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.

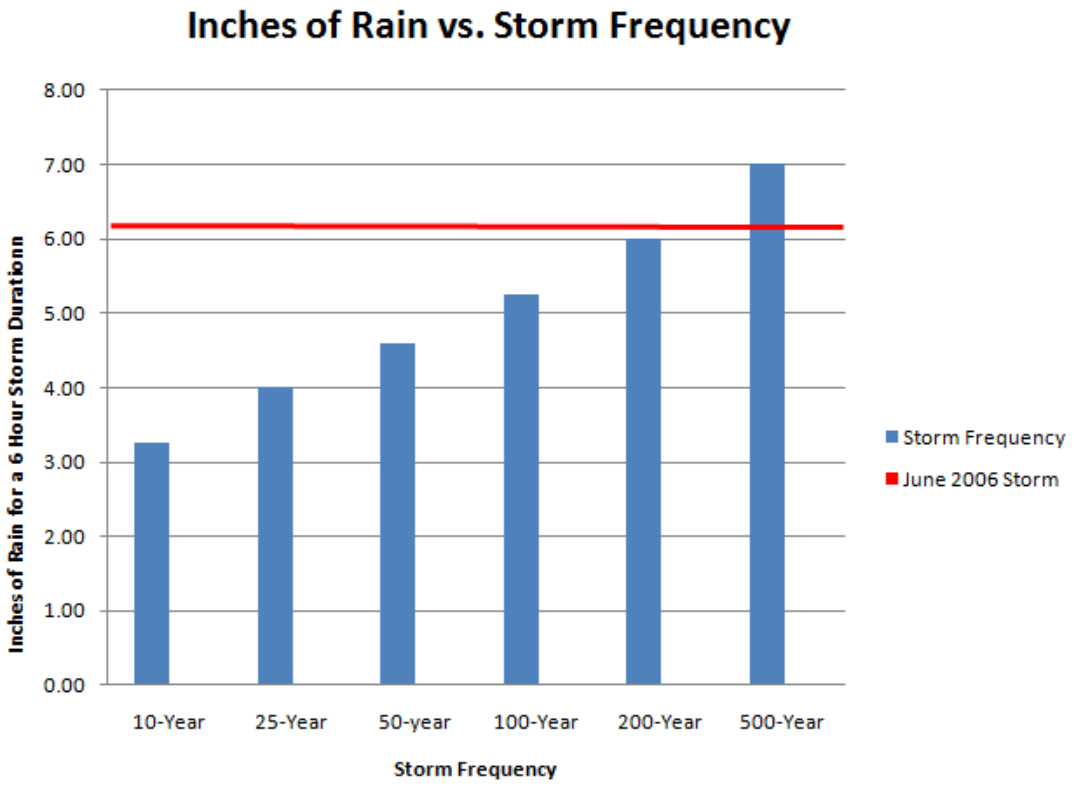
- Identify alternatives to monitor rain and or the sewer system, to provide an early warning of when flooding may occur in the Federal Triangle area.
- Evaluate the alternatives in terms of cost, benefits, and practicality for implementation.

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.

