FLOOD MITIGATION STRATEGIES
FOR THE CITY OF ANNAPOLIS, MD:
CITY DOCK AND EASTPORT AREA

Prepared for

City of Annapolis
Department of Neighborhood and Environmental Programs

Prepared by:

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave
Baltimore, Maryland 21226

March 2011

TABLE OF CONTENTS

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 STUDY PURPOSE

This study was prepared by Whitney, Bailey, Cox & Magnani, LLC at the request of the City of Annapolis. The City is looking to identify option to mitigate flood events in the vicinity of the City Dock in downtown Annapolis and the Eastport area.

The goal of this study was to 1) Identify the most likely extent of sea level rise in the Chesapeake Bay, 2) Identify the highest observed storm surges in the Annapolis area, 3) Identify and map areas susceptible to flooding now an projected into the future, 4) Identification of structural options for protecting property in flood threatened areas, and 5) Estimation of design and construction costs associated with the structural protection measures.

1.2 STUDY AREA

The study area is the downtown historic district of the City of Annapolis which is bounded on the North by the US Naval Academy, the East by the confluence of Spa Creek and the Severn River, the South by Spa Creek, and the West by the center of the City.

1.3 PROBLEM IDENTIFICATION/FLOOD CONDITIONS

Flooding that occurs at City Dock is generally caused by high tides and storm surges associated with Tropical Cyclones (Hurricanes) and Northeasters. Flood conditions are at their worst when storms pass the area to the west of the Chesapeake Bay. This is caused by the southeasterly winds driving water into the mouth of the Bay and piling the water up against the Bay's head.[1]

Hurricane Isabel (2003) was one such storm that tracked to the west of the Bay producing record breaking storm surges in the Chesapeake Bay. According to the Federal Emergency Management Agency (FEMA) Flood Insurance Study for the City of Annapolis (May 4, 1981), the 100-year flood elevation for this area is estimated to be 7.78 feet. Figure 1-2 shows the area that was flooded during Hurricane Isabel, which is nearly equivalent to the 100-year floodplain.

Minor localized flooding is experienced on a regular basis due to tidal fluctuations and the relative ground elevations. Around City Dock, ground elevations vary from approximately elevation 2.0 to elevation 4.50. Storm drains within the public parking lot will begin to back up when tides begin to exceed elevation 1.90.

[1] Li, Zhong, Boicourt, Zhang, Zhang, Ming, Liejun, William C., Shunli, Da-Lin. "Hurricane-induced storm surges, currents and destratification in a." *GEOPHYSICAL RESEARCH LETTERS* 33.L02604 (2006): 1-4. Web. 10 Jun 2010. <http://www.atmos.umd.edu/~dalin/Li-etal-storm-surge-grl06.pdf>.

FIGURE 1-1 STUDY AREA MAP

1.4 DATA COLLECTION

This study was conducted using existing data pertaining to topography, soils, floodplains, tidal data and weather data. Much of the data was extracted from data found on the National Oceanographic and Atmospheric Administration (NOAA) web site. Table 1-1 outlines the data sources used for this study.

TABLE 1-1: DATA SOURCES

Data Type	Source	Use/Comments
Topography	Base mapping layers, including topography, were provided by the City of Annapolis.	All base mapping layers were in AutoCADD and were provided electronically.
Soils	Natural Resource Conservation Service	
Floodplain Elevations	FEMA's Flood Insurance Study (FIS) for City of Annapolis, MD, Panel No. 240009 0005B dated 11/04/1981.	The FIS shows elevations in NGVD 29 datum; FIS shows 100-year flood elevation at 7.0 feet NGVD 29. This is equivalent to 7.8 feet in NGVD 88.
Storm Drain Infrastructure	Storm drain AutoCADD layers provided by City of Annapolis.	Storm drain drawings were used to understand the system.
Tidal Data	National Oceanographic and Atmospheric Administration (NOAA)	

The following provides additional information regarding the data collection phase of the study.

Soils

According to soil data found on the National Resources Conservation Service (NRCS) website, the area of the City Dock is constructed on material described as "Urban Land" in the soil information. No soil borings were taken as part of this concept study. Soil information from the adjacent Naval Academy indicates soil conditions consist of varying depths of fill (up to 30 feet deep) consisting of predominantly sands with some areas of clay, shells, and cinders. The upper 10 feet of the fill is generally loose to medium dense. Below the fill is a thick layer of loose sands to very soft clays to depths up to 100 feet. Below this zone lies a dense silty sand layer. Groundwater is encountered generally around elevation + 2 feet.[2]

Storm Drain System

There are 3 main storm drain system outfalls from the City and several small outfalls along the bulkhead. None of the outfalls have flap gates. The lower portions of storm drains near the outfalls back up daily during high tides. During storm events, the outfalls are below the water surface limiting the flow out of the storm drain system. This causes water to back up in the pipes

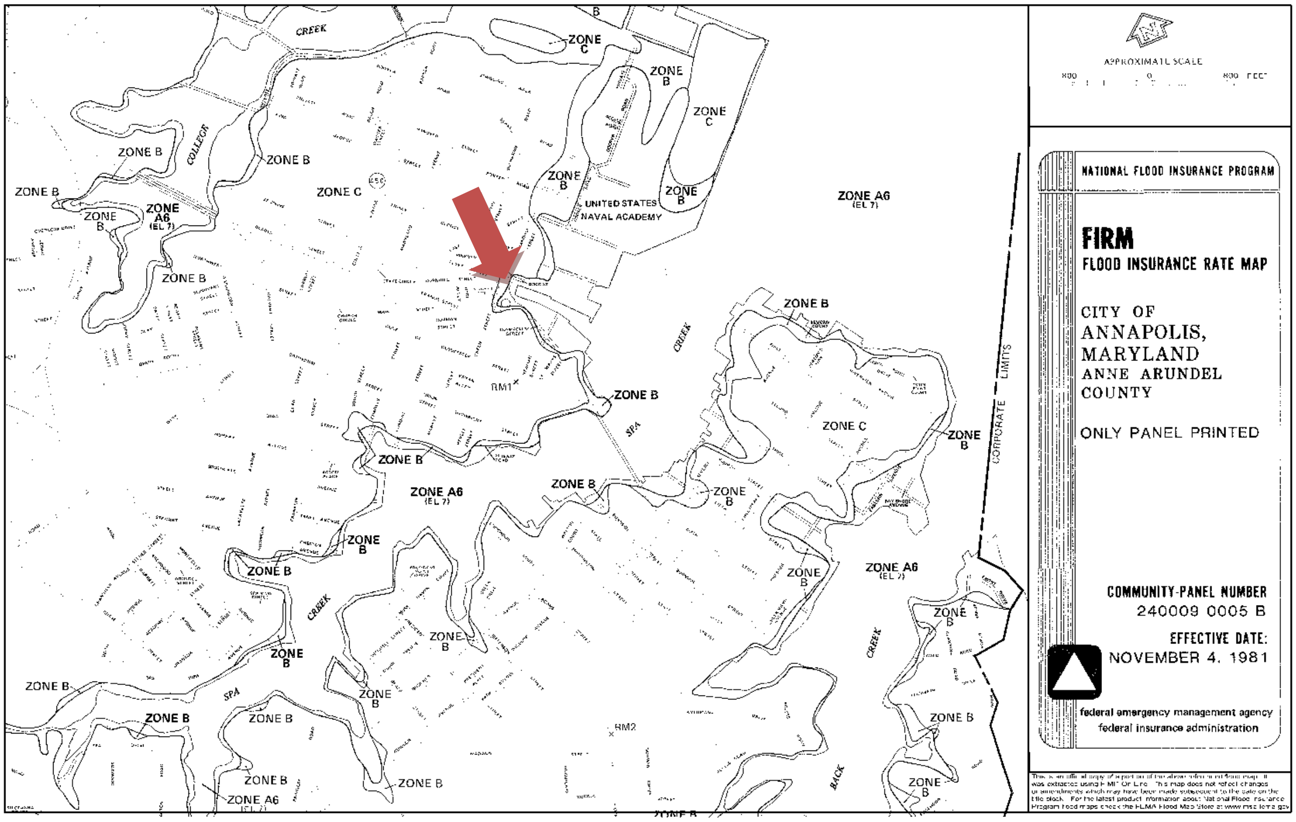
[2] U.S. Army Corps of Engineers Baltimore District, (February 2006), *FINAL FLOOD DAMAGE REDUCTION ANALYSIS FOR THE UNITED STATES NAVAL ACADEMY*, Baltimore, MD

and results in ponding at inlets and discharging of stormwater from the inlets compounding the flooding problems.

Flood Plain

According to the Federal Emergency Management Agency the 100-year flood elevation for the City Dock area is estimated to be 7 feet according to the National Geodetic Vertical Datum of 1929 (NGVD 29). Current surveys are based on North American Vertical Datum of 1988 (NAVD 88) which correlates to a 100-year flood elevation of 7.8+/- Figure 1-2 shows the 100-year floodplain.

FIGURE 1-2: 100-YEAR FLOODPLAIN



2.0 SEA LEVEL RISE

Sea level changes have been going on since the beginning of time. The Chesapeake Bay is the drowned, ancestral valley of the Susquehanna River. Continuous tide gauge records around the Chesapeake Bay show that the rate of sea-level rise during the 20th century has not been constant and that modern rates are more rapid than those determined by geologic studies conducted two decades ago. The current rate of sea-level rise at the mouth of the Chesapeake is about 4 millimeters per year (about 1.3 feet per century) and decreases northward. Tide gauges with longer periods of record, like that at Solomons Island, Md., midway along the length of the bay, record mean sea level since 1937 and illustrate a 3-millimeter-per-year rate of rise (about 1 foot per century).[3]

Minor nuisance flooding around the City Dock begins to occur when tides rise above elevation 1.9 feet. At that level, water begins to flow out of the existing storm drain system even during sunny days. The most recent highest tide without influence of a tropical storm or hurricane occurred in 2006 with an elevation of 2.92 feet (NAVD 88). Projecting to the year 2050, the occurrence of nuisance flooding is expected to more than double.

[3] "The Chesapeake Bay: Geologic Product of Rising Sea Level." U.S. Geological Survey, 18 11 1998. Web. 14 Jun 2010. <http://pubs.usgs.gov/factsheet/fs102-98/>.

FIGURE 2-1 HIGH-HIGH TIDE PHOTO – NEWMAN ST. IN THE DISTANCE

3.0 STORM SURGE

Storm surge is simply water that is pushed toward the shore by the force of the winds swirling around a storm. This advancing surge combines with the normal astronomical tides to create the storm tide, which can increase the mean water level several feet. In addition, wind driven waves are superimposed on the storm tide. This rise in water level can cause severe flooding in coastal areas, particularly when the storm tide coincides with the normal high tides.

From January 1, 2010 to September 30, 2010 high tides in the Annapolis area were recorded between a high of elevation 3.51 feet on September 30 to -1.85 feet on January 3. NOAA predicts the astronomical tides every year. The predicted high tide for January 25 was 0.12 feet. Weather data from Weather Underground (wunderground.com) indicates a storm with relatively strong winds (16 mph with gusts of 34 mph) from the south was occurring on this date and coincided with the high tide. The difference between the predicted high tide and the observed high tide is the storm surge.

The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is the computer model utilized by the National Oceanic and Atmospheric Administration (NOAA) for coastal inundation risk assessment and the operational prediction of storm surge. The SLOSH model computes the maximum potential impact of the storm in these "computational domains" based on storm intensity, track, and estimates of storm size provided by hurricane specialists at NHC.[4] The SLOSH model has an advertised accuracy of plus or minus 20%.

