At this time the stormwater began to back up into basements, penetrate perimeter moats and penetrate window assemblies. The electrical rooms within the GSA buildings were located in the basement and as storm flows entered the basements, the electrical equipment were flooded and failed. The GSA study identified potential flood prevention alternatives that could be made to the buildings.

1.3 PROJECT FUNDING

The Flood Study is funded and supported by the District of Columbia Department of the Environment (DDOE), District of Columbia Office of Planning (OP), District of Columbia Water and Sewer Authority (DC Water), National Capital Planning Commission (NCPC), U.S. General Services Administration (GSA), Smithsonian Institution (SI), District of Columbia Homeland Security and Emergency Management Agency (DC HS & EMA), and the Federal Emergency Management Agency (FEMA).

Appendix A contains the Memorandum of Understanding (MOU), dated September 30, 2009, which outlines the roles and responsibilities of the partner agencies as follows:

- All parties are responsible for identifying and designating the appropriate staff for administrative, project coordination and planning purposes during the course of the agreement. Responsibilities also include supplying reports/documents that NCPC requests for production of summary reports, coordination with the NCPC Project Manager at key project milestones in order to schedule appropriate FPSC meetings, participating in facilitated workshop to review recommendations from and consider next steps of the study.
- NCPC is responsible for facilitating completion of the Flood Study for the benefit of critical Federal and local stakeholders. Other responsibilities include engaging the relevant parties in consideration of possible solutions and mitigating measures.
- DC Water is responsible for entering a contract with an engineering company (Greeley and Hansen) to complete the tasks identified in the Flood Study Scope of Work (see Appendix A) as well as providing all project management services including the timely completion of tasks for the scope of work.

1.4 FEDERAL TRIANGLE STORMWATER STUDY WORKING GROUP

This study is the result of the collaborative effort of the federal and District agencies that comprise the Federal Triangle Stormwater Study Working Group (Working Group). The Working Group guided the consultants in the scope of the Study, the design parameters for the modeling, the range of alternatives for flood mitigation, and the findings of this Study. The Working Group consists of 23 representatives of Federal and District stakeholders including the various building occupants in the Federal Triangle and the other entities with properties along constitution Avenue, namely:

- General Services Administration (GSA)
- District of Columbia Office of Planning (DCOP)
- District of Columbia Department of the Environment (DDOE)
- District of Columbia Homeland Security and Emergency Management Agency (DC HS&EMA)
- District of Columbia Water and Sewer Authority (DC Water)
- Federal Emergency Management Administration (FEMA)
- National Archives and Records Administration (NARA)
- National Capital Planning Commission (NCPC)
- National Gallery of Art (NGA)
- National Park Service (NPS)
- Smithsonian Institution (SI)

- U.S. Department of Justice (US DOJ)
- U.S. Environmental Protection Agency (US EPA)
- Washington Metropolitan Area Transit Authority (WMATA)

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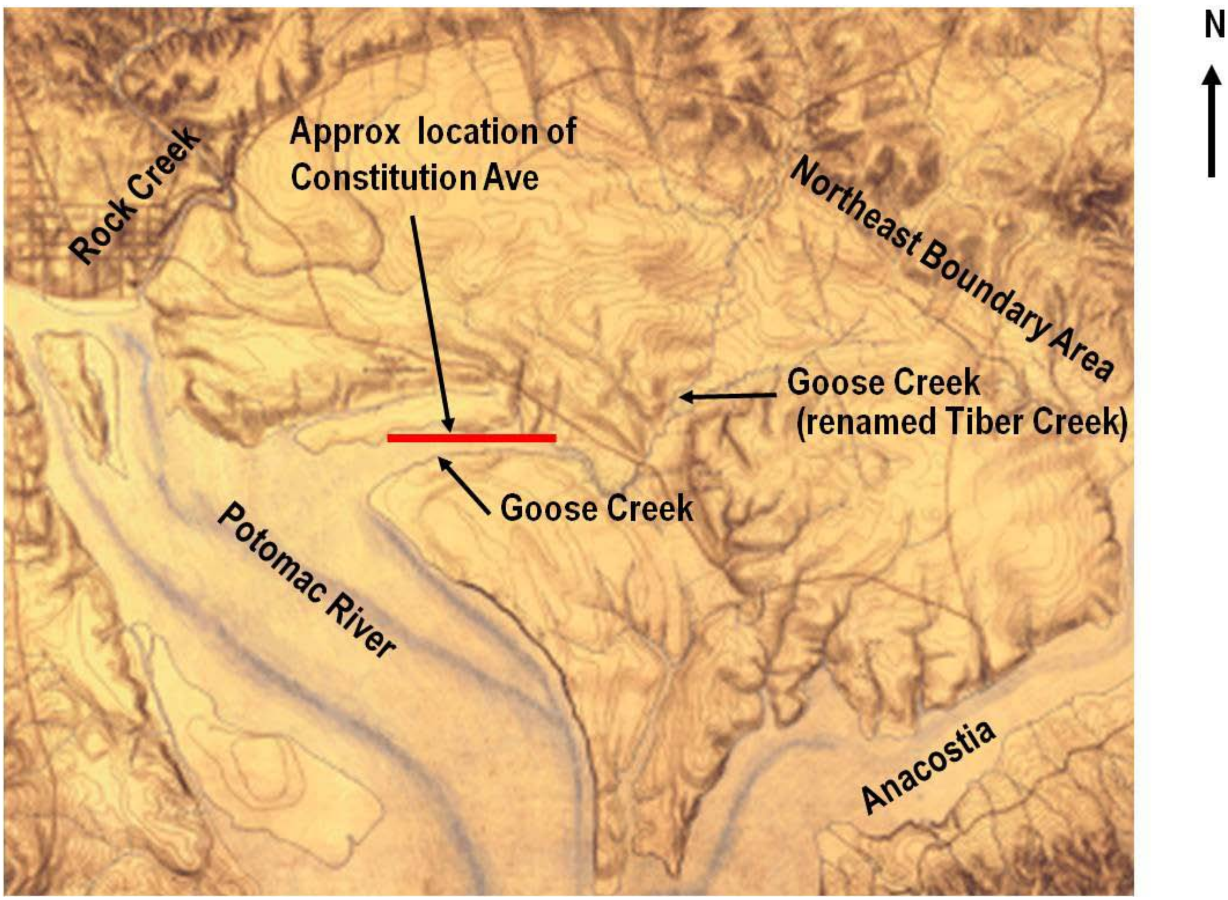
Section 2 EXISTING CONDITIONS

2.1 STUDY AREA

Washington DC has undergone many changes throughout the years. Figure 2-1 shows Washington DC and the Federal Triangle area circa 1791. Goose Creek is in the approximate location of Constitution Avenue. In the early 1800s the Washington City Canal was constructed on the site of Goose Creek, which can be found in Figure 2-2. In the late 1800s the Canal was being used less frequently for transportation, had begun to deteriorate, and was being used as an open sewer and storm drain. The Canal was an eye sore and a source of unpleasant odors. In 1884 the Washington City Canal was filled in and Constitution Avenue was constructed in its place, which can be found in Figure 2-3. Other canals in the area were also covered over to create sewers.

Figure 2-1

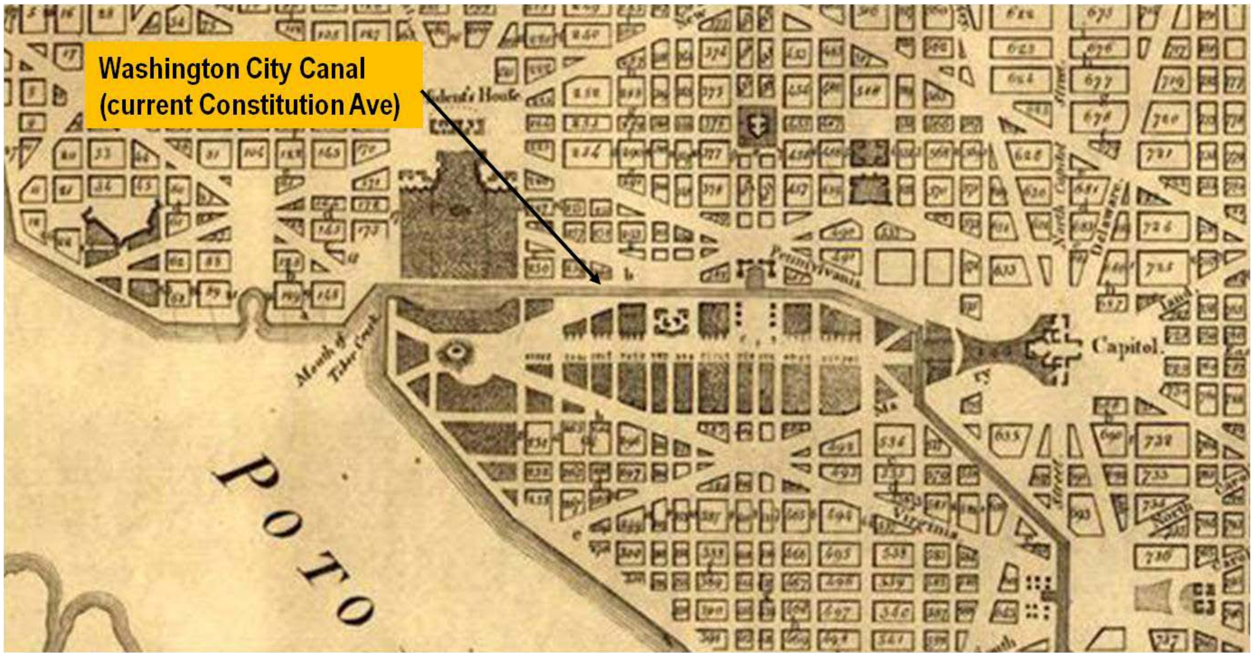
Federal Triangle and Goose Creek circa 1791



(1) Photo courtesy of Don A. Hawkins

Figure 2-2

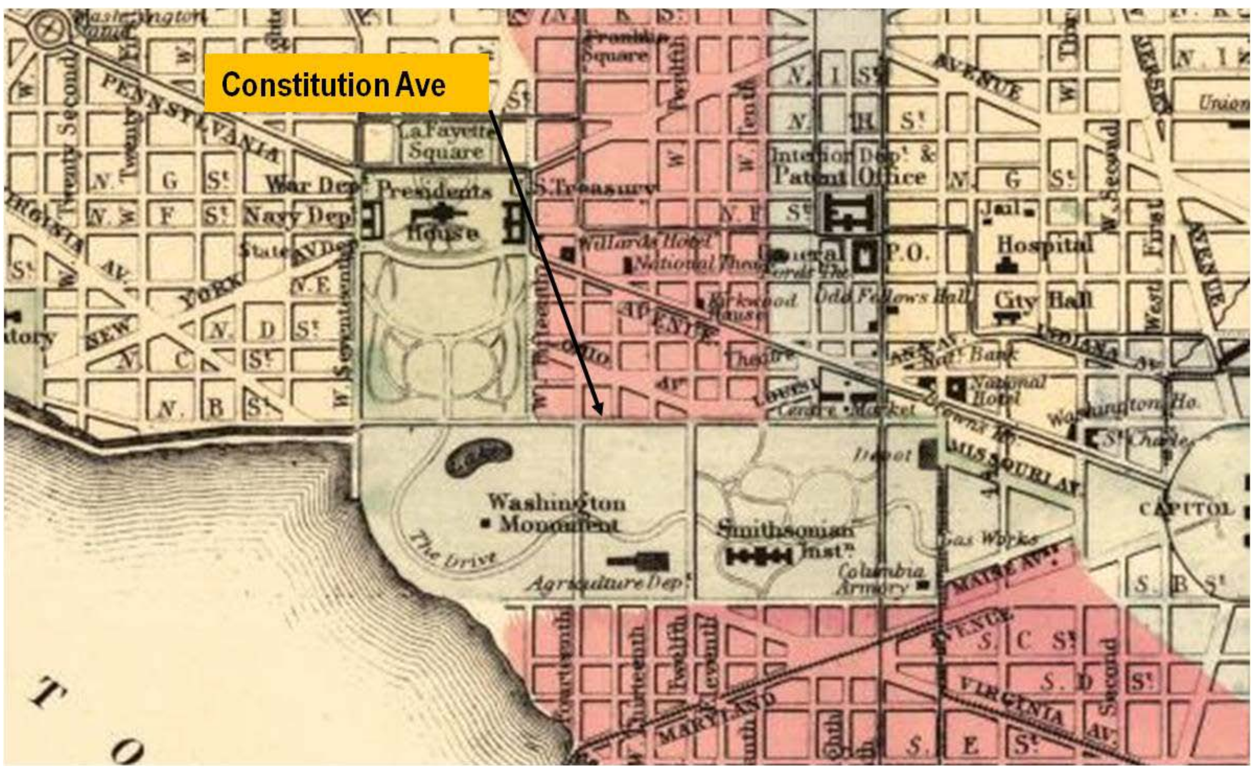
Federal Triangle and Washington City Canal circa 1800



(1) Photo courtesy of Don A. Hawkins

Figure 2-3

Federal Triangle and Constitution Avenue circa 1884



(1) Photo courtesy of Don A. Hawkins

The Federal Triangle area has continued to change over the years and is shown as it stands today in Figure 2-4. The Federal Triangle area is home to several prominent buildings owned by the Federal Government. Figure 2-5 shows the agencies that manage each building shown in Figure 2-4. These agencies include the General Services Administration (GSA), Smithsonian Institution (SI), National Archives and Records (NARA), National Gallery of Art (NGA), and the District Government. Table 2-1 lists each building in the Federal Triangle area, street address, and property owner and party responsible for maintenance.

Table 2-1

List of Properties and Owners in the Federal Triangle Area

PROPERTY	ADDRESS	OWNERSHIP & MAINTENANCE
Ariel Rios Federal Building	1200 Pennsylvania Avenue NW	GSA
Apex Building	Constitution Avenue NW & 7th St	GSA
Department of Commerce	1401 Constitution Ave NW	GSA
Department of Justice	950 Pennsylvania Avenue NW	GSA
District Building	Pennsylvania Avenue NW & 14th St	GSA
Environmental Protection Agency	1200 Pennsylvania Avenue NW	GSA
Internal Revenue Service	1111 Constitution Avenue NW	GSA
National Archives and Record Administration	700 Pennsylvania Avenue NW	NARA
National Gallery of Art	401 Constitution Avenue NW	NGA
National Sculpture Garden	700 Constitution Avenue NW	NGA
National Museum of African American History and Culture	1400 Constitution Avenue NW	SI
National Museum of American History	1400 Constitution Avenue NW	SI
National Museum of Natural History	Constitution Avenue NW & 10th St	SI
Old Post Office Pavilion	1100 Pennsylvania Avenue NW	GSA
Ronald Regan Building and International Trade Center	1300 Pennsylvania Avenue NW	GSA
WMATA Metrorail Tunnels and Station Entrances	Various locations	WMATA

Figure 2-4

Federal Triangle Buildings

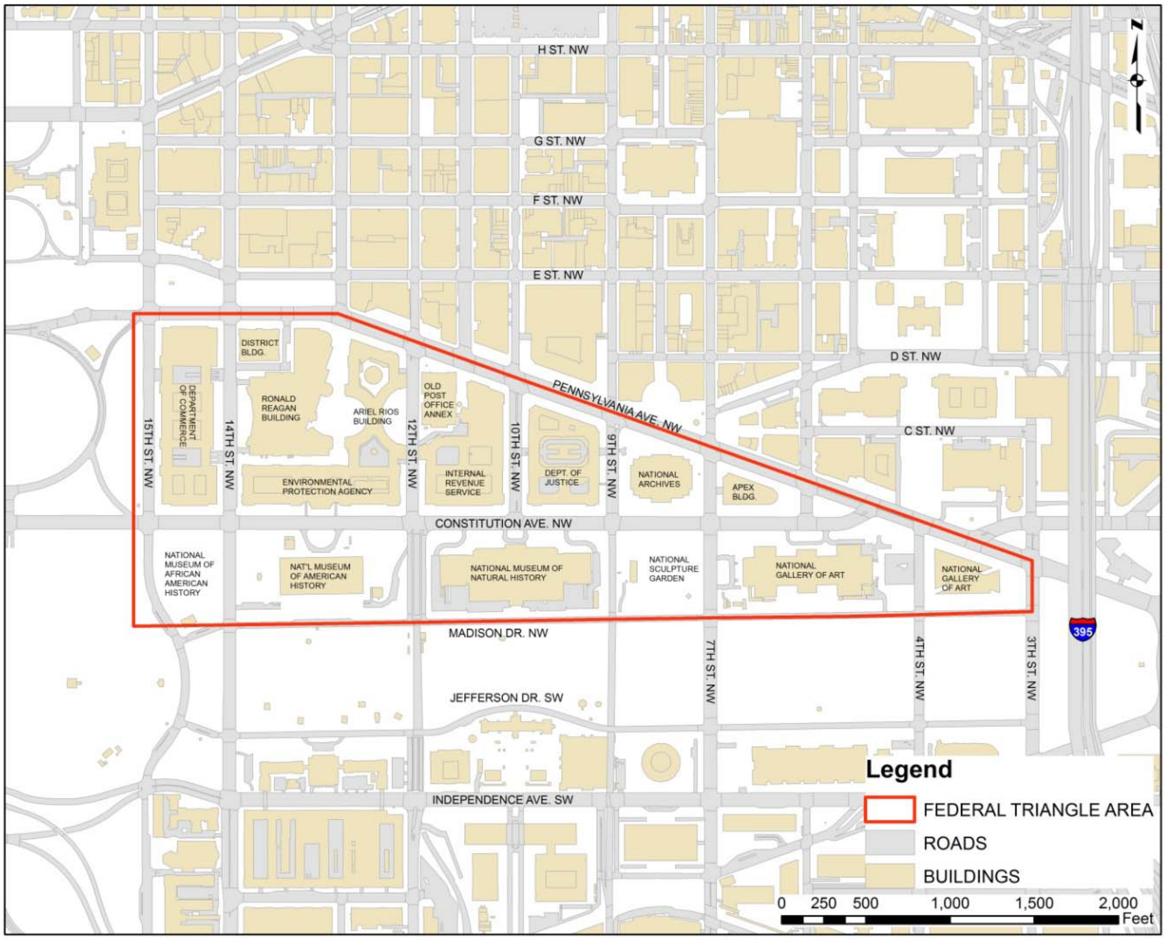
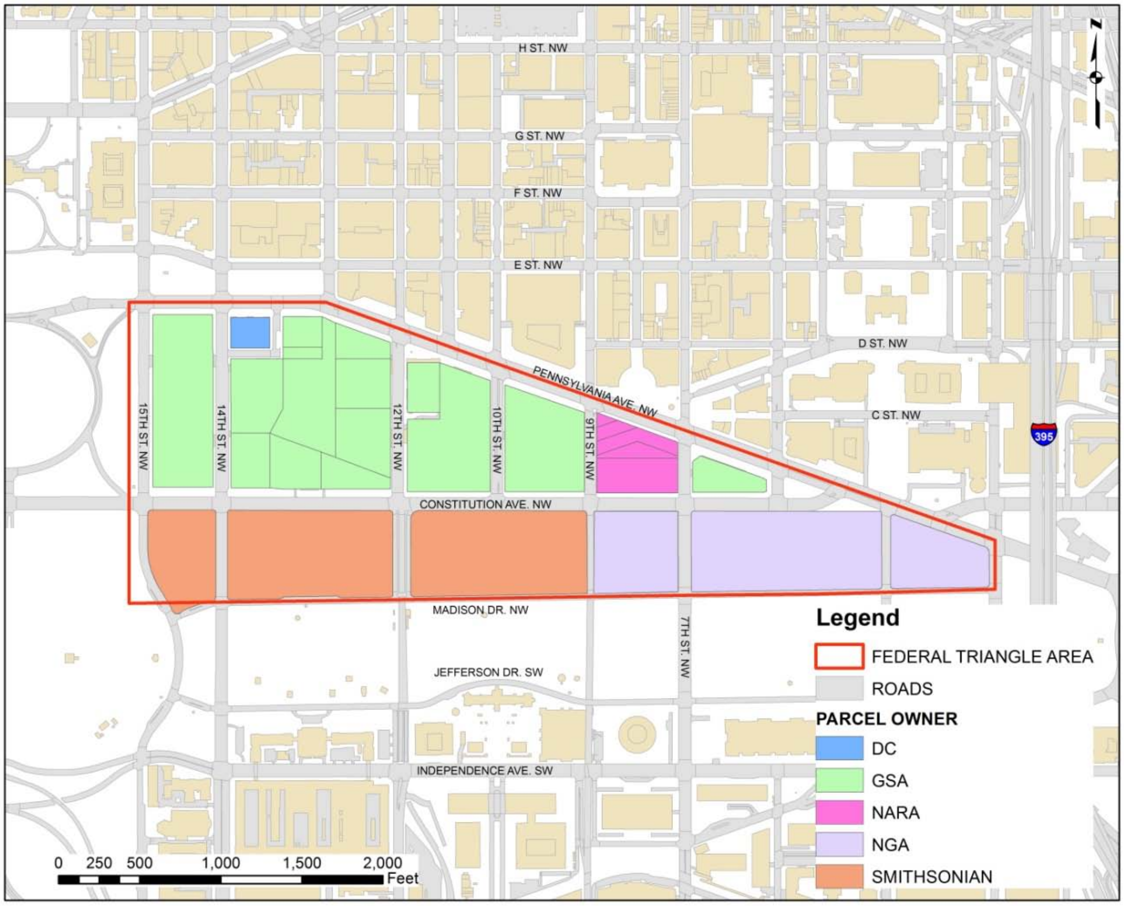


Figure 2-5

Federal Triangle Property Management



2.2 TOPOGRAPHY

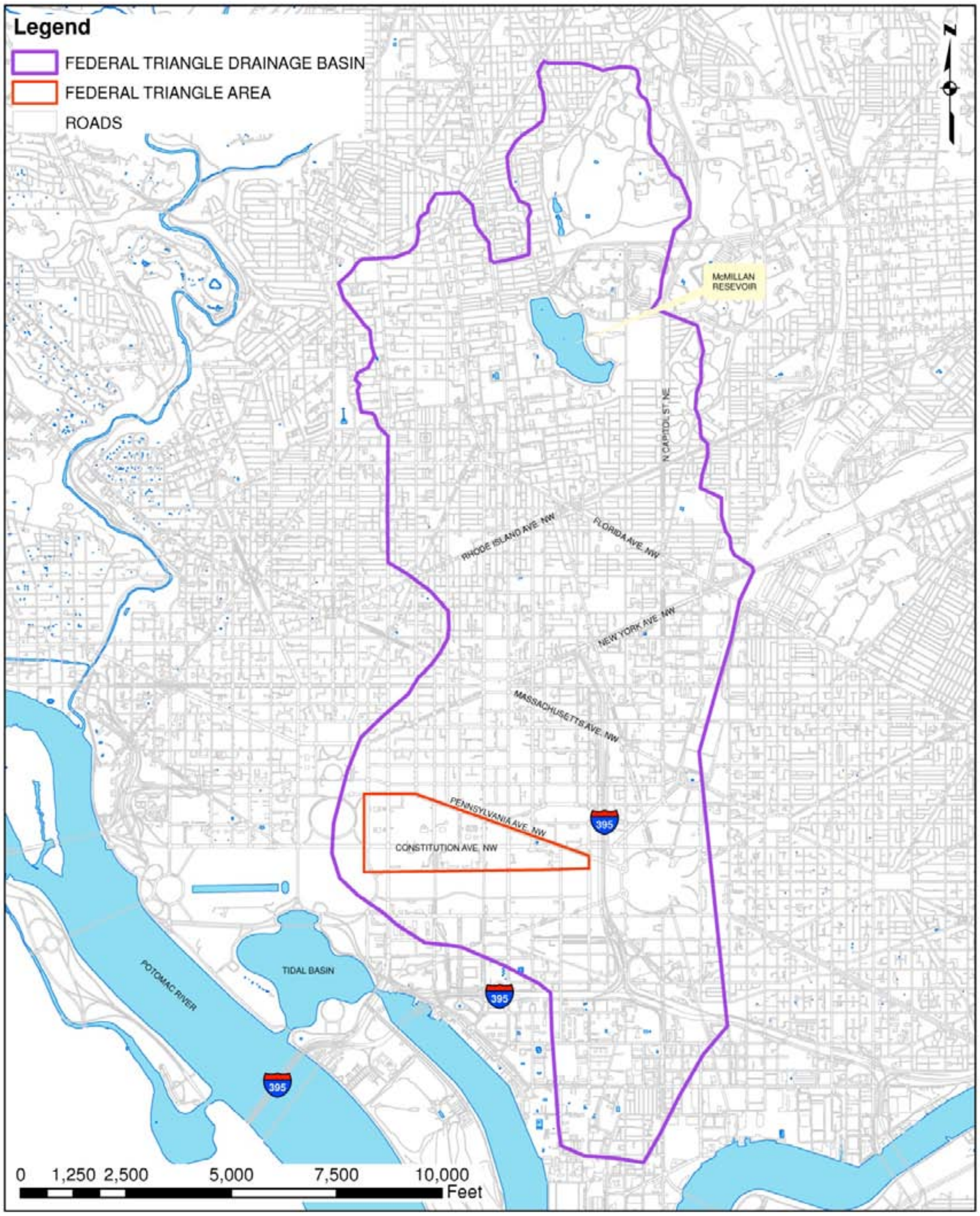
2.2.1 Federal Triangle Drainage Basin

Within the Federal Triangle drainage basin there are two types of drainage basins, a sewer drainage basin and a topographic drainage basin. Catch basins on the streets throughout the Federal Triangle drainage basin collect and convey rainfall to a myriad of underground sewers. These sewers convey rainfall by gravity to pumping stations and the rainfall is discharged away from the Federal Triangle. When the capacity of the sewers are exceeded, as happened during the June 2006 storm event, the rainfall backs up and ponds above ground.

The topography of the drainage basin can carry the excess rainfall (runoff) by gravity to the lowest spot, which is the Federal Triangle. The Federal Triangle drainage basin is 5.83 square miles (3,732 acres) as shown on Figure 2-6. In comparison, the Federal Triangle has a total area of 153 acres. Its lowest point is located at 15th and Constitution Avenue at an elevation of 5.02 feet (DC Engineering Datum) This elevation is approximately 10 inches higher than the 1-year flood elevation from the Potomac River and is approximately 21 inches lower than the 10-year flood elevation. Due to the low elevation in the Federal Triangle area, storm water runoff that is unable to enter sewer (combined and storm) pipes eventually flows over land to the Federal Triangle area and can pond to significant depths.

Figure 2-6

Federal Triangle Drainage Basin



2.2.2 Topographic Data Sources

A number of topographic data sources were available as part of this Flood Study. Table 2-2 shows a summary of the different data sources.

Table 2-2

Topographic Data Sources

Data Source	***Contour Interval***	***Year***	***Elevation (feet, DC Datum) at Low Point Along Constitution Ave & 15th Street***
DCGIS OCTO(1)	1-meter (3.22 ft)	1999	6.48
DCGIS OCTO(1)	2-foot	2008	3.62
WASA Sewer Counter Maps	None – spot elevations	varies	6.00
D.C Surveyor's Office Paper Maps	5 ft	1965	7.30

(1) DC Geographic Information System Office of the Chief Technology Officer

However, there is a significant discrepancy among the different data sources related to these elevations. Accurate topographic data is essential in the modeling effort in its ability to predict ponding elevations and volumes for a various storm and flood events. Although not part of the original scope of work, it was determined that a topographic site survey was needed as part of this Flooding Study. The additional topographic survey was performed in April 2010 by Mercado Consultants, Inc. A total of 421 spot elevations were obtained during the April 2010 survey, including top and bottom of curb elevations and sidewalk elevations for the flood extent area along Constitution Avenue and side streets between 7th and 16th Streets NW, 9th and 12th Streets NW tunnel crest elevations, and WMATA elevations where floodwaters could enter the Metro. In addition, planter elevations (top, bottom and June 2006 flood level) were collected at 15th and 9th Streets NW. These planter elevations were used in the modeling effort as part of the model calibration to the June 2006 flood event.

Figure 2-7 shows the existing contours of the Federal Triangle area. Figure 2-8 shows the survey points from the April 2010 survey. Refer to Appendix B for the detailed April 2010 survey drawings showing survey coordinates and elevations. The surface topography used for the modeling effort is from the DC Office of the Chief Technology Officer (DC OCTO). The existing contours in the Federal Triangle area were then revised as needed to be consistent with the April 2010 topographic survey. In general, the DC OCTO contours and the April 2010 topographic survey were a close match, but some significant adjustments were made, especially at the low spots. Figure 2-9 shows the resultant contour elevations in the Federal Triangle area used in the modeling effort. Figure 2-10 is a profile of the top of sidewalk elevation and bottom of curb elevation along Constitution Avenue. This figure shows how the entire area is relatively flat and how 15th and Constitution Avenue represents the low point for the entire Federal Triangle area.