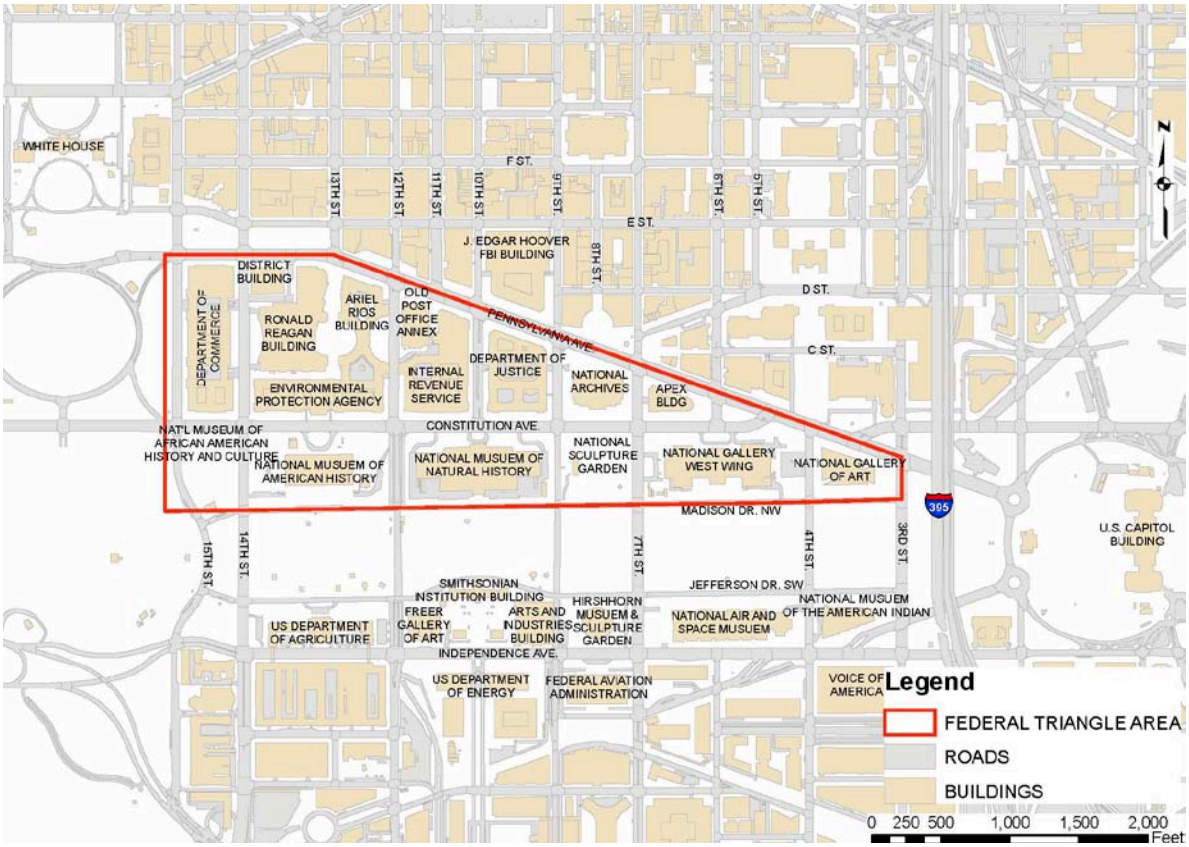


- The Federal Triangle is the lowest point of a large, predominantly impervious drainage area of the District, so excess stormwater from the upland areas flowed down to the Federal Triangle, and further exacerbated the flooding.
- The Federal Triangle is very flat so water on the surface does not easily 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