SLOSH models are run by Emergency Management Agencies to make preparedness decisions. According to a May 2, 2006 article in the Insurance Journal, recent SLOSH models indicate the potential for 18 or 20 feet storm surges in Baltimore at high tide during a Category 4 hurricane – 10 feet above Isabel's high water mark. Annapolis would see slightly lower levels.

---

[4] "Hurricane Research Division." *Hurricane FAQ*. NOAA, May 14, 2010. Web. 15 Jun 2010. <http://www.aoml.noaa.gov/hrd/tcfaq/F7.html>.

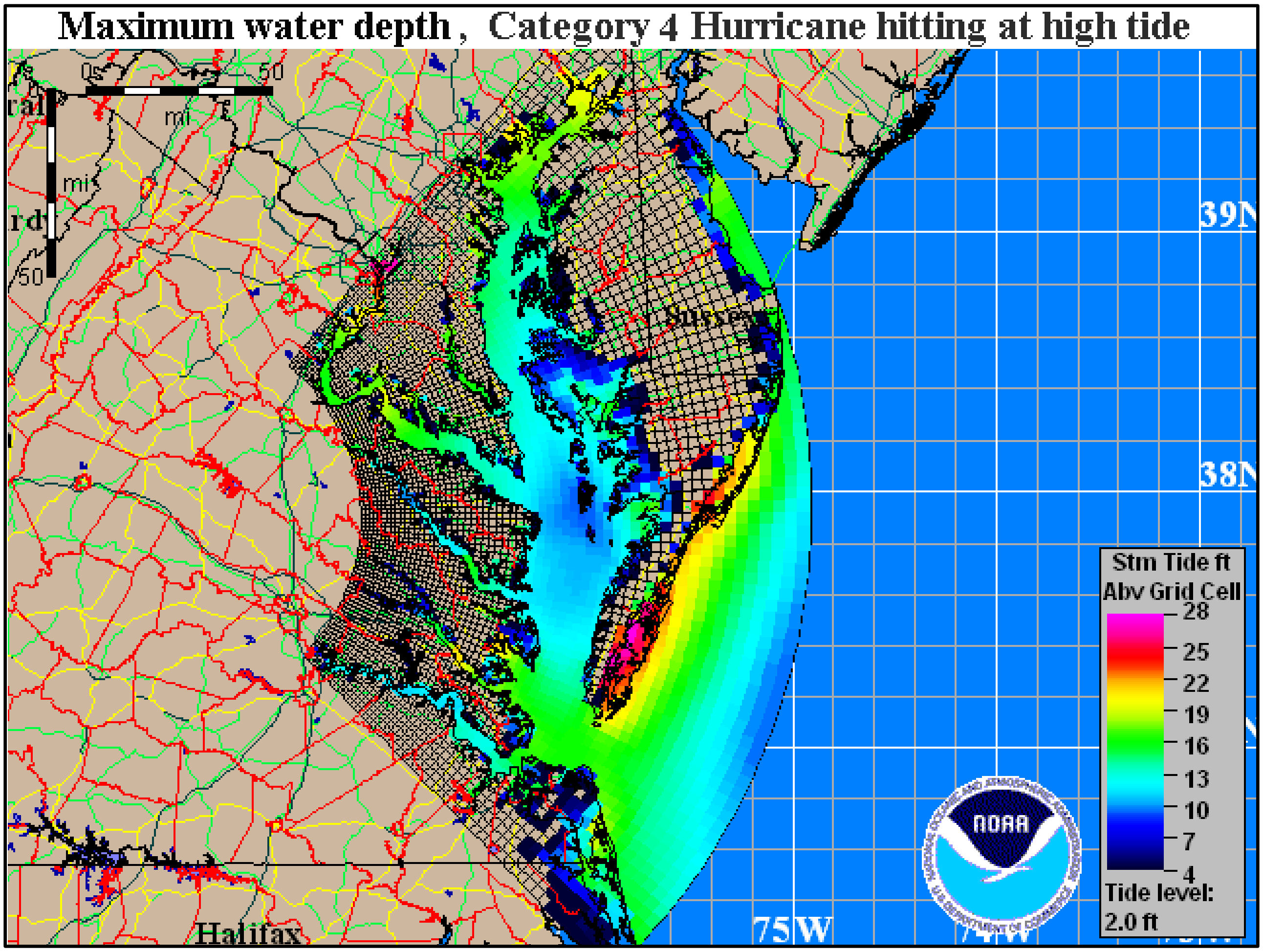
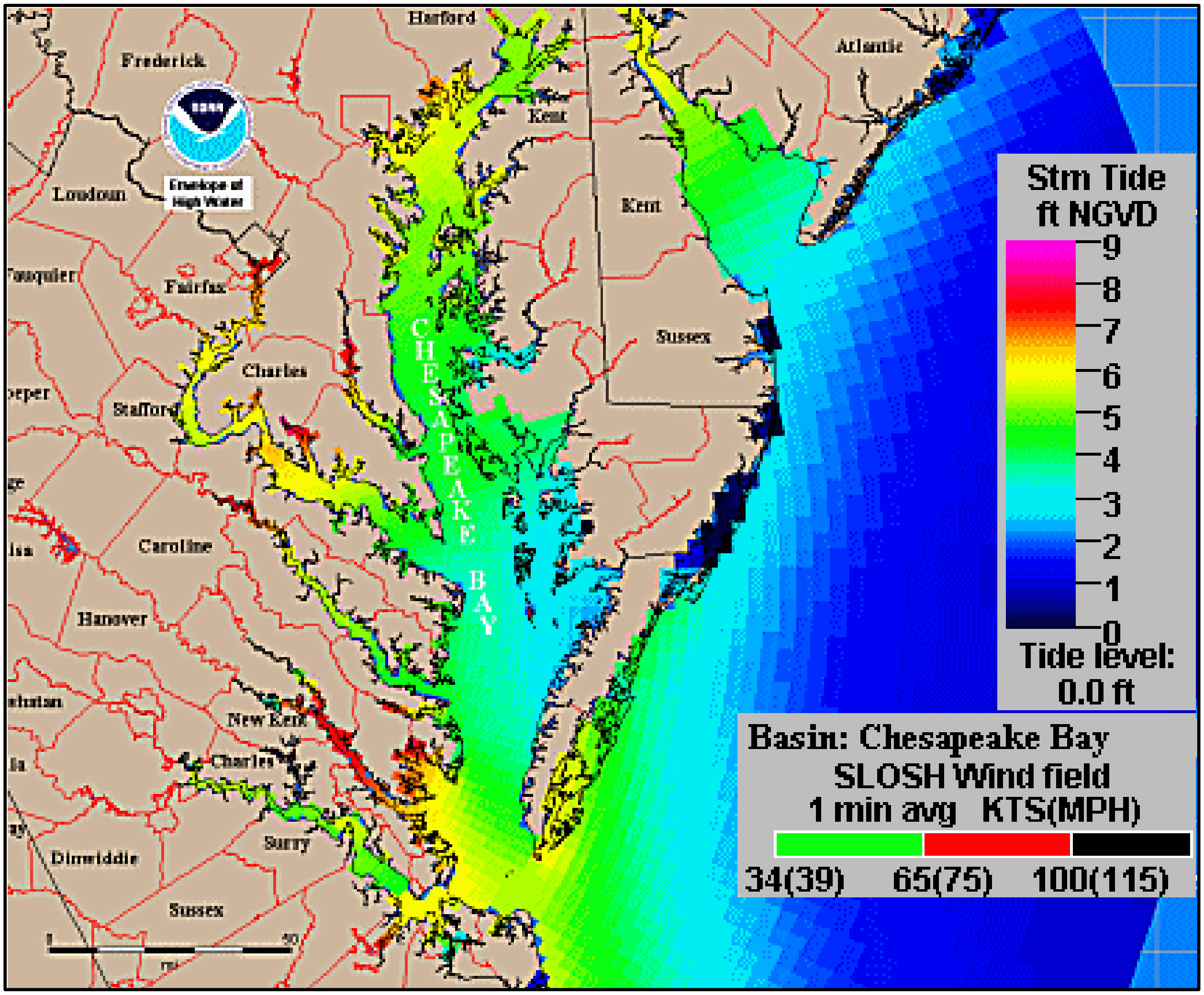


FIGURE 3-1 CHESAPEAKE BAY WATER DEPTH – 2009 SLOSH MODEL[5]

[5] "Storm Surge Inundation Maps for the U.S. Coast." *Weather Underground* . Weather Underground , 2010. Web. 16 Jun 2010. <http://www.wunderground.com/hurricane/MidAtlSurge.asp>.



MAXIMUM WATER LEVELS REACHED THROUGHOUT THE BAY OVER THE COURSE OF THE STORM SURGE. OUTPUT FROM THE SEA, LAKE, AND OVERLAND SURGE FROM HURRICANES (SLOSH) COMPUTER MODEL, RUN WITH ACTUAL STORM DATA[6]

FIGURE 3-2 STORM SURGE MODEL OF ISABEL FLOODING[7]

[6] W. Shaffer, 2003, National Oceanic and Atmospheric Administration (NOAA)

[7] Hennessee, Lamere; Halka, Jeffrey P. "Hurricane Isabel and Shore Erosion in Chesapeake Bay, Maryland ." *Coastal and Estuarine Geology Program*. MD Department of Natural Resources, Dec. 2004. Web. 16 Jun 2010. <http://www.mgs.md.gov/coastal/isabel/index.html>.

4.0 FLOOD SUSCEPTIBLE AREAS

The flooding caused by hurricane Isabel was nearly equivalent to the 100-year flood as noted on the Federal Emergency Management Agency (FEMA) Flood Insurance Study for the City of Annapolis (May 4, 1981). The FEMA map identifies the flood limits as the edge of land from the 6th Street/Compromise Street bridge northwest along the waterfront until the approximate intersection of Compromise Street and St. Marys Street where the limit runs south to the south side of Compromise Street and St. Marys Street, along the south side of Compromise Street to Church Circle, then along the West side of Randall Street from Main Street to Dock Street, east along the north side of Dock to Craig Street, then North across Prince George's Street. The elevation for this limit has been confirmed with the City of Annapolis GIS topography and is shown on Figure 4-1.