Figure 2-7

Interior Federal Triangle Topography Based on D.C. OCTO Elevation Data

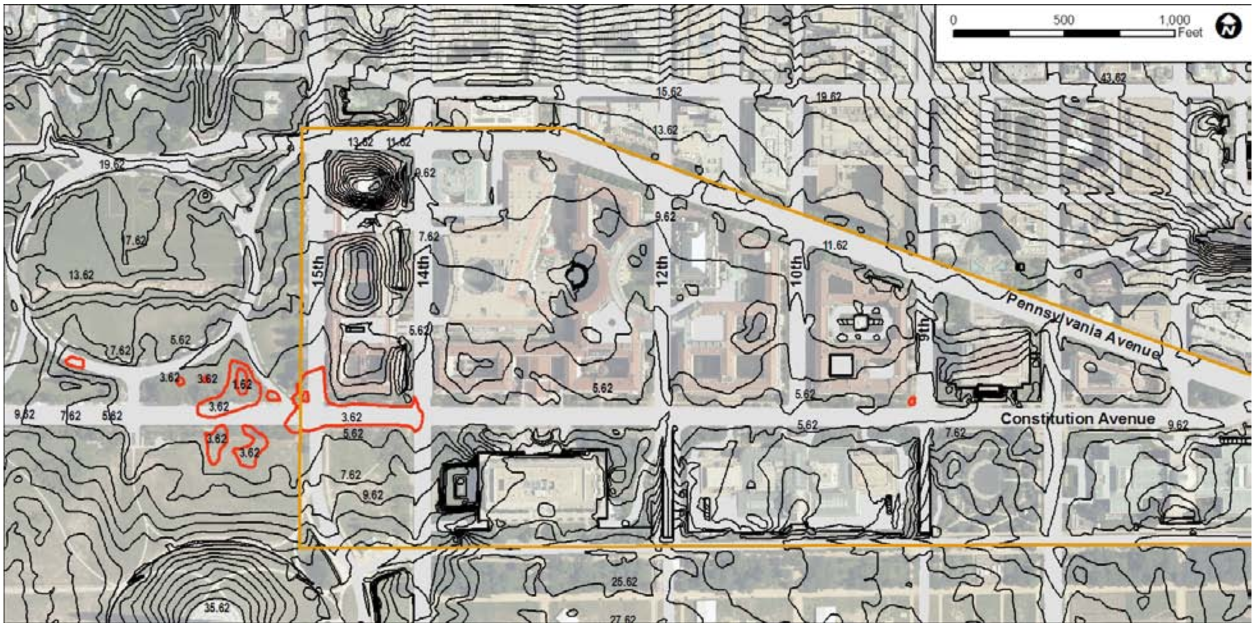


Figure 2-8

Survey Locations from April 2010

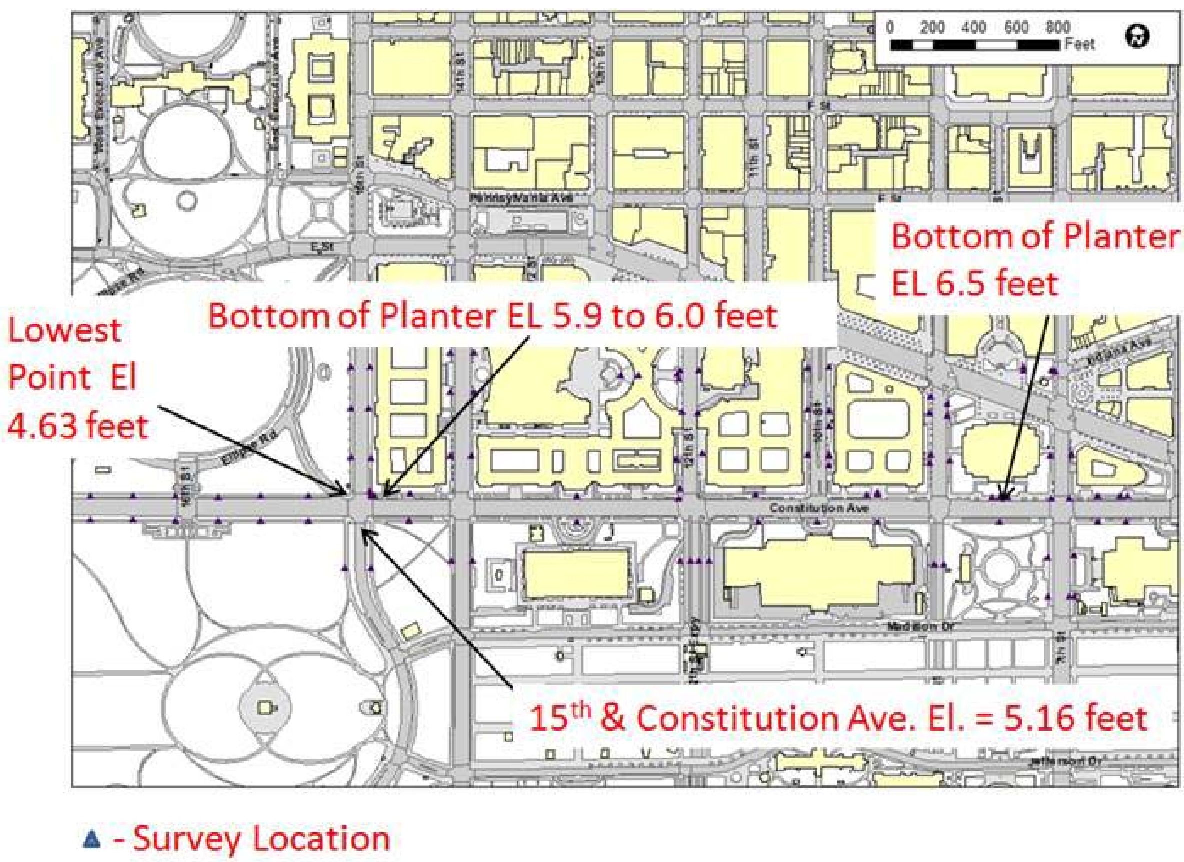


Figure 2-9

Federal Triangle Topography with Survey Data Incorporated

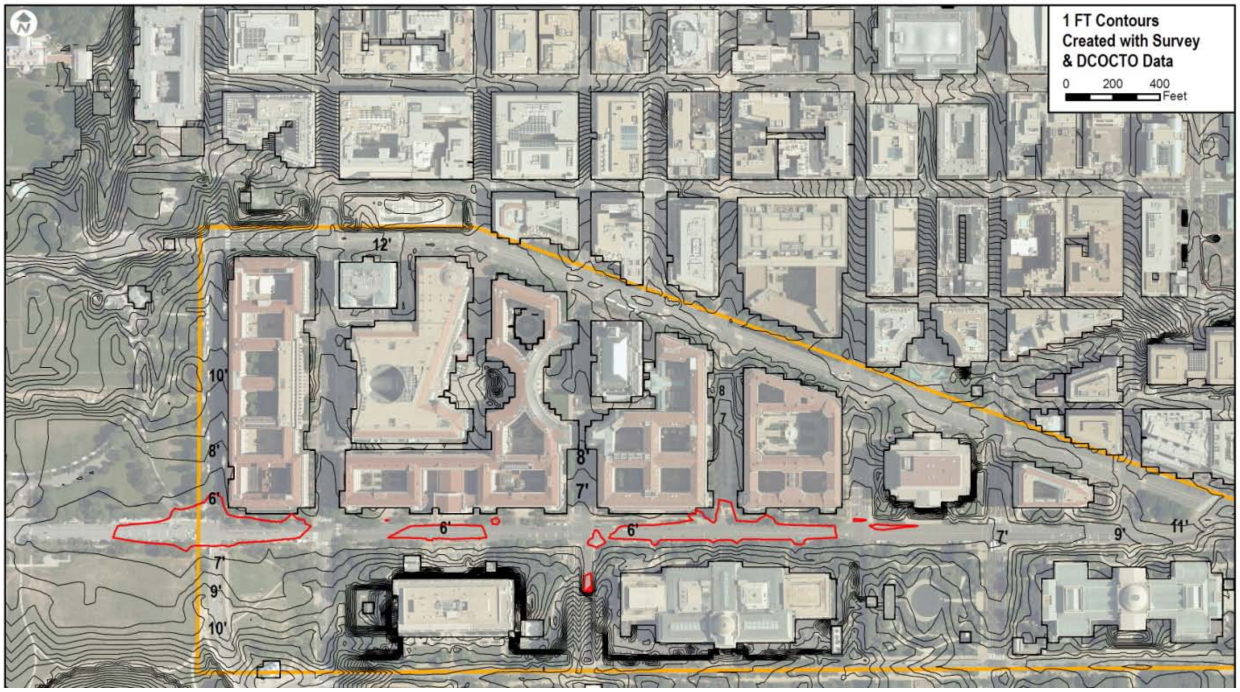
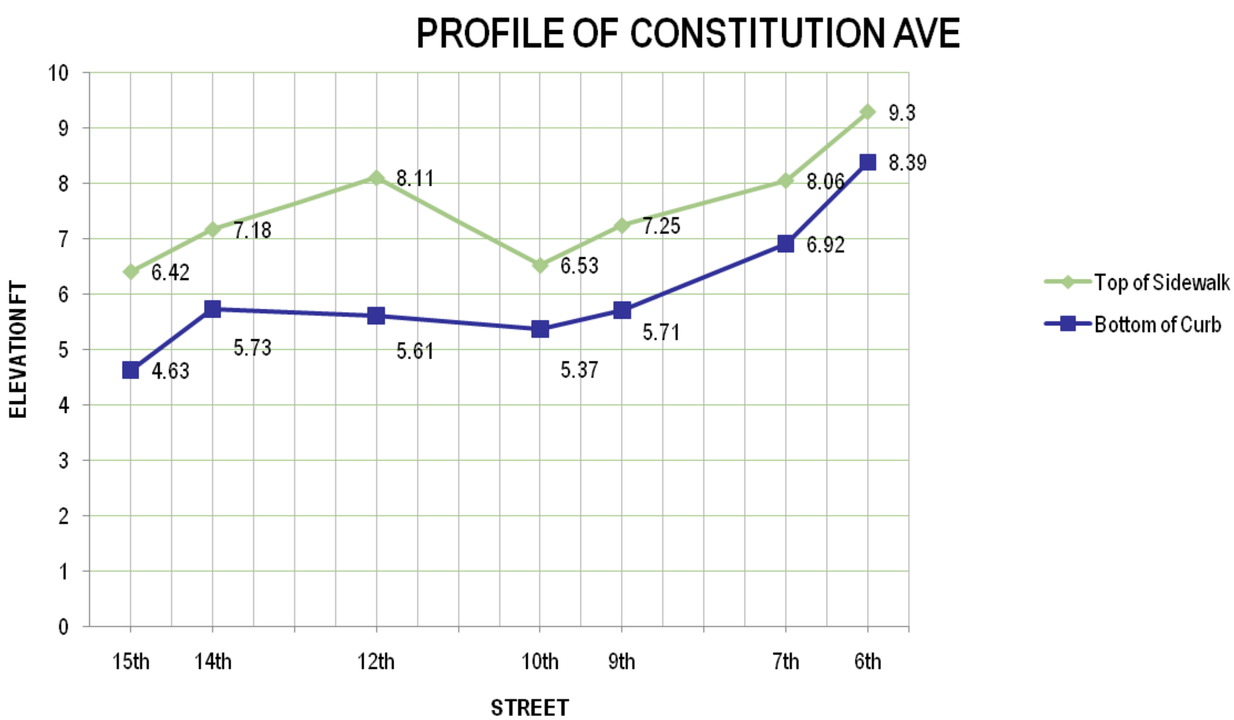


Figure 2-10

Survey Locations from April 2010



2.2.3 Project Datum

There are several different datum planes referenced in the Washington D.C metropolitan area. The datum plane used for this Flood Study is the D.C. Engineering Department Datum. All elevations referenced in this report are based on this datum. Table 2-3 shows the relationship between the D.C. Engineering Department Datum and other commonly used datum planes.

Table 2-3

Datum Planes

Relationship to Project Datum	***Elevation Relative to Project Datum (ft)***	***Datum***
Above Project Datum	0.24	Washington Aqueduct and Filtration Plants (W.A.D.)
	0.084	NAVD 1988
Project Datum	0.00	D.C. Engineering Department Datum
Below Project Datum	0.70	National Geodetic Vertical Datum 1929 General Adjustment
	0.85	Sea Level Datum (1912 General Adjustment)
	1.32	Mean Lower Low Water (MLLW) Datum
	2.11	National Park Service
	2.33	Bolling Air Force Base Datum

The datum conversion between NGVD 29 and NGVD 88 varies with location. The Datum Planes used for this Study are for the corner of 15th and Constitution Avenue. The following are the conversions:

- DC Eng Dept = NGVD 29 – 0.70’
- DC Eng Dept = NAVD 88 + 0.084’
- NAVD 88 = NGVD 29 – 0.0784’

The datums shown in Appendix E refer to specific stations; therefore, the conversion between NAVD 88 and NGVD 29 are as shown.

2.3 RAINFALL CONDITIONS

The duration of a storm (be it 6-hours, 12-hours, 24-hours, or more) has a dramatic effect on a storm’s total precipitation and peak intensity. The Federal Triangle drainage area is a relatively small area, consequently a storm does not require a long duration to produce the greatest intensity. A 6-hour duration storm accurately reflects the storm conditions experienced in the Federal Triangle drainage basin. Based on a 6-hour storm duration, the June 2006 storm had a return frequency of more than 200 years, or the storm having a 0.5% chance of being equaled or exceeded in any given year. Therefore, a series of 6-hour design storms were used as part of this Flood Study in order to assess the impact that interior rain events and concurrent river floods would have on flooding in the Federal Triangle area. Table 2-4 shows a summary of 6-hour design storms, along with their corresponding total precipitation and peak intensities. The storms analyzed ranged from a 1-year to a 500-year storm event. This information was obtained from the National Oceanic & Atmospheric Administration (NOAA).

Table 2-4

Design Storm Summary – NOAA 6Hr Duration

Return Frequency	Total Precipitation (inches)	5 Minute Peak Intensity (feet/hour)
1 year	1.86	0.39
2 year	2.22	0.46
5 year	2.82	0.54
10 year	3.30	0.60
15 year	3.81	0.62
25 year	4.02	0.67
50 year	4.62	0.72
100 year	5.28	0.77
200 year	6.00	0.82
500 year	7.08	0.87

Rainfall hyetographs, in 5-minute intervals, for the specified return frequencies presented in Table 2-4 can be found in Appendix H.

2.4 RIVER FLOOD STAGES

Flood stages for the Potomac River from confluence with the Anacostia River upstream to the Tidal Basin (Federal Triangle area) were obtained and are presented in this section of the Flood Study. The river flood stages were obtained for use in assessing the impact of concurrent river floods with interior rain events and the resultant flooding in the Federal Triangle area. The following two sources were used to determine river flood stages in the Federal Triangle area as part of this Flood Study and can be found in Appendix E. The Design River stage for Blue Plains WWTP Technical Memorandum was prepared to establish the basis of design for DC Water's tunnel system used for control of combined sewer overflows.

- *Flood Insurance Study, District of Columbia, Washington D.C.*, Federal Emergency Management Agency, updated September 27, 2010, Community No. 110001
    - The Federal Emergency Management Agency (FEMA) prepared a Flood Insurance Study (FIS) of the waterways of the District in November 1985 and was updated in September 2010. The FIS is based on hydrologic and hydraulic analyses of the drainage areas and waterways. Profiles of the waterways with corresponding water surface elevations are presented for storms with return frequencies of 10, 50, 100 and 500 years.

- *Design River Stage for BPWWTP*, G*reeley and Hansen*, March 03, 2006, Technical Memorandum drafted by John Cassidy
    - NOAA operates a water level gage in the Washington Ship Channel (Station # 8594900) located along Water Street in South West Washington DC as shown on Figure 2-11. The above memo presents Potomac River water surface elevations for a variety of tide conditions including the Mean Higher High Water Level (MHHWL) elevations and Mean Tide Level (MTL) elevations. These elevations are located at the confluence with the Anacostia River and the data was obtained from NOAA for periods between (5/1/1931 to 1/31/2006).

The Design River Stage for BPWWTP Technical Memorandum was developed using the 1985 FEMA (FIS). The Design River Stage for BPWWTP Technical Memorandum has not been updated to reflect the FEMA (FIS) update released in September of 2010.

The Army Corps of Engineers is in the process of raising the levees in the District to provide a greater level of protection from river flooding. FEMA has updated the District flood maps to show the revised extent of inland ponding from river flooding. The higher levees means that it will take a higher flood return frequency for the river to be able to crest the levees. Consequently, the area of land affected by overbank river ponding in the District will be reduced. However, the work being done to the levees will not alter the water surface elevation of the river. Table 2-5, which shows the river stage elevation at the Tidal Basin for each flood return frequency used as part of this Flood Study, remains unchanged. Additional information regarding river flood profiles, flood return frequencies, and river elevations can be found in Appendix E.

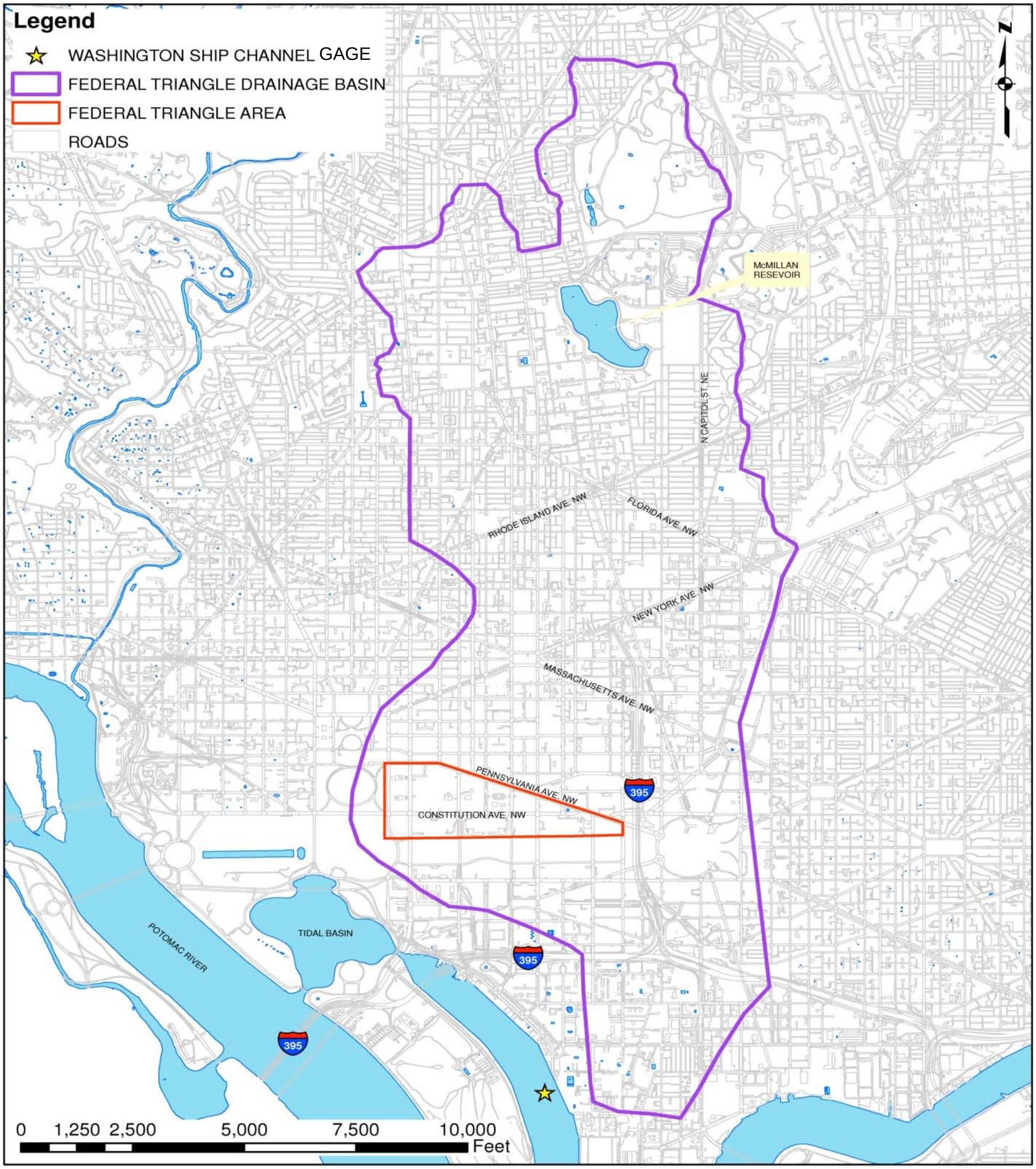
Table 2-5

Summary of Tidal Elevations (WSEL in D.C. Engineering Department Datum)

Flood Return Frequency	Data Source	Tidal Basin
MHHWL[(1)]	NOAA data analysis	2.1
MTL[(2)]	NOAA data analysis	0.1
1-year	NOAA data analysis	4.2
10-year	FEMA FIS	6.8
15-year	Interpolation of FEMA and NOAA data	7.9
25-year	Interpolation of FEMA and NOAA data	8.8
50-year	FEMA FIS	10.3
100-year	FEMA FIS	12.3
500-year	FEMA FIS	16.3

Figure 2-11

Location of Washington Ship Channel Gage (Station #8594900)



2.5 SEWER SYSTEM OVERVIEW

DC Water provides wastewater collection and treatment for the District, and wastewater treatment for surrounding areas including parts of suburban Virginia and Maryland at the District's Advanced Wastewater Treatment Plant (Blue Plains). The Blue Plains service area covers approximately 735 square miles. Figure 2-12 displays the Blue Plains service area. The vast majority of the sewers that were constructed more than one hundred years ago are still in operation today.

As discussed previously, DC Water operates a wastewater collection system comprised of separate and combined sewers. The Combined Sewer Service (CSS) area is located primarily in the older central part of the District. The Federal Triangle area is located in the CSS area of the District as shown on Figure 2-13. During dry weather, sanitary wastewater collected in the CSS area is conveyed to Blue Plains for treatment. During periods of heavy rainfall, the capacity of a combined sewer may be exceeded and the excess flow, which is a mixture of storm water and sanitary wastewater, is discharged directly to the Anacostia River, Rock Creek, the Potomac River or their tributary waters. This excess flow is called Combined Sewer Overflow (CSO). Release of this excess flow is necessary to prevent flooding in homes, businesses, and streets. Figure 2-14 depicts how a combined sewer system and separate sewer system functions. The occurrence of a CSO event depends on many factors other than the total rainfall amount, such as temporal and spatial rainfall distribution, rainfall intensity, antecedent moisture conditions, and the operations of the control measures in the combined sewer system. Approximately 66% of the combined sewer area drains to the lower Anacostia River, with the remainder tributary to Rock Creek and the Potomac River.

Figure 2-12

Blue Plains Service Area

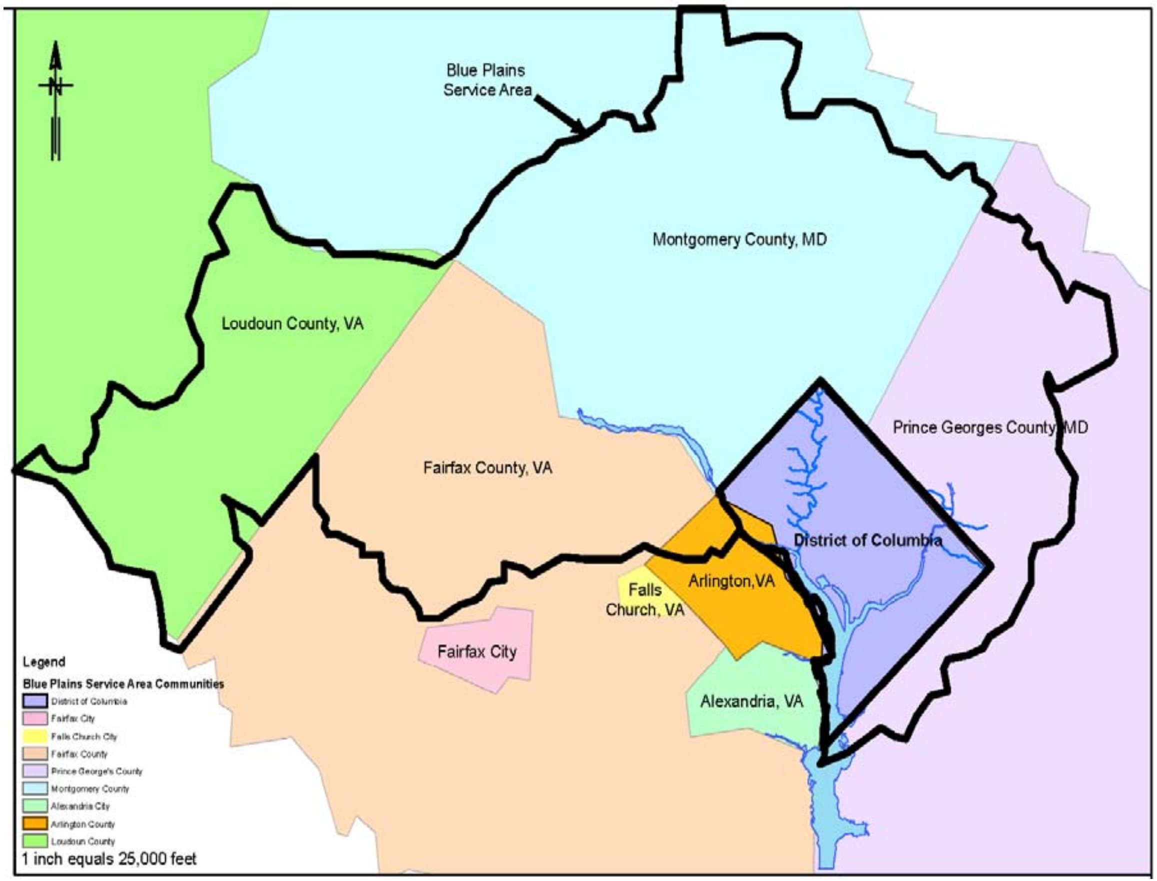


Figure 2-13

Combined Sewer Service Area in the District of Columbia

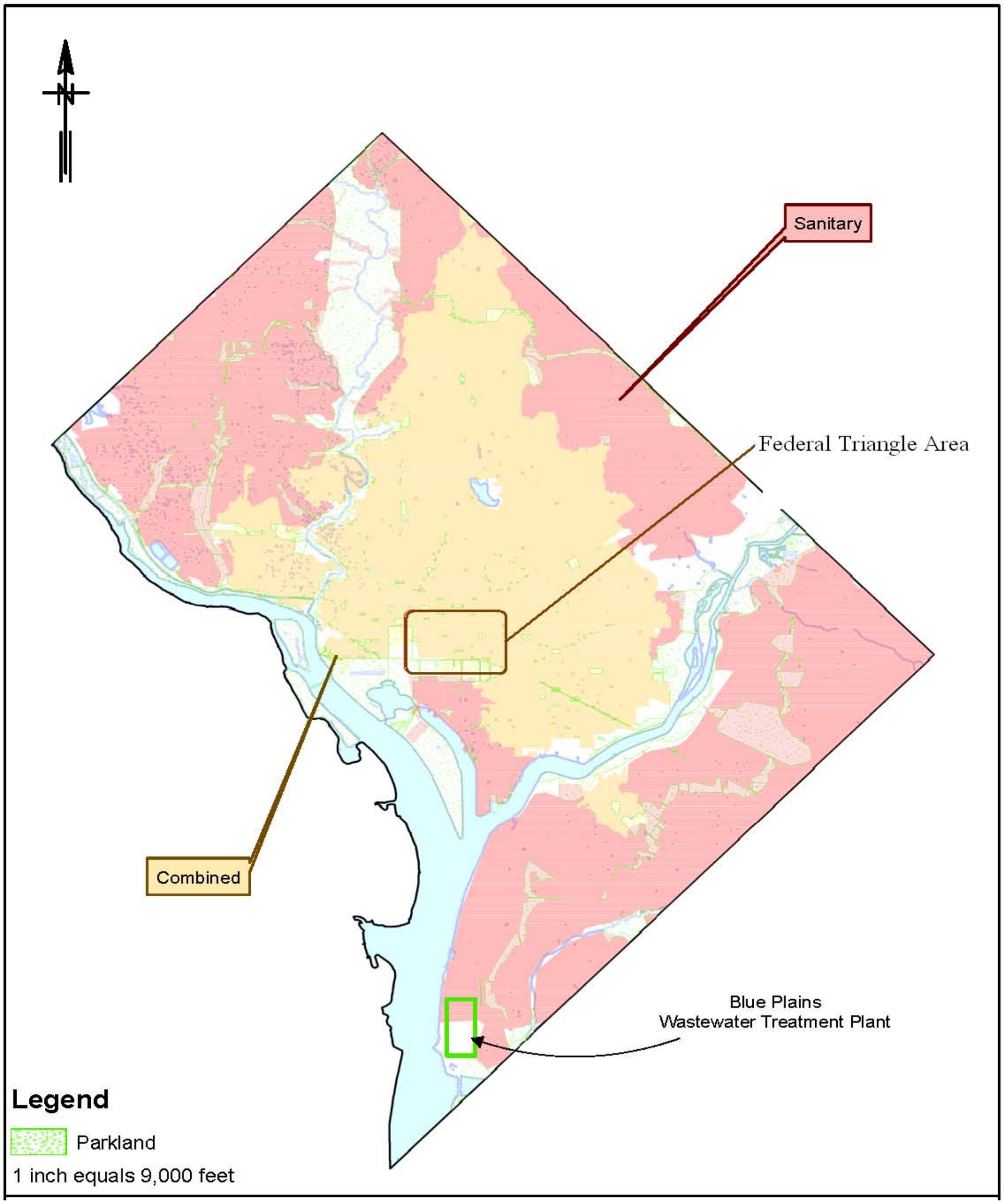
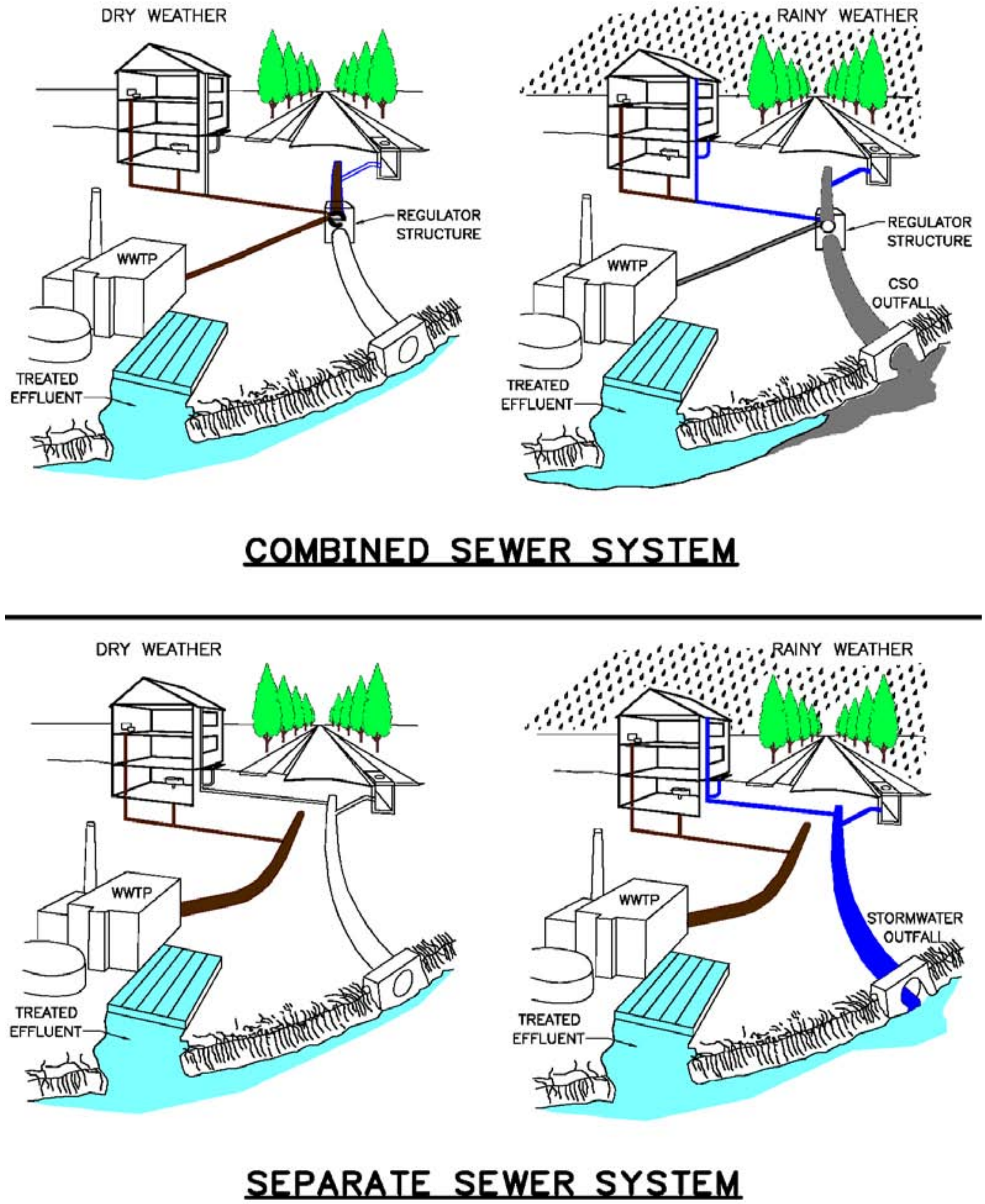


Figure 2-14

Combined and Separate Sewer System



2.5.1 Sewer System

A schematic of the major conveyance pipelines and pumping stations in the DC WATER's sewer system is presented on Figure 2-15. The drainage area is divided into two subsystems - an Anacostia system and a Potomac/Rock Creek system. The Northeast Boundary, Navy Yard, Fort Stanton, and Tiber Creek drainage areas are part of the Anacostia system. The other drainage areas are part of the Potomac/Rock Creek system, with the B St./New Jersey Avenue drainage area serving as a link between the Anacostia and Potomac/Rock Creek systems. The B St./New Jersey Avenue sewer trunk serves the federal triangle area and conveys combined sewer flows to the Main pumping station. This pumping station lifts the combined flows for treatment at the Blue Plains. The Federal Triangle is also served by the Constitution

Avenue Storm Sewer. The Constitution Avenue Storm Sewer conveys storm flows to the Tidal Basin by gravity. Figure 2-16 shows a plan of the Constitution Avenue Storm Sewer and the B St./New Jersey Avenue Sewer at the Federal Triangle.