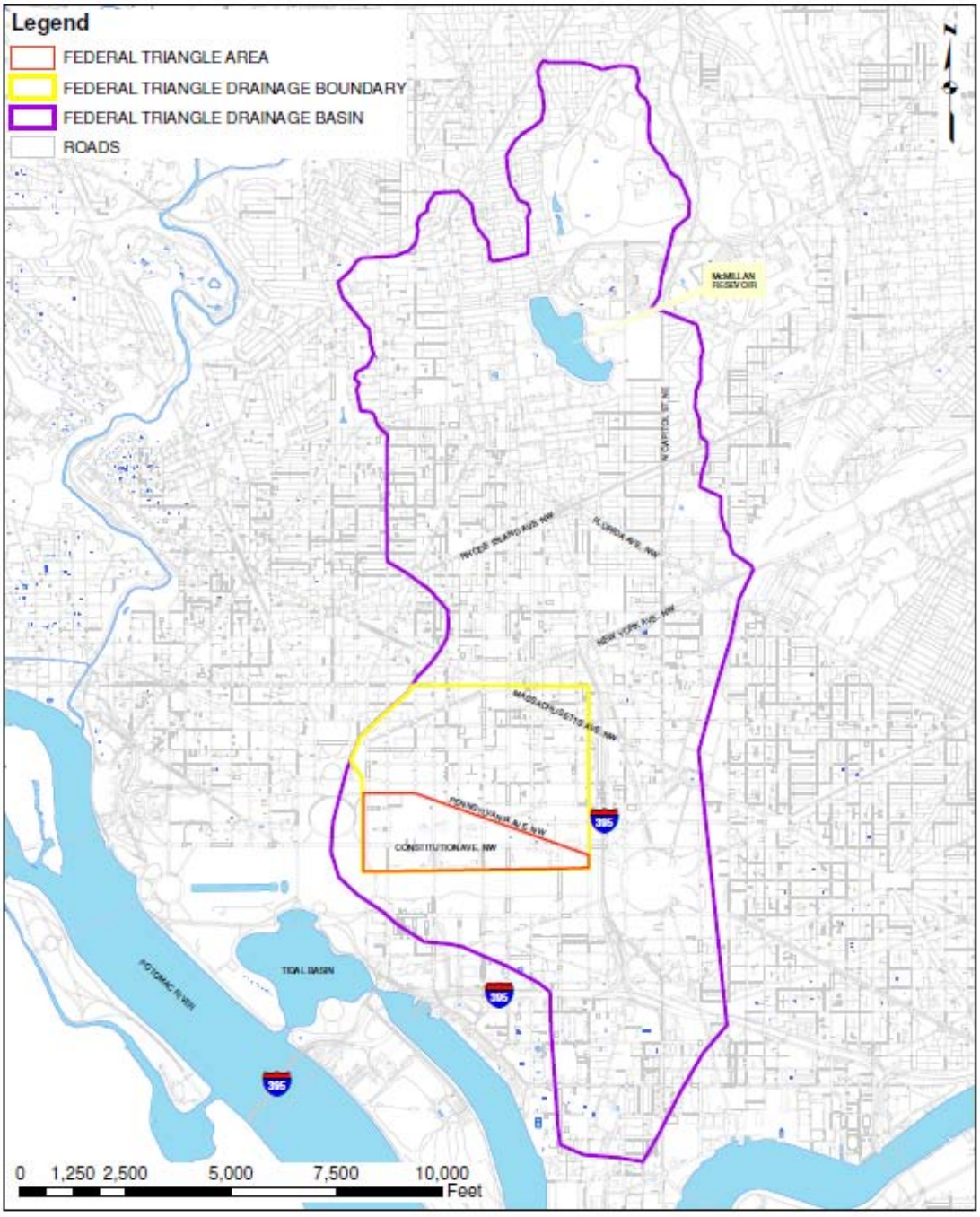
The Federal Triangle study area is in the northwest quadrant of the District and is bounded by 15th St NW to the west, Madison Dr. NW to the South, 3rd St. NW to the east, and Pennsylvania Ave. NW to the north and northeast. The Federal Triangle area is the home of many prominent buildings owned by the 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.