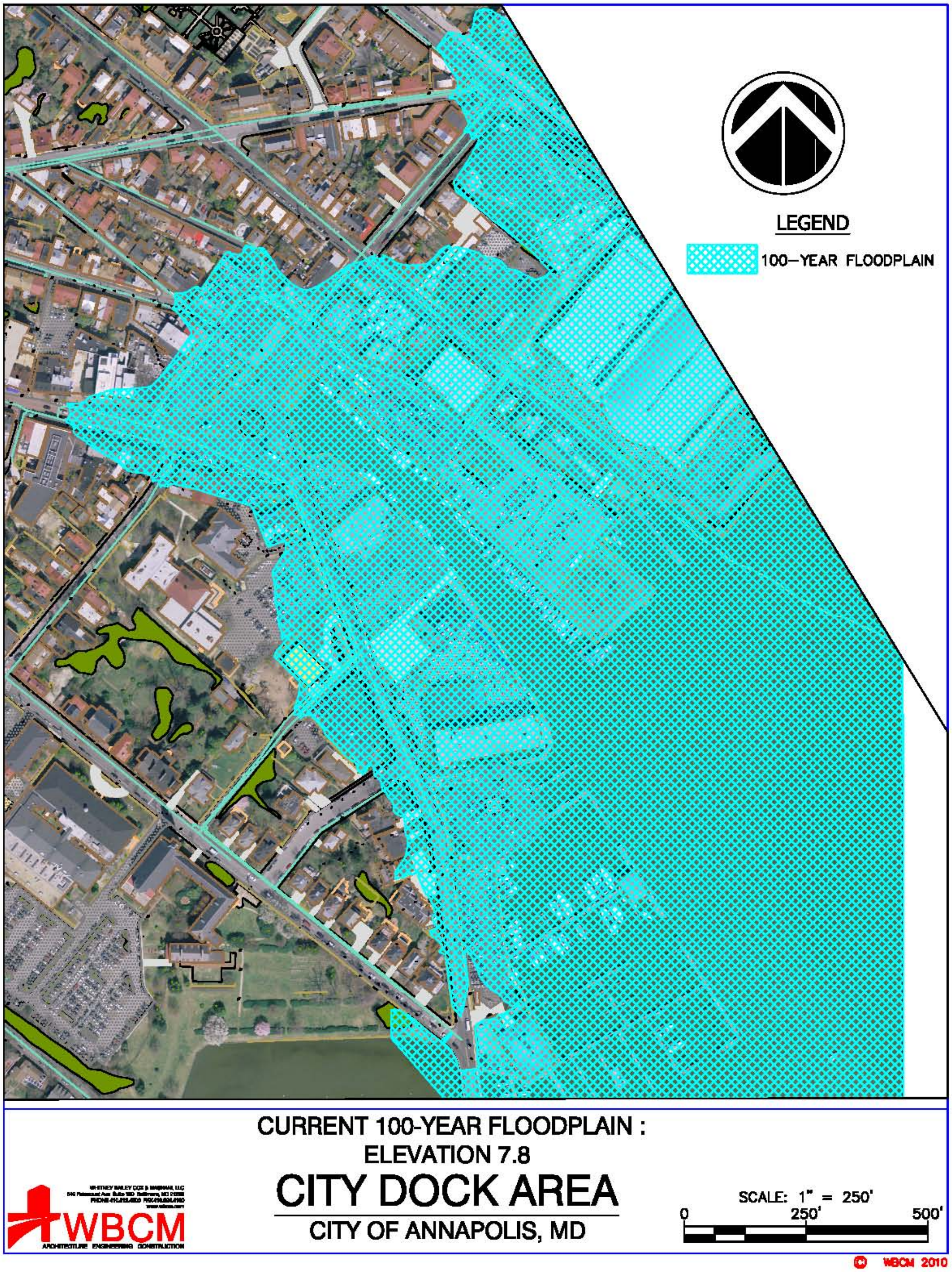


FIGURE 4-1: CURRENT 100-YEAR FLOODPLAIN

Based on the current rise in the sea level, the limit of flooding is expected to increase as shown on Figure 4-2. This limit is based on a six (6”) inch rise in sea level by the year 2050. Flooding from normal high tides is expected to increase in frequency as well.

The flooding caused by the projected highest tide in 2050 with a water surface elevation 3.4 is shown in Figure 4-3. The map identifies the flood limits as the edge of land from the 6th Street/Compromise Street bridge northwest along the waterfront until just south of the intersection of Compromise Street and Newman Street. At this point, the flooding runs along Compromise Street southeast to St Marys Street and northwest to the south east side of the Main Street traffic circle. The flooding continues down Dock Street over the waterfront businesses and up Prince George Street to the intersection of Craig Street and Prince George Street.

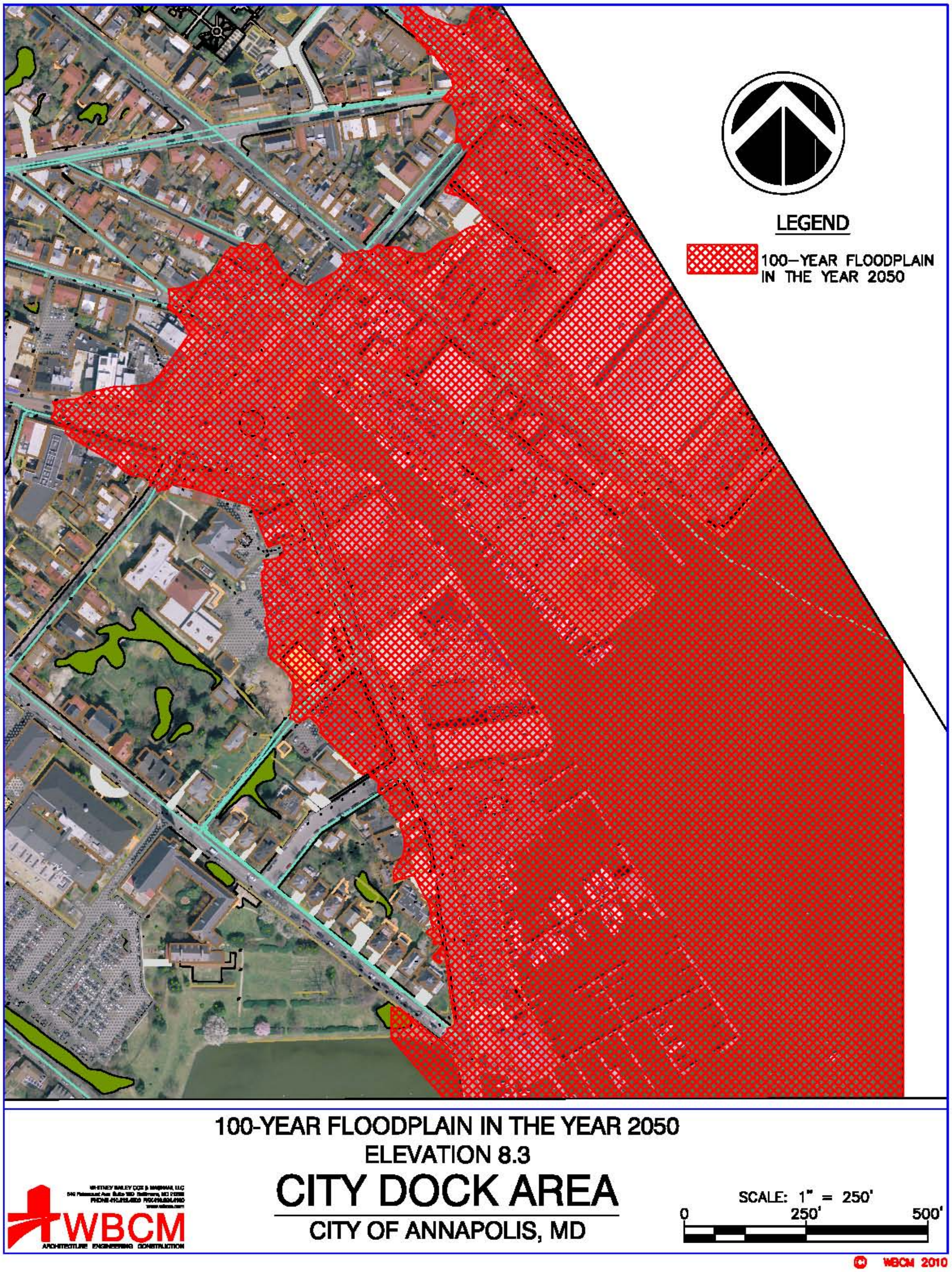


FIGURE 4-2: 100-YEAR FLOODPLAIN IN THE YEAR 2050

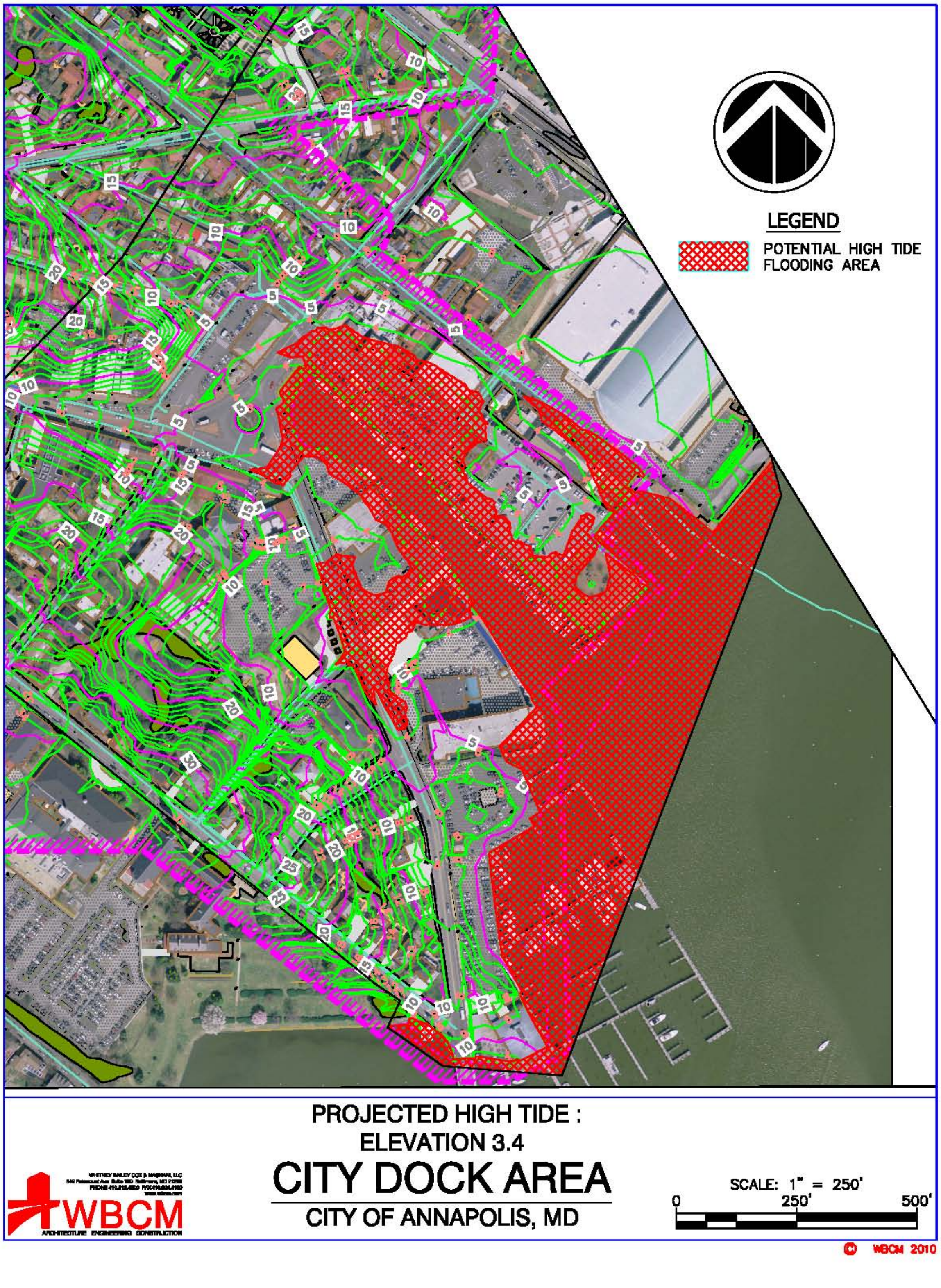


FIGURE 4-3: PROJECTED HIGHEST LUNAR TIDE FLOODPLAIN IN THE YEAR 2050

5.0 FLOOD DAMAGE REDUCTION MEASURES

The United States Naval Academy, the City Dock neighbor to the North, underwent a Flood Damage Reduction Analysis in 2006. The report prepared by the Army Corp of Engineers detailed the measures available and they are presented here.