Figure 2-15

Sewer System Schematic

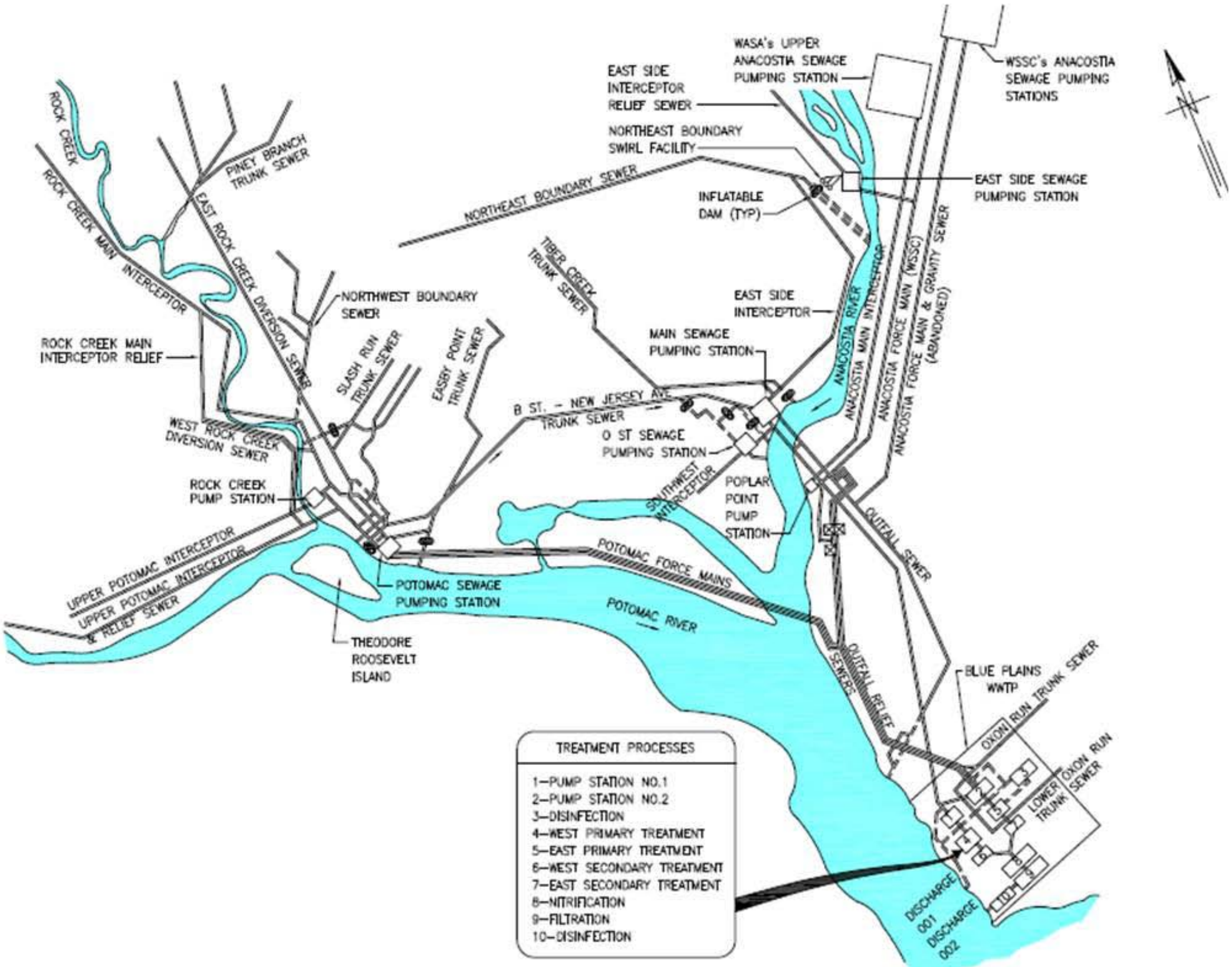
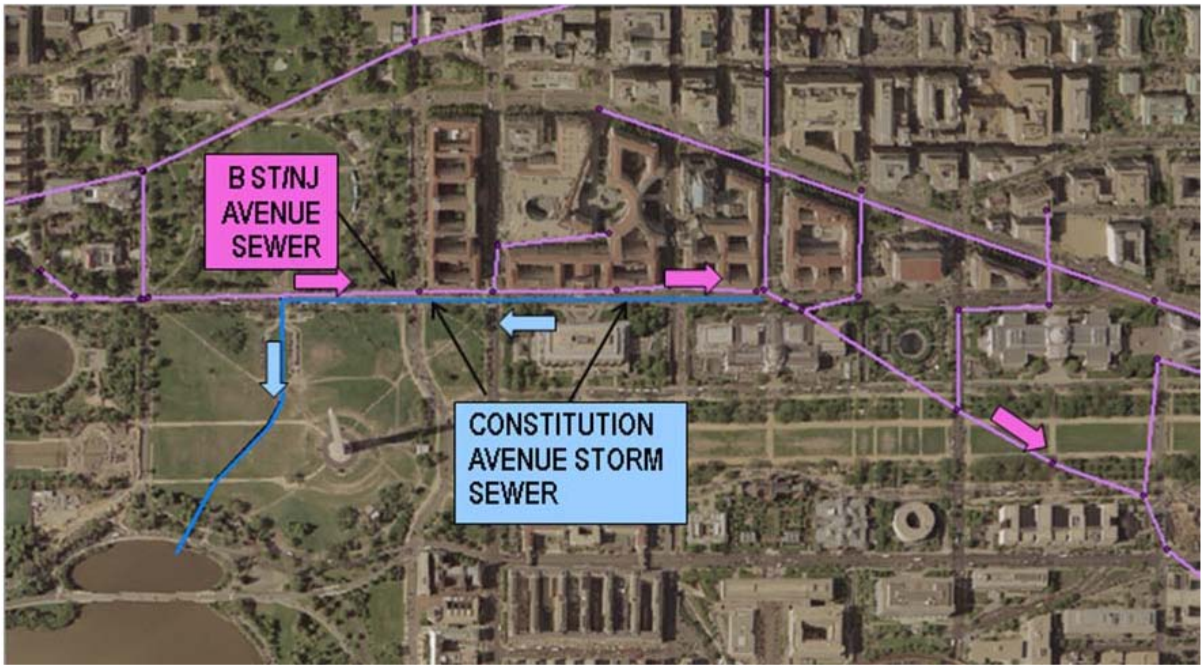


Figure 2-16

Major Sewers Serving the Federal Triangle



2.5.2 Pumping Stations

The Main and O Street Pumping Stations rehabilitations were completed in 2008. The Potomac Pumping Station is projected to be completed by the end of 2011. Rehabilitation of the remaining stations was substantially completed in 2008. The Main and O Street Pumping Stations serve the Federal Triangle area.

A brief description of the major wastewater pumping stations follows:

- Potomac Pumping Station: This station was designed to have a firm capacity of 460 mgd and pumps the wastewater from the Potomac/Rock Creek system to Blue Plains via force mains that cross under the Anacostia River at the confluence with the Potomac River. It also conveys wastewater loads from surrounding jurisdictions that enter the District via the Rock Creek Main Interceptor and the Potomac Interceptor.
- Main Pumping Station: This station is split into a sanitary side and a storm side. Main PS has three 90-mgd pumps and one 60- mgd pump. The sanitary side primarily handles dry weather flows. Main PS pumps wastewater from the Tiber Creek and B St./New Jersey Ave. drainage areas, as well as flows from the Potomac/Rock Creek system that enters the B St./NJ Ave. Trunk Sewer, under the Anacostia River via siphons to Blue Plains. The station has a firm sanitary pumping capacity of 240 mgd. The storm side is used during wet weather events, with a firm capacity of 400 mgd, to lift storm overflows into the Anacostia River and prevent flooding of basements and streets in the surrounding low-lying drainage areas.
- O Street Pumping Station: Like the Main Pumping Station, this station is split into sanitary and storm sides and was designed to have firm capacities of 450 and 500 mgd, respectively. The sanitary side pumps wastewater from the Southwest Interceptor, which serves a low-lying area, to one of the siphons that run under the Anacostia River to Blue Plains. The storm side pumps combined sewage from the B Street/New Jersey Avenue Relief Sewer, which serves a low lying area of the B St./New Jersey Avenue drainage area, to the Anacostia River. A series of inflatable

dams have been located in the sewers to direct flow to the different pumping stations. Set points have been established for different liquid levels that will trigger the inflatable dams to inflate or deflate accordingly. When the dams are inflated, no flow is able to get past. When a set point is reached it triggers the dam to deflate and flow is allowed to continue downstream. The inflatable dams are currently installed to direct flow to the Main Pumping Station and maximize the amount of storm sewer available for storage. If the liquid levels rise high enough, some dams will deflate and allow flow to go to O Street Pumping Station. If the liquid levels continue to rise a final set of dams will deflate and allow storm water to overflow to the river.

2.5.3 Drainage from Federal Triangle

As previously mentioned, the Federal Triangle area is a topographic bowl. All the rainfall in the Federal Triangle drainage basin will flow by gravity to this low point. The only way to remove the rainfall that accumulates in the Federal Triangle is via the Constitution Avenue storm sewer or the B Street/New Jersey Avenue sewer. The Constitution Avenue storm sewer is a gravity sewer and is limited in capacity by the river elevation. As the river elevation rises, the capacity of the Constitution Avenue sewer decreases. The B Street/New Jersey Avenue sewer is a pumped discharge and is not limited by the river. Instead the B Street/New Jersey Avenue sewer is only limited by the ability of the sewers to convey flow to the pumping stations and the pumping capacity available at the pumping stations.

2.5.4 Sewer System Operation During River Flood Stages

Varying volumes of the Constitution Avenue storm sewer are submerged depending upon the river elevation. As the river flood stage rises, the capacity of the Constitution Avenue storm sewer decreases. A tide gate is used to prevent the river from flowing backwards through the storm sewer and into the Federal Triangle. The tide gate is normally closed to prevent flow from going upstream. The tide gate is designed to only open in one direction, allowing flow to go downstream. As the liquid levels in the Federal Triangle rise, the pressure in the Constitution Avenue storm sewer rises and forces the tide gate open. When the river flood stages rise, the amount of pressure required to open the tide gate increases also. If the river flood stage rises high enough stop logs are installed in the Constitution Avenue storm sewer, isolating the river from the Federal Triangle. Additionally, stop logs are removed at Str. 15F and rainfall in the Federal Triangle is pumped out against the high river level by the Main and O Street Pumping Stations.

2.5.5 Sewer System Design Basis

The sewers in the District have been built since the 1870s and were constructed to handle a wide range of storm frequencies (1-year, 5-year, 10-year, etc). These original sewers were constructed under the direction of the Federal Government. After DC Water was created, it took over responsibility for most sewers in the District. DC Water adopted a design basis of 15-years storms for new storm sewers in the service area. It is not DC Waters policy to rebuild all existing sewer to achieve a design basis of 15-years for all existing sewers. Sewers in the Federal Triangle area were analyzed to assess their design capacity. The Constitution Avenue storm sewer has a design capacity of approximately a 2-year to 5-year storm. The B Street/New Jersey Avenue sewer has a design capacity of approximately a 15-year storm.

Section 3 JUNE 2006 FLOOD EVENT

3.1 RAINFALL DATA

From June 24, 2006 through June 26, 2006, intense rainfall inundated the District with approximately 14-inches of rainfall. Figure 3-1 shows the rainfall collected at the National Airport rain gauges during the storm.

Figure 3-1

Rainfall Data from National Airport Rain Gauges

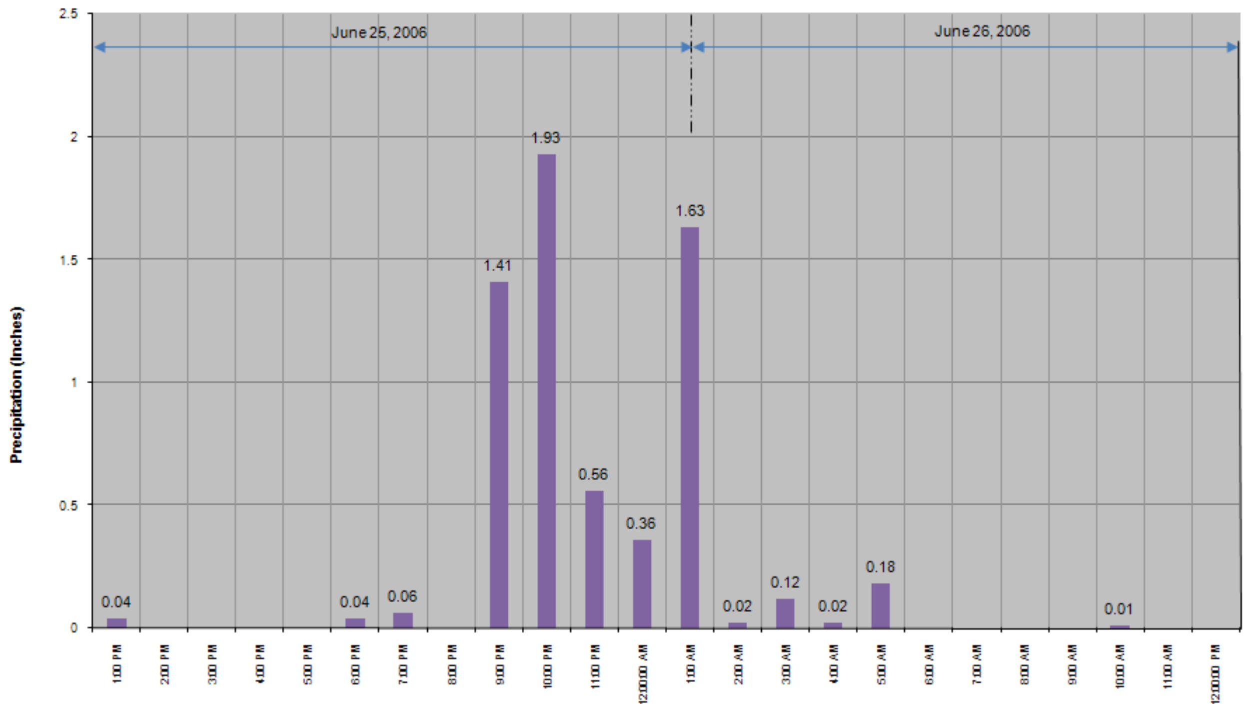
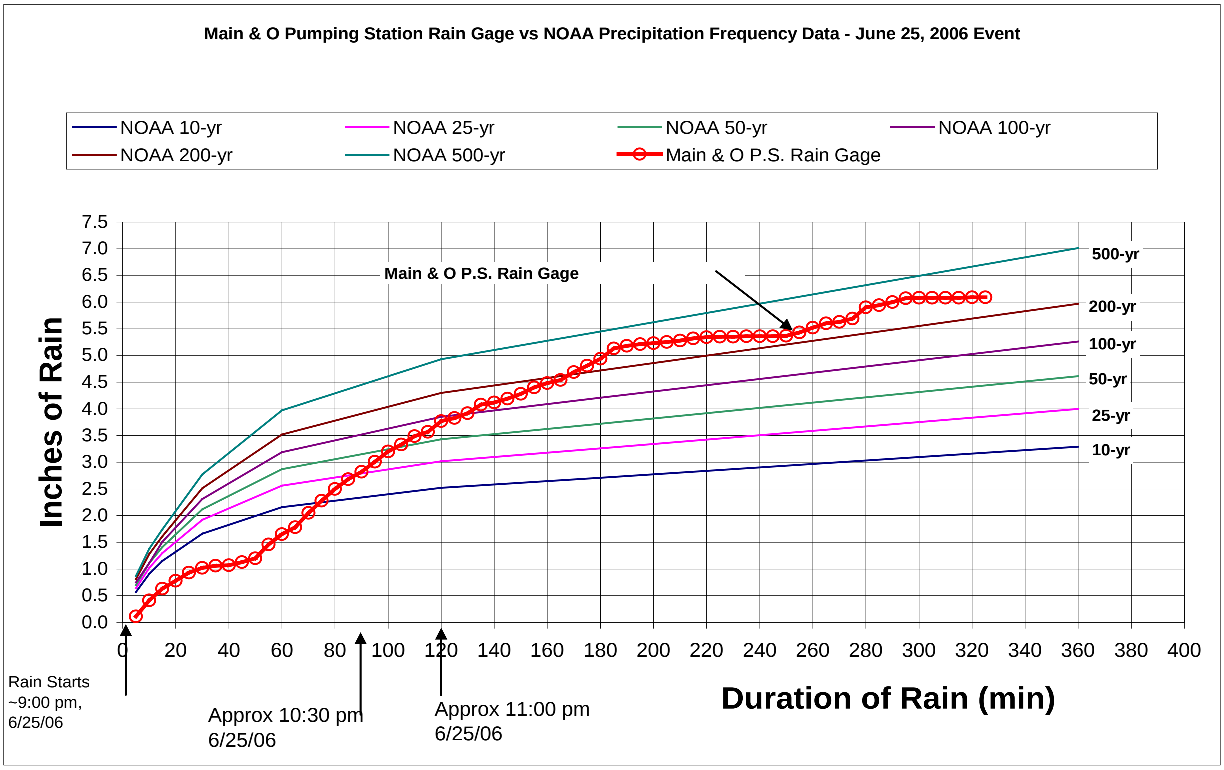


Figure 3-2 shows the rainfall collected at the Main and O Street Pumping Stations vs. the National Oceanic and Atmospheric Administration (NOAA) design storm frequencies. This rainfall data shows that the June 2006 storm exceeded a 200-year design storm.

Figure 3-2

Rainfall Data from Main & O Pumping Stations vs. NOAA Precipitation Frequency Data



3.2 DISTRICT OBSERVATIONS

From June 24 to June 26, 2006 the Washington, DC Metropolitan Area received an uncommonly heavy rainfall. Being the topographic low point of the District, the Federal Triangle area was hit hardest of all. City streets were flooded, the 9th and 12th Street tunnels under the mall were flooded and impassable, and two Metro stations experienced significant flooding. Businesses in the area were closed due to flooding and power outages. A 100-year-old American elm tree fell near the front door of the White House. Some members of the House of Representatives could not fly into Washington DC and the House of Representatives was forced to cancel votes scheduled for June 26. A state of emergency was declared in the District of Columbia and government officials have estimated damage to personal and public property in the tens of millions of dollars from the June 2006 storm. The agencies located within the Federal Triangle experienced the most extensive flooding that caused severe property damage. The Federal Triangle buildings suffered major property damage, power loss, and equipment and furnishings damage. Some federal operations were dislocated for a period of up to six months while the damage was repaired. Flooding in the Federal Triangle poses a significant risk to the countless historic and cultural national treasures and a security risk given the concentration of key federal functions. Below are pictures that were taken after the June 2006 storm event showing the extent of flooding within the Federal Triangle area.

Location: Constitution Ave. & 10th Street NW
(Showing Internal Revenue Service's Building) Source: GSA

Location: Constitution Ave. & 10th Street NW
(Showing Internal Revenue Service's Building and Department of Justice Building) Source: GSA

Location: 12th Street Tunnel
Source: NCPC

Location: Constitution Avenue
Source: GSA

3.3 EXISTING SEWER SYSTEM PERFORMANCE DURING JUNE 2006 STORM

3.3.1 Constitution Avenue Storm Sewer Inspection and Assessment

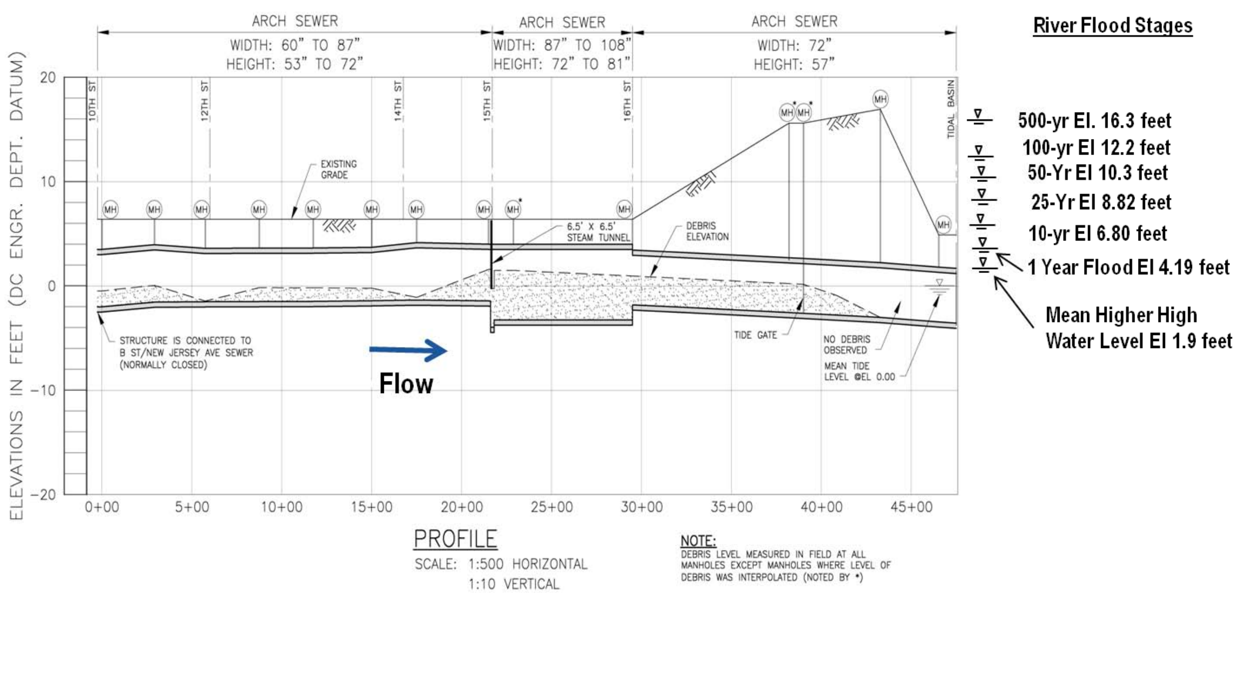
The Constitution Avenue Storm Sewer was inspected to determine how it performed during the June 2006 storm. Video camera inspection of the storm sewer was not possible due to the profile of the sewer and sedimentation that has collected in the storm sewer. Instead, silt measurements were taken from the manholes along the length of the storm sewer.

The Constitution Avenue storm sewer capacity is limited by many factors. The low grade elevation at the Federal Triangle compared to the Tidal Basin water surface elevation means there is not a lot of available head to push water out of the Federal Triangle and into the tidal basin without flooding. From surveys we know that the elevation of the grade at 15th and Constitution Avenue is El. 4.63, which is only slightly higher than the mean tide level at EL. 0.0, the mean higher high water level at El. 1.9, or the 1-year river flood at El. 4.58. The Constitution Avenue storm sewer is also intersected by a GSA steam tunnel, which significantly restricts the capacity of the storm sewer. Additionally, the Constitution Avenue Storm Sewer was "created" from portions of abandoned sewer in an attempt to reduce the number of combined sewer overflows. Looking at a profile of the sewer one can see that the sewer has steps in it and portions of the sewer are actually sloped towards the Federal Triangle, not the Tidal Basin. DC Water is making arrangements to clean the storm sewer; however the sewer will always be prone to accumulating sediment.

While a large portion of the Constitution Ave. Storm Sewer was filled with sediment during the June 2006 storm event, rainfall would not have been able to be conveyed from the Federal Triangle to the Tidal Basin even if the storm sewer had been completely unclogged for the reasons described above. The Constitution Avenue Storm Sewer has limited effectiveness, particularly during large storms. Figure 3-3 shows the profile of the Constitution Ave. Storm Sewer and findings from the inspection.

Figure 3-3

Constitution Ave. Storm Sewer Inspection Results

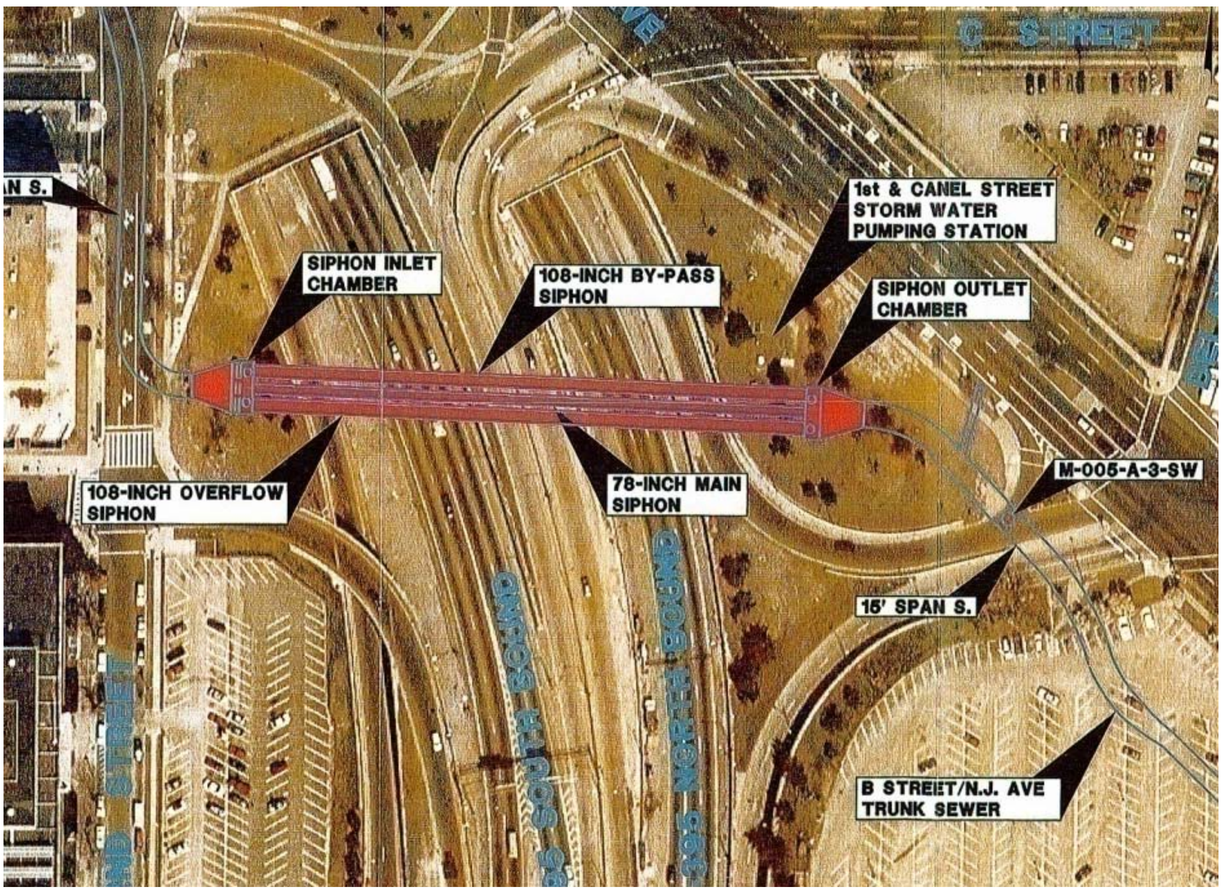


3.3.2 B Street/New Jersey Avenue Inspection and Assessment

The B Street/New Jersey Ave. Sewer was also inspected to determine how it functioned during the June 2006 storm event. The sewer size is 7-foot to 12-foot in diameter in the Federal Triangle and increases to 18-foot by 16-foot sewer at Main Pumping Station. An inspection of the sewer was performed in 2004 and at that time the sewer was found to be clean except for the siphons beneath I-395. There is one 78-inch siphon and two 108-inch siphons. Routine operation is to have flow go through the 78-inch siphon and one of the 108-inch siphons. The remaining 108-inch siphon is used as a bypass if maintenance is required on the siphons. During the inspection, the 78-inch siphon was found to be about 90% obstructed with debris while both 108-inch siphons were found to have only light debris. The siphons were cleaned by DC Water from August to November 2006. Figure 3-4 shows the location of the B Street/New Jersey Avenue Storm Sewer Siphons

Figure 3-4

B St./NJ Ave. Storm Sewer Siphons

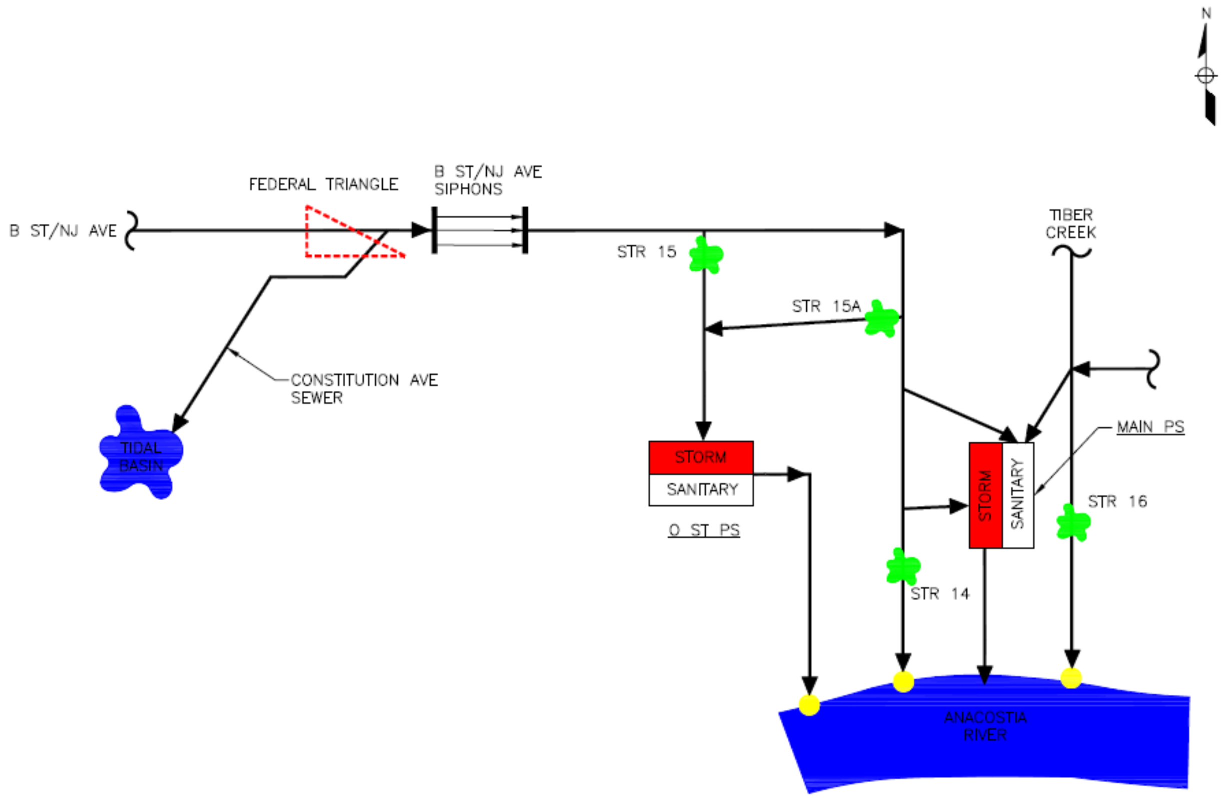


3.3.3 Pumping Station Assessment

A series of inflatable dams are installed at various locations in the sewer system to direct flow in different directions and for maximizing storage within the sewer system. Figure 3-5 shows the existing interconnections of the sewer system, pumping stations, and the inflatable dams.

Figure 3-5

Existing B Street/New Jersey Ave Sewer Flow Diagram



Normal operation for the B Street/NJ Avenue sewer is to direct as much stormflow as possible to the sanitary pumps located in the Main Pumping Station. This stormflow can then be pumped to the Blue Plains WWTP for treatment along with flows from Tiber Creek and other sewersheds. To accomplish this, inflatable dams Str. 15 and Str. 15a have been installed to direct flow to either the Main Pumping Station or O Street Pumping Station. These dams are set to deflate once liquid within the sewer reaches EL. -1.0. Once these dams deflate, stormflow can then travel to the O Street Pumping Station storm pumps. During the June 2006 storm, inflatable dam Str. 15 deflated, flow was sent to the O Street Pumping Station storm pumps, and the storm pumps all operated at maximum capacity.

Inflatable dam Str. 14 is located upstream of the Main Pumping Station storm pumps. Like Str. 15, and Str. 15a, Str. 14 is designed to be normally inflated and direct flow in the B Street\New Jersey Avenue Sewer to the Main Pumping Station sanitary pumps. Str. 14 is also designed to maximize the storage volume within the sewer system and to minimize the number and duration of combined sewer overflows to the river. During storms, when liquid levels get too high within the sewer system, Str. 14 is designed to deflate and send flow to the storm pumps in the Main Pumping Station. The B Street/NJ Avenue sewer is very shallow and in fact the crown of the sewer is very close to street level. The low grade elevation of the Federal Triangle (EL. 4.63) is almost equal to the crown of the B Street/NJ Avenue storm sewer (approximately EL. 3.0) and the elevation that Str. 14 is set to deflate at (EL. 3.0). The stormflow experiences friction loss as it travels through the sewer. This causes the liquid level, or hydraulic grade line (HGL), in the sewer to in turn increase. The HGL ultimately rises above the crown of the sewer and because the grade and sewer elevations are so close to each other, the HGL rises above grade and flooding occurs. During large storm events the rainfall will pond on the street at the Federal Triangle prior to the liquid level triggering Str. 14 to deflate. This was the case during the June 2006 storm. Even though the rainfall was ponding and causing flooding at the Federal Triangle, the liquid levels at Str. 14 never got high enough to trigger Str. 14 to deflate. Consequently the Main Pumping Station storm pumps were not utilized during the storm event. Even if Str. 14 had deflated, it would not have been possible to prevent flooding because the friction on the stormflow traveling through the sewer would have caused the HGL to rise above grade. Significantly larger sewers would be required in order to convey sufficient flow to the pumping stations to prevent flooding.

As part of the Three Party Consent Decree, DC Water was required to rehabilitate the Main and O Street Pumping Stations to improve their ability to handle combined sewer overflows. This rehabilitation work is part of a major commitment of capital funds and resources by DC Water. It requires that portions of the pumping facilities must be taken out of service to be worked on. This work was sequenced so that interruptions to the pumping capacity of the pumping stations would be minimized. During the June 2006 storm event, one of the Main Pumping Station sanitary pumps was out of service for rehabilitation. The two remaining sanitary pumps that were available operated to peak capacity during this storm.

There was no evidence of a power failure or equipment failure of the pumping station that resulted from the storm. All pumps and facilities that were available for service operated as they were intended. The intensity and duration of the June 2006 storm event was of such magnitude that it overwhelmed the capacity of the sewer system.

3.3.4 Impact of Sewer System Conditions on Ponding Conclusions

An analysis was performed to calculate the effect on the ponding level during the June 2006 storm assuming that the existing sewer system was optimized, which would require the following sewer system conditions:

- Assume Constitution Avenue Storm Sewer had no sedimentation accumulation during flood event
- Assume the 78" B Street/New Jersey siphon was clean during flood event.
- Assume that one of the Main Pumping Station sanitary pumps was not out of service, thereby allowing the station to achieve its design firm pumping capacity of 240 mgd

The above noted conditions consist of optimizing the existing sewer system to maximize the ability to drain floodwaters from the Federal Triangle. The collection system model was utilized to analyze the impact of these conditions on the June 2006 ponding event. The collection system model found that the ponding depth on the Federal Triangle during the June 2006 storm would have only been decreased by approximately 4-inches. A 4-inch reduction in ponding levels would not have stopped flooding from occurring and damaging the federal buildings. The magnitude of the June 2006 storm was so far above and beyond the capacity of the sewer system that flooding could not have been avoided.

Section 4 MODEL DEVELOPMENT AND CALIBRATION

4.1 BACKGOUND

Hydrologic and hydraulic models of the DC Water combined and sanitary sewer systems were initially developed to support CSO Long Term Control Planning in the period 1998 to 2001. The initial model used the Danish Hydraulic Institute's (DHI's) MOUSE software and was calibrated in 2000. The current model uses DHI's MIKE URBAN modeling platform, but continues to use the MOUSE model engines. The hydrologic model in MOUSE uses a Kinematic Wave solution, and the hydraulic model uses a one-dimensional Dynamic Wave solution.