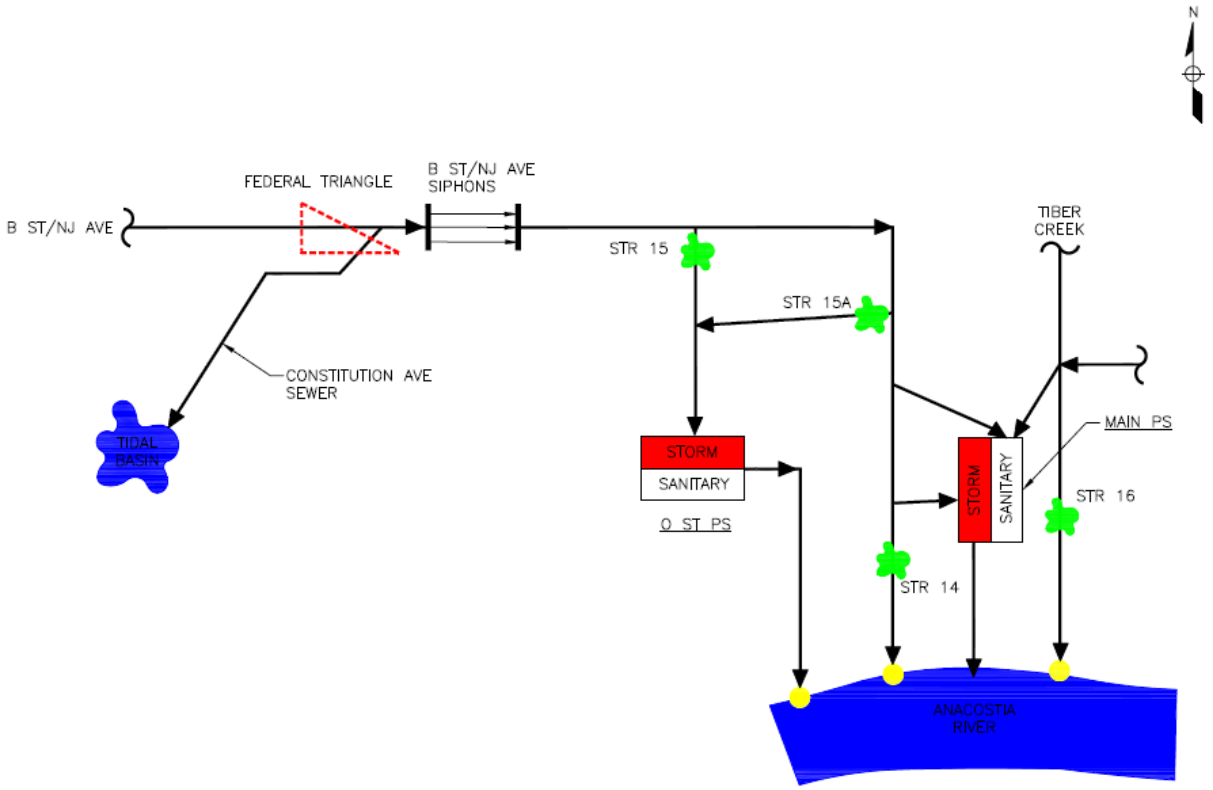


In the figure above, the purple line represents the topographic boundary of the Federal Triangle drainage basin. The yellow line represents the area that was determined by modeling that will flow overland to the Federal Triangle when storm events exceed the capacity of the existing sewer system.

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

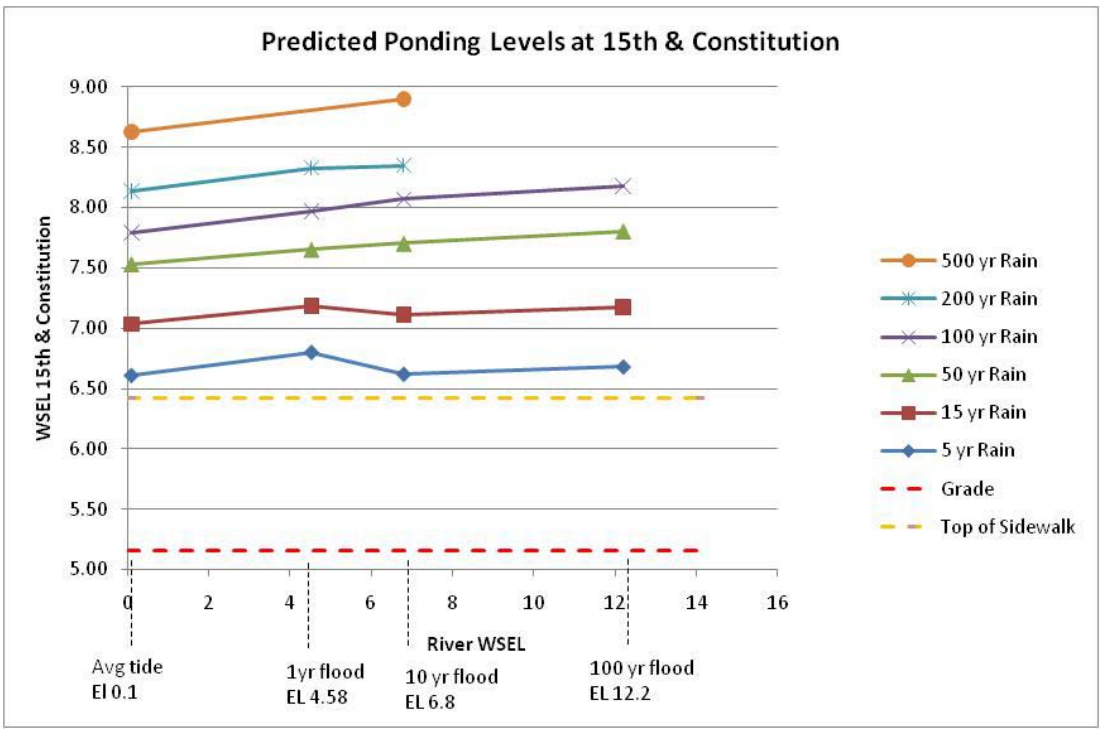
Storm Design Return Frequency Analyzed

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.