Flood damage reduction consists of two basic techniques – structural and non-structural. Structural methods modify the flood and “take the flood away from people” by measures such as levees, floodwalls, and dams. Non-structural flood damage reduction techniques basically “take the people away from the floods” leaving the flood to pass unmodified. Non-structural techniques consist of measures such as relocation, flood proofing, acquisition, and flood preparedness. To familiarize the reader with these flood damage reduction measures, general descriptions are presented below.

- Structural Techniques
  - Levees and Berms (small levees)
  - Floodwalls
  - Sea Walls
  - Closures
  - Pumping Station
  - Portable Coffer Dams
- Non-Structural Techniques
  - Elevation
  - Relocation
  - Demolition and Reconstruction
  - Flood Proofing
  - Dry Flood Proofing
  - Wet Flood Proofing

5.1 STRUCTURAL TECHNIQUES

The types of structural measures that were investigated include levees and berms, floodwalls, sea wall modifications, closure, pumping station, and portable coffer dam structures. Floodwalls, berms and sea walls are freestanding structures located adjacent to or away from the building that prevent the encroachment of floodwaters. They may completely surround the building or buildings, or protect only the low side of the property. Unlike other flood proofing measures, a well designed and constructed freestanding floodwall or berm results in no water pressure on the structure itself. Consequently, as long as the floodwall or berm holds or is not overtopped, the building should not be exposed to damaging hydrostatic or hydrodynamic forces. Another advantage with this technique is that there is no need to make major structural alterations to the building.

When constructing a floodwall or levee around buildings, sump pumps must be incorporated to provide proper interior drainage from groundwater seepage and rainwater from the building side of the protection.

Floodwalls, berms and sea walls require periodic maintenance, including removing debris from any check valves on pump discharge pipes after each storm, inspecting the sump pump for proper operation, and maintenance of the flap gates. In addition, the property owner will have to inspect levees for signs of erosion, settlement, animal burrows, and trees. Floodwalls need inspection for signs of cracking and spalling. Construction of floodwalls and berms may require local, state and/or Federal permits.

Floodwalls or levees/berms can create a false sense of security about property protection. Every flood is different, and one could exceed the design height and overtop the floodwall or berm at anytime. For this reason, the protected area should always be evacuated prior to flooding.

If a floodwall, sea wall or berm fails due to overtopping, damage to the protected structure will be as great or greater than if no protection was provided. Additional damage could result because it takes longer to remove the flood water from the inside of the floodwall or berm once flood levels subside.

5.1.1 Levees or Berms

Typically, levees and berms are constructed of compacted fill taken from locally available impervious soils. Depending upon the availability of suitable local soil, levees may be one of the least expensive flood proofing measures. Levees and berms have the advantage of being compatible with the landscape since they are easy to shape. The property owner can plant grass and other forms of light vegetation on an earthen levee to help prevent erosion and provide aesthetic enhancement.

Although levees may be attractive in terms of economics and appearance, one potential drawback is the amount of property space required. To minimize erosion and to provide adequate stability, their embankment slopes must be fairly gentle, usually a ratio of one vertical to two or three horizontal. A levee's width will be several times its height. This option is not considered feasible for the City of Annapolis since there is limited room

5.1.2 Floodwalls

Similar to levees, floodwalls also keep water away from the building. However, floodwalls are constructed of stronger materials, are thinner, take less space, and generally require less maintenance than levees. Floodwalls can be constructed using a variety of designs and materials. By taking into account the individual building design, siting, and topography, a floodwall can be constructed that not only protects a building, but also enhances its appearance.

A temporary flood control wall (Figure 5-1) – installed when needed and removed when the threat is over – is an option. This method is similar to Closures.

FIGURE 5-1: TYPICAL TEMPORARY FLOOD CONTROL WALL

5.1.3 Sea Walls

In certain situations, a sea wall may already exist that may be modified to be used as a flood protection measure. Similar to a floodwall, sea walls take up little space and can be constructed of various materials. Sea walls are not considered feasible for the City Dock.

5.1.4 Closures

Closures must be provided for roads, sidewalks, driveways, and other openings left in a floodwall or levee. Closures act to close the openings in floodwalls and levees and prevent water from entering. They can be of a variety of shapes, sizes, and materials. In some cases closures are permanently attached to the closure structure abutments using hinges so that they can remain open when there is no flood threat, such as a swing gate (Figure 5-2). Another type of closure is a roller gate that slides into place along a track (Figure 5-3). There are also stop log closures which are portable, normally stored in a convenient location, and put into place when a flood threatens (Figure 5-4). Typically, sandbags must be placed at the bottom of most closure structures to prevent leakage.

FIGURE 5-2: TYPICAL SWING GATE CLOSURE STRUCTURE

Closures can be considered as an option only if a flooding situation provides sufficient warning time to properly install them. The need for both sufficient warning time and human action is critical, since all closure systems require personnel to install them and make certain they are properly sealed. Closures that are stored between floods must be readily accessible. Swing gates and roller gates take less time to install than stop log structures, which must be transported to the site and put in place. Typically, swing and roller gates can be installed in less than two hours. However, stop log structures can take 2-3 hours to install a small pedestrian closure structure, and roughly 3-6 hours for a larger vehicular closure structure. The effectiveness of an entire system will be compromised if the closures are stored such that flooding renders them inaccessible, or if even one closure is improperly installed. Closure systems are most effective where there are a limited number of openings. If there are too many, leakage could overwhelm and defeat the system.

FIGURE 5-3: TYPICAL ROLLER GATE CLOSURE STRUCTURE

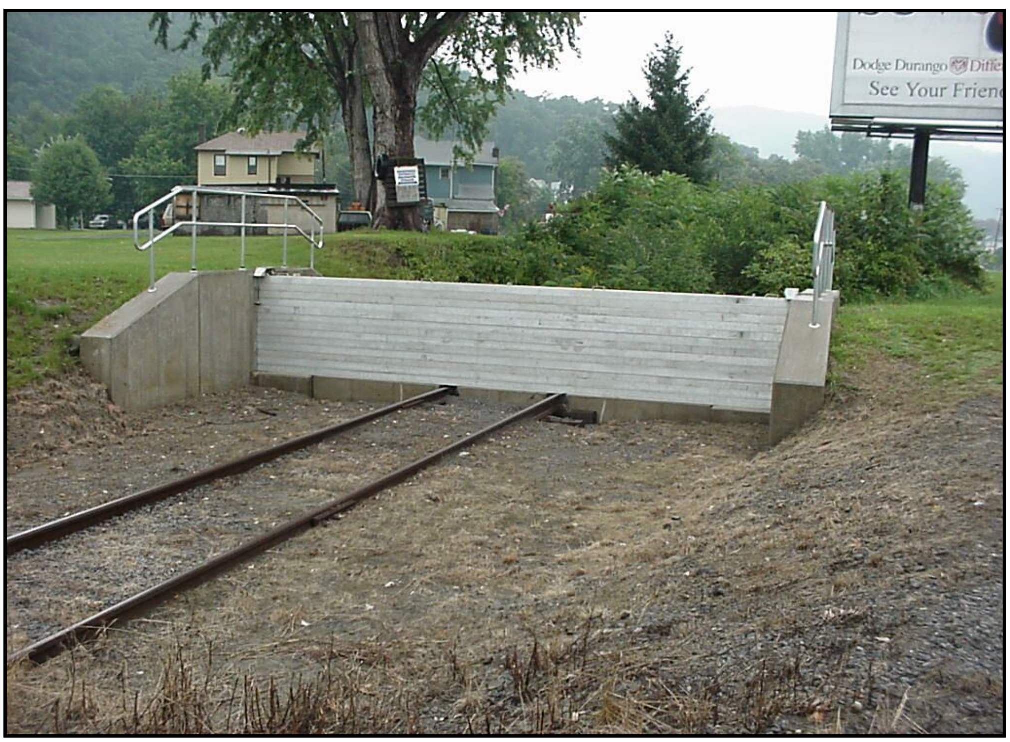


FIGURE 5-4: TYPICAL STOP LOG CLOSURE STRUCTURE

In addition to closure structures for roads, sidewalks, etc., closure gates need to be provided for any storm pipe to prevent back flow. Any sewers or drain pipes passing through or under a floodwall or levee will require closure valves (Figures 5-5 & 5-6) to prevent backup and flooding inside the building and protected area.

Because there will likely be ample warning time (2-3 days) prior to a flood event, closures are a potential option for use with the floodwall alternatives.

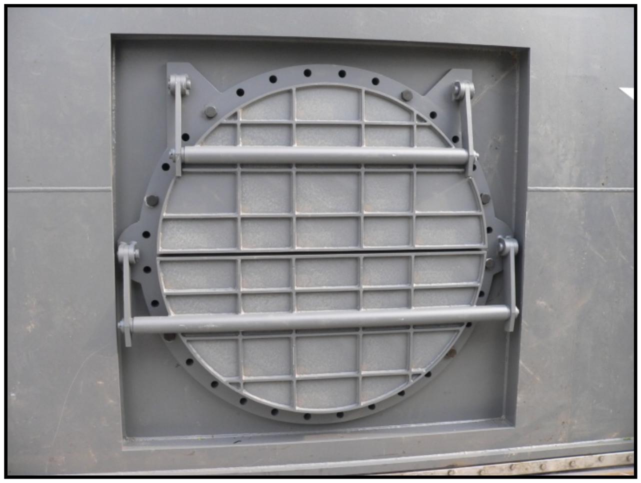


FIGURE 5-5: FLAP VALVE

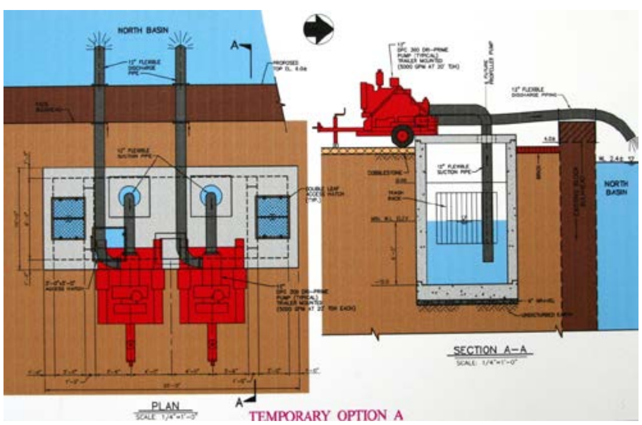
FIGURE 5-6: RUBBER DUCKBILL VALVE

5.1.5 Pumping Station

One option to mitigate the flooding caused by surging storm drains would be to install an underground pumping station(s) at the end of the City Dock. The previously mentioned flap valves or rubber duckbill installed at the outfall locations of the storm drain systems would be closed in order to keep sea water from backing up into the storm drains. The pump station(s) would relieve the backwater pressure on the storm drain system and allow the existing inlets to continue to drain. The pumping station would be built behind the existing sea wall/bulkhead. The pump would discharge the stormwater into Spa Creek beyond the sea wall/bulkhead.

For major storm events when additional flood protection measures are installed, i.e. temporary flood walls or cofferdams, the pumps would need to have adequate capacity to handle the estimated 100-year flow of 197,060 gallons per minute. The pumps would have pipes that discharged through the existing seawall/bulkhead directly into the water.