The hydrologic/hydraulic models had previously been used to evaluate localized flooding issues within the DC Water service area. These model applications have approximated surface flow using a combination of detailed runoff catchment delineation and simulation of surface flow paths such as roads by defining one-dimensional open channel segments within the hydraulic model. The size of the Federal Triangle drainage area and potentially complex surface flow patterns necessitated the use of a two-dimensional surface model that could simulate surface flow, ponding level, and interaction with the hydraulic model. DHI's two-dimensional Mike 21 hydrodynamic flow model was chosen both for its flood-prediction capabilities and for its ability to connect with the existing collection system model.

4.2 HYDROLOGIC MODEL

The hydrologic (runoff) model used for this study of flooding in the Federal Triangle area, the Federal Triangle Model, is based on the hydrologic model of the combined sewer system model that was last calibrated in 2006. This model consists of smaller combined sewer catchments used to predict the direct runoff response from rainfall, and larger sanitary sewersheds that have been calibrated to use a regression-based approach to the indirect wet weather response from these areas. There are approximately 350 runoff catchments represented in the model. During the calibration of the Federal Triangle Model, several changes were made to the runoff model:

- No existing catchment delineations were changed, but stormwater-only catchments in the southernmost portion of the Federal Triangle drainage area were added to the model.
- During calibration, several catchments in the immediate Federal Triangle area were sub-divided into smaller parcels by proportionally reducing their physical characteristics (area, overland flow length), running the hydrologic simulation, and applying the resulting time series at multiple locations within the original catchment. Initial calibration revealed that the response time from some of the larger catchments was attenuated by catchment size and flow path length.
- Early in calibration, when it was determined that more runoff volume was necessary, catchments within the local, densely-developed Federal Triangle area had all pervious areas reassigned as Hydrologic Soil Group D low-infiltration type soils.
- To produce a quicker runoff response, Manning's roughness values for type-D soil pervious areas was reduced from 0.15 to 0.1.

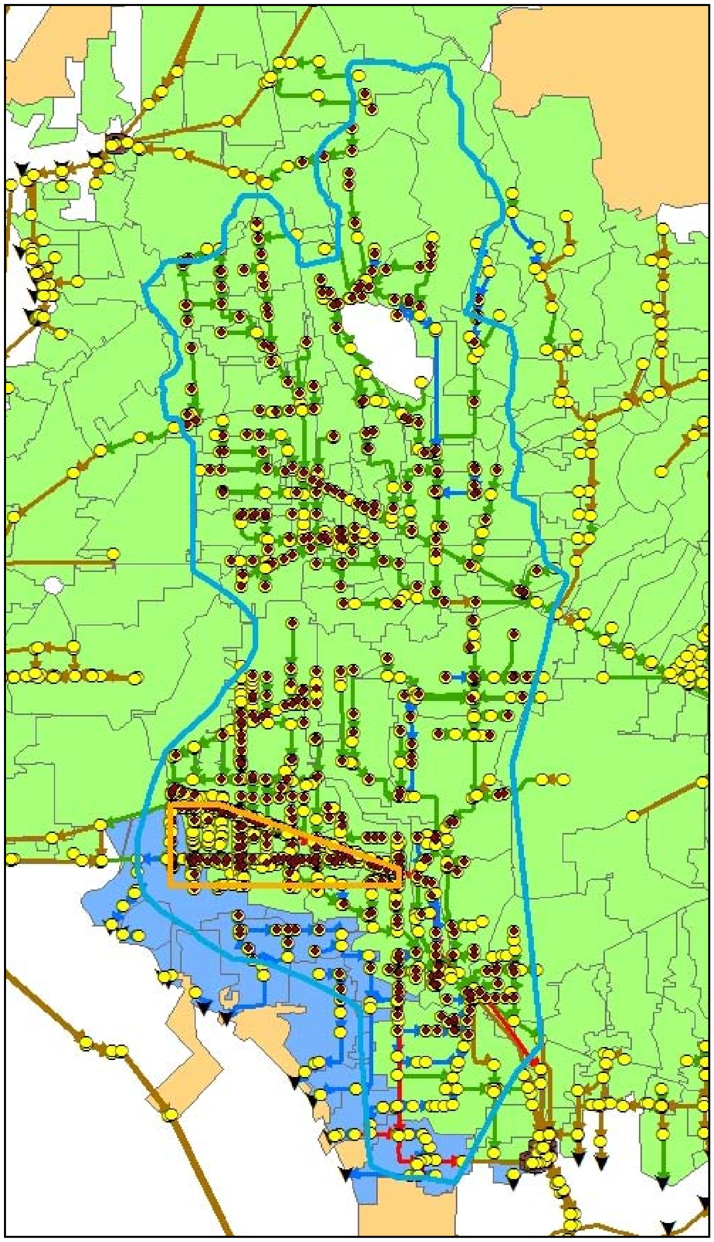
4.3 HYDRAULIC MODEL

The hydraulic (pipe) model is based on the original collection system model that was last calibrated in 2006. This model consists of interceptor and trunk sewers for most of the combined sewer area, with finer resolution in certain sewersheds. For the separate sanitary sewer areas, a reduced level of pipe detail is included. This original collection system model did not include the storm sewer network.

The level of pipe detail throughout the Federal Triangle drainage area was increased so that many of the pipes of diameter 24" and above are represented in the updated Flood Study model. This doubled the number of pipe segments represented in the model from about 1,100 to over 2,200. Every pipe in the immediate Federal Triangle area, apart from laterals, was added to the model. The Constitution Avenue storm sewer was also added to the updated Flood Study model. The pipe network for the drainage area is depicted in Figure 4-1.

Figure 4-1

Federal Triangle Drainage Area Pipe Network in MIKE URBAN



All catch basin locations in the immediate Federal Triangle area were added to the updated Flood Study model as manhole nodes connected to the surface flow model. In the remainder of the drainage area, catch basins were grouped together and amalgamated at single nodes, so that one hydraulic-surface connection point represented multiple catch basins. The number of inlets per catch basin was another factor that was quantified by counting inlets in the Federal Triangle area and in catchments outside of the Federal Triangle, and weighting the catch basin area (the opening available for drainage into and out of the sewer system) model input accordingly. Available catch basin area was a critical calibration parameter. The degree that catch basins were obstructed or clogged was assessed. This parameter would also need to account for catch basins that were not located in areas that maximized flow capture. Examples of this include catch basins on the side of a hill where a substantial portion of the runoff bypasses the basin due to the steep road slope. The value determined from calibration was that forty percent of the total catch basin opening was available to accept flow. This forty percent value was determined to be reasonable based on field observations of catch basin inlets.

Operational parameters for pump stations and inflatable dams were set in the calibration model to reflect the status of these controls at the time of the storm and subsequent flooding in June 2006, as determined from DC Water operational records and monitoring data.

Storage elements for the roadway tunnels under the Mall and the building basements that were affected by flooding were also added to the updated Flood Study model. Flows entered these storage nodes across weir elements with crest levels and lengths designed to approximate the most likely elevations at which flows entered these storage elements.

4.4 SURFACE MODEL

The surface flow model was created using the two-dimensional MIKE 21 modeling software. This software operates using either a grid or a flexible mesh framework. The rectangular single grid approach was chosen due to ease of setup and model simulation run time when compared to the irregular polygon-based mesh approach. The model grid was based on the most recent data available and included:

- D.C. OCTO (Office of the Chief Technology Officer) GIS elevation data from December 2009, which included mass points and break lines.
- OCTO building, road, and sidewalk layers.
- May 2010 survey of Constitution Avenue.
- USGS survey benchmarks (for quality control).

The creation of a DEM (Digital Elevation Model) based on the 2009 OCTO elevation data revealed potential inaccuracies that led to artificially low elevations at certain locations along Constitution Avenue. These locations can be seen in Figure 2-7. These elevations impacted the ponding volumes calculated using this DEM. As previously discussed, the April 2010 survey was ordered specifically to correct problems with the initial elevation dataset by checking elevations along Constitution Avenue and adding additional data points to the available elevation data. The data sets were combined to create a new DEM of the Federal Triangle drainage basin, as seen in Figure 2-9.

The resulting model grid based on the new DEM was a 25 foot by 25 foot raster composed of about 640,000 cells. Cells that were populated primarily with building footprints or that were outside of the Federal Triangle drainage area were defined automatically as dry cells, to reduce computation time. This reduced the number of cells actively involved in computation to around 340,000.

Catch basin areas were characterized in the surface model by defining areas, maximum flow rates, and weir lengths. The standard single-inlet catch basin dimensions of 3.5 feet long and 5 inches high, and a maximum flow rate of 1.8 mgd per inlet, were used for all catch basin sizing calculations. The degree of obstruction, or available area, was applied to these characteristics. The calibration scenario also included three manholes located along the north-south streets just north of Constitution Avenue that were reported to have been dislodged during the June 2006 flood event. These manholes were defined as orifices in the model and assigned an area equal to that of a standard manhole opening with a 30 inch diameter.

4.5 BOUNDARY CONDITIONS

The runoff model's boundary inputs are rainfall time series. For the June 2006 calibration event, the source of the rainfall data was a radar rainfall dataset that consisted of 297 time series representing a one-kilometer square grid each, with a 5-minute temporal resolution.

The hydraulic model's boundary inputs include dry weather flows to represent sanitary sewage originating from within Washington D.C., boundary flow time series for sanitary flows originating in the suburbs, and water level time series at tidally-influenced CSO and stormwater outfalls. Dry weather flow inputs are defined in the model as having separate baseflow (groundwater & infiltration) and sanitary flow components. Baseflow values vary by sewershed, but are constant values that are scaled according to annual average rainfall. Sanitary flows are also constant values, with diurnal use patterns applied. Suburban flow time series are input at nine locations, and are a combination of average dry weather flows, according to DC Water Blue Plains Service Area Flow Reports, and the wet weather response of a hydrologic, regression-based sub-model of the suburban service areas. Boundary flow time series are capped at the jurisdiction-specific transmission limits defined by the current Inter-Municipal Agreement (IMA). Water level time series are taken from NOAA tide data for Washington, D.C.

Limitations in the coupled hydraulic/surface model led to the creation of another set of boundary inputs related to the runoff model results. To set an initial condition for the runoff discharge – whether that discharge entered the pipe network initially or was deposited directly onto the surface - runoff results were processed into time series and split based upon the total peak capacity of all the catch basins within each runoff catchment. Flow at or below the peak limit were connected to the hydraulic model as one set of time series, while flows above the peak catch basin capacity were connected directly to the surface model.

As a check to the validity of the calibration done for the June 2006 storm model, another set of inputs which described an August 2001 storm were also created and simulated using the calibration model. The boundary conditions for this event included 240 radar rainfall time series with 15-minute temporal resolutions. The averages of all radar time series indicate that this storm event produced approximately 11.2 inches of rain in Washington, D.C., with a maximum total of over 26 inches reported by one radar gage. Most of the precipitation fell in a 48-hour period, starting on the afternoon of August 11. The model did not predict any substantial surface flooding in the Federal Triangle during this rain event, which matched what happened in the real world.

4.6 CALIBRATION RESULTS

For the June 2006 flood event, there were several anecdotal observations available upon which the model calibration could be based. The primary calibration point was the observation of water just below the top of a concrete planter located on the sidewalk on the northeast corner of the intersection of 15th Street and Constitution Avenue NW. The water depth at that location was estimated to be just above 3 feet. Other calibration points included the estimated volume of water in the basements of area building and the presence of water in the 12th Street tunnel under the National Mall.

The 2007 GSA report estimates that served as the initial calibration targets, in addition to the approximately 3 feet of water at the corner of 15th and Constitution, were:

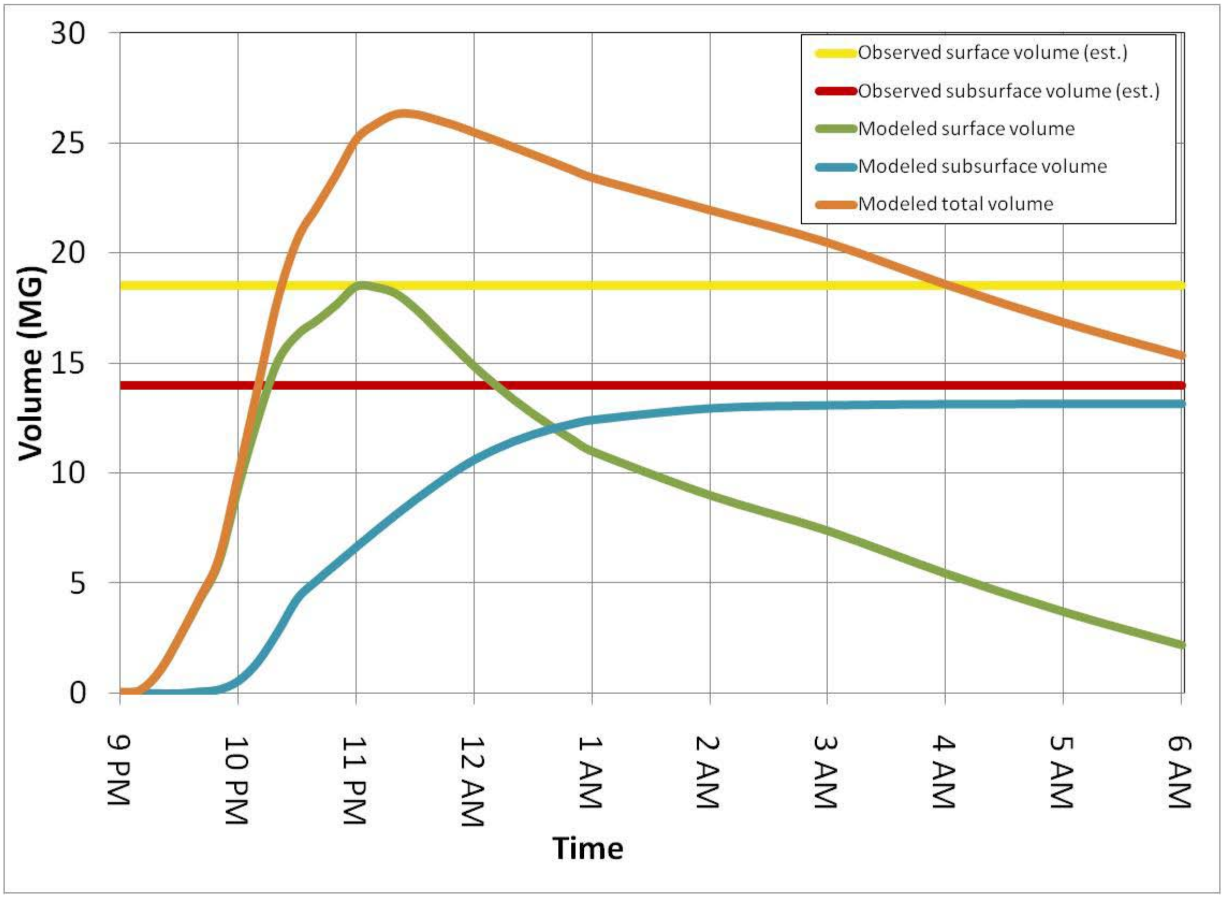
- A total street ponding volume of 32.9 million gallons (MG).
- Total volume in four building basements (Old Post Office, IRS Building, Department of Justice, and Department of Commerce) of approximately 13.3 MG.
- Metro inflow of about 1 MG.
- Photos of 12th Street Tunnel flooding.
- Ponding was still present in the early-morning hours of June 26th.

The referenced surface volume of 32.9 MG was based on older contour lines that were found to be inaccurate. A revised surface ponding estimate was reestablished at 18.5 MG based on the new DEM which incorporated the April/May 2010 survey data. Earlier estimates of total stored volumes that added GSA report estimates with estimates for other area buildings, Metro subway tunnels, and the 9th and 12th Street roadway tunnels was 18 MG. This estimate was revised downwards to around 14 MG based primarily on the fact that the GSA report did not consider basement contents and structures that subtracted from available storage volumes.

The final calibration resulted in the appropriate water depth of approximately 3.2 feet at the observation point at 15th and Constitution, a maximum ponding volume of approximately 18.5 MG, a maximum storage volume of around 13 MG, and a total volume of just over 26 MG. At 5 AM on June 26th, the model predicts just below 4 MG remaining on the surface. Figure 4-2 is a plot of surface and storage volumes over time. The subsurface volume refers to the combined volumes of flood water stored in the building basements and in the 9th and 12th Street tunnels. The surface volume recedes over time as catch basin capacities and sewer system conveyance as they drain down the collective water. The calibration model results match the observed maximum surface ponding volume of 18.5, and the predicted 13 MG subsurface volume is close to the revised 14 MG stored volume estimate.

Figure 4-2

Calibration Results: Volume on Surface and in Storage, Over Time



4.7 FORECAST MODEL

Table 4-1 lists assumptions that were made in the model for the existing sewer system for both the calibration and design storm (forecast) models. While the calibration model replicated system conditions as they were in June 2006, the forecast model needs to reflect current and near-future conditions. The forecast model assumes operational capacities for rehabilitated pump stations, a siphon and storm sewer that are cleaned and operated in accordance with maintenance guidelines, and inflatable dams that operate according to pre-programmed logic. The forecast model also assumes that in the future, building basements will not be available for flood water storage. The forecast model does not assume that manholes will remain bolted down during design storm events. It also does not assume an idealized capture rate for catch basins. The 40% available catch basin area used in the calibration model was also applied in the forecast model; while catch basins are cleaned according to a regular maintenance schedule, there is a low probability of a flood-producing rain event occurring immediately following scheduled catch basin maintenance.

Table 4-1

Sewer System Model Assumptions

	Calibration Scenario	Design Storm Scenarios
Rainfall	June 2006 flood event	Design Storms
Available Catch Basin Area	40%	40%
Siphon Status	78" capacity reduced by 90%, 108" at full capacity	2 barrels at full capacity
Constitution Ave. Storm Sewer Status	reduced capacity due to sediment	full capacity
Constitution Ave. Tide Gate Status	open	open, closed for 10-year flood stages and above
Structure 15F Status	closed	closed, open for 10-year flood stages and above
Open Manholes	3 open, to simulate popped manholes	3 open to simulate popped manholes
Basement Storage	yes	no
12th Street Tunnel Storage	yes	yes
Inflatable Dam Status	functioning as observed (Dam 15 deflated, other M&O-area inflatable dams did not)	functioning according to operational logic
Main PS Capacity	160 mgd	240 mgd
Potomac PS Capacity	360 mgd	460 mgd

The rationales for the assumptions made in the sewer system model for the design storm scenarios are as follows:

- **Available Catch Basin Area** – The same percentage of catch basin area available during the June 2006 storm was used for both the calibration scenario and the design storm scenarios. This parameter represents the practical catch basin area available to remove water from the streets. It is a lumped parameter that takes into account catch basin placement, street grades, and debris in the basins. This parameter was not changed between the calibration and design storm scenarios because there are no significant changes to the drainage areas planned and because changes to the catch basin cleaning frequency are not planned.
- **Siphon and Constitution Avenue Storm Sewer** – DC Water has instituted a maintenance plan that provides for regular inspection and cleaning (if required), to ensure siphon capacity is maintained. Because this will ensure capacity going forward, the design storm scenarios assumed the siphons and storm sewer were clean and operated in accordance with DC Water's standard operating procedures.

- **Constitution Avenue Tide Gate** - The Army Corps of Engineers Flood Emergency Manual for DC has established an operational protocol for the Constitution Avenue tide gates that was in effect in June 2006 and is still being utilized.
- **Structure 15F** - The Army Corps of Engineers Flood Emergency Manual for DC has established an operational protocol for Structure F that was in effect in June 2006 and is still being utilized.
- **Open Manholes** – Because the capacity of the upstream sewer system is not proposed to be changed, the same number of surcharged manholes were used for both the June 2006 storm and the design storms scenarios.
- **Basement Storage** – Basement storage was not utilized for the design scenarios because the purpose of the project is to provide relief from flooding and modeling in this way allows accurate prediction of flood volumes to be handled.
- **12th Street Tunnel Storage** – The amount of water stored in 12th Street Tunnel during the June 2006 storm was used for the model design storms. There are no proposed changes to the 12th Street Tunnel, so the same storage was used for both the June 2006 storm and the design storm scenarios.
- **Inflatable Dam Status** – The dams operated as intended during the June 2006 storm. The way the inflatable dams operate was not changed between the calibration and design storm scenarios because there are no changes to the way the inflatable dams are planned to operate in the future.
- **Main Pumping Station Capacity** – During the June 2006 storm, the pumps in the Main Pumping Station were undergoing rehabilitation. Consequently, not all of the pumps were available during the June 2006 storm. The rehabilitation project has been completed and all of the pumps are available for operation if required. Additionally, there is a standby pump that could be utilized if one of the pumps were to fail.
- **Potomac Pumping Station Capacity** – The pumps in the Potomac Pumping Station are undergoing rehabilitation that should be completed by the end of 2011. When the project is completed all of the pumps will be available for operation if required. Additionally, there is a standby pump that could be utilized if one of the pumps were to fail.

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Section 5 BASELINE PONDING PREDICTIONS

5.1 INTRODUCTION

The older downtown areas of Washington, DC are at elevations that are very close to sea level. Flooding in low spots, like the Federal Triangle area, can be caused by high tides in the Potomac River as well as by localized rainfall events. The Potomac River can reach elevated flood stages for a variety of reasons: watershed wide flooding, tidal surge due to a combination of wind and astronomical tidal conditions, and surge due to coastal storms including tropical storms. The joint occurrence of high tide in the Potomac River and flooding due to localized rainfall potentially presents the worst flooding conditions because the natural drainage into the Potomac is decreased by high river conditions. Consequently, the development of design storms for planning purposes requires use of conditions that represent the combined probability of river flooding associated with heavy localized rainfall. Planning alternatives are judged according to their ability to alleviate flood problems under the design conditions.

The coupled surface/pipe model was calibrated to the June 2006 event so that it could be applied to several combined-probability design storm and river stage scenarios to predict baseline ponding levels as a function of return frequency for the existing conditions without implantation of any flood control measures. Use of synthetic design storms is an accepted practice when evaluating surface runoff, sewer capacity, and flood control needs. The methodology for development of synthetic design storms has been established by the National Oceanic and Atmospheric Administration (NOAA). Design storms have defined return periods specific to a geographic region. Potomac River stage is another design condition that is critical to flood relief in the Federal Triangle because Constitution Avenue storm sewer operation depends on river stage, and because many of the combined and storm sewer outfalls that relieve the Federal Triangle area can be affected by river stage. Combined-probability scenarios that simulate the joint occurrence of various return-frequency design storms and river flood stages are necessary so that all of those operational rules and constraints on system performance can be thoroughly evaluated.

The model applied to evaluate baseline ponding conditions reflected the following sewer system best case operating conditions:

- All Pumping Stations were modeled at their full post-rehabilitation capabilities
- All inflatable dams were considered to be fully operational
- Storage elements for Federal Triangle buildings were removed from the model
- Both available B Street siphons were modeled at full capacity, free of any obstructions or debris
- Constitution Avenue storm sewer was also modeled at full capacity and assumed to be free of sedimentation
- The calibrated catch basin area parameter remained at forty percent

Figure 5-1 through Figure 5-7 shows the expected ponding levels or water surface elevations (WSEL) at intersections along Constitution Avenue from 15th Street to 6th Street for various storm frequencies at existing conditions. The water surface elevations of the river at different river flood conditions are also shown. Being a flat area at a low elevation, the Federal Triangle can experience ponding even for very small storms

Figure 5-1

Predicted Ponding Levels at 15th & Constitution Ave.

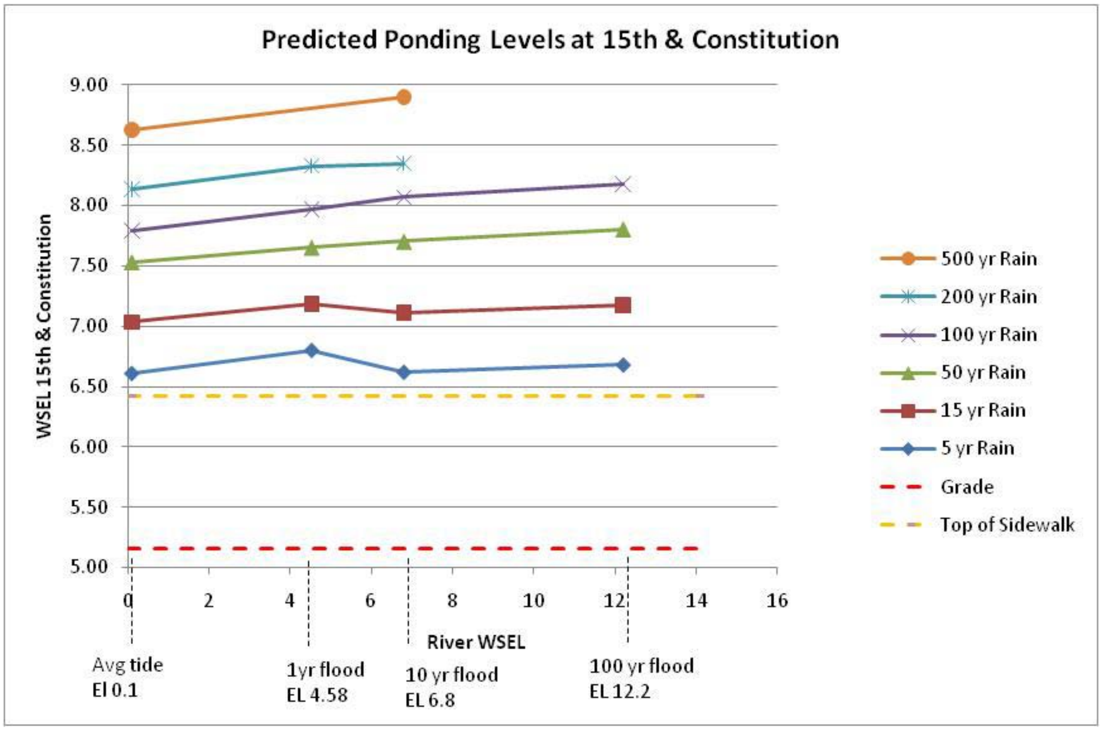


Figure 5-2

Predicted Ponding Levels at 14th & Constitution Ave.

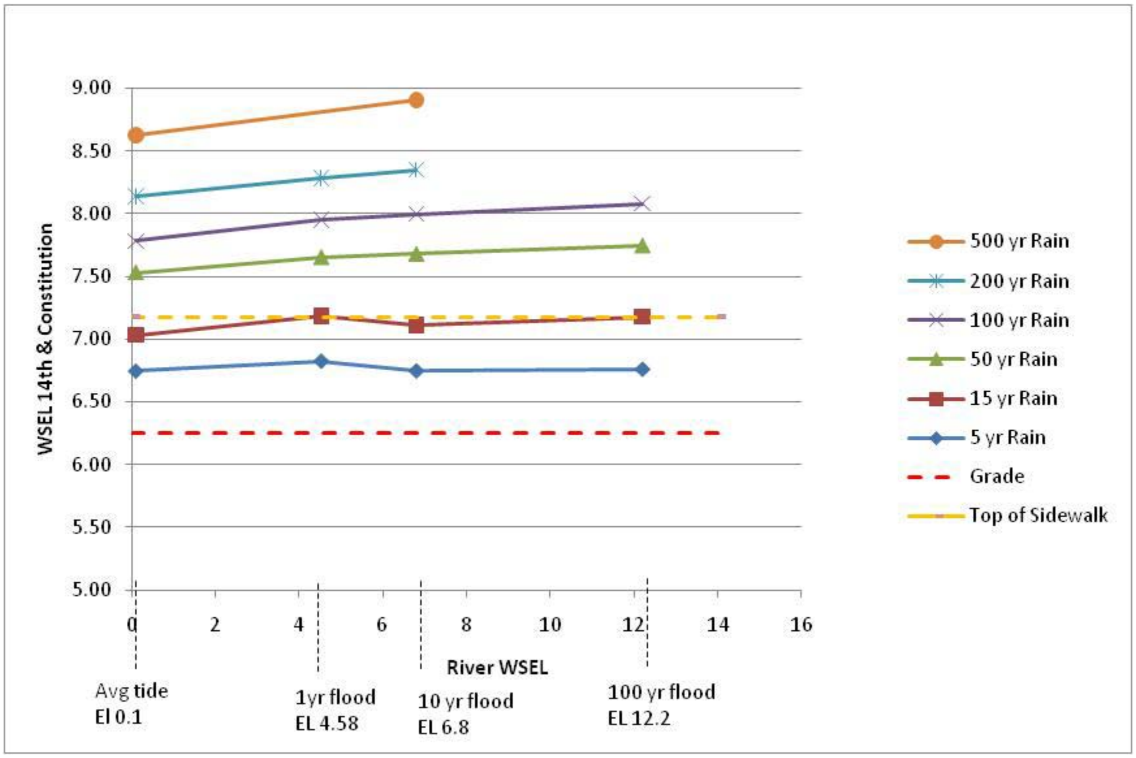


Figure 5-3

Predicted Ponding Levels at 12th & Constitution Ave.

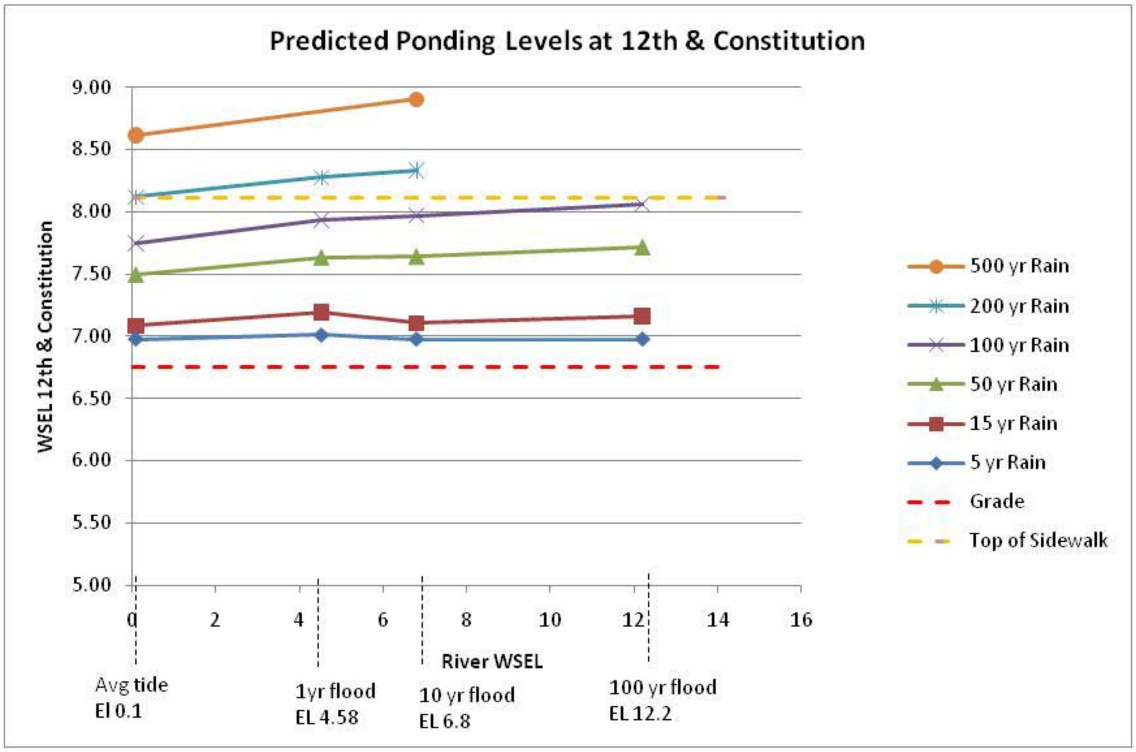


Figure 5-4

Predicted Ponding Levels at 10th & Constitution Ave.