Alternative A – Early Warning Systems

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

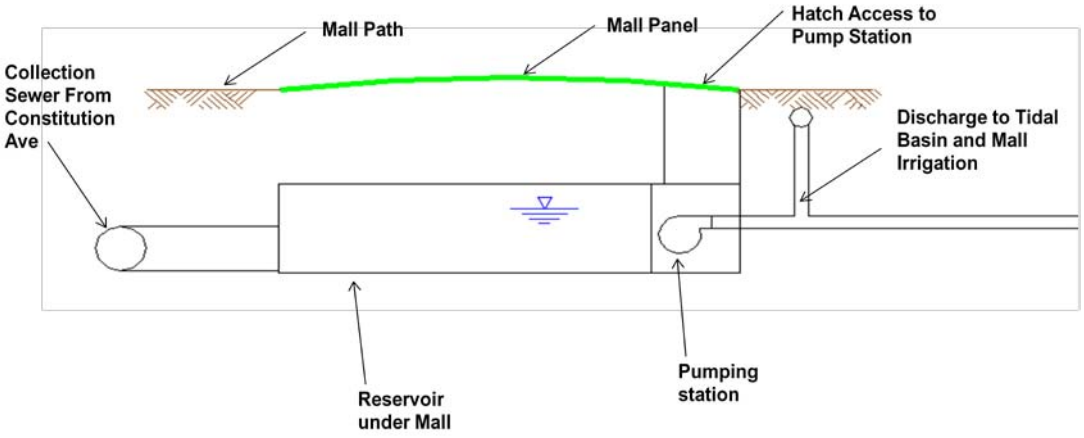
Alternative C looks at opportunities to prevent excess rainfall upstream in the drainage area from flowing down to the Federal Triangle. The Federal Triangle drainage area is 24 times larger than the size of the Federal Triangle itself and the existing sewers in the Federal Triangle are designed to convey 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.

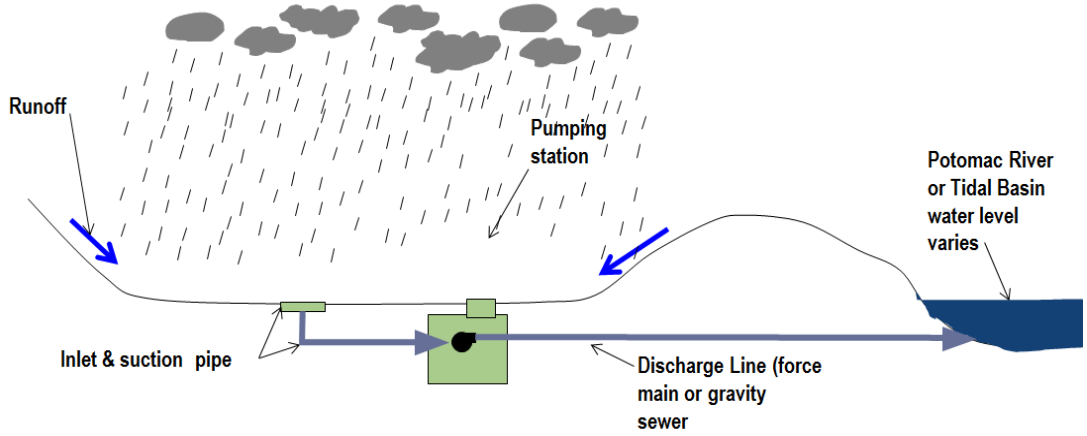
Alternative E – Storage Beneath the National Mall

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.