If a pumping station(s) is not installed, any water collected by the existing storm drain system would accumulate behind the flood protection system, thereby defeating the purpose of that system. Temporary portable pumps generally do not have the capacity to handle the amount of water that would be collected by the existing storm drain system. Figure 5-8 demonstrates the potential flooding behind flood walls for a 100-year frequency storm with a one-hour duration. The area shown is based on approximately 11.8 million gallons of water produced during the storm event.



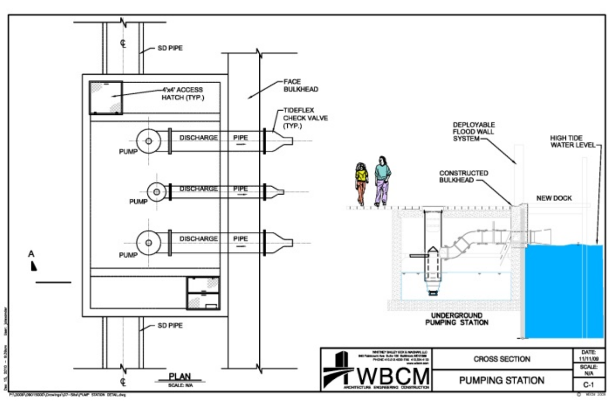


Figure 5-7: Pump Stations

FIGURE 5-8: POTENTIAL FLOODING BEHIND FLOOD WALLS

5.1.6 Portable Coffer Dams

Portable coffer dams are another method that can be used to protect City Dock from flooding. The coffer dam, made of commercial grade vinyl coated polyester, is a water inflated dam which consists of a self contained single tube with an inner restraint baffle/diaphragm system for stability. The dam has ability to stand alone as a positive water barrier without any additional external stabilization devices. The system can be installed easily in the field when needed and removed when the threat is over. Once laid out, it can be inflated using any available water source. Each unit is up to 100 feet long and 8 feet high. With 2 feet of freeboard, it can control water up to 6 feet high. Coffer dam units can be joined together by overlapping end to end at any angle to protect larger areas.

The system is lightweight, compact in storage, easy to install, repairable, reusable, and less expensive than some previous mentioned methods. However, there are few things that need to be considered when using this system. The unit cannot be installed too close to any building or structure (to avoid adding pressure on walls), and should be used where there is at least 25 feet of open space available for installation. Installation time should also be a considered factor. It typically takes approximately a day to install 500 linear feet of 8 feet high barriers with two pumps, which means the system may need to begin installation six or more days prior to the flood event. A Portable Coffer dam is a good solution to prevent flooding at City Dock. However, at areas where space is not available, other method(s) will need to be used.

FIGURE 5-9: COFFER DAM PROTECTING SHORELINE[8]

[8] Courtesy of Independent Flood Defence Products, www.ifdp.co.uk

FIGURE 5-10: TYPICAL PORTABLE COFFER DAM[9]

5.2 NON-STRUCTURAL TECHNIQUES

5.2.1 Elevation

Elevation involves raising the building in place so that the lowest floor is above the flood level for which flood proofing protection is provided. The building is jacked up and set on a new or extended foundation. Elevation is not an option for the buildings around City Dock.

5.2.2 Relocation

Relocating a building is the most dependable, but generally the most expensive, way to flood proof. This method involves moving the building to another location away from flood hazards, either to a higher elevation on the existing lot or to a new site. This procedure involves raising the building, as described above and placing it on a trailer. The building is then transported to a new location and placed on a new foundation. Relocating the buildings at the City Dock was not considered a feasible option.

5.2.3 Demolition and Reconstruction

If a free standing building is found to lie within a flood prone area, the owner may opt to demolished the building and construct a new one at a higher elevation. The other option is for the existing building to be raised so that the finished floor is above the projected floodplain. These options, of course, would be at great expense for the property owner(s).

---

[9] Courtesy of Sconsa Environmental Services, www.water-dam.com

5.2.4 Flood Proofing

There are two types of flood proofing techniques: dry flood proofing and wet flood proofing. Dry flood proofing keeps the floodwaters from entering the structure, while wet flood proofing allows the floodwaters to enter the building, but minimizes the damages.

Dry Flood Proofing

Dry flood proofing typically involves sealing the exterior building walls with waterproofing compounds, impermeable sheeting, or other materials and using shields for covering and protecting openings from floodwaters. Shields can be used on doors, windows, vents, and other building openings. Shields placed directly on buildings must be strong enough and sufficiently watertight to withstand flood forces. Sewer lines should be fitted with cutoff or check valves that close when flood waters rise in the sewer to prevent backup and flooding inside the building.

Generally, dry flood proofing should only be employed on buildings constructed of concrete block or brick veneer on a wood frame. Weaker construction materials, such as a wood frame without a brick veneer, will fail at much lower water depths from hydrostatic forces. Even brick or concrete block walls should not be flood proofed above a height of approximately three feet, due to the danger of structural failure from hydrostatic forces, unless a structural engineer has confirmed that the building is designed to handle the forces.

Some waterproofing compounds cannot withstand significant water pressure or may deteriorate over time. For effective dry flood proofing, a good interior drainage system must be provided to collect the water that leaks through the sealant or sheeting and around the shields. These systems can range from small wet-vacs to a group of collection drains running to a central point from which water is removed by a sump pump. Though dry flood proofing may seem simple, it is a sophisticated method that requires full understanding of the possible dangers stemming from poor planning, design, or installation.

Most wall materials, except for some types of high-quality concrete, will leak unless special construction techniques are used. These techniques require a high level of workmanship if they are to be effective. For flood proofing existing structures, the best way to seal a wall is to add an additional layer of brick with a seal between the two layers. It is possible to apply a sealant to the outside of a brick or block wall, but any coating must be applied carefully. Cement- or asphalt-based coatings are the most effective materials for sealing a brick wall, while clear coatings such as epoxies and polyurethanes tend to be less effective. As a result, the aesthetic advantages of a brick wall are lost with the use of better sealant coatings.

The difficulty and complexity of sealing a structure also depends on the type of foundation, since all structural joints, such as those where the walls meet foundations or slabs, require treatment. For very low flood levels, such as a few inches of water, a door can be flood proofed by installing a waterproof gasket and reinforcing the door jamb, hinge points, and latch or lockset and coating it with a waterproof paint or sealant.

If there is a chance of higher flood levels, some type of shield will be needed. If the expanse across the door is three feet or greater, the shield will have to be constructed of heavy materials, such as heavy aluminum or steel plate. The resulting weight may require the shield to be permanently installed, using either a hinged or slide-in design. Typical hinged and drop-in gates for a doorway are shown in Figure 5-2. The frame for such installations must be securely anchored into the structure. When windows are exposed to flooding, some form of protection is needed because standard plate glass cannot withstand flood forces. One solution is to brick up all or part of the window. It may also be possible to use glass block, instead of brick, to admit light.

FIGURE 5-11: TYPICAL HINGED GATE AND DROP-IN GATE (courtesy of Reelan Industries)

For normal-sized windows, shields can also be used. They should be made of materials such as heavy plexiglas, aluminum, or framed exterior plywood. These can be screwed in place, or slid into predesigned frame slots. Another alternative is to replace the glass with heavy plexiglas; however, the window must be sealed shut and waterproofed using water resistant caulking. Dry flood proofing is not considered as an option for the City Dock area.

Wet Flood Proofing

Wet flood proofing allows the structure to flood inside while ensuring that there is minimal damage to the building and its contents. Interior flooding allows water forces on the inside of the building walls to counteract the hydrostatic forces on the outside, thus reducing the chance of structural damage. When the structure is designed for wet flood proofing, vulnerable items, such as utilities, appliances, and furnaces, should be relocated or waterproofed with plastic bags and sheeting. Utilities and appliances may be moved permanently or temporarily to a place in the building higher than a selected flood level, or to a small addition that would serve as a utility room.

If there is no space for relocating utilities, appliances, and other contents, these items may be protected in place. In the case of very shallow flooding, a mini-floodwall built around these items would provide protection. For deeper waters, they could be elevated on a platform or suspended overhead from floor or ceiling joists.

The property owner must have sufficient warning time to employ wet flood proofing methods by temporarily moving items. In addition, the property owner must be aware that flooding an area containing a source of electricity or hazardous materials can be dangerous. Also, clean-up will be required after each flood.

Wet flood proofing is not considered as an option for the City Dock.

6.0 ESTIMATING DESIGN AND CONSTRUCTION COSTS

Flood protection measures of public areas for the City Dock are very limited due to the fact that the vast majority of the land is privately owned. Protecting City Dock from major flooding events will necessitate a public/private partnership in order to fully utilize available options. City of Annapolis could also share responsibility with the United State Naval Academy for protecting the shoreline at the area where the Dock is adjacent to the Academy. There is roughly 4,500 linear feet of shoreline that will need protection. In addition to structural measures for surface flooding, sewer and electrical services will need to be evaluated to determine if they could be affected by water during flood events. Backflow preventers would need to be installed at each sewer connection.

From the available information, a combination of floodwalls, coffer dams, pumping station, temporary pumps, backflow preventers, flap valves and duckbill valves will be needed. Based on data provided by manufacturers, costs have been estimated for purchase of materials and some design. Labor cost for installation, removal, storage places (for temporary protecting systems), operating, and maintenance of protection measures have not been investigated and are not included in the cost estimates.

Unlike permanent structures (pumping station, flap/duckbill valves, floodwall foundations and backflow preventers) only need to be installed once, labor cost for temporary systems (floodwalls, coffer dams, and pumps) should include the cost for both installation and removal at every flood events. For floodwalls installation, minimum of three people would be needed to complete the installation before the flood occurs. Coffer dams installation requires more people, six to eight people would be needed. In addition, these temporary systems, except for the temporary pumps that could be rented from local rental companies, require storage places when they are not in use. Cost for these storage places, either from being built or rented, should also be included in the detailed design phase.

Item	Quantity	Cost/Unit	Total Cost
Flap Valve/Duckbill Valve	4 EA	$2,500	$10,000
Floodwall	2,500 LF	$500	$1,250,000
Floodwall Foundations	2,500 LF	$50	$125,000
Coffer dams	2,000 LF	$300	$600,000
Pumping Station	2 EA	$500,000	$1,000,000
Temporary Pumps	6 EA	$30,000	$180,000
Backflow Preventers	100 EA	$750	$75,000
Collection Chambers	Allowance	$500,000	$500,000

Total			$3,740,000

TASKS TO BE CONDUCTED DURING THE DETAILED DESIGN PHASE

The scope of this study was to evaluate various alternative plans and select a plan for implementation. The final selected plan was only designed to a 10% concept-level. During the detailed design phase, many technical issues must be further evaluated, and other typical approval procedures must be completed. The following list identifies some of the tasks that should be completed as part of the detailed design phase:

- Coordinate with local/state/Federal agencies and receive specific permits/approvals
- Prepare an Environmental Assessment
- Evaluate the interior drainage further to confirm the location and size of pumping stations
- Perform subsurface exploration and laboratory testing along the actual project alignment to aid in designing the floodwall
- Further evaluate the design of the floodwall, including depth needed, and the design of the tunnel compartmentalization
- Determine depth (or necessity) of sheetpile along the walls of the dry flood proofed buildings
- Select exact alignment of floodwall based on location of utilities, trees, and other structures
- Further evaluate and design the flood proofed building

p:\2009\09015000\design\reports\sea rise study report city dock 12-15-10.docx

APPENDICIES

7.1 10-YEAR STORM DRAIN ANALYSIS

7.2 100-YEAR STORM DRAIN ANALYSIS

APPENDIX

7.1 10-YEAR STORM DRAIN ANALYSIS

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 10yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
			A	ΣA	C	CA	ΣCA		T_c	I	Q		D	n	S_f	L	V_f	TIME	INVERT ELEVATION		S	V	Q		
FROM	TO	AREA NO.	AREA (AC)	TOTAL AREA (AC)	RUNOFF COEF.			DESIGN STORM (YRS)	TIME OF CONC. (MIN)	RAINFALL INTENS (IN/HR)	QUANTITY (CFS)	TYPE	SIZE (IN)	MANN-INGS COEF	FRICTION SLOPE (%)	LENGTH (FT)	VELOC (FT/SEC)	IN PIPE (MIN)	UPPER (FT)	LOWER (FT)	ACTUAL SLOPE (%)	FULL FLOW VELOCITY (FT/SEC)	CAPACITY (CFS)	PIPE TYPE	
DRAINAGE AREA A																									
		A1	2.84	2.84	0.40	1.14	1.14	10	5.00	7.00	7.95	Circular	24	0.013	0.12%	33.0	2.53	0.22			0.00%	0.00	0.00	RCP	
		A2	0.74	0.74	0.75	0.56	0.56	10	5.00	7.00	3.89	Circular	12	0.013	1.18%	27.0	4.95	0.09			0.00%	0.00	0.00	RCP	
		A3	0.42	0.42	0.85	0.36	0.36	10	5.00	7.00	2.50	Circular	12	0.013	0.49%	27.0	3.18	0.14			0.00%	0.00	0.00	RCP	
		A1-3		4.00		0.00	2.05	10	5.22	6.95	14.23	Circular	18	0.013	1.84%	371.0	8.06	0.77			0.00%	0.00	0.00	RCP	
		A4	1.00	1.00	0.35	0.35	0.35	10	5.00	7.00	2.45	Circular	15	0.013	0.14%	205.0	2.00	1.71			0.00%	0.00	0.00	RCP	
		A1-4		5.00		0.00	2.40	10	5.98	6.78	16.26	Circular	18	0.013	2.40%	292.0	9.20	0.53			0.00%	0.00	0.00	RCP	
		A5	0.72	0.72	0.50	0.36	0.36	10	5.00	7.00	2.52	Circular	12	0.013	0.50%	13.0	3.21	0.07			0.00%	0.00	0.00	RCP	
		POND	10.10	10.10	0.50	5.05	5.05	10	5.00	7.00	35.35	Circular	18	0.013	11.33%	80.0	20.01	0.07			0.00%	0.00	0.00	RCP	
		A6	0.15	10.25	0.20	0.03	5.08	10	5.07	6.99	35.51	Circular	18	0.013	11.44%	34.0	20.10	0.03			0.00%	0.00	0.00	RCP	
		A1-6		15.97		0.00	7.84	10	6.51	6.66	52.20	Circular	24	0.013	5.34%	344.0	16.61	0.35			0.00%	0.00	0.00	RCP	
		A7	1.41	1.41	0.50	0.71	0.71	10	5.00	7.00	4.94	Circular	12	0.013	1.91%	9.0	6.29	0.02			0.00%	0.00	0.00	RCP	
		A8	1.75	1.75	0.70	1.23	1.23	10	5.00	7.00	8.58	Circular	12	0.013	5.77%	23.0	10.92	0.04			0.00%	0.00	0.00	RCP	
		A1-8		19.13		0.00	9.77	10	6.86	6.57	64.18	Circular	30	0.013	2.45%	554.0	13.07	0.71			0.00%	0.00	0.00	RCP	
		A9	1.57	1.57	0.25	0.39	0.39	10	5.00	7.00	2.75	Circular	12	0.013	0.59%	38.0	3.50	0.18			0.00%	0.00	0.00	RCP	
		A9		1.57		0.00	0.39	10	5.18	6.97	2.74	Circular	18	0.013	0.07%	377.0	1.55	4.06			0.00%	0.00	0.00	RCP	
		A10	1.52	1.52	0.25	0.38	0.38	10	5.00	7.00	2.66	Circular	12	0.013	0.56%	22.0	3.39	0.11			0.00%	0.00	0.00	RCP	
		A11	2.85	2.85	0.40	1.14	1.14	10	5.00	7.00	7.98	Circular	12	0.013	5.00%	22.0	10.17	0.04			0.00%	0.00	0.00	RCP	
		A12	0.31	3.16	0.55	0.17	1.31	10	5.04	7.00	9.17	Circular	12	0.013	6.60%	7.0	11.69	0.01			0.00%	0.00	0.00	RCP	
		A9-12		6.25		0.00	2.08	10	9.24	6.11	12.73	Circular	24	0.013	0.32%	43.0	4.05	0.18			0.00%	0.00	0.00	RCP	
		A13	2.07	2.07	0.55	1.14	1.14	10	5.00	7.00	7.97	Circular	12	0.013	4.98%	21.0	10.15	0.03			0.00%	0.00	0.00	RCP	
		A9-13		8.32		0.00	3.22	10	9.42	6.05	19.49	Circular	24	0.013	0.74%	608.0	6.20	1.63			0.00%	0.00	0.00	RCP	
		A14	2.43	2.43	0.55	1.34	1.34	10	5.00	7.00	9.36	Circular	12	0.013	6.87%	4.0	11.92	0.01			0.00%	0.00	0.00	RCP	
		A9-14		10.75		0.00	4.56	10	11.05	5.70	25.98	Circular	24	0.013	1.32%	41.0	8.27	0.08			0.00%	0.00	0.00	RCP	
		A15	0.79	0.79	0.85	0.67	0.67	10	5.00	7.00	4.70	Circular	12	0.013	1.73%	29.0	5.99	0.08			0.00%	0.00	0.00	RCP	
		A16	1.50	1.50	0.55	0.83	0.83	10	5.00	7.00	5.78	Circular	12	0.013	2.62%	24.0	7.36	0.05			0.00%	0.00	0.00	RCP	
		A9-16		13.04		0.00	6.05	10	11.13	5.68	34.39	Circular	24	0.013	2.32%	424.0	10.95	0.65			0.00%	0.00	0.00	RCP	
		A1-16		**32.17**		0.00	15.82	10	11.78	5.58	**88.29**	Circular	36	0.013	1.76%	266.0	12.49	0.35			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 10yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
			A	ΣA	C	CA	ΣCA		T_c	I	Q		D	n	S_f	L	V_f	TIME	INVERT ELEVATION		S	V	Q		
FROM	TO	AREA NO.	AREA (AC)	TOTAL AREA (AC)	RUNOFF COEF.			DESIGN STORM (YRS)	TIME OF CONC. (MIN)	RAINFALL INTENS (IN/HR)	QUANTITY (CFS)	TYPE	SIZE (IN)	MANN-INGS COEF	FRICTION SLOPE (%)	LENGTH (FT)	VELOC (FT/SEC)	IN PIPE (MIN)	UPPER (FT)	LOWER (FT)	ACTUAL SLOPE (%)	FULL FLOW VELOCITY (FT/SEC)	CAPACITY (CFS)	PIPE TYPE	
DRAINAGE AREA B																									
		B1	1.20	1.20	0.75	0.90	0.90	10	5.00	7.00	6.30	Circular	15	0.013	0.95%	12.0	5.13	0.04			0.00%	0.00	0.00	RCP	
		B2	0.06	1.26	0.90	0.05	0.95	10	5.04	7.00	6.68	Circular	15	0.013	1.07%	12.0	5.44	0.04			0.00%	0.00	0.00	RCP	
		B3	0.73	1.99	0.80	0.58	1.54	10	5.08	6.99	10.75	Circular	15	0.013	2.76%	42.0	8.76	0.08			0.00%	0.00	0.00	RCP	
		B4	1.52	1.52	0.50	0.76	0.76	10	5.00	7.00	5.32	Circular	15	0.013	0.68%	68.0	4.34	0.26			0.00%	0.00	0.00	RCP	
		B5	3.64	3.64	0.65	2.37	2.37	10	5.00	7.00	16.56	Circular	15	0.013	6.55%	17.0	13.50	0.02			0.00%	0.00	0.00	RCP	
		B1-5		7.15		0.00	4.66	10	5.26	6.94	32.37	Circular	24	0.013	2.05%	134.0	10.30	0.22			0.00%	0.00	0.00	RCP	
		B6	0.16	0.16	0.90	0.14	0.14	10	5.00	7.00	1.01	Circular	15	0.013	0.02%	5.0	0.82	0.10			0.00%	0.00	0.00	RCP	
		B1-6		7.31		0.00	4.81	10	5.48	6.90	33.18	Circular	24	0.013	2.15%	77.0	10.56	0.12			0.00%	0.00	0.00	RCP	
		B7	0.08	0.08	0.80	0.06	0.06	10	5.00	7.00	0.45	Circular	15	0.013	0.00%	15.0	0.37	0.68			0.00%	0.00	0.00	RCP	
		B1-7		7.39		0.00	4.87	10	5.60	6.87	33.47	Circular	24	0.013	2.19%	107.0	10.65	0.17			0.00%	0.00	0.00	RCP	