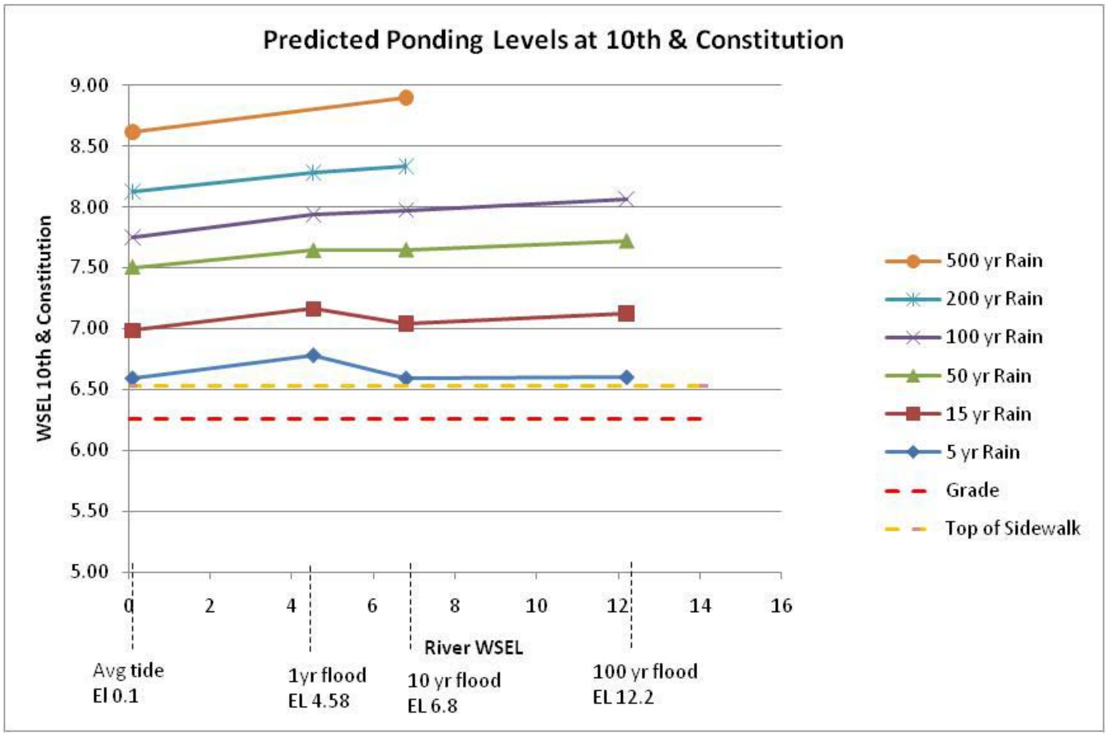


Figure 5-5

Predicted Ponding Levels at 9th & Constitution Ave.

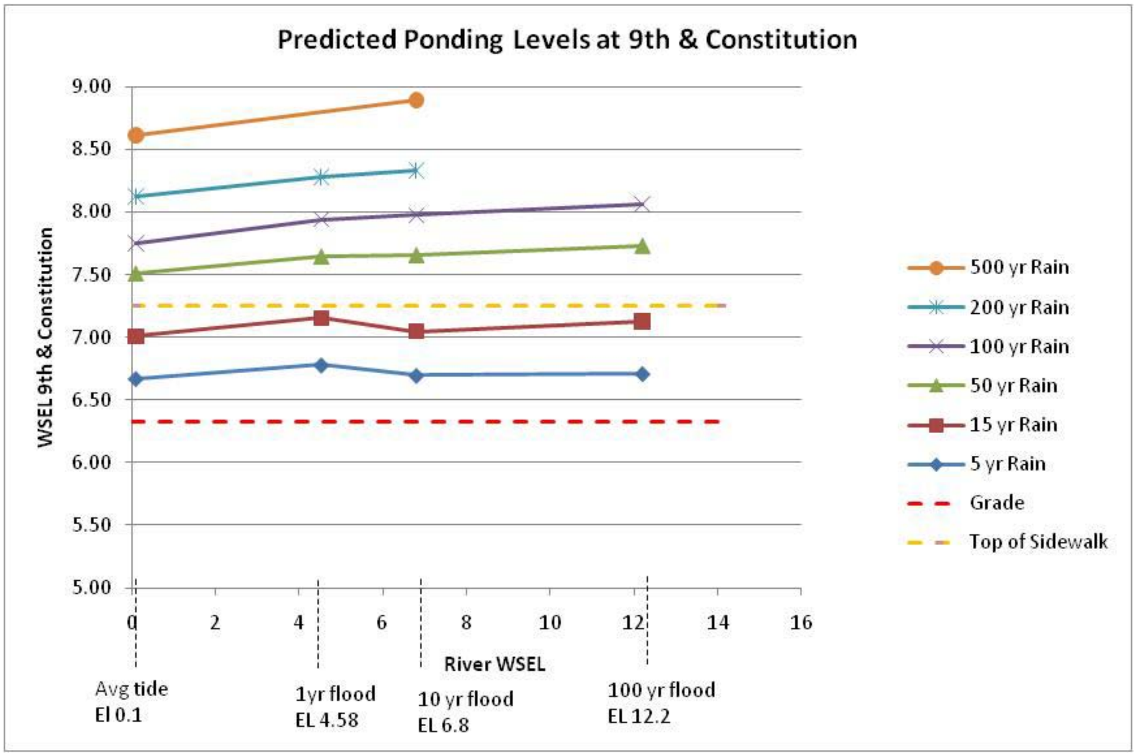


Figure 5-6

Predicted Ponding Levels at 7th & Constitution Ave.

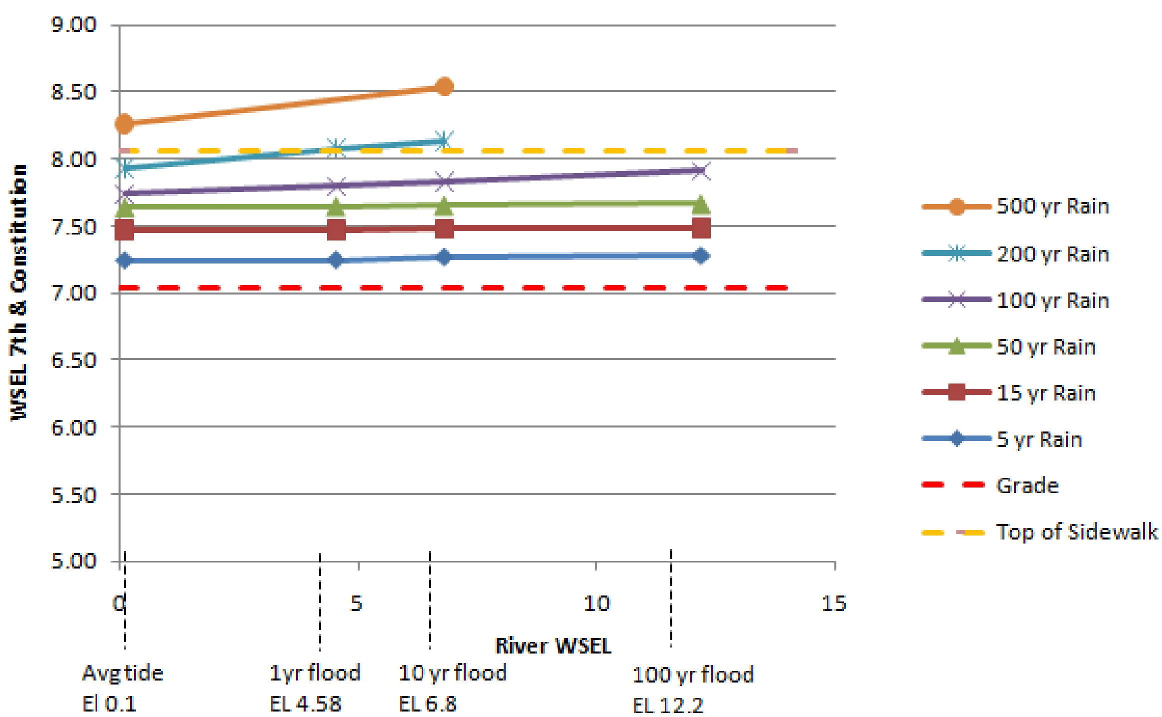
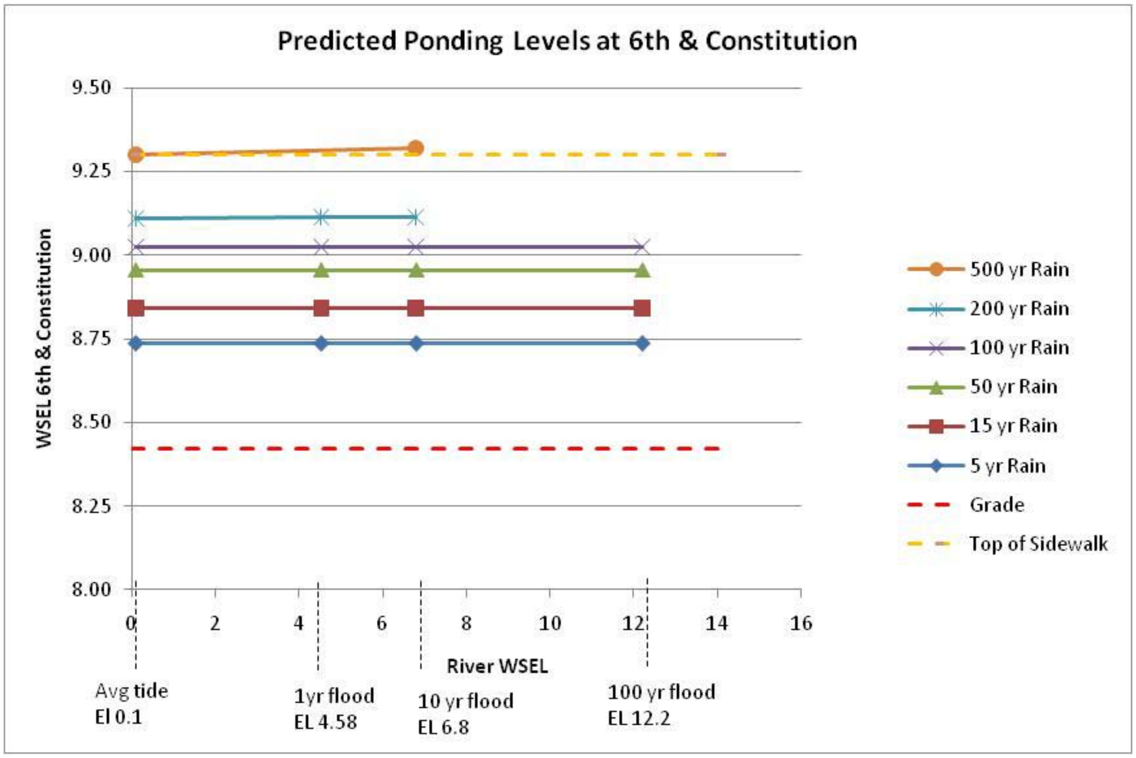


Figure 5-7

Predicted Ponding Levels at 6th & Constitution Ave.



5.2 COMBINED PROBABILITY EVENTS

We used the Hydraulic Analysis of Interior Areas, EM-1110-2-1413, US Army Corps of Engineers, January 1987, as a source for determining the likelihood of a river flood and flooding from an intense District rain happening at the same time. There are two methods that may be used to determine the probability of both floods occurring. They are the continuous record analysis method and the coincident frequency analysis method. The continuous record analysis method requires large amounts of reliable data and a degree of coincidence and dependence between the river floods and the floods from interior rains. The coincident frequency analysis method is suitable where there is independence between river flood and the floods from interior rains and is also suitable for relatively small interior areas located along large rivers. As you can see in Figure 5-8 the District is a very small drainage area compared to the Potomac River watershed and Table 5-1 shows there is not a degree of coincidence between river floods and interior rains. Figure 5-9 shows the log probability plot of river flooding and interior rain using the coincident frequency analysis method.

Figure 5-8

Potomac River Watershed vs. D.C. Drainage Area

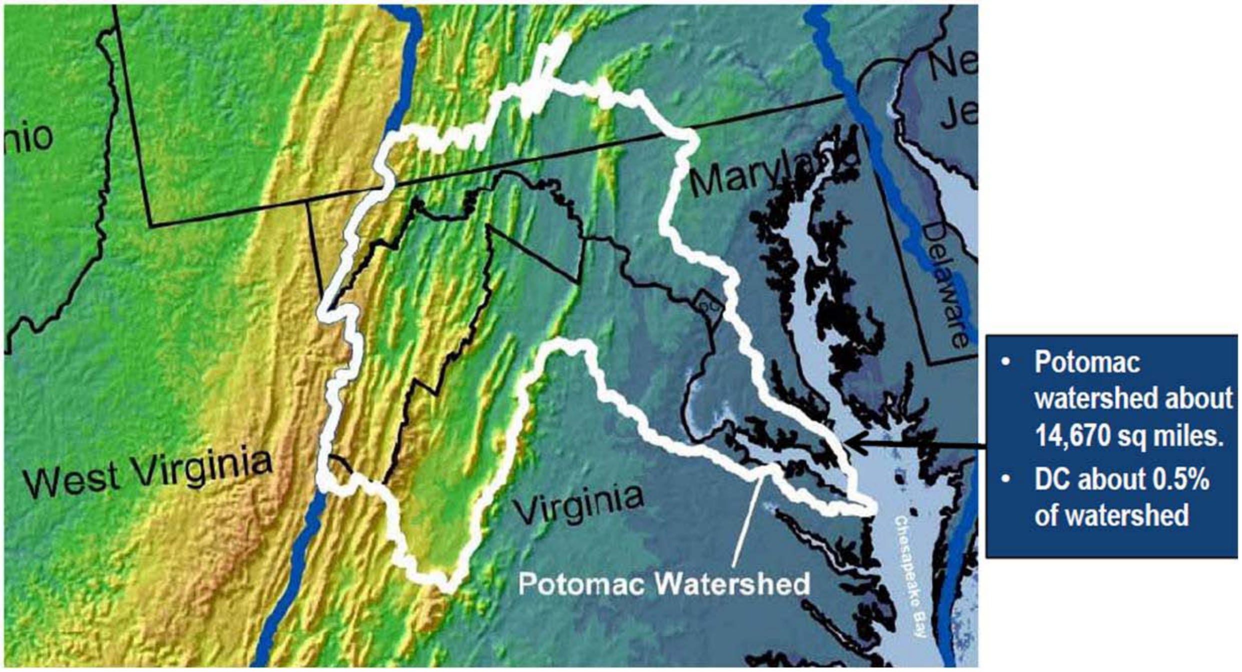


Table 5-1

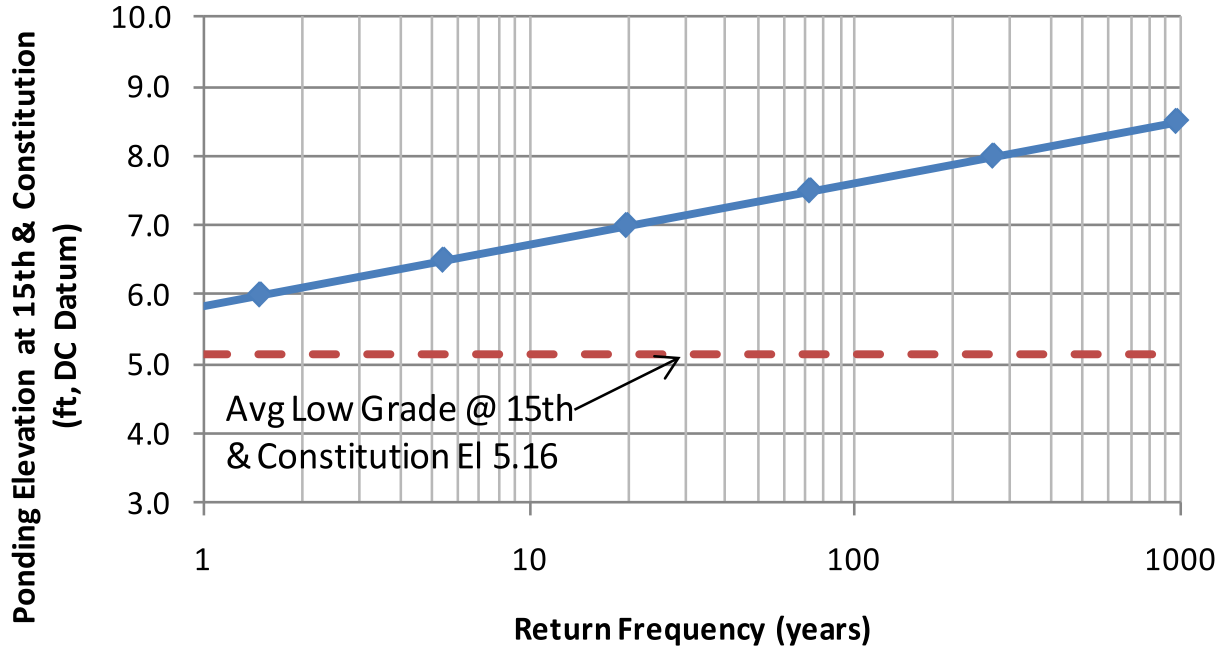
Worst Flood Events on Potomac River in DC

Event Date	Type of Event	Recurrence	Description	Rainfall at Nat'l Airport (in)
June 1-2 1889	Flood, Potomac River Basin	50 to >100		No data
February 18, 1889	Ice Jam, Potomac River	-		No data
March 28-30 1924	Snowmelt & intense rainfall runoff, Potomac River Basin	20 to> 100		No data
May 12-14 1924	Rainfall	-		No data
August 23, 1933	Tidal surge	-		No data
March 17-19, 1936	Thick Ice, snowmelt and intense rainfall runoff, Potomac River basin	20 to> 100		No data
April 25-28, 1937	Rainfall	-		No data
October 13-17, 1942	Flood from extended rainfall	>100		No data
August 12-13 1955	Flood, Rock Creek, Potomac, Anacostia River Basins	5 to 10	Hurricanes Connie and Diane	6.6
June 21-23, 1972	Flood, Rock Creek	>100	Hurricane Agnes	7.91
September 5-6, 1979	Flood, Rock Creek	50 to >100	Hurricane David	3.69

Event Date	Type of Event	Recurrence	Description	Rainfall at Nat'l Airport (in)
June 1-2 1889	Flood, Potomac River Basin	50 to >100		No data
November 4-7, 1985	Flood, Potomac River basin	2 to>100	Hurricane Juan	1.02
May 5, 1989	Flood	-		2.24
January 19-21, 1996	Snowmelt flood	-		0
September 6-8, 1996	Flood, Potomac River	-	Hurricane Fran	0.29
Aug 11, 2001	Flash Flood, Rock Creek	-		4.1

Figure 5-9

Joint Probability of River Flood and Interior Rain



The combined-probability scenarios consisted of 6-hour duration rainfall design storms of various return frequencies from 1 to 500 years coupled with Potomac River stage levels from mean tide (0.1 feet) up to a 100 year river flood (12.2 feet). Rainfall design storms are based on NOAA Intensity-Frequency-Duration (IDF) curves. The 6-hour duration design storms are defined by hyetographs with increasing rainfall intensities from the start of the storm to the peak mid-way through the 6-hour period, with decreasing intensities thereafter. The rate of change in rainfall intensities that are characteristic of the region and storm duration is factored into the design storm definitions. River flood stages are also based on NOAA data and were held constant where assigned to tidally-influenced combined sewer and stormwater outfalls. Wet weather sanitary and suburban sewershed flows associated with inflow and infiltration were developed using design storm rainfall inputs. River stage levels were constant values assigned to tidally-influenced combined sewer and stormwater outfalls.

For the 10 and 100 year river flood scenarios, the Constitution Avenue storm sewer outfall to the Tidal Basin was modeled as closed, and the connection with the B Street Trunk Sewer at the beginning of the storm sewer (DC Water Structure 15F) was opened. This mimics the operational protocol established in the Army Corps of Engineers Flood Emergency Manual for DC. Otherwise, the combined-probability scenarios analysis assumes that the storm sewer and siphon and pump stations are free of sediment and operating at their fully-rehabilitated rated capacities. In addition, it was assumed that drainage into building basement storage is not possible.

The combined-probability design storms and river stage scenarios that were evaluated are described in Table 5-2. The maximum water depth location (the peak flood depth location) is at the northeast corner of 15th Street and Constitution Avenue.

Table 5-2

Combined Probability Model Scenario Results

River Stage Condition	River Stage Level (ft.)	6-Hour Design Storm	Rainfall Depth (in.)	Peak 5-minute Intensity (in/hr)	Max. Water Depth (ft.)	Max. Ponding Volume (mg)
Mean tide	0.1	5-year	2.94	6.69	1.34	2.73
Mean tide	0.1	15-year	3.65	7.88	1.76	4.99
Mean tide	0.1	50-year	4.76	8.82	2.24	9.09
Mean tide	0.1	100-year	5.40	9.38	2.47	11.78
Mean tide	0.1	200-year	6.04	9.89	2.77	15.46
Mean tide	0.1	500-year	6.98	10.44	3.11	19.89
1-year flood	4.53	5-year	2.94	6.69	1.53	3.28
1-year flood	4.53	15-year	3.65	7.88	1.91	5.75
1-year flood	4.53	50-year	4.76	8.82	2.36	10.38
1-year flood	4.53	100-year	5.40	9.38	2.63	13.89
1-year flood	4.53	200-year	6.04	9.89	2.96	17.72
10-year flood	6.8	5-year	2.94	6.69	1.35	2.74
10-year flood	6.8	15-year	3.65	7.88	1.84	5.20
10-year flood	6.8	50-year	4.76	8.82	2.41	10.72
10-year flood	6.8	100-year	5.40	9.38	2.68	14.91
10-year flood	6.8	200-year	6.04	9.89	2.98	17.94
10-year flood	6.8	500-year	6.98	10.44	3.38	23.77
100-year flood	12.2	1-year	1.88	4.70	0.43	0.7
100-year flood	12.2	5-year	2.94	6.69	1.41	2.85
100-year flood	12.2	15-year	3.65	7.88	1.90	5.64
100-year flood	12.2	50-year	4.76	8.82	2.46	12.06
100-year flood	12.2	100-year	5.40	9.38	2.76	15.37
100-year flood	12.2	200-year *	6.04	9.89	n/a	n/a
100-year flood	12.2	500-year *	6.98	10.44	n/a	n/a

*Results not available.

The results in Table 5-2 indicate that while the severity of the flooding generally increases as return frequencies for both rainfall and river stage increase, the operational rule that opens Structure 15F and relieves the Constitutional Avenue storm sewer mitigates the effects of the 10 and 100-year river stages. Taking the 200-year rainfall design storms as an example, the maximum water depth between the 1 and 10-year river stage scenarios only increases by 0.02 feet, and the maximum ponding volume only increases by 0.26 million gallons. For smaller design storms such as 5 and 15-year events, this operational rule leads to decreases in water depth and ponding volume from the 1-year river stage scenarios to the 10 and 100-year river stage scenarios.

5.3 FEDERAL TRIANGLE FLOODING STUDY MODEL COMPARISON TO TETRA TECH STUDY

Table 5-3 shows a comparison of the design criteria used by the Army Corps of Engineers 1992 study, the Tetra Tech 2008 ponding levels study, and this study. Figure 5-10 shows the expected ponding calculated by the calibrated model and how the ponding compares to prior studies.

In March 2009, Tetra Tech performed an interior drainage analysis of the Federal Triangle area. The analysis was performed as part of the Conditional Letter of Map Revision (CLOMR) request for the Potomac Park levee project. A 100-year 24-hour duration design storm was used in the Tetra Tech analysis. The Tetra-Tech study utilized available topographic data and did not include a detailed collection system model.

As part of the Federal Triangle Flooding Study, ponding levels in the Federal Triangle were predicted by Greeley and Hansen and Limno-Tech (GH/LTI) for 6-hour duration design storms with return frequencies of 5, 15, 50, 100, 200 and 500 years. This study included an elevation survey in the Federal Triangle area and utilized the detailed collection system model prepared by DC Water for development of its Long Term CSO Control Plan.

In order to compare the Tetra Tech results to the results predicted by the Federal Triangle Flooding Study, DC Water authorized running the collection system model for 100-year 6-hour, 12-hour and 24-hour duration storms.

5.3.1 Model Conditions

The model used to develop the Federal Triangle Flooding Study was used to perform the analysis. As mentioned previously, the Federal Triangle model has several configurations as follows:

- Calibration model - this represents sewer system conditions as they existed during the June 2006 flood event. The Main and O Pumping Stations were being rehabilitated and thus their capacity was reduced, and the Constitution Avenue storm sewer and B Street/ New Jersey Avenue siphons were partially obstructed.
- Forecast Model - this model assumes the pumping stations have been rehabilitated and the Constitution Avenue storm sewer and B Street/ New Jersey Avenue siphons have been cleaned. It represents the system as it is intended to operate. The model also assumes that building basements are not available for flood water storage.
- Alternatives Models – these models included various structures and facilities (e.g. pumping station) designed to reduce flooding.

The Federal Triangle model was used to make the predictions for comparison to Tetra Tech because it best represents the system in its long term condition if no structural alternative is constructed to provide increased flood protection.

To be consistent with the Tetra Tech study, the water level in the Potomac River used for these scenarios was EL. 12.2 feet (DC Eng. Datum), which represents the 100-year return-period Potomac River flood. Under the 100-year flood condition, the operating rules for the Constitution Avenue storm sewer call for the outlet to be closed and for the upstream end to be connected to the B Street Trunk Sewer at Structure 15f. These operating rules were reflected in the collection system model. The 17th Street levee system that is currently under construction was also assumed to be in place.

5.3.2 Rainfall Conditions

The Tetra Tech study used a 100-year 24-hour return period design storm that was based on NOAA Atlas 14 data and an SCS Type-II distribution. The Federal Triangle model created three design storms which were also based on NOAA rainfall intensity tabular data but used an alternating-block distribution method. Table 5-3 below summarizes the design storms.

Table 5-3

Design Storm Summary

Study	Storm Return Period	Storm Duration	Depth (inches)	Average Intensity	Peak 5-minute Intensity
Tetra Tech	100-year	24 hours	8.30	n/a	n/a
Federal Triangle Flooding Study	100-year	24 hours	8.40	0.35 in/hr	9.96 in/hr
Federal Triangle Flooding Study	100-year	12 hours	6.72	0.56 in/hr	10.56 in/hr
Federal Triangle Flooding Study	100-year	6 hours	5.28	0.88 in/hr	11.04 in/hr

5.3.3 Results

The attached three figures compare the flooding predictions from the Tetra Tech study with the flooding predictions form the coupled Mike Urban/Mike Flood models. Table 5-4 shows the predicted ponding elevations.

Table 5-4

Predicted Ponding Elevations

Study	Storm Return Period	Storm Duration	Ponding Elevation (DC Eng Dept Datum)
Tetra Tech	100-year	24 hours	10.88 ft(1)
Federal Triangle Flooding Study	100-year	24 hours	8.04 ft
Federal Triangle Flooding Study	100-year	12 hours	8.15 ft
Federal Triangle Flooding Study	100-year	6 hours	8.20 ft

(1) Tetra Tech ponding elevations of 10.8 ft. (NAVD88) was converted to 10.88 ft. (DC Eng. Datum)

The following are comments on the model results comparison:

- The Federal Triangle model was created to predict ponding in the Federal Triangle. A high degree of detail was added to the model in the Federal Triangle and the necessary amount of detail was added to predict upstream flows which would be conveyed via overland flow to the Triangle. The Tetra Tech results include a significant flooding area east of 6th Street and south of Constitution Avenue all the way to the Southwest Freeway. This area was not modeled in detail by the Federal Triangle model and thus ponding levels predicted by this model are not shown. If this area were modeled in detail, it is likely that significant reductions in ponding would also be predicted for this area.
- Figures 5-10, 5-11, and 5-12 show the computed ponding area on Constitution Avenue.
- The predicted flooding area is shown on the figures in blue assuming that floodwaters cannot penetrate buildings. However, FEMA flood maps typically do not account for buildings. Therefore, the predicted ponding area has also been shown assuming the buildings do not obstruct floodwaters.
- The variation in interior drainage flooding between the Tetra Tech study and this study can be accounted in the fact that the Tetra Tech study utilized available topographic data and did not include a detailed collection system model.