		B8	1.54	1.54	0.75	1.16	1.16	10	5.00	7.00	8.09	Circular	15	0.013	1.56%	45.0	6.59	0.11			0.00%	0.00	0.00	RCP	
		B9	1.16	1.16	0.90	1.04	1.04	10	5.00	7.00	7.31	Circular	15	0.013	1.28%	19.0	5.96	0.05			0.00%	0.00	0.00	RCP	
`		B10	0.82	1.98	0.85	0.70	1.74	10	5.05	6.99	12.17	Circular	15	0.013	3.54%	42.0	9.92	0.07			0.00%	0.00	0.00	RCP	
		B1-10		10.91		0.00	7.77	10	5.77	6.83	53.06	Circular	24	0.013	5.51%	228.0	16.89	0.23			0.00%	0.00	0.00	RCP	
		B11	1.86	1.86	0.75	1.40	1.40	10	5.00	7.00	9.77	Circular	12	0.013	7.48%	48.0	12.44	0.06			0.00%	0.00	0.00	RCP	
		B1-11		12.77		0.00	9.16	10	5.99	6.78	62.13	Circular	30	0.013	2.30%	394.0	12.66	0.52			0.00%	0.00	0.00	RCP	
		B18	2.44	2.44	0.50	1.22	1.22	10	5.00	7.00	8.54	Circular	15	0.013	1.74%	54.0	6.96	0.13			0.00%	0.00	0.00	RCP	
`		B19	4.45	6.89	0.55	2.45	3.67	10	5.13	6.98	25.60	Circular	15	0.013	15.65%	28.0	20.86	0.02			0.00%	0.00	0.00	RCP	
`		B20	0.08	6.97	0.90	0.07	3.74	10	5.15	6.97	26.06	Circular	15	0.013	16.23%	11.0	21.24	0.01			0.00%	0.00	0.00	RCP	
		B18-20		6.97		0.00	3.74	10	5.16	6.97	26.06	Circular	15	0.013	16.23%	68.0	21.24	0.05			0.00%	0.00	0.00	RCP	
		B1-11& 18-20		19.74		0.00	12.90	10	6.51	6.66	85.93	Circular	30	0.013	4.39%	63.0	17.50	0.06			0.00%	0.00	0.00	RCP	
		B12	0.49	0.49	0.85	0.42	0.42	10	5.00	7.00	2.92	Circular	15	0.013	0.20%	24.0	2.38	0.17			0.00%	0.00	0.00	RCP	
`		B13	1.20	1.69	0.75	0.90	1.32	10	5.17	6.97	9.18	Circular	15	0.013	2.01%	22.0	7.48	0.05			0.00%	0.00	0.00	RCP	
		B12-13		1.69		0.00	1.32	10	5.22	6.95	9.15	Circular	24	0.013	0.16%	232.0	2.91	1.33			0.00%	0.00	0.00	RCP	
		B14	0.79	0.79	0.55	0.43	0.43	10	5.00	7.00	3.04	Circular	15	0.013	0.22%	40.0	2.48	0.27			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 10yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
			A	ΣA	C	CA	ΣCA		T_c	I	Q		D	n	S_f	L	V_f	TIME	INVERT ELEVATION		S	V	Q		
FROM	TO	AREA NO.	AREA (AC)	TOTAL AREA (AC)	RUNOFF COEF.			DESIGN STORM (YRS)	TIME OF CONC. (MIN)	RAINFALL INTENS (IN/HR)	QUANTITY (CFS)	TYPE	SIZE (IN)	MANN-INGS COEF	FRICTION SLOPE (%)	LENGTH (FT)	VELOC (FT/SEC)	IN PIPE (MIN)	UPPER (FT)	LOWER (FT)	ACTUAL SLOPE (%)	FULL FLOW VELOCITY (FT/SEC)	CAPACITY (CFS)	PIPE TYPE	
		B15	1.88	1.88	0.55	1.03	1.03	10	5.00	7.00	7.24	Circular	15	0.013	1.25%	25.0	5.90	0.07			0.00%	0.00	0.00	RCP	
		B12-15		4.36		0.00	2.79	10	6.55	6.66	18.55	Circular	24	0.013	0.67%	375.0	5.90	1.06			0.00%	0.00	0.00	RCP	
		B16	0.74	0.74	0.70	0.52	0.52	10	5.00	7.00	3.63	Circular	15	0.013	0.31%	17.0	2.96	0.10			0.00%	0.00	0.00	RCP	
		B12-16		5.10		0.00	3.30	10	7.60	6.40	21.14	Circular	24	0.013	0.87%	185.0	6.73	0.46			0.00%	0.00	0.00	RCP	
		B17	0.45	5.55	0.40	0.18	3.48	10	8.06	6.30	21.94	Circular	24	0.013	0.94%	15.0	6.98	0.04			0.00%	0.00	0.00	RCP	
		B1-20		25.29		0.00	16.39	10	8.10	6.30	103.23	Circular	36	0.013	2.40%	111.0	14.60	0.13			0.00%	0.00	0.00	RCP	
		B21	0.50	0.50	0.40	0.20	0.20	10	5.00	7.00	1.40	Circular	8	0.013	1.34%	30.0	4.01	0.12			0.00%	0.00	0.00	RCP	
`		B22	1.25	1.75	0.75	0.94	1.14	10	5.12	6.98	7.94	Circular	15	0.013	1.51%	69.0	6.47	0.18			0.00%	0.00	0.00	RCP	
		B1-22		27.04		0.00	17.52	10	8.22	6.28	110.04	Circular	36	0.013	2.73%	119.0	15.57	0.13			0.00%	0.00	0.00	RCP	
		B23	1.42	1.42	0.60	0.85	0.85	10	5.00	7.00	5.96	Circular	24	0.013	0.07%	159.0	1.90	1.40			0.00%	0.00	0.00	RCP	
		B24	0.17	0.17	0.90	0.15	0.15	10	5.00	7.00	1.07	Circular	15	0.013	0.03%	55.0	0.87	1.05			0.00%	0.00	0.00	RCP	
		B23-24		1.59		0.00	1.01	10	6.40	6.69	6.72	Circular	24	0.013	0.09%	82.0	2.14	0.64			0.00%	0.00	0.00	RCP	
		B25	0.18	0.18	0.80	0.14	0.14	10	5.00	7.00	1.01	Circular	12	0.013	0.08%	18.0	1.28	0.23			0.00%	0.00	0.00	RCP	
		B23-25		1.77		0.00	1.15	10	7.03	6.54	7.51	Circular	36	0.013	0.01%	82.0	1.06	1.29			0.00%	0.00	0.00	RCP	
		B1-25		**28.81**		0.00	18.67	10	8.35	6.26	**116.89**	Circular	36	0.013	3.08%	26.0	16.54	0.03			0.00%	0.00	0.00	RCP	
DRAINAGE AREA C																									
		C1	0.38	0.38	0.35	0.13	0.13	10	5.00	7.00	0.93	Circular	18	0.013	0.01%	164.0	0.53	5.19			0.00%	0.00	0.00	RCP	
		C2	0.62	0.62	0.35	0.22	0.22	10	5.00	7.00	1.52	Circular	12	0.013	0.18%	22.0	1.94	0.19			0.00%	0.00	0.00	RCP	
		C1-2		1.00		0.00	0.35	10	10.19	5.84	2.04	Circular	24	0.013	0.01%	116.0	0.65	2.97			0.00%	0.00	0.00	RCP	
		C3	4.20	4.20	0.35	1.47	1.47	10	5.00	7.00	10.29	Circular	12	0.013	8.31%	25.0	13.11	0.03			0.00%	0.00	0.00	RCP	
		C1-3		5.20		0.00	1.82	10	13.16	5.35	9.74	Circular	24	0.013	0.19%	21.0	3.10	0.11			0.00%	0.00	0.00	RCP	
		C4	0.33	0.33	0.65	0.21	0.21	10	5.00	7.00	1.50	Circular	15	0.013	0.05%	42.0	1.22	0.57			0.00%	0.00	0.00	RCP	
`		C5	0.79	1.12	0.60	0.47	0.69	10	5.57	6.87	4.73	Circular	15	0.013	0.53%	50.0	3.85	0.22			0.00%	0.00	0.00	RCP	
		C6	2.61	2.61	0.55	1.44	1.44	10	5.00	7.00	10.05	Circular	15	0.013	2.41%	6.0	8.19	0.01			0.00%	0.00	0.00	RCP	
		C4-6		3.73		0.00	2.12	10	5.79	6.83	14.51	Circular	24	0.013	0.41%	195.0	4.62	0.70			0.00%	0.00	0.00	RCP	
		C7	0.66	0.66	0.80	0.53	0.53	10	5.00	7.00	3.70	Circular	18	0.013	0.12%	64.0	2.09	0.51			0.00%	0.00	0.00	RCP	
		C4-7		4.39		0.00	2.65	10	6.49	6.67	17.69	Circular	24	0.013	0.61%	32.0	5.63	0.09			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 10yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
FROM	TO	AREA NO.	A AREA (AC)	ΣA TOTAL AREA (AC)	C RUNOFF COEF.	CA	ΣCA	DESIGN STORM (YRS)	T_c TIME OF CONC. (MIN)	I RAINFALL INTENS (IN/HR)	Q QUANTITY (CFS)	TYPE	D SIZE (IN)	n MANN-INGS COEF	S_f FRICTION SLOPE (%)	L LENGTH (FT)	V_f VELOC (FT/SEC)	TIME IN PIPE (MIN)	INVERT ELEVATION UPPER (FT)	INVERT ELEVATION LOWER (FT)	S ACTUAL SLOPE (%)	V FULL FLOW VELOCITY (FT/SEC)	Q CAPACITY (CFS)	PIPE TYPE	
		C8	1.91	**11.50**	0.55	1.05	5.52	10	13.27	5.33	**29.43**	Circular	60	0.013	0.01%	74.0	1.50	0.82			0.00%	0.00	0.00	RCP	
DRAINAGE AREA D																									
		D1	0.54	0.54	0.65	0.35	0.35	10	5.00	7.00	2.46	Circular	18	0.013	0.05%	60.0	1.39	0.72			0.00%	0.00	0.00	RCP	
		D2	0.41	0.41	0.90	0.37	0.37	10	5.00	7.00	2.58	Circular	24	0.013	0.01%	27.0	0.82	0.55			0.00%	0.00	0.00	RCP	
		D3	0.16	**1.11**	0.85	0.14	0.86	10	5.72	6.84	**5.86**	Circular	24	0.013	0.07%	31.0	1.86	0.28			0.00%	0.00	0.00	RCP	