Figure 5-10

Comparison of Interior Drainage Flooding for a 6 Hour 100 Year Storm

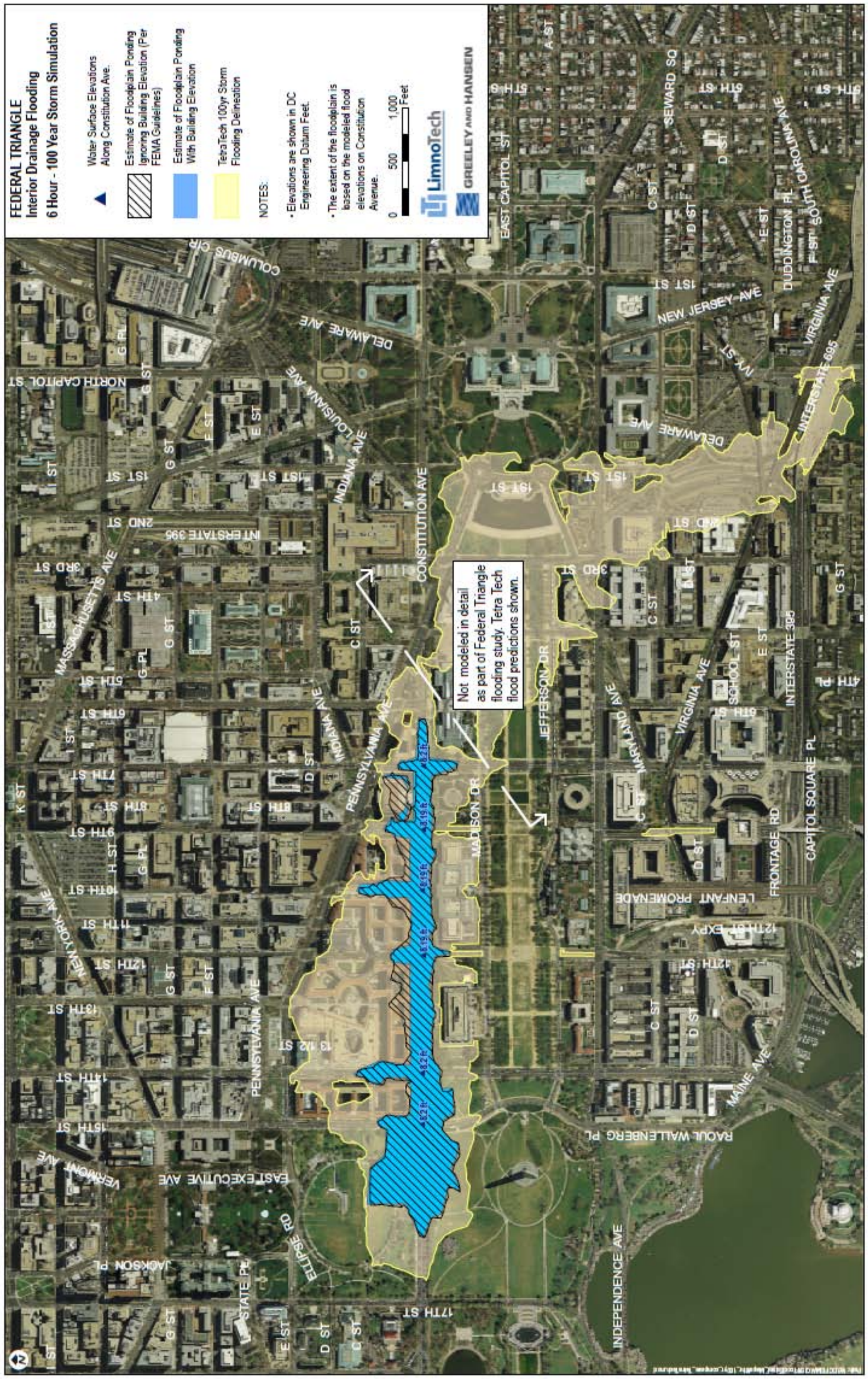


Figure 5-11

Comparison of Interior Drainage Flooding for a 12 Hour 100 Year Storm

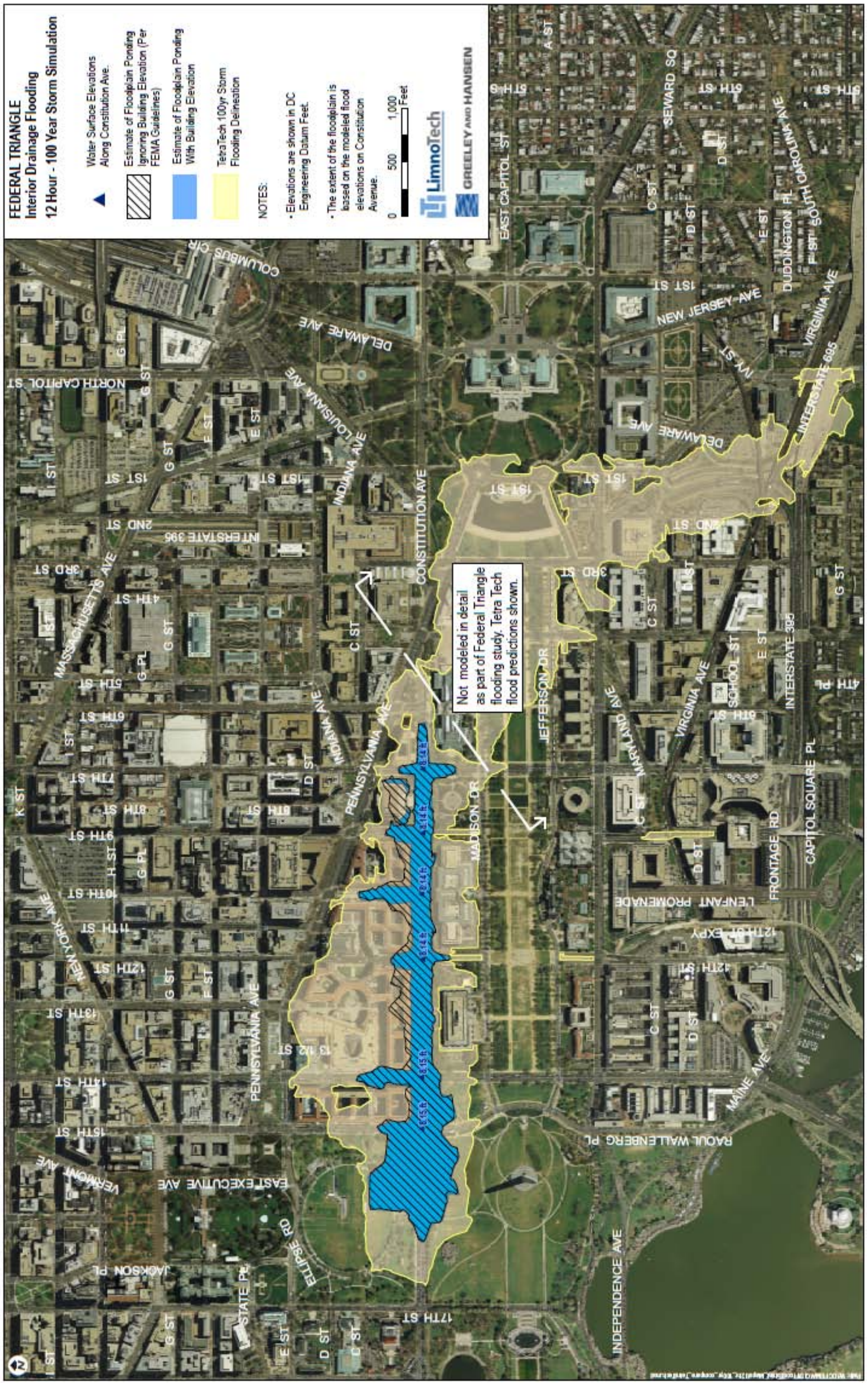
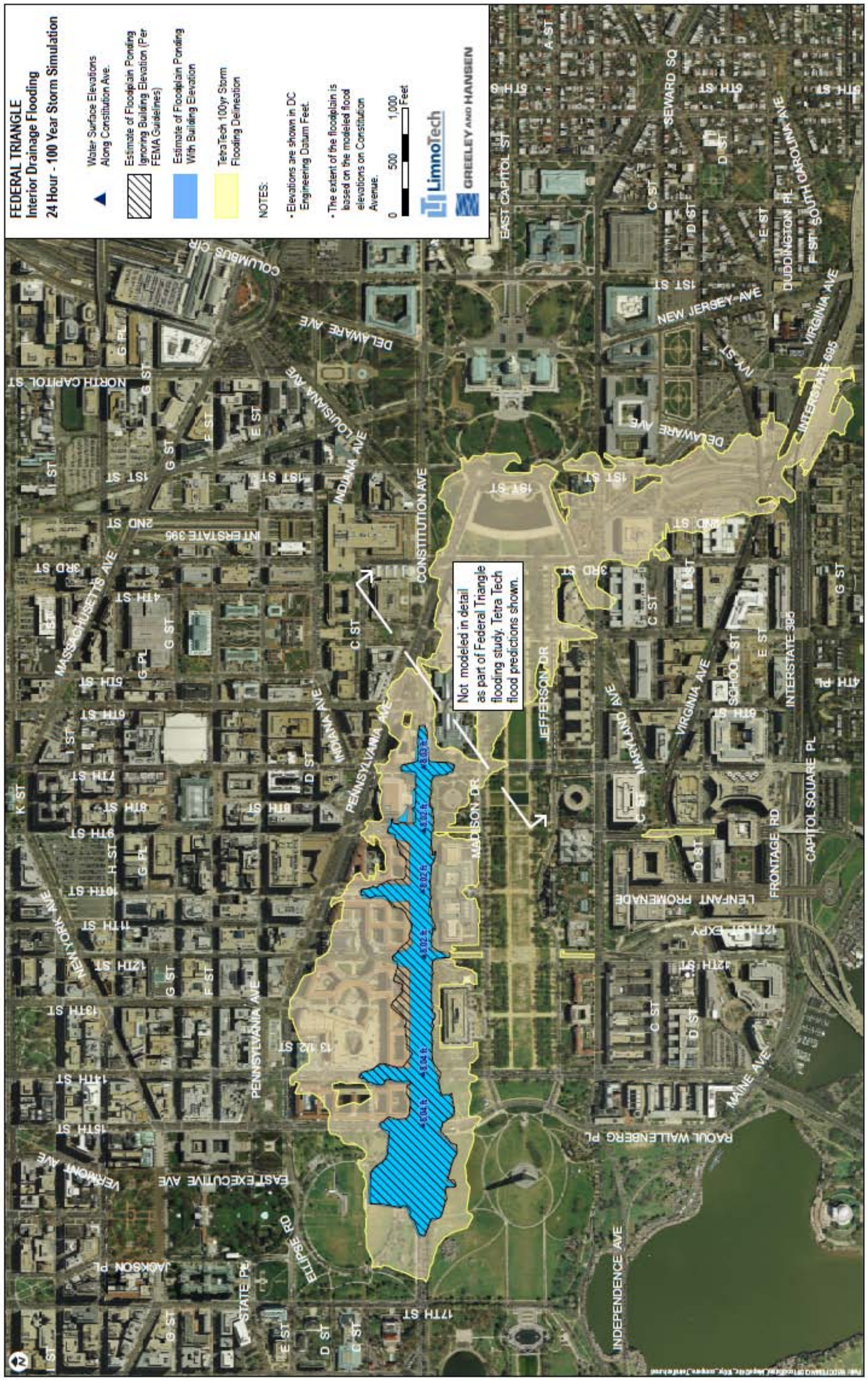


Figure 5-12

Comparison of Interior Drainage Flooding for a 24 Hour 100 Year Storm



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Section 6 IDENTIFICATION AND EVALUATION OF ALTERNATIVES

6.1 IDENTIFIED ALTERNATIVES

The partner agencies developed a preliminary list of potential strategies to prevent flooding within the Federal Triangle. These potential strategies are:

Strategy	No.	Description	Keep/Reject
Warning System	A	Early Warning Systems	Evaluate these alternatives
Reduce floodwaters entering Federal Triangle	B	Low Impact Development (green practices)	
	C	Storage Upstream of Federal Triangle	
Convey floodwaters out of Federal Triangle or store them	D	Use GSA Condensate Line	
	E	Storage Beneath National Mall	
	F	Pumping Station Serving National Mall	
	G	Tunnel to Main & O Pumping Stations	
	I	Maximize use of sewer system	Reject - existing sewer system not designed for 50 to 200 year storms
	J	Gravity sewer to Tidal Basin	Reject – Federal Triangle too low for reliable drainage by gravity
Protect properties from flood waters	H	Flood-proof buildings	Not part of scope of study – should be evaluated by others

Through a series of meetings with the Working Group, Alternative I was rejected because the existing sewer systems were not designed to handle large scale storms and changing operational parameters would not measurably reduce flooding risk. Alternative J was rejected, because the grade elevation of the Federal Triangle is too low relative to the Potomac River and Tidal Basin for a new gravity sewer to function reliably. Alternative H, Flood Proofing of Structures within the Federal Triangle is a viable solution but is not within the scope of this Study. Consequently, seven (7) alternatives were identified as potential projects that may prevent flooding in the Federal Triangle area and warranted further investigation. These alternatives are:

- Alternative A – Early Warning Systems
- Alternative B – Low Impact Development Strategies (Green Infrastructure)
- Alternative C – Storage Upstream of Federal Triangle Area
- Alternative D – Utilize GSA Condensate Line
- Alternative E – Storage Beneath the National Mall

- Alternative F – New Pumping Station Serving the National Mall
- Alternative G – New Tunnel to the Existing O Street Pumping Station

Alternatives A through G were evaluated in terms of cost, benefits, and other technical factors. This section includes a description of each alternative and an evaluation of each strategy as follows.

6.1.1 Bases for Sizing Alternatives

Discussions with the partner agencies have determined that at 15th and Constitution Ave. NW, the low point of the Federal Triangle, critical elevations are:

- Grade El. 5.16
- Top of the curb El. 5.28
- Top of the sidewalk El. 6.42

Due to the relatively flat grade in the Federal Triangle area, some level of stormwater ponding on the surface must occur simply for the stormwater to flow to the inlet catch basins. Furthermore, it has been agreed that the maximum acceptable level of ponding is El. 6.42, the top of the sidewalk. Any ponding in excess of 6.42 has the potential to exit the street right of way and flood public lands or buildings located out of the right of way.

Additionally the partner agencies have agreed that the storm return frequencies to be evaluated are:

- 50-year
- 100-year
- 200-year

The working group decided that since the magnitude of capital investment for flood protection would be large, it would only be worth implementing for large storms. The 100-year storm is the FEMA standard by which the National Flood Insurance Program (NFIP) Flood Insurance Rate Maps (FIRM) maps are developed. The working group agreed that the 100-year storm was an acceptable standard to analyze. It was also agreed that storms one size smaller and one size larger should be analyzed to give a range of data. The 50-year storm was chosen as one size smaller storm. The 200-year storm was selected as one size larger storm. Additionally, the 200-year storm was selected to account for the potential effects that global warming may have upon the ecosystem and to recognize that more severe storms are becoming more around the country.

Each of the selected storm frequencies had a safety factor of 25% added to the selected storm. Safety factors allow a margin of safety for calculated quantities to actual applied quantities. They can help accommodate future changes to the sewer system or future changes to storm sizes due to climate changes. Alternatives B, C, and E utilize construction of a finite capacity of storage volume to capture the storm flow. It is possible that back-to-back storms may occur, where the entire flood prevention capacity might not be available. The first storms rainfall may not have been entirely conveyed out of the Federal Triangle before the second storm hit, similar to what happened in June of 2006 To account for the possibility of back-to-back storms, an additional safety factor of 50% of a 5 year storm was added to each selected storm frequency.

6.2 ALTERNATIVES DESCRIPTION AND EVALUATION

6.2.1 Alternative A – Early Warning Systems

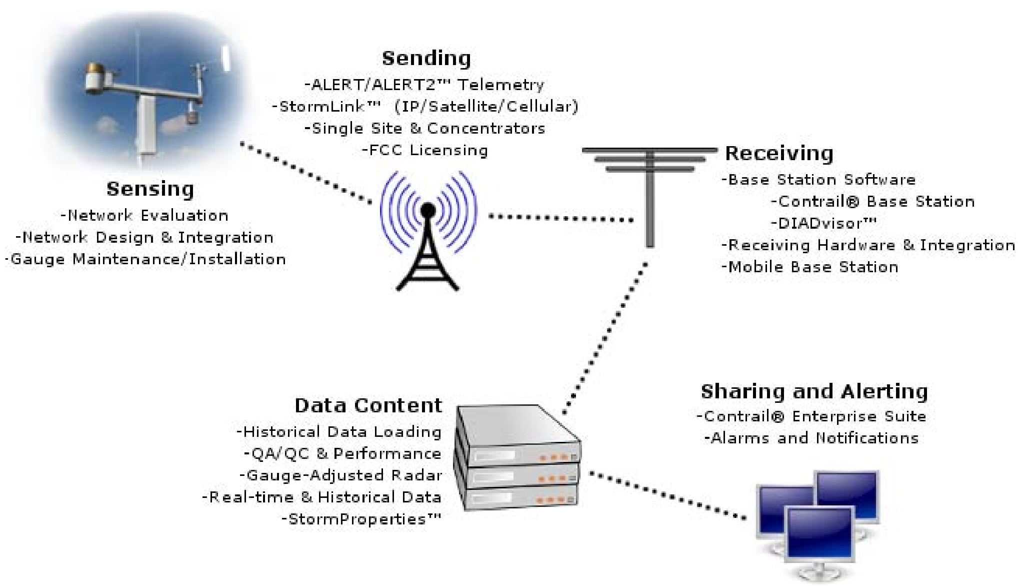
6.2.1.1 Description

Early warning systems are used by many municipalities across the U.S. in areas that are prone to flooding to provide advance warning of a possible flooding event. These early warning systems enable municipalities to issue warnings to residents in flood prone areas and enable them to put into action any flood protection protocols they may have developed. Early warning systems are mainly used by areas subject to river and creek flooding but may also be used by areas subject to flooding caused by low lying topography such as the Federal Triangle area.

Early warning systems can vary greatly in complexity and warning accuracy, from a region wide system consisting of hundreds of weather stations and weather radar measurements, to simpler systems consisting of a handful of sensors located at areas that are known to be prone to flooding to provide advance warning of flooding events. These systems usually consist of a system of monitoring stations that transmit weather data to a central control center, where the data is compiled with other weather measurements such as radar rainfall information. At these control centers the risk of flooding for the area in question is assessed and if necessary a flood warning is issued to the area. Systems of various sizes and complexity are currently used in Richmond, VA, Austin, TX and Denver, CO, to help provide warning of flooding in susceptible areas. Early warning systems could be set up in a number of ways, from a system run independently by an outside specialist that will control all aspects of the system and issue warnings, to a system where the equipment is purchased by the Federal Triangle building owners and operated and maintained by operators from the Federal Triangle. A diagram of an example system is shown in Figure 6-1.

Figure 6-1

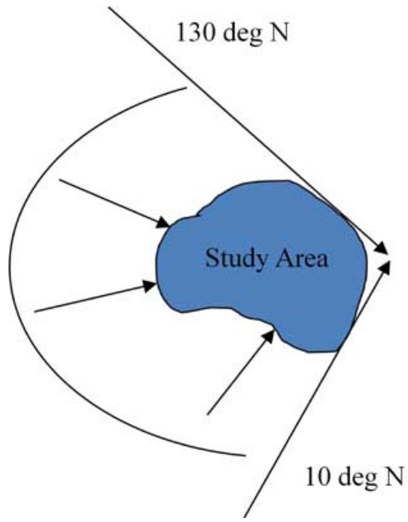
Typical Early Warning System Components and Operation



For the Federal Triangle area, a system could incorporate weather sensors in various outlying areas such as Virginia and Maryland at appropriate distances that are deemed suitable to provide accurate data. For example, a 30 minute warning time would require sensors to be installed approximately 10 miles to the west of the Federal Triangle study area, as illustrated in Figure 6-2. Weather radar data from the National Weather Service and other meteorological information recorded at the ground sensors is then collected at a central command and control center located in the Federal Triangle area, where the data is complied and if necessary a warning is issued to the various building managers. Typically a warning time of between one to four hours could be expected depending on the type and scale of the system implemented.

Figure 6-2

Location of Monitoring Stations in Relation to Study Area



6.2.1.2 Evaluation

Most early warning systems that have been used by other cities or municipalities have been for early warning for river floods. As we have previously discussed the major source of flooding at the Federal Triangle is interior rains, not river floods. An early warning system for interior rains is more difficult to monitor and is susceptible to false positives. If an excessive amount of false positives are created by the early warning system, this would lead to a strain on manpower and resources to respond to these warnings. Ultimately this could lead to the various agencies discounting the early warning system and abandoning it.

Aside from the reliability of the early warning system, the system could be a benefit to the various agencies that own buildings in the Federal Triangle if the warning was given far enough in advance that the building owners had sufficient time to implement flood protection measures and if the various agencies had actual flood protection measures to implement. An early warning system alone however, will not solve the problem of flooding in the Federal Triangle as it does not provide any infrastructure to mitigate the problem of excess storm water. The costs associated with implementing an early warning system vary greatly depending on the complexity of the system, the operational requirements of the system, the required warning time to be generated, and what additional flood protection infrastructure must be constructed to be utilized once the warning has been made. The viability of an early warning system cannot be assessed without knowing the specifics for each of the Federal Triangle facilities flood protection measures that would need to be implemented. This analysis of the Federal Triangle facilities was beyond the scope of this study.

6.2.2 Alternative B – Low Impact Development Strategies (Green Infrastructure)

6.2.2.1 Description

Low Impact Development (LID) strategies, also known as Green Infrastructure, are approaches to design to recreate predevelopment hydrological conditions at a new development or redevelopment site. LID strategies use many different techniques to reduce the amount of impervious cover and to maximize the undeveloped landscape and the hydrologic capacity of the developed landscape. Typical LID strategies include engineered structures like green roofs, bioretention, vegetated swales, permeable pavement, rain barrels and cisterns, as well as natural practices like planting trees and native landscaping. Below are examples of a typical green roof and of permeable pavement courtesy of the EPA website.

Green Roof

Permeable Pavement

LID strategies on a large scale refers to forested or otherwise vegetated open spaces that provide valuable “ecosystem services”, such as cleaner water, cleaner air, cooler local temperatures, reduced carbon footprint, wildlife habitat, and recreational opportunities. LID on a local scale, in an urban setting like the District, often is used as a stormwater management technique that can be integrated into a dense urban landscape to recreate natural hydrological processes. LID strategies represent decentralized alternatives to the traditional approach of capture, conveyance, and downstream discharge of stormwater. While stormwater management is the primary function of LID strategies in this localized form, it is important to note that it also provides many of those same ecosystem services that larger scale LID strategies provide.

The draft National Pollutant Discharge Elimination System (NPDES) permit for the separate storm sewer system issued to the District by EPA sets on-site retention standards for all new development and redevelopment over 5,000 square feet. The standard for non-Federal facilities requires that stormwater controls achieve on-site retention of 1.2-inches from a 24 hour storm with a 72 hour antecedent dry period through evapotranspiration, infiltration, and/or stormwater harvesting. The 1.2-inch event corresponds to the 90th percentile storm event in the District. The standard for Federal facilities requires on-site retention of 1.7-inches from a 24 hour storm, which corresponds to a 95th percentile storm event in the District. Assuming LID strategies are implemented to the entire Federal Triangle drainage basin, a 1.2-inch storm equates to 17,000,000 gallons of on-site retention. If LID strategies are implemented to 50% of the Federal Triangle drainage basin, that would equate to a 0.6-inch storm and 9,000,000 gallons of on-site retention. Table 6-1 shows the stormwater volumes retained by LID technologies for a 0.6-inch and 1.2-inch storm and the rainfall for 15, 50, 100, 200 year storms.

Table 6-1

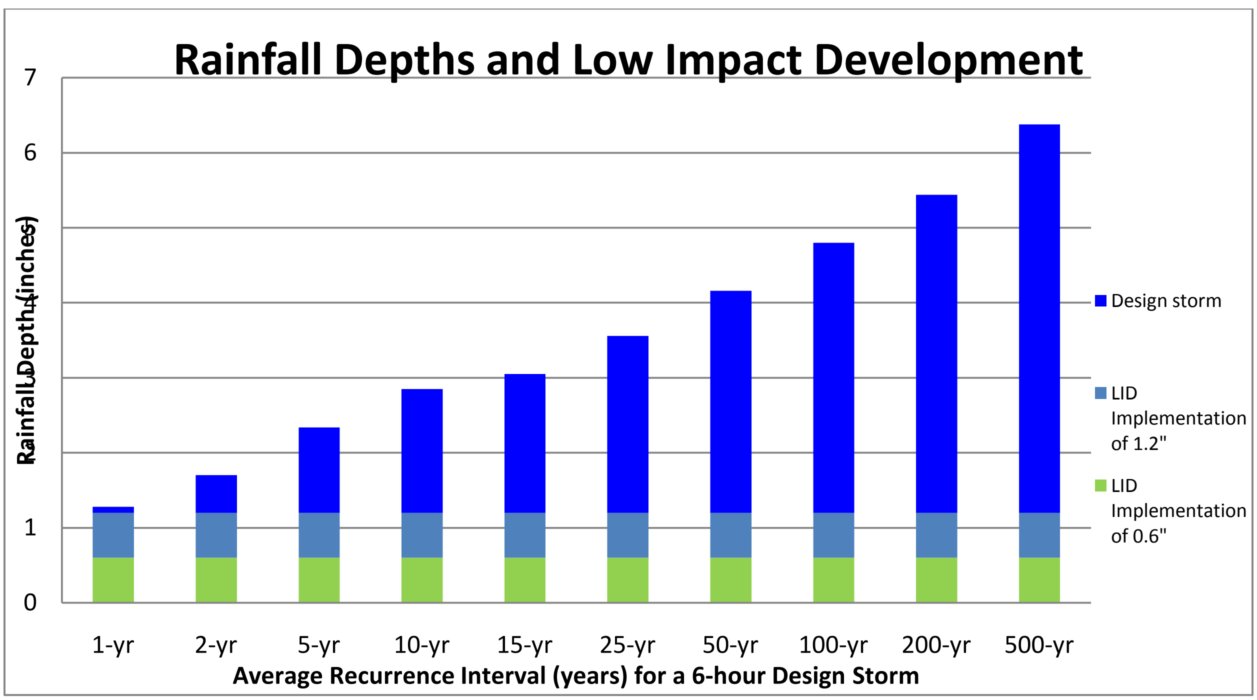
Stormwater Volumes

		LID Strategies			
		0.6-inch		1.2-inch	
Storm Event (Year)	Rainfall Volume (Million Gallons)	Retention Volume (Million Gallons)	% of Rainfall Retained by LID	Retention Volume (Million Gallons)	% of Rainfall Retained by LID
15	77	9	11.7	17	22.1
50	103	9	8.5	17	17.0
100	117	9	7.4	17	14.9
200	132	9	6.6	17	13.3

Figure 6-1 shows the impact of LID technologies on rainfall depth for various storms. For a 100 year storm, LID technologies for a 0.6-inch and 1.2-inch storm reduces the ponding at 15th and Constitution Avenue by 0.03-feet and 0.11-feet respectively.

Figure 6-3

Rainfall Depths and Low Impact Development



6.2.2.2 Evaluation

LID technologies and their implementation have advantages and disadvantages in regards to preventing flooding in the Federal Triangle area. Some of these advantages are:

- Recreates hydrological conditions of original environment – LID technologies recreate the natural "ecosystem services", such as cleaner water, that can be integrated into a dense urban landscape to recreate natural hydrological processes.

- Reduction in the volume of stormwater reaching the sewer system – LID technologies maximize the hydraulic capacity of natural landscapes. Stormwater that is captured and utilized by LID technologies does not use capacity of the sewer system or treatment facilities. Potential reductions in scale of new flood prevent facilities could be realized.

- Reduction in size of capital facilities – Stormwater that is captured and utilized by LID technologies does not enter the sewer system, freeing capacity that would otherwise have been required to capture, convey, and treat stormwater. LID technologies allow for potential reduction in size of facilities depending on the scale of LID implementation.

- Rainfall capture for small storms – As can be seen in Figure 6-3, LID technologies are capable of capturing rainfall expected from small storms. LID technologies would likely protect the Federal Triangle from flooding from small storms with a high degree of certainty.

There are disadvantages to implementation of LID technologies as an alternative for flood prevention in the Federal Triangle. Some of these disadvantages are:

- Implementation of LID technologies – Institutional issues will need to be addressed to facilitate implementation. The District is largely built-out. Implementation of LID technologies would require extensive redevelopment of existing facilities. There are also many private properties in the District that could provide resistance to redevelopment. There is a large capital cost associated with redevelopment and implementation of LID technologies.

- Long term operation and maintenance – The LID technologies constructed will require maintenance and possibly operation. The questions of who will be responsible to operate and maintain the LID technologies will need to be addressed. The LID technologies will be relied upon to operate as designed or flooding will become a distinct possibility.

- Rainfall capture for medium and large storms – As can be seen in Figure 6-3, LID technologies are capable of capturing and utilizing increasingly smaller percentages of larger storms. Construction of LID technologies will have to be layered with additional flood prevention facilities. Additional capital costs would be required.

There are additional considerations to implementation of LID technologies as an alternative for flood prevention in the Federal Triangle. Some of these additional considerations are:

- Ancillary benefits – LID technologies have ancillary benefits above and beyond storm water capture and utilization. Some such ancillary benefits are improved aesthetics, reduced heat island effect, recreational opportunities, and wildlife habitat.

- Institutional Issues – LID technologies have some institutional issues that would need to be addressed to facilitate implementation, such as private property issues.

LID technologies are not a standalone solution to flooding in the Federal Triangle area, but can augment or improve other flood control measures. LID technologies coupled or layered with other flood prevention technologies could be a viable option for preventing flooding in the Federal Triangle.

6.2.3 Alternative C – Storage Upstream of Federal Triangle Area

6.2.3.1 Description

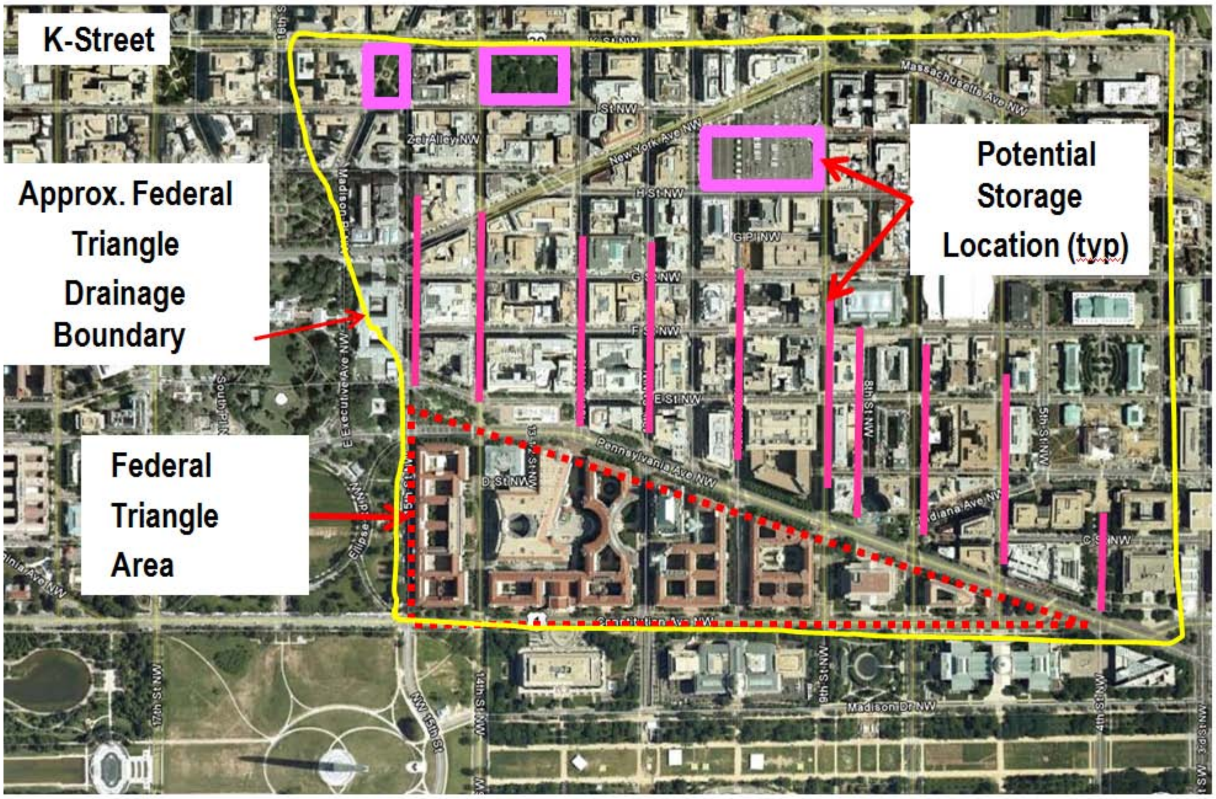
As previously mentioned, the Federal Triangle area is the low point elevation of the District. Rainfall that falls upstream of the Federal Triangle area will be conveyed via storm sewers to the Federal Triangle.

Rainfall in excess of what the storm sewers are capable of conveying will travel overland to the Federal Triangle. If the rainfall is captured upstream of the Federal Triangle in underground collection basins, the volume of storm water would not reach the Federal Triangle and would not contribute to the possibility of flooding in the Federal Triangle.

Upstream Storage can be classified in two ways, consolidated storage and distributed storage. Consolidated storage would be centralized locations that stormwater is conveyed to and stored. Examples of consolidated storage would be cisterns or storage basins beneath parking lots or vacant land or tunnels located beneath roads. In addition to construction of new storage facilities, conveyance pipes to transfer the runoff to the basins would be required and pumps to then discharge the collected runoff at the appropriate time would be required. Figure 6-4 shows potential locations and footprints for consolidated upstream storage basins located in the District.

Figure 6-4

Upstream Storage Locations



Distributed storage would be implementing rainfall storage capabilities across the entire area that could drain to the Federal Triangle. The distributed (or decentralized) storage would be the equivalent of implementing LID technologies across this area. LID technologies are the proposed flood prevention technology in Alternative B and are discussed there.

6.2.3.2 Evaluation

Storage upstream of the Federal Triangle has many disadvantages in regards to preventing flooding in the Federal Triangle area. Multiple upstream storage facilities would be needed to intercept flow from many locations in the drainage area. Additionally, this would not address the problems of surcharged sewers and would not capture the runoff in the immediate Federal Triangle area. Construction of these facilities would be expensive and extremely disruptive. Potential land acquisition cost for upstream storage could be prohibitive. Storage upstream of the Federal Triangle is not considered to be a practical solution to preventing flooding in the Federal Triangle.

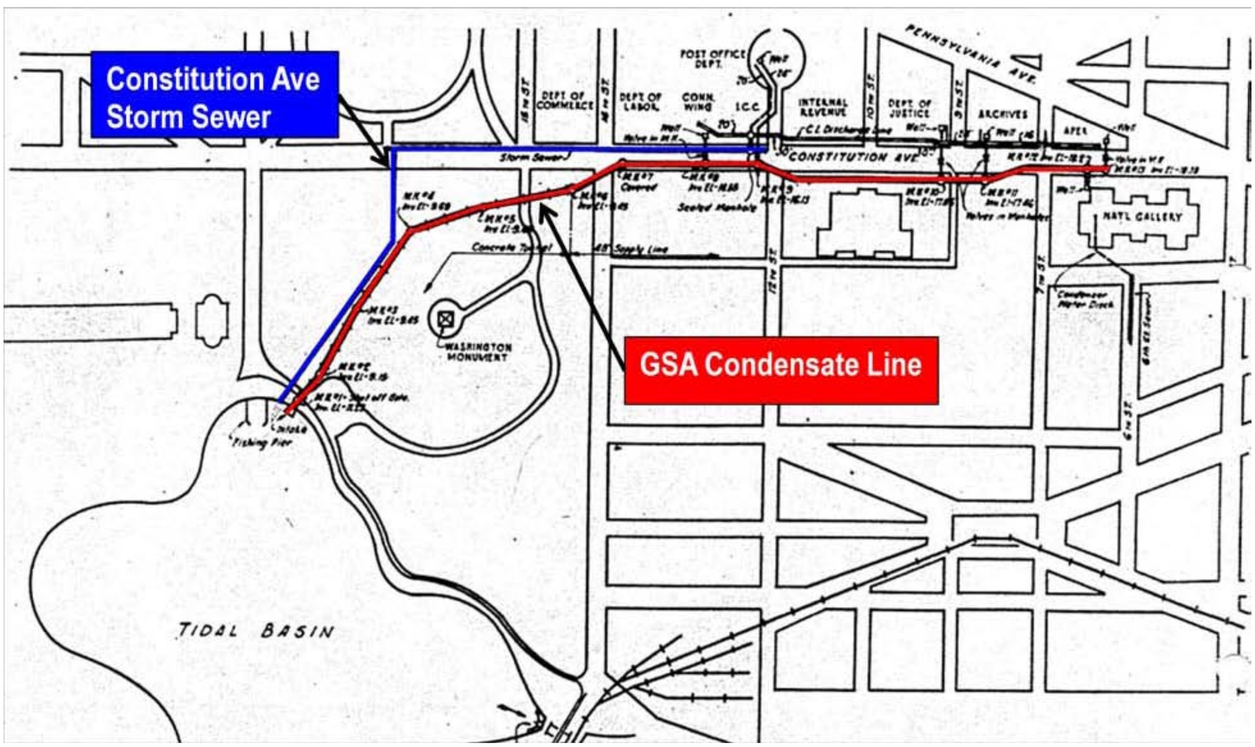
6.2.4 Alternative D – Utilize GSA Condensate Line

6.2.4.1 Description

Figure 6-5 shows the routing of the 48-inch gravity GSA Condensate line that runs along Constitution Avenue from east of 7th Street to the Tidal Basin.

Figure 6-5

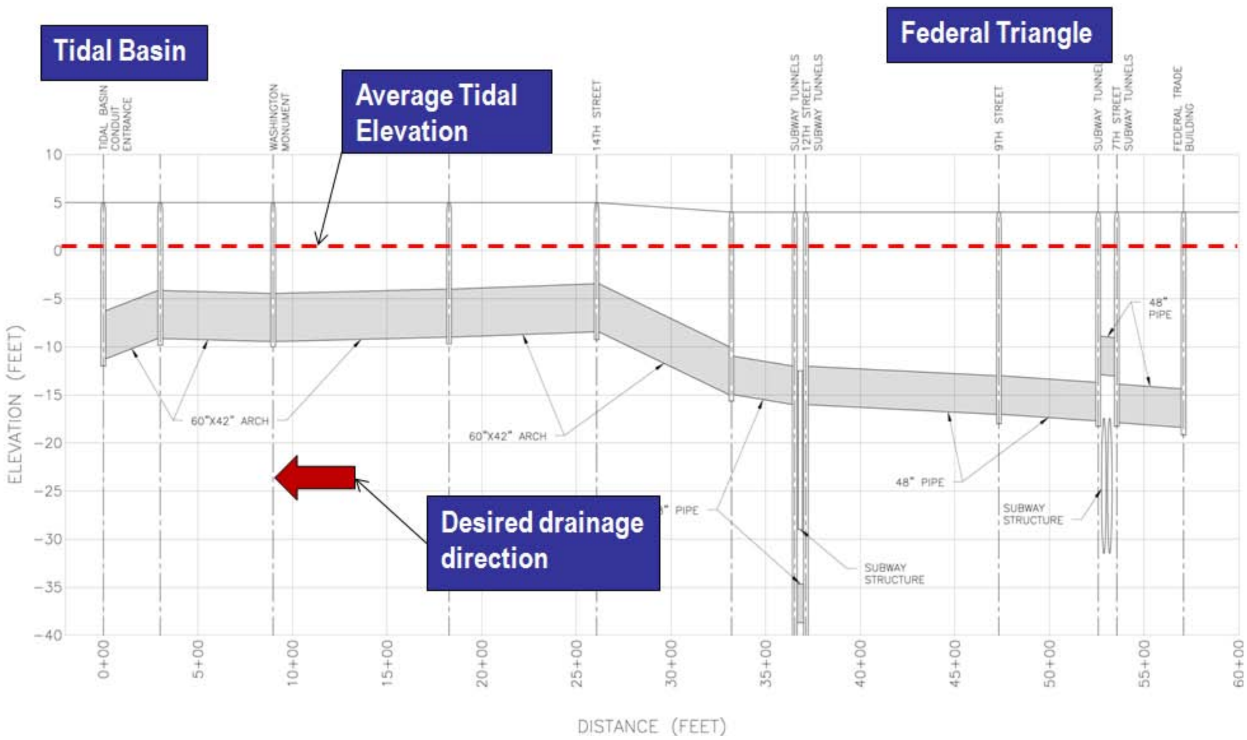
GSA Condensate Line Plan



The GSA Condensate Line was formerly used to bring water from the Tidal Basin to the Federal Triangle buildings to be used for cooling purposes, such as condensing steam. The Federal Triangle buildings no longer require this line and it is now abandoned. The December 1937 report states that the low tide capacity of the GSA Condensate Line is 26,000 gpm (37MGD). Due to the original intent of bringing water to the Federal Triangle, the GSA Condensate Line is sloped from the Tidal Basin towards the Federal Triangle. Figure 6-6 shows a profile of the GSA Conduit Line. In addition to sloping in the wrong direction, the GSA Condensate Line elevation is below the average tidal elevation. Since the GSA Condensate Line flows by gravity, there is a limited amount of flow that can be conveyed due to the tidal elevation. The GSA Condensate Line is also prone to siltation from the Tidal Basin.

Figure 6-6

GSA Condensate Line Profile



6.2.4.2 Evaluation

The capacity of the GSA Condensate Line to drain the Federal Triangle is severely limited by several conditions:

- GSA Condensate Line slopes in the wrong direction
- High tides limit the GSA Condensate Line capacity
- GSA Condensate Line is prone to siltation
- GSA Condensate Line is undersized for volumes of rainfall that would have to conveyed to prevent flooding

The limitations to the GSA Condensate Line make this alternative not viable for flood prevention in the Federal Triangle area.

6.2.5 Alternative E – Storage Beneath the National Mall

6.2.5.1 Description

The National Park Services (NPS) is preparing to construct two new underground cisterns to capture and store a total of 500,000 gallons of rainfall beneath the National Mall as part of the May 2010 Reconstruct Turf and Soil on the National Mall Project. The captured storm water would then be used for irrigation of the National Mall. The 500,000 gallons of rainfall comprises just a fraction of the irrigation requirements for the National Mall. In coordination with NPS, the construction of additional storage basins beneath the National Mall could serve as flood protection for the Federal Triangle, while providing a source for the additional irrigation capacity required by the National Mall. Table 6-2 shows the storage basin volumes and footprints required for different storm events. These volumes are the amount of rainfall above and beyond the capacity of the existing sewer system and would have to be collected to prevent flooding. Figure 6-7 shows the potential locations and footprints of storage basins located beneath the National Mall.

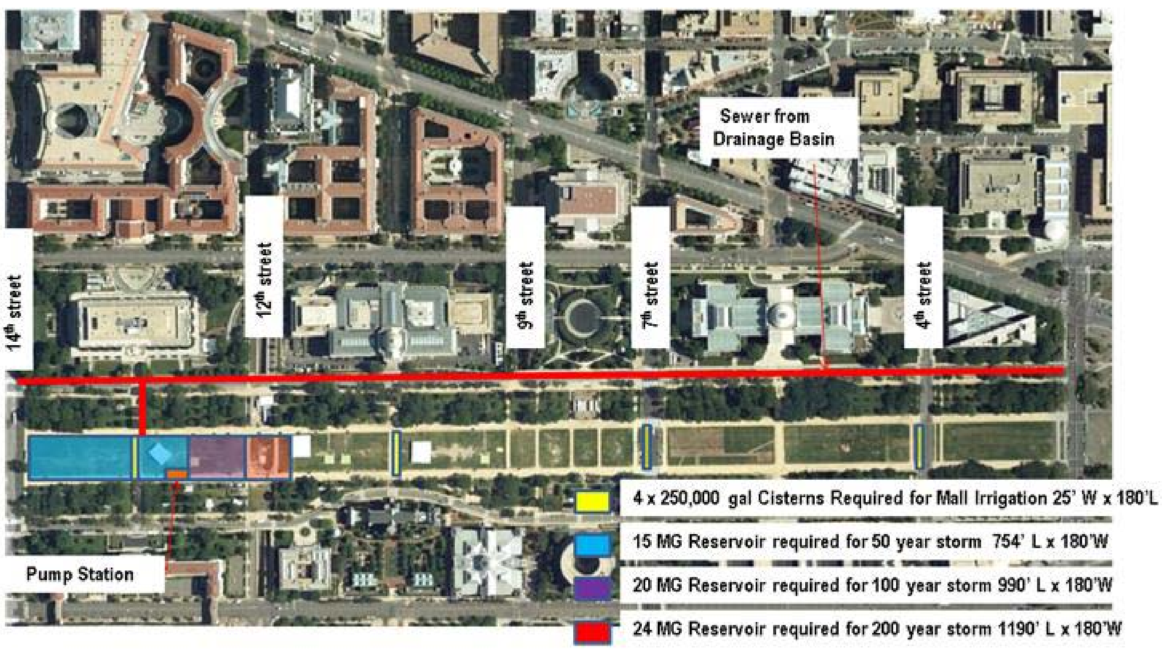
Table 6-2

Storage Requirements

Storm Event (Year)	Storage Volume (Gallons)	Storage Volume (ft^3)	Side Water Depth (ft)	Surface Area (ft^2)	Number of Panels Available	Number of Panels Required
NPS Cistern	500,000	66,900	15	4,500	8	0.05
50	15,000,000	2,006,000	15	133,700	8	1.55
100	20,000,000	2,674,000	15	178,300	8	2.06
200	24,000,000	3,209,000	15	213,900	8	2.48

Figure 6-7

Storage Basins Beneath the National Mall



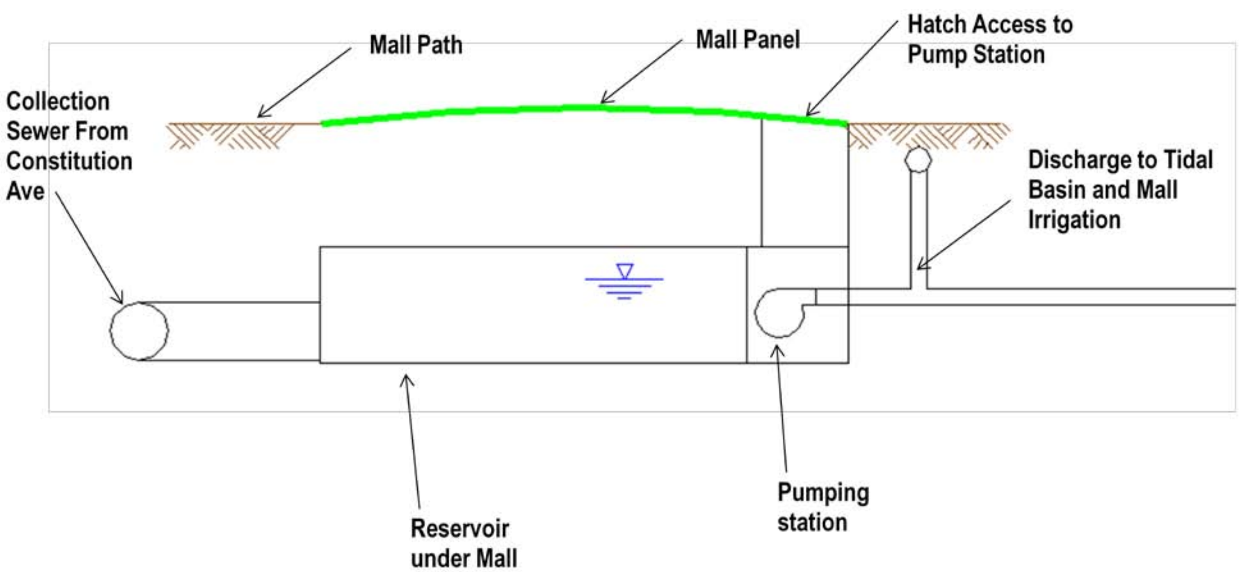
A new collection sewer would need to be constructed adjacent to the National Mall to capture and convey the rainfall to the storage basins. The rainfall that is collected within the storage basins must then either be pumped up to the National Mall for irrigation or be pumped to the sewer system. To achieve this, a new pump station would have to be located on or adjacent to the National Mall. The pump station could be located primarily below grade; however, there will have to be an entrance for personnel and access hatches for equipment maintenance located at or above grade. Depending on the year storm selected, the new pump station may have an approximate footprint of 40 feet by 40 feet below grade and an approximate footprint of 15 feet by 15 feet at or above grade. Additionally, the new pump station shown in Figure 6-7 is conceptual and is one of many possible locations on or near the National Mall. If this alternative is selected it is anticipated that there will be numerous public meetings and consultations with federal stakeholders on the appropriate location of the new pump station.

Additionally, depending on the type of irrigation method selected, disinfection of the collected rainfall may be required. This would lead to additional equipment costs, operation and maintenance costs, and potentially increase the footprint of the structure at or above grade. Figure 6-8 shows a typical cross section of storage basin and below ground pumping station beneath the National Mall.

The NPS has stated that they do not grant easements for utilities, piping, or anything that runs beneath the National Mall. Instead, NPS issues 10 year right of ways. At the end of the 10 years NPS reviews the permit and determines if the right of way will be approved for an additional 10 years or if the utility in question must instead be removed. It would be impractical to construct the large storage basins beneath the National Mall for 10 years and then potentially remove them. An agreement with NPS would have to be reached prior to design and construction for the permanent location of the storage basins beneath the National Mall if this is the selected alternative. NPS is open to the idea of using the collected stormwater for irrigation of the National Mall, but did not commit to construction or funding of this alternative.

Figure 6-8

Typical Cross Section of Storage Basin Beneath the National Mall



6.2.5.2 Evaluation

Storage beneath the National Mall has many advantages and disadvantages in regards to preventing flooding in the Federal Triangle area. Some of these advantages are:

- Stormwater can be used for irrigation of the National Mall – Capturing and utilizing stormwater for irrigation of the National Mall would help reduce the costs associated with using treated potable water for irrigation. Additionally, portions of the collected stormwater would not be required to be pumped through the sewer system to treatment or in the vent of large storm events would potentially reduce the volume of CSO discharge to the river.

- Finished facility can be located almost entirely below grade – the National Mall is dedicated to facilities and events that honor the nation’s historic, scientific, and cultural accomplishments. Consequently, many public gatherings and events are held on the National Mall. Minimizing the facilities at or above grade that could limit or impede these events or the public’s enjoyment of the National Mall would be advantageous.

Some of the disadvantages to construction of storage basins beneath the National Mall are:

- Significant disruption to activities on the National Mall – In order to adequately protect the Federal Triangle from flooding, large storage basins will be required. Construction of these basins will restrict the public's use of the National mall during this time. Events usually located on the National Mall may have to be reduced in size or even canceled during construction. Portions of the National Mall may also be used for construction staging, further reducing the amount of land available to the public.

- NPS does not issue easements, NPS issues 10 year right of way permits – Facilities the size and expense of the storage basins would be expected to last a minimum of 50 years. It would not be a cost effective or long term solution to the Federal Triangle flooding issue to potentially remove the storage basins after only 10 years.

- Back to Back storms reduce the effectiveness of basins – The storage basins have a finite volume of storage capacity. If there are sufficiently sized storms or back to back storms, the basins could be filled or may not have been pumped down prior to the next storm occurring. Consequently, pumping capacity would have to be sized to rapidly draw down the captured stormwater.

There are additional considerations to construction of storage basins beneath the National Mall as an alternative for flood prevention in the Federal Triangle. Some of these additional considerations are:

- Ancillary facilities – Ancillary facilities will have to be constructed in addition to the storage basins. A new collection sewer will need to be constructed adjacent to the National Mall to capture and convey the rainfall to the storage basins. A pumping station on or near the National Mall will be required to pump the captured rainfall out of the basins to treatment after the storm event has subsided.

- DDOE requirement for treatment of bacteria in spray water irrigation – Depending on the type of irrigation method selected, additional disinfection of the stormwater may be required. This additional equipment would increase the footprint of the facilities below grade and potentially increase the footprint of the structure at or above grade. Personnel would also be required to operate and maintain this equipment.

- Construction will be expensive due to restrictions on design of basins – NPS has stated that any facilities beneath the National Mall would have to be constructed a minimum of eight feet below grade to not impact any future events located on the National Mall. The deeper the basins are located beneath grade, the greater the construction expense, construction schedule, and construction area will be.

Storage beneath the National Mall is a viable option for preventing flooding in the Federal Triangle. There are some disadvantages that would have to be overcome, but the potential benefits of this alternative could make it an attractive solution.

6.2.6 Alternative F – New Pumping Station Serving the National Mall

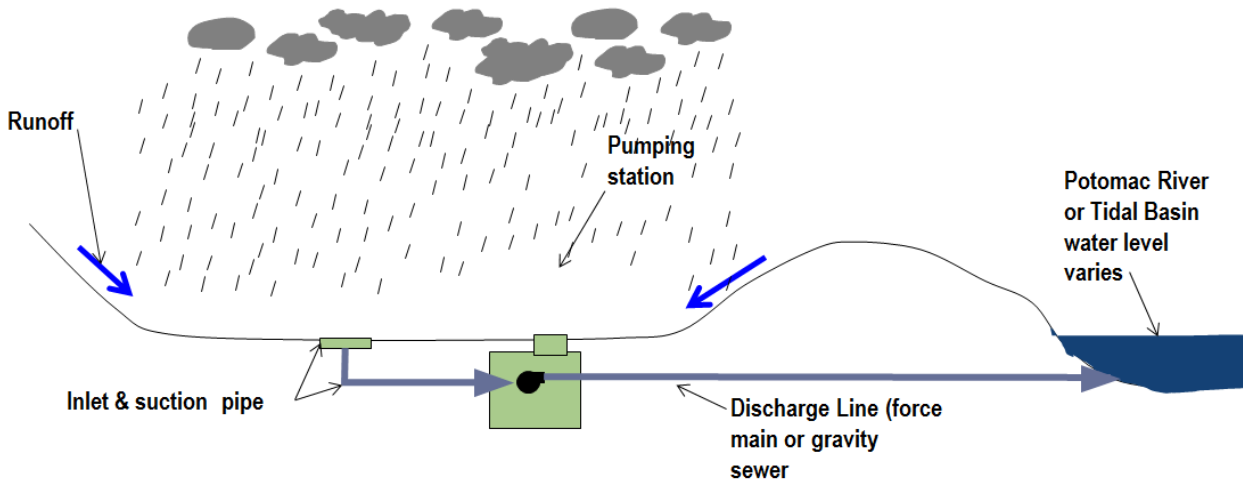
6.2.6.1 Description

To alleviate flooding in the Federal Triangle a new collection sewer could be constructed adjacent to the National Mall to capture and convey rainfall to a new Pumping Station serving the National Mall. The new

Pumping Station would pump collected rainfall to the Tidal Basin. To achieve this, a new Pumping Station would have to be located on or adjacent to the National Mall. The Pumping Station could be located primarily below grade; however, there will have to be an entrance for personnel and access hatches for equipment maintenance located at or above grade. Figure 6-9 shows a cross section of a new below grade Pumping Station servicing the National Mall. The Pumping Station servicing the National Mall would be sized to reduce ponding on Constitution Avenue to acceptable levels for the selected design storm.

Figure 6-9

Pumping Station Serving National Mall Cross Section



A new Pumping Station servicing the National Mall may be located either on the National Mall or adjacent to the National Mall. Figure 6-10 shows potential locations on or adjacent to the National Mall. Figure 6-11 shows capacities for the new Pumping Station for different design storms. The new Pumping Station shown in Figure 6-10 is conceptual and shows two of many possible locations on or near the National Mall. If this alternative is selected it is anticipated that there will be numerous public meetings and consultations with federal stakeholders on the appropriate location of the new pump station.

Figure 6-10

Potential Locations for PS Servicing national Mall

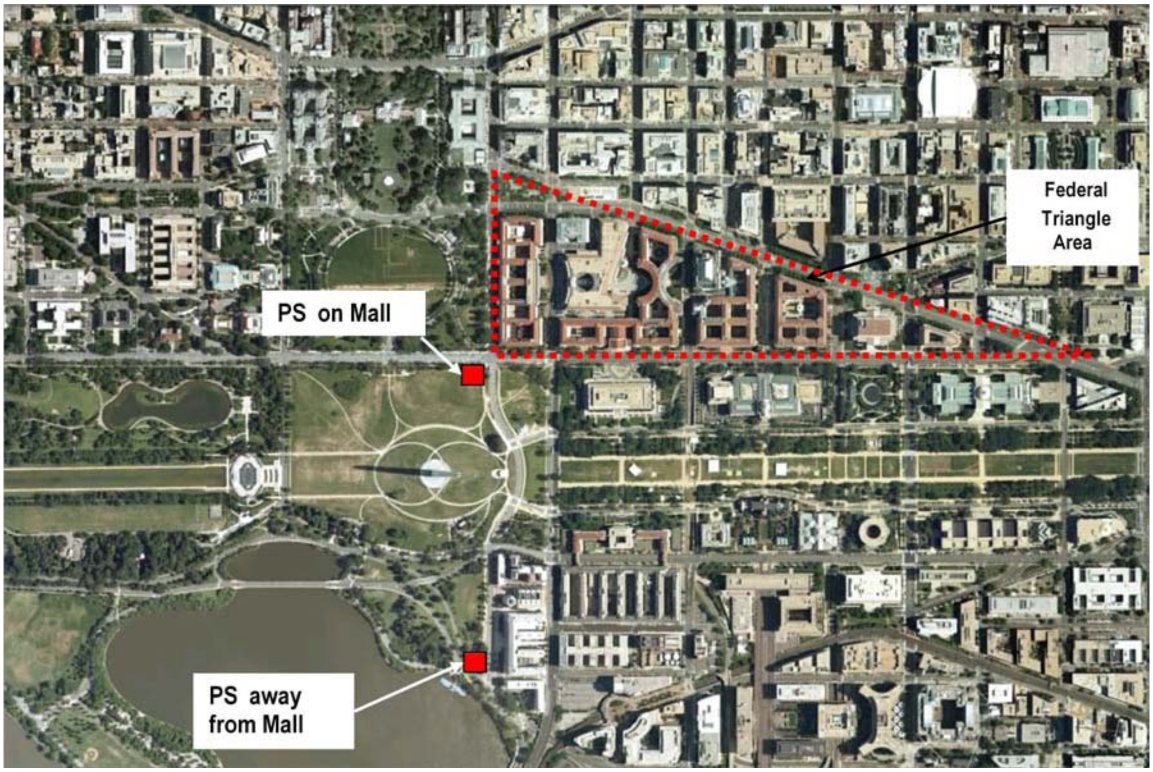
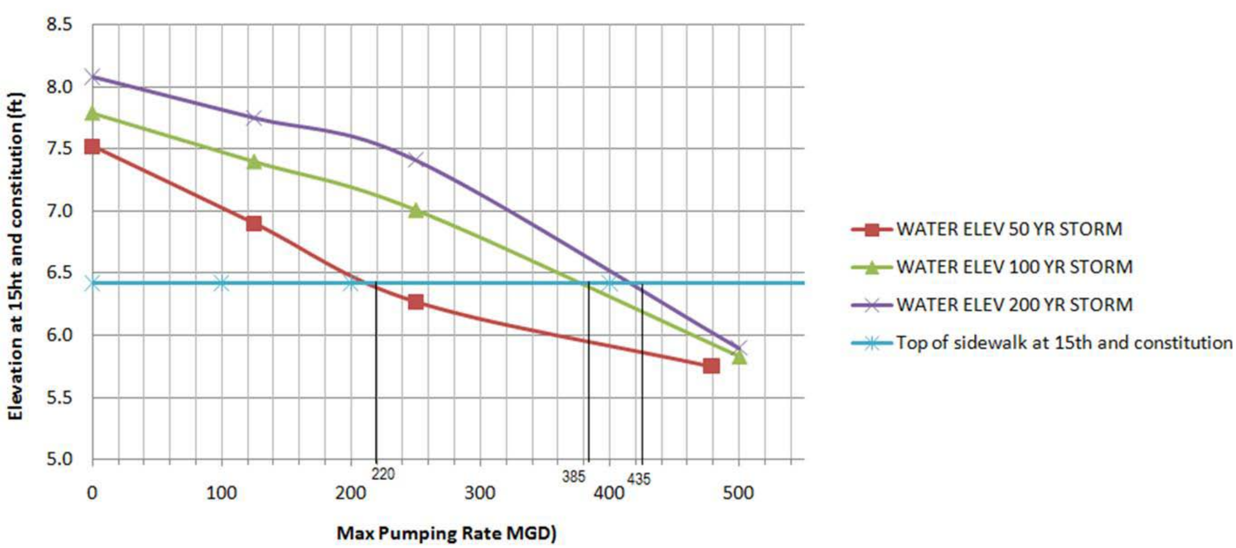


Figure 6-11

Sizing Criteria for PS Servicing the National Mall



6.2.6.2 Evaluation

A new Pumping Station servicing the National Mall has many advantages and disadvantages in regards to preventing flooding in the Federal Triangle area. Some of these advantages are:

- Pumping Station will operate at any river elevation – The low grade elevation of the Federal Triangle in relation to the elevation of the Potomac River severely limits the amount of stormwater that could flow to the river by gravity. A Pumping Station would be able to convey stormwater to the Potomac River regardless of the river elevation, ensuring that stormwater could be removed from the Federal Triangle under any condition.

- System does not have complex operating parameters – The new Pumping Station would not be a challenge to operate. Minimizing the complexity of the controls to operate the Pumping Station will help reduce the construction cost and associated operation and maintenance costs.

- Pumping Station is independent of outside system influences – The new Pumping Station will operate autonomously from other flood prevention systems or the sewer system elsewhere in the District. The Pumping Station will not require outside systems to activate or be manipulated to function.

Some of the disadvantages to construction of a new Pumping Station servicing the National Mall are:

- Significant disruption to activities on the National Mall – The National Mall is dedicated to facilities that honor the nation's historic, scientific, and cultural accomplishments. Land on or near the National Mall is at a premium. During construction the new Pumping Station could cause disruption to portions of the National Mall. Additionally to maintain the availability and aesthetic of the National Mall, the Pumping Station would be required to be a subsurface facility. Only access for personnel and equipment would be located at or above grade. Being located underground will add time and expense to the construction schedule.

- Limited sites for staging access – The District is a very built-out area. There is not a lot of available land for construction staging. Additionally the National Mall is an area with a high concentration of visitors and any disruption to the National Mall is to be minimized.

There are additional considerations of a new Pumping Station servicing the National Mall Some of these additional consideration are:

- Security issues – The Federal Triangle and National Mall is the home of many government agencies. Some of these agencies may contain highly sensitive facilities underground in the area that could make the project infeasible. If there are sensitive government facilities in the area, the agencies are unlikely to share this information with the designers until late in the design and could cause major changes or delays to the project.

- Operation, maintenance, and upgrade of Pumping Station – Once constructed the Pumping Station would need to be operated, maintained, and upgraded over time to function properly. Personnel and fiscal responsibility for this Pumping Station will have to be coordinated by the stakeholders.

- NPS does not issue easements, NPS issues 10 year right of way permits – A new Pumping Station would be expected to last a minimum of 50 years. It would not be a cost effective or long term solution to the Federal Triangle flooding issue to potentially remove the Pumping Station after only 10 years.

A new Pumping Station servicing the National Mall is a viable option for preventing flooding in the Federal Triangle.

6.2.7 Alternative G – New Tunnel to the Existing Main and O Street Pumping Stations

6.2.7.1 Description

Presently the B Street/New Jersey sewer conveys collected rainfall to the Main and O Street Pumping Stations. The B Street/New Jersey sewer does not have sufficient capacity to convey rainfall from large storm events away from the Federal Triangle to prevent flooding in the Federal Triangle area. Main and O Street Pumping Stations have pumping capacity that isn't utilized during large storms, because the flow cannot get to the pumping stations quickly enough. Constructing a new Federal Triangle tunnel to capture and convey rainfall from the Federal Triangle directly to O Street Pumping Station would maximize the pumping capacity of Main and O Street Pumping Stations and provide a level of flood protection for an appropriately sized storm. The new tunnel would expect to be constructed using underground tunnel boring machines in lieu of open cutting at the surface level. This would limit the disturbance of surface structures and potential impact on vehicle and pedestrian traffic. The actual location and alignment of the new tunnel will require a more detailed analysis than what this study can offer.

The new Federal Triangle Tunnel would require construction of a new sewer and inlets along Constitution Avenue to collect rainfall from the streets. This sewer would discharge into the new Federal Triangle Tunnel, which would flow by gravity to the Main and O Street Pumping Stations. Once the new Federal Triangle Tunnel is connected to the existing Pumping Stations, the rainfall would ultimately be connected to the Blue Plains Tunnel and can be conveyed to the Blue Plains WWTP. The Main and O Street Pumping Stations have a firm capacity of 400 mgd and 500 mgd, respectively. If a very large frequency of storm is selected to provide flood protection against, the pumping capacity at the stations may be exceeded. If this were to occur, supplemental pumping capacity may be required. The new Federal Triangle Tunnel has two options:

- Alternative G1 – Construct new Tunnel from Main and O Street Pumping Stations to Federal Triangle (Stop at Federal Triangle)
- Alternative G2 - Construct new Tunnel from Main and O Street Pumping Stations to Federal Triangle (Connect to Potomac CSO Tunnel)

The actual location and alignment of a new Tunnel from O Street Pumping Station to the Federal Triangle will require a more detailed analysis that is beyond the scope of this study. Additionally, using boring technologies to construct the new tunnel will limit the amount of surface excavation required.

DC Water is implementing a Long Term Control Plan (LTCP) to control Combined Sewer Overflows (CSOs) to the District's waterways. The LTCP comprises multiple projects designed to meet the CSO control objectives of DC Water and to meet water quality standards in the District. Alternative G looks at how new facilities constructed to provide flood protection to the Federal Triangle area can be combined with facilities being constructed across the District to provide CSO control to achieve an integrated District wide solution. See Appendix G for details off the LTCP for CSO control, Total Nitrogen Removal/Wet Weather Plan, and DC Water Consent Decrees. .

6.2.7.2 Alternative G1 Description

Alternative G1 provides flood protection for the Federal Triangle area as a standalone solution. Collected rainfall will flow by gravity from the Federal Triangle via the new Federal Triangle Tunnel to Main and O Street Pumping Stations. After the rain has subsided and the Blue Plains Tunnel has been emptied, a gate will be opened and liquid in the Federal Triangle Tunnel will drain by gravity to the Blue Plains WWTP. If liquid levels become too high in the Federal Triangle Tunnel before it may be drained into the Blue Plains Tunnel, the Main and O Street Pumping Station pumps will turn on and pump the water out to the river. Figure 6-12 shows a flow diagram of the new Federal Triangle Tunnel connected to the existing sewer system.

Figure 6-12

New Federal Triangle Tunnel Flow Diagram

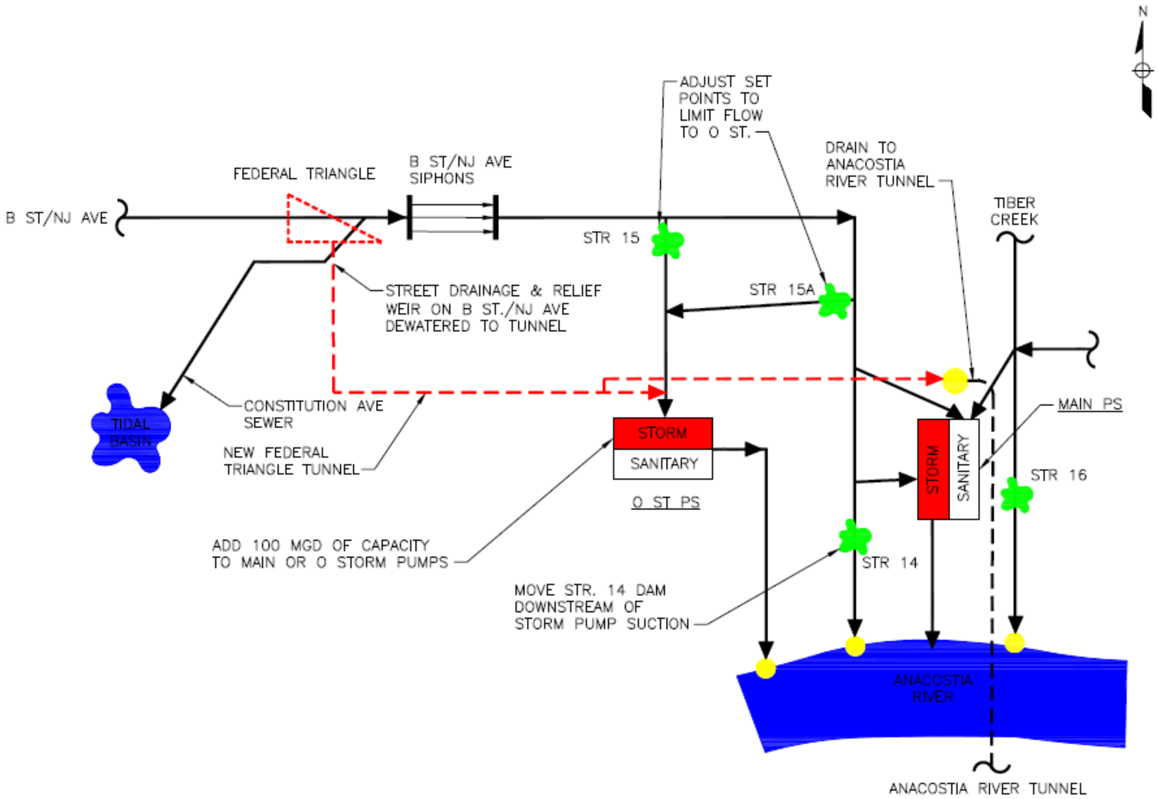


Figure 6-13 shows one potential routing of the new Federal Triangle Tunnel to O Street Pumping Station. Figure 6-14 shows a profile of the new Federal Triangle Tunnel.

Figure 6-13

Alternative G1 – Tunnel form Federal Triangle to O St. PS

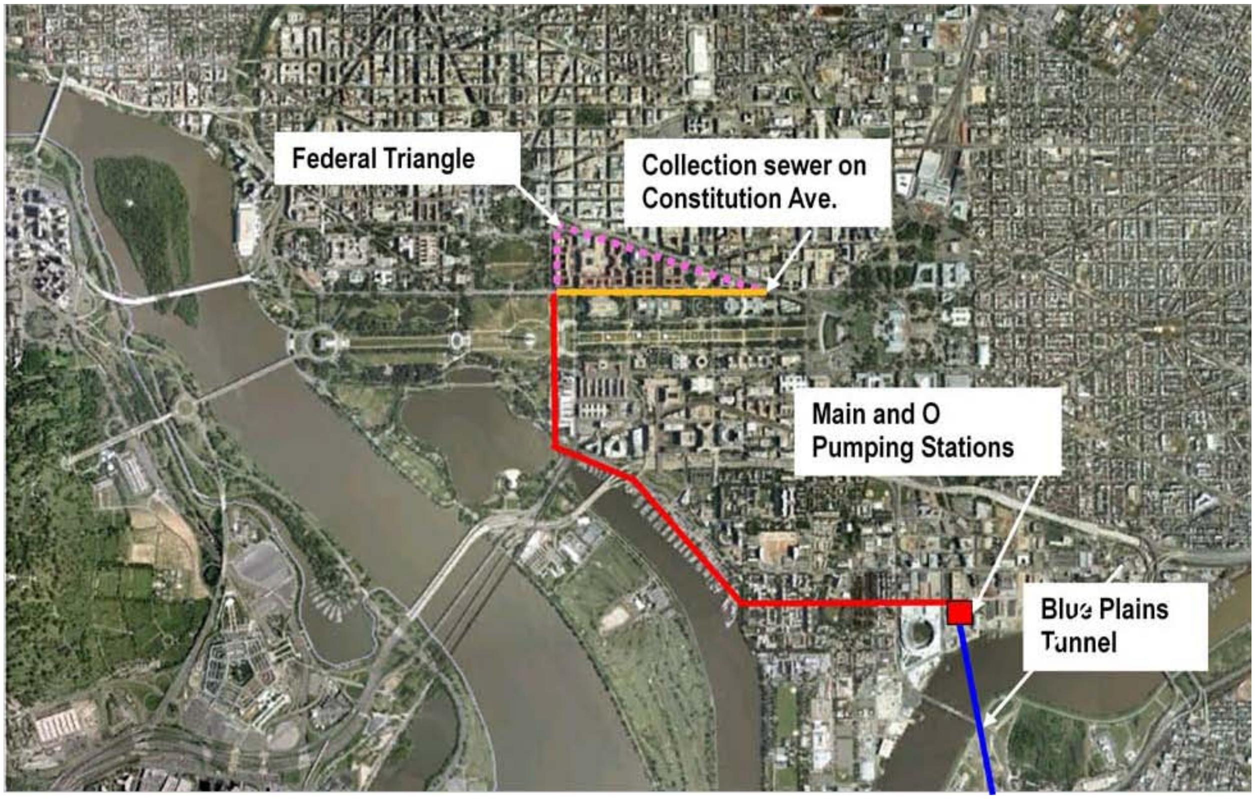
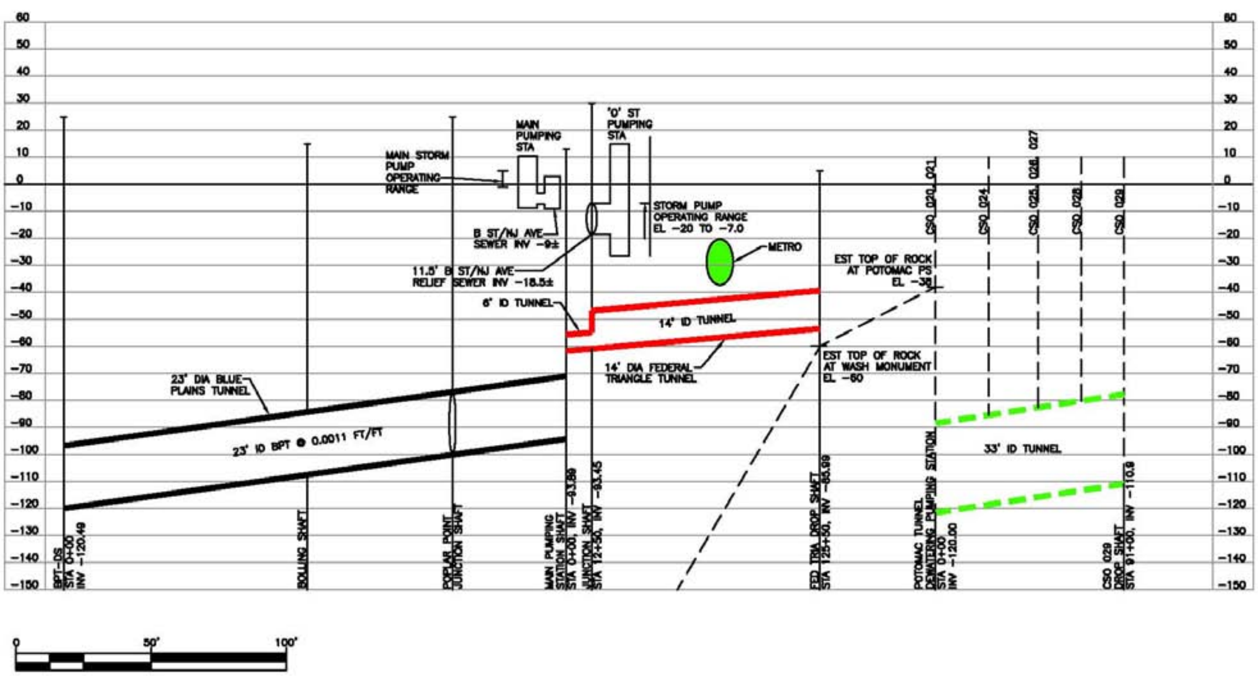


Figure 6-14

Alternative G1 – Tunnel form Federal Triangle to O St. PS Profile



6.2.7.3 Alternative G2 Description

Alternative G2 combines new facilities providing flood protection to the Federal Triangle area with facilities being constructed to provide CSO control to achieve an integrated District wide solution Alternative G2 would operate the same as Alternative G1; however, the new Federal Triangle Tunnel could be extended to connect to the Potomac CSO Tunnel for additional CSO control within the District. Figure 6-16 shows a flow diagram of the new Federal Triangle Tunnel connected to the existing sewer system and the Potomac CSO Tunnel. Figure 6-17 shows one potential routing connecting the Potomac CSO Tunnel to the new Federal Triangle Tunnel. By connecting the Potomac CSO Tunnel to the Main and O Street Pumping Stations, a new Pumping Station for the Potomac CSO Tunnel would not have to be built. Not having to construct the new Potomac CSO Pumping Station would result in a capital cost savings, maintenance and operation saving and would avoid the difficulties of having to site the CSO Pumping Station in a congested high demand area. Figure 6-18 shows a profile of the new Federal Triangle Tunnel connected to the Potomac CSO tunnel.

Figure 6-15

New Federal Triangle Tunnel Connected to Potomac CSO Flow Diagram

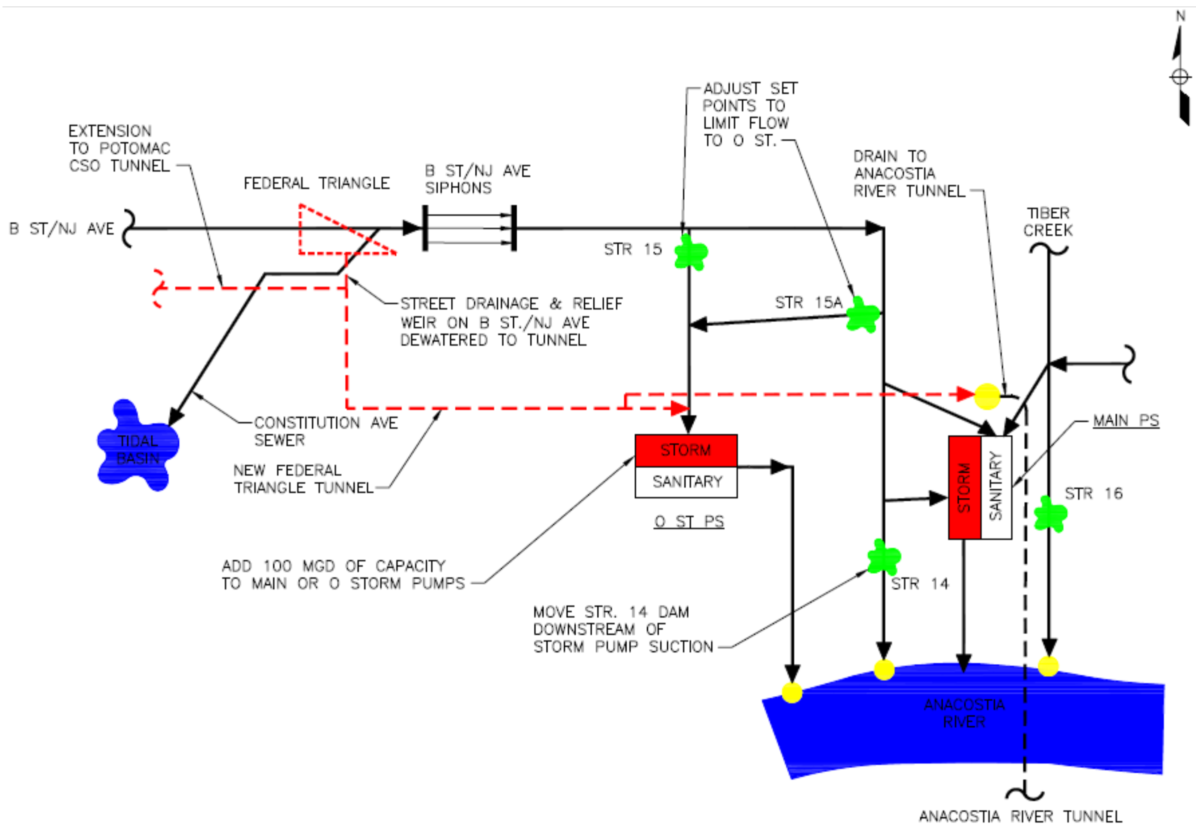


Figure 6-16

Alternative G2 – Tunnel form Federal Triangle to O St. PS Connected to Potomac CSO Tunnel

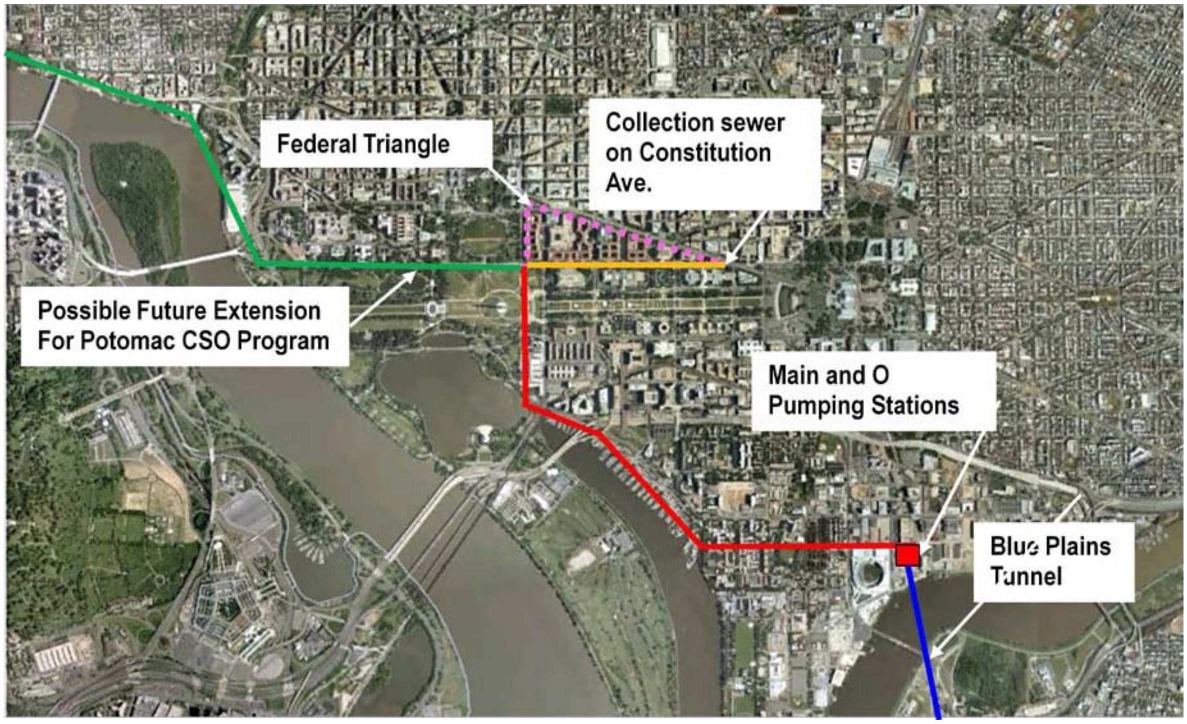
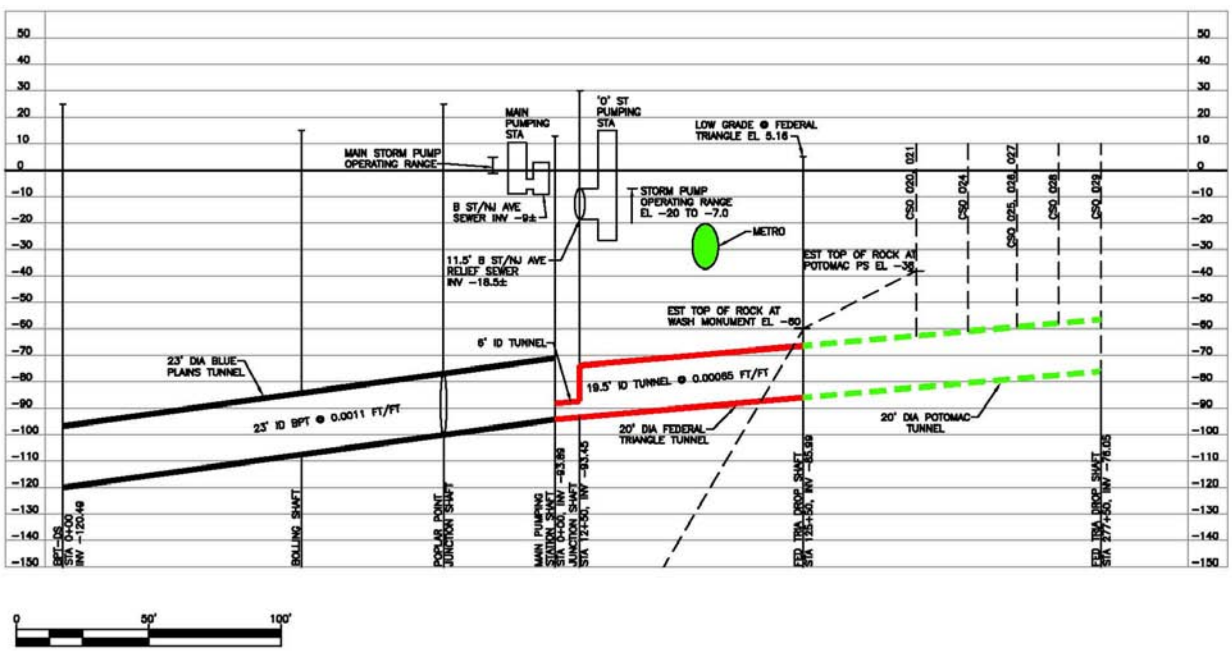


Figure 6-17

Alternative G2 – Tunnel from Fed. Triangle to O St. PS Connected to Potomac CSO Tunnel Profile



6.2.7.4 Alternative G1 Evaluation

The new Federal Triangle Tunnel to existing Main and O Street Pumping Stations has many advantages and disadvantages in regards to preventing flooding in the Federal Triangle area. Some of these advantages are:

- Maximizes the use of existing facilities – As discussed above, there is existing infrastructure (capacity) that is not being fully utilized. By connecting the new Tunnel to existing facilities that are underutilized, these existing facilities can be fully utilized and would not require construction of additional facilities.

- Does not require construction of pumping station on or near the National Mall – The National Mall is dedicated to facilities that honor the nation’s historic, scientific, and cultural accomplishments. Land on or near the National Mall is at a premium. Avoiding construction of new flood prevention facilities here does not prevent future construction of new buildings on the National Mall and would not preclude public enjoyment of the National Mall during an extended construction period. A new tunnel would have a significantly lower operation and maintenance cost than a new pumping station

- Boring Tunnels will minimize the disruption to the surface streets or properties – Rather than excavating from ground level down, which means tearing up streets, sidewalks, and other public areas, the use of tunnel boring machines would minimize the disruption to the public, streets, and sidewalks.

Some of the disadvantages to construction of a new Federal Triangle Tunnel are:

- Security issues – The Federal Triangle and National Mall is the home of many government agencies. Some of these agencies may contain highly sensitive facilities underground in the area that could make the project infeasible. If there are sensitive government facilities in the area, the agencies are unlikely to share this information with the designers until late in the design and could cause major changes or delays to the project.

- Solid/Rock Interface – Tunneling is most economical when it is performed through soil or rock, not both. In this area, there is a transition from rock to soil. Tunneling through a soil/rock interface will add to the complexity and cost of tunneling.

- Limited sites for staging access – The District is a very built-out area. There is not a lot of available land for construction staging. Additionally the National Mall is an area with a high concentration of visitors and any disruption to the National Mall is to be minimized.

A new tunnel from the Main and O Street Pumping Stations to the Federal Triangle is a viable option for preventing flooding in the Federal Triangle. While there are some disadvantages that would have to be overcome with this alternative, the benefits of this alternative would make it an attractive solution.

6.2.7.5 Alternative G2 Evaluation

The new Federal Triangle Tunnel to existing Main and O Street Pumping Station Connected to Potomac CSO Tunnel has many advantages and disadvantages in regards to preventing flooding in the Federal Triangle area. Some of the advantages are:

- Eliminates the need for the Potomac CSO Tunnel Dewatering Pumping Station – Integrating the Potomac CSO Tunnel with the new Federal Triangle Tunnel would allow the Main and O Street Pumping Stations to pump both tunnels. The Potomac CSO Tunnel Dewatering Pumping Station would be very difficult to site. It would be near many high profile government and cultural landmarks and would take up available land that would otherwise be used for future government or cultural expansion. Eliminating the Pumping Station would also avoid an expensive operation and maintenance that would be otherwise required.

- Simplifies overall CSO Program Operation – By taking a holistic approach to the CSO program across the District and unifying independent parts into one system that could be controlled from the Blue Plains WWTP, the operation and control of the system would be greatly simplified.

- Maximizes the use of existing facilities – As discussed above, there is existing infrastructure (capacity) that is not being fully utilized. By combining CSO programs, existing facilities that are underutilized can be fully utilized and would not require construction of additional facilities.

- Does not require construction of pumping station on or near the National Mall – The National Mall is dedicated to facilities that honor the nations historic, scientific, and cultural accomplishments. Land on or near the National Mall is at a premium. Avoiding construction of new flood prevention facilities here does not prevent future construction of new buildings on the National Mall and would not preclude public enjoyment of the National Mall during an extended construction period. A new tunnel would have a significantly lower operation and maintenance cost than a new pumping station.

There are disadvantages to construction of a new Federal Triangle Tunnel that is also connected to the Potomac CSO Tunnel. Some of these disadvantages are:

- Security issues – The Federal Triangle and National Mall is the home of many government agencies. Some of these agencies may contain highly sensitive facilities underground in the area that could make the project infeasible. If there are sensitive government facilities in the area, the agencies are unlikely to share this information with the designers until late in the design and could cause major changes or delays to the project.

- Solid/Rock Interface – – Tunneling is most economical when it is performed through soil or rock, not both. In this area, there is a transition from rock to soil. Tunneling through a soil/rock interface will add to the complexity and cost of tunneling.

- Limited sites for staging access – The District is a very built-out area. There is not a lot of available land for construction staging. Additionally the National Mall is an area with a high concentration of visitors and any disruption to the National Mall is to be minimized.

A new tunnel from the Main and O Street Pumping Station to the Federal Triangle is a viable option for preventing flooding in the Federal Triangle. While there are some disadvantages that would have to be overcome with this alternative, connecting the new tunnel to the Potomac CSO tunnel would provide additional benefits to the District as a whole that would make it an attractive solution.

6.2.8 Capital Cost Comparison of Alternatives

Table 6-3 is a summary of capital costs in millions of dollars, for the alternatives identified above sized for various design storms. See Appendix C for Bases for Cost Estimates and Appendix D Cost Estimate for how the capital costs were developed for these alternatives.

At this conceptual stage of alternative analysis, detailed facility layouts have not been prepared. Conceptual level costs are based on typical costs for actual facilities of similar capacity and experience on other projects. For example, costs are developed using $/linear foot for pipelines or $/mgd for pumping stations. A 30% contingency is added to the total cost (on top of normal contingencies) to account for special costs associated with working in highly sensitive, highly congested areas like the National Mall and Federal Triangle. In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be “Concept Level” estimates with an accuracy of +50%/-30%. For example, a concept level cost estimate of $100,000,000 could be as high as

$150,000,000 or as low as $70,000,000. When an alternative or alternatives have been selected for a more detailed design, the contingencies will begin to be reduced and a more accurate cost can be developed.

Table 6-3

Capital Costs: Comparison of Alternatives ($ Millions)

No.	Alternative	Storm Design Return Frequency		
		50-yr	100-yr	200-yr
B[(1)]	Low Impact Development	$135	$135	$135
E	Storage Beneath National Mall	$325	$400	$455
F	Pumping Station Serving National Mall	$240	$360	$400
G1	Tunnel from O St. to Fed Triangle – Stop at Fed Triangle	$405	$405	$470
G2	Tunnel from O St. to Fed Triangle – Connect to Potomac	$480	$480	$545

(1) Alternative B is not a viable alternative on its own, supplements other alternatives
(2) Costs are in Year 2010 dollars, ENR Construction Cost Index = 8805
(3) In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be "Concept Level" estimates with an accuracy of +50%/-30%

Table 6-4 is a summary of operation and maintenance costs in thousands of dollars, for the alternatives identified above sized for various design storms. The operation and maintenance costs are present worth costs calculated over a lifetime of 20 years, a 6.5% interest rate, and 3% inflation rate. See Appendix C for Bases for Cost Estimates and Appendix D Cost Estimate for how the operation and maintenance costs were developed for these alternatives.

Table 6-4

Operation and Maintenance Costs: Comparison of Alternatives ($ Thousands)

No.	Alternative	Storm Design Return Frequency		
		50-yr	100-yr	200-yr
B[(1)]	Low Impact Development	$845	$845	$845
E	Storage Beneath National Mall	$2,535	$3,099	$3,512
F	Pumping Station Serving National Mall	$1,427	$2,103	$2,329
G1	Tunnel from O St. to Fed Triangle – Stop at Fed Triangle	$798	$798	$920
G2	Tunnel from O St. to Fed Triangle – Connect to Potomac	$939	$939	$1,061

(1) Alternative B is not a viable alternative on its own, supplements other alternatives
(2) Costs are in Year 2010 dollars, ENR Construction Cost Index = 8805
(3) In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be "Concept Level" estimates with an accuracy of +50%/-30%

The purpose of this study is to analyze various alternatives to prevent flooding in the Federal Triangle area. Table 6-3 lists costs for these alternatives while looking at the Federal Triangle area as a standalone system. The Federal Triangle area isn't a standalone system; it is an integral part of the entire District watershed. The alternatives identified can also be analyzed as a District wide integrated solution. Table 6-5 compares the capital costs for not integrated alternatives vs. an integrated alternative for a 100 year storm for the various alternatives

Table 6-5

Capital Costs: Integrated Solution for 100 year Storm

Federal Triangle			Potomac CSO Plan		Total
No.	Description	Capital Cost ($M)	Description	Capital Cost ($M)	Capital Cost ($M)
NOT INTEGRATED SOLUTION					
E	Storage Beneath National Mall	$400	34' dia Potomac Tunnel (No Fed. Tri. Connection)	$510	$910
F	Pumping Station Serving National Mall	$360	34' dia Potomac Tunnel (No Fed. Tri. Connection)	$510	$870
G1	14' dia Tunnel Connected to Main and O St.	$405	34' dia Potomac Tunnel (No Fed. Tri. Connection)	$510	$915
INTEGRATED SOLUTION					
G2	20' dia Tunnel Connected to Main and O St.	$480	20' dia Potomac Tunnel (Connected to Fed. Tri.)	$430	$910

(1) Costs are in Year 2010 dollars, ENR Construction Cost Index = 8805
(2) In accordance with the Association for the Advancement of Cost Engineering (AACE), cost estimates are considered to be "Concept Level" estimates with an accuracy of +50%/-30%

As can be seen in Table 6-5, the costs for an integrated solution for flood prevention are very similar to the costs for a not integrated solution for flood prevention.

Alternative G2 consists of flood prevention facilities to protect the Federal Triangle Area combined with CSO control facilities to provide an integrated District wide solution to stormwater capture, conveyance, and treatment. As such the financial considerations of Alternative G2 need not be endured by the partner agencies alone. If Alternative G2 is selected for implementation, detailed discussions to how associated costs will be shared between the beneficiaries of the flood control project and DC Water.

6.2.9 Alternative H – Flood Proofing Structures within the Federal Triangle Area

6.2.9.1 Description

Another alternative that the partner agencies could consider is flood proofing, or "armoring", their facilities and buildings to prevent flooding from occurring within these facilities and buildings. This could range from sealing grade level or below grade walls and windows, moving equipment and stored items out of the below grade levels, or installing barriers to prevent liquid ponding above grade from reaching the buildings. This is not part of the scope of this project and will have to be identified in a separate study by the partner agencies.

6.3 FLOOD PREVENTION UTILIZING A LAYERED APPROACH

The Federal Triangle flood prevention alternatives analyzed in this study have varying degrees of effectiveness. Some of the alternatives cannot prevent flooding by themselves. Some alternatives have to be implemented in conjunction with other alternatives, in a layered approach to be effective.

6.3.1 Alternatives Suitable for a Layered Approach

LID strategies, Upstream Storage, and flood proofing of facilities cannot prevent flooding by themselves. For example, LID strategies are only capable of containing rainfall associated with small storm events. Large storm events far exceed the capacity of LID strategies and would require an additional alternative to prevent flooding for storms exceeding the capacity of LID. While LID is not a standalone solution, it is possible that constructing LID strategies could help reduce the magnitude and costs of a different flood prevention alternative. This would be similar for upstream storage and flood proofing of buildings.

6.3.2 Alternatives not Suitable for a Layered Approach

A new tunnel from the Federal Triangle to Main and O Street Pumping Stations is not suitable for a layered approach. If the new tunnel were layered with another flood prevention alternative, the potential reduction in size or cost of the tunnel would be marginal. As we have discussed, LID strategies only contain a small portion of the capacity needed for large storms. Consequently, the tunnel would not realize a significant reduction in size. Additionally, the construction costs associated with tunneling do not vary significantly by changing the size of the tunnel by a foot or two in diameter.

6.3.3 Alternatives Marginally Suitable for a Layered Approach

A new Pumping Station and storage beneath the National Mall are alternatives that are marginally suitable for a layered approach. These alternatives will have to be sized to handle the large storms, but reductions in size of these alternatives, due to LID strategies will have a greater impact to cost and size than for a new tunnel. Reductions in size of these alternatives will reduce excavation, size of the facility, disruption to the National Mall, and other factors that realize a greater savings than the tunnel.

Section 7 FINDINGS

7.1 FINDINGS

The District of Columbia experienced a severe storm from June 24, 2006 to June 26, 2006, which caused extensive flooding within the Federal Triangle area resulting in millions of dollars in damage, displacement of workers, and interruption of government services. Several Federal and District agencies formed a Federal Triangle Study Working Group to identify measures to reduce the risk and impact of flooding in the future. This section identifies the findings of this study in regards to the capabilities of the existing sewer system, magnitude of the June 2006 storm, impacts of different storm frequencies on ponding within the Federal Triangle area, and evaluated alternatives to reduce the frequency of flooding within the Federal Triangle area, and develop a plan for further investigations to finalize a flood control strategy .

- The June 24-26, 2006 rain event exceeded a 200-year return frequency storm. The volume of water from this storm exceeded the capacity of the sewer system in the Federal Triangle area, which is designed for a 5 to 15 year storm, and is typical of the capacity of sewers in other parts of the District.

- The Federal Triangle is at the bottom of a topographic bowl, with the land sloping upward in all directions. This condition exacerbated the flooding in June 2006 because stormwater runoff from the drainage area, which is 24 times the size of the Federal Triangle, flowed down to the Federal Triangle within a 6-hour period and overwhelmed the sewers.

- The Federal Triangle is at a low elevation compared to the Potomac River, making it difficult and sometimes impossible to drain runoff to the river by gravity. This also makes the area susceptible to flooding due to high river levels. While the modeling used in this Study considered the combined effects of river and interior drainage flooding simultaneously occurring in the vicinity of the Federal Triangle, it was found that the Potomac River was not at flood stage during the June 2006 flood.

- While the Constitution Avenue Storm Sewer siphons at the B Street/New Jersey Sewer contained some siltation during the June 24-26, 2006 storm event, these conditions did not significantly exacerbate flooding in the Federal Triangle. If the sewers had been clean, the ponding depth in the Federal Triangle would have been about 4" lower. The magnitude of the storm far exceeded the design capacity of the sewer system.

- Since the Federal Triangle is a topographic low point, it is important to note that any alternative for flood control could be overwhelmed if a sufficiently large storm occurs. No structural solution will be able to completely eliminate the risk of flooding

- The 17th Street Levee Project currently under construction in the National Mall will provide a higher degree of protection for the Monumental Core of Washington from river flooding. However, it does not mitigate interior rainfall flooding. Thus, the DC Flood Insurance Rate Map, which will be revised to reflect the effect of the levee in reducing the flood areas of the Monumental Core, will still show the Federal Triangle area in the 100-Year floodplain.

- A model was developed to enable prediction of ponding levels in the Federal Triangle for various return frequency storms and River levels. The model was calibrated to the June 2006 flood event and is now available as a predictive tool.

- Baseline ponding levels were predicted for the existing system for 50, 100 and 200 year storm events and as a function of river levels. Detailed information on the results is included in the report.

- The following engineered alternatives were evaluated in detail to provide flooding protection for the Federal Triangle:

Alternative	Description	Finding	Capital Cost for 100-Year Level of Protection ($M, Year 2010 dollars)
A	Early Warning Systems	Does not provide Flood Protection, could prove 1 to 4 hours advance warning	Not Applicable(1)
B	Low Impact Development Strategies (Green Infrastructure	Cannot provide flood relief by itself. Could supplement another flood control strategy	Not Applicable(1)
C	Storage Upstream of Federal Triangle Area	Not an effective method for providing flood relief	Not Applicable(1)
D	Utilize GSA Condensate Line	Not an effective method for providing flood relief	Not Applicable(1)
E	Storage Beneath the National Mall	Viable alternative for providing flood relief	$400
F	New Pumping Station Serving the National Mall	Viable alternative for providing flood relief	$360
G1	New Tunnel to the Existing O Street Pumping Station	Viable alternative for providing flood relief	$405
G2	New Tunnel to the Existing O Street Pumping Station, connect to Potomac CSO Control Tunnel	Viable alternative for providing flood relief, has many holistic and ancillary benefits	$480

(1) Not Applicable – This alternative will not provide flood protection against a 100 Year storm for the Federal Triangle a standalone solution. Consequently a capital cost for flood protection from a 100 Year storm has not been provided.

- Alternative A, Early Warning System, and Alternative D, Use of GSA Condensate Line, as stand-alone solutions, are ineffective in mitigating the effects of flooding in the Federal Triangle due to the incompatibility between their inherent purposes and the goals of the Working Group for protecting the Federal Triangle from a flood event. Most early warning systems are used to predict river flooding and assumes a slower rising flood that allows emergency management personnel enough time to prepare for it; however, the Study found that the Federal Triangle is susceptible to interior drainage flooding due to systemic and topographic conditions.

- Alternative B – LID Strategies and Alternative C – Storage Upstream of the Federal Triangle Area, cannot prevent flooding as standalone solutions. It is possible to use one of these alternatives along with another flood prevention alternative in a layered approach to flood prevention. The layered approach could potentially realize benefits from each alternative to help reduce the magnitude and costs of the alternatives. For example, constructing Alternative B – LID strategies could help reduce the magnitude and costs of Alternative G2 - Construct new Tunnel from O Street Pumping Station to Federal Triangle (Connect to Potomac CSO Tunnel).

- Flood proofing existing structures (Alternative H) was not evaluated because it was not included in the scope of this study. Because the capital cost of the engineered alternatives is large, it is recommended that a study be conducted to assess the practicality and cost associated with flood proofing buildings. The results of the flood proofing study could then be compared to the results of this study to develop the most cost effective and practicable solution.

- The following alternatives were found to be viable engineered or structural solutions for handling floods due to storms of various frequencies in the Federal Triangle:
  - Alternative E, Storage beneath the National Mall;
  - Alternative F, Pumping Station serving the National Mall; and
  - Alternative G, Sewer Tunnel connected to the O Street Pumping Station

  The actual location of these facilities will require a more detailed analysis than this Study intended to evaluate, and consultation with various public stakeholders will be necessary to further evaluate the feasibility of each. Other political, aesthetic, and logistical considerations will also need to be addressed by the Working Group and other stakeholders.

  Alternative G2 consists of flood prevention facilities to protect the Federal Triangle Area combined with CSO control facilities to provide an integrated District wide solution to stormwater capture, conveyance, and treatment. As such the financial considerations of Alternative G2 need not be endured by the partner agencies alone. If Alternative G2 is selected for implementation, detailed discussions to how associated costs will be shared between the beneficiaries of the flood control project and DC Water.

- Since the Federal Triangle is a topographic low point, it is important to note that any alternative for flood control could be overwhelmed if a sufficiently large storm occurs. Flood control alternatives will be able to reduce the risk of the occurrence of flooding and the magnitude of impact. No alternative will be able to completely eliminate the risk of flooding.

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Appendix – A

Memorandum of Understanding

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Appendix – B

April 2010 Survey Results

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Appendix – C

Basis for Cost Opinions

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Appendix – D

Cost Estimates

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Appendix – E

Combined Probability Calculations

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Appendix – F

Constitution Avenue Storm Sewer Flow Meter Results

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Appendix – G

DC Water CSO Objectives

- **DC Water Combined Sewer Overflow Long Term Control Plan**
- **Total Nitrogen Removal/Wet Weather Plan**
- **Consent Decrees**

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Appendix – H

Storm Hyetographs

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