TOTAL DISCHARGE ON 10-YEAR STORM EVENT

AREA A	Q_{10} =	88	cfs	=	2,377,461	gph	=	39,624	gpm
AREA B	Q_{10} =	117	cfs	=	3,147,526	gph	=	52,459	gpm
AREA C	Q_{10} =	29	cfs	=	792,624	gph	=	13,210	gpm
AREA D	Q_{10} =	6	cfs	=	157,665	gph	=	2,628	gpm
AREA E	Q_{10} =	36	cfs	=	969,408	gph	=	16,157	gpm
TOTAL	Q_{10} =	276	cfs	=	7,444,683	gph	=	124,078	gpm

APPENDIX

7.2 100-YEAR STORM DRAIN ANALYSIS

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 100yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
FROM	TO	AREA NO.	A AREA (AC)	ΣA TOTAL AREA (AC)	C RUNOFF COEF.	CA	ΣCA	DESIGN STORM (YRS)	T_c TIME OF CONC. (MIN)	I RAINFALL INTENS (IN/HR)	Q QUANTITY (CFS)	TYPE	D SIZE (IN)	n MANN-INGS COEF	S_f FRICTION SLOPE (%)	L LENGTH (FT)	V_f VELOC (FT/SEC)	TIME IN PIPE (MIN)	INVERT ELEVATION UPPER (FT)	INVERT ELEVATION LOWER (FT)	S ACTUAL SLOPE (%)	V FULL FLOW VELOCITY (FT/SEC)	Q CAPACITY (CFS)	PIPE TYPE	
DRAINAGE AREA A																									
		A1	2.84	2.84	0.40	1.14	1.14	100	5.00	10.00	11.36	Circular	24	0.013	0.25%	33.0	3.62	0.15			0.00%	0.00	0.00	RCP	
		A2	0.74	0.74	0.75	0.56	0.56	100	5.00	10.00	5.55	Circular	12	0.013	2.42%	27.0	7.07	0.06			0.00%	0.00	0.00	RCP	
		A3	0.42	0.42	0.85	0.36	0.36	100	5.00	10.00	3.57	Circular	12	0.013	1.00%	27.0	4.55	0.10			0.00%	0.00	0.00	RCP	
		A1-3		4.00		0.00	2.05	100	5.15	10.00	20.48	Circular	18	0.013	3.80%	371.0	11.59	0.53			0.00%	0.00	0.00	RCP	
		A4	1.00	1.00	0.35	0.35	0.35	100	5.00	10.00	3.50	Circular	15	0.013	0.29%	205.0	2.85	1.20			0.00%	0.00	0.00	RCP	
		A1-4		5.00		0.00	2.40	100	5.69	10.00	23.98	Circular	18	0.013	5.22%	292.0	13.57	0.36			0.00%	0.00	0.00	RCP	
		A5	0.72	0.72	0.50	0.36	0.36	100	5.00	10.00	3.60	Circular	12	0.013	1.02%	13.0	4.59	0.05			0.00%	0.00	0.00	RCP	
		POND	10.10	10.10	0.50	5.05	5.05	100	5.00	10.00	50.50	Circular	18	0.013	23.13%	80.0	28.58	0.05			0.00%	0.00	0.00	RCP	
		A6	0.15	10.25	0.20	0.03	5.08	100	5.05	10.00	50.80	Circular	18	0.013	23.41%	34.0	28.75	0.02			0.00%	0.00	0.00	RCP	
		A1-6		15.97		0.00	7.84	100	6.04	9.90	77.60	Circular	24	0.013	11.79%	344.0	24.70	0.23			0.00%	0.00	0.00	RCP	
		A7	1.41	1.41	0.50	0.71	0.71	100	5.00	10.00	7.05	Circular	12	0.013	3.90%	9.0	8.98	0.02			0.00%	0.00	0.00	RCP	
		A8	1.75	1.75	0.70	1.23	1.23	100	5.00	10.00	12.25	Circular	12	0.013	11.77%	23.0	15.61	0.02			0.00%	0.00	0.00	RCP	
		A1-8		19.13		0.00	9.77	100	6.28	9.90	96.70	Circular	30	0.013	5.56%	554.0	19.70	0.47			0.00%	0.00	0.00	RCP	
		A9	1.57	1.57	0.25	0.39	0.39	100	5.00	10.00	3.93	Circular	12	0.013	1.21%	38.0	5.00	0.13			0.00%	0.00	0.00	RCP	
		A9		1.57		0.00	0.39	100	5.13	10.00	3.93	Circular	18	0.013	0.14%	377.0	2.22	2.83			0.00%	0.00	0.00	RCP	
		A10	1.52	1.52	0.25	0.38	0.38	100	5.00	10.00	3.80	Circular	12	0.013	1.13%	22.0	4.84	0.08			0.00%	0.00	0.00	RCP	
		A11	2.85	2.85	0.40	1.14	1.14	100	5.00	10.00	11.40	Circular	12	0.013	10.20%	22.0	14.52	0.03			0.00%	0.00	0.00	RCP	
		A12	0.31	3.16	0.55	0.17	1.31	100	5.03	10.00	13.11	Circular	12	0.013	13.48%	7.0	16.69	0.01			0.00%	0.00	0.00	RCP	
		A9-12		6.25		0.00	2.08	100	7.96	9.50	19.79	Circular	24	0.013	0.77%	43.0	6.30	0.11			0.00%	0.00	0.00	RCP	
		A13	2.07	2.07	0.55	1.14	1.14	100	5.00	10.00	11.39	Circular	12	0.013	10.17%	21.0	14.50	0.02			0.00%	0.00	0.00	RCP	
		A9-13		8.32		0.00	3.22	100	8.07	9.50	30.60	Circular	24	0.013	1.83%	608.0	9.74	1.04			0.00%	0.00	0.00	RCP	
		A14	2.43	2.43	0.55	1.34	1.34	100	5.00	10.00	13.37	Circular	12	0.013	14.02%	4.0	17.03	0.00			0.00%	0.00	0.00	RCP	
		A9-14		10.75		0.00	4.56	100	9.11	9.30	42.39	Circular	24	0.013	3.52%	41.0	13.49	0.05			0.00%	0.00	0.00	RCP	
		A15	0.79	0.79	0.85	0.67	0.67	100	5.00	10.00	6.72	Circular	12	0.013	3.54%	29.0	8.55	0.06			0.00%	0.00	0.00	RCP	
		A16	1.50	1.50	0.55	0.83	0.83	100	5.00	10.00	8.25	Circular	12	0.013	5.34%	24.0	10.51	0.04			0.00%	0.00	0.00	RCP	
		A9-16		13.04		0.00	6.05	100	9.16	9.30	56.31	Circular	24	0.013	6.21%	424.0	17.92	0.39			0.00%	0.00	0.00	RCP	
		A1-16		**32.17**		0.00	15.82	100	9.55	9.30	**147.15**	Circular	36	0.013	4.88%	266.0	20.82	0.21			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 100yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
FROM	TO	AREA NO.	A AREA (AC)	ΣA TOTAL AREA (AC)	C RUNOFF COEF.	CA	ΣCA	DESIGN STORM (YRS)	T_c TIME OF CONC. (MIN)	I RAINFALL INTENS (IN/HR)	Q QUANTITY (CFS)	TYPE	D SIZE (IN)	n MANN-INGS COEF	S_f FRICTION SLOPE (%)	L LENGTH (FT)	V_f VELOC (FT/SEC)	TIME IN PIPE (MIN)	INVERT ELEVATION UPPER (FT)	INVERT ELEVATION LOWER (FT)	S ACTUAL SLOPE (%)	V FULL FLOW VELOCITY (FT/SEC)	Q CAPACITY (CFS)	PIPE TYPE	
DRAINAGE AREA B																									
		B1	1.20	1.20	0.75	0.90	0.90	100	5.00	10.00	9.00	Circular	15	0.013	1.93%	12.0	7.33	0.03			0.00%	0.00	0.00	RCP	
		B2	0.06	1.26	0.90	0.05	0.95	100	5.03	10.00	9.54	Circular	15	0.013	2.17%	12.0	7.78	0.03			0.00%	0.00	0.00	RCP	
		B3	0.73	1.99	0.80	0.58	1.54	100	5.05	10.00	15.38	Circular	15	0.013	5.65%	42.0	12.53	0.06			0.00%	0.00	0.00	RCP	
		B4	1.52	1.52	0.50	0.76	0.76	100	5.00	10.00	7.60	Circular	15	0.013	1.38%	68.0	6.19	0.18			0.00%	0.00	0.00	RCP	
		B5	3.64	3.64	0.65	2.37	2.37	100	5.00	10.00	23.66	Circular	15	0.013	13.37%	17.0	19.28	0.01			0.00%	0.00	0.00	RCP	
		B1-5		7.15		0.00	4.66	100	5.18	10.00	46.64	Circular	24	0.013	4.26%	134.0	14.84	0.15			0.00%	0.00	0.00	RCP	
		B6	0.16	0.16	0.90	0.14	0.14	100	5.00	10.00	1.44	Circular	15	0.013	0.05%	5.0	1.17	0.07			0.00%	0.00	0.00	RCP	
		B1-6		7.31		0.00	4.81	100	5.33	10.00	48.08	Circular	24	0.013	4.53%	77.0	15.30	0.08			0.00%	0.00	0.00	RCP	
		B7	0.08	0.08	0.80	0.06	0.06	100	5.00	10.00	0.64	Circular	15	0.013	0.01%	15.0	0.52	0.48			0.00%	0.00	0.00	RCP	
		B1-7		7.39		0.00	4.87	100	5.42	10.00	48.72	Circular	24	0.013	4.65%	107.0	15.51	0.12			0.00%	0.00	0.00	RCP	
		B8	1.54	1.54	0.75	1.16	1.16	100	5.00	10.00	11.55	Circular	15	0.013	3.19%	45.0	9.41	0.08			0.00%	0.00	0.00	RCP	
		B9	1.16	1.16	0.90	1.04	1.04	100	5.00	10.00	10.44	Circular	15	0.013	2.60%	19.0	8.51	0.04			0.00%	0.00	0.00	RCP	
`		B10	0.82	1.98	0.85	0.70	1.74	100	5.04	10.00	17.41	Circular	15	0.013	7.24%	42.0	14.19	0.05			0.00%	0.00	0.00	RCP	
		B1-10		10.91		0.00	7.77	100	5.53	10.00	77.68	Circular	24	0.013	11.81%	228.0	24.72	0.15			0.00%	0.00	0.00	RCP	
										10.00															
		B11	1.86	1.86	0.75	1.40	1.40	100	5.00	10.00	13.95	Circular	12	0.013	15.27%	48.0	17.77	0.05			0.00%	0.00	0.00	RCP	
		B1-11		12.77		0.00	9.16	100	5.69	10.00	91.63	Circular	30	0.013	4.99%	394.0	18.67	0.35			0.00%	0.00	0.00	RCP	
		B18	2.44	2.44	0.50	1.22	1.22	100	5.00	10.00	12.20	Circular	15	0.013	3.56%	54.0	9.94	0.09			0.00%	0.00	0.00	RCP	
`		B19	4.45	6.89	0.55	2.45	3.67	100	5.09	10.00	36.68	Circular	15	0.013	32.13%	28.0	29.89	0.02			0.00%	0.00	0.00	RCP	
`		B20	0.08	6.97	0.90	0.07	3.74	100	5.11	10.00	37.40	Circular	15	0.013	33.41%	11.0	30.48	0.01			0.00%	0.00	0.00	RCP	
		B18-20		6.97		0.00	3.74	100	5.11	10.00	37.40	Circular	15	0.013	33.41%	68.0	30.48	0.04			0.00%	0.00	0.00	RCP	
		B1-11& 18-20		19.74		0.00	12.90	100	6.04	9.90	127.73	Circular	30	0.013	9.71%	63.0	26.02	0.04			0.00%	0.00	0.00	RCP	
		B12	0.49	0.49	0.85	0.42	0.42	100	5.00	10.00	4.17	Circular	15	0.013	0.41%	24.0	3.39	0.12			0.00%	0.00	0.00	RCP	
`		B13	1.20	1.69	0.75	0.90	1.32	100	5.12	10.00	13.17	Circular	15	0.013	4.14%	22.0	10.73	0.03			0.00%	0.00	0.00	RCP	
		B12-13		1.69		0.00	1.32	100	5.15	10.00	13.17	Circular	24	0.013	0.34%	232.0	4.19	0.92			0.00%	0.00	0.00	RCP	
		B14	0.79	0.79	0.55	0.43	0.43	100	5.00	10.00	4.35	Circular	15	0.013	0.45%	40.0	3.54	0.19			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 100yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
			A	ΣA	C	CA	ΣCA		T_c	I	Q		D	n	S_f	L	V_f	TIME	INVERT ELEVATION		S	V	Q		
FROM	TO	AREA NO.	AREA (AC)	TOTAL AREA (AC)	RUNOFF COEF.			DESIGN STORM (YRS)	TIME OF CONC. (MIN)	RAINFALL INTENS (IN/HR)	QUANTITY (CFS)	TYPE	SIZE (IN)	MANN-INGS COEF	FRICTION SLOPE (%)	LENGTH (FT)	VELOC (FT/SEC)	IN PIPE (MIN)	UPPER (FT)	LOWER (FT)	ACTUAL SLOPE (%)	FULL FLOW VELOCITY (FT/SEC)	CAPACITY (CFS)	PIPE TYPE	
		B15	1.88	1.88	0.55	1.03	1.03	100	5.00	10.00	10.34	Circular	15	0.013	2.55%	25.0	8.43	0.05			0.00%	0.00	0.00	RCP	
		B12-15		4.36		0.00	2.79	100	6.07	9.90	27.57	Circular	24	0.013	1.49%	375.0	8.78	0.71			0.00%	0.00	0.00	RCP	
		B16	0.74	0.74	0.70	0.52	0.52	100	5.00	10.00	5.18	Circular	15	0.013	0.64%	17.0	4.22	0.07			0.00%	0.00	0.00	RCP	
		B12-16		5.10		0.00	3.30	100	6.79	9.85	32.53	Circular	24	0.013	2.07%	185.0	10.35	0.30			0.00%	0.00	0.00	RCP	
		B17	0.45	5.55	0.40	0.18	3.48	100	7.08	9.80	34.13	Circular	24	0.013	2.28%	15.0	10.86	0.02			0.00%	0.00	0.00	RCP	
		B1-20		25.29		0.00	16.39	100	7.11	9.70	158.94	Circular	36	0.013	5.70%	111.0	22.48	0.08			0.00%	0.00	0.00	RCP	
		B21	0.50	0.50	0.40	0.20	0.20	100	5.00	10.00	2.00	Circular	8	0.013	2.73%	30.0	5.73	0.09			0.00%	0.00	0.00	RCP	
`		B22	1.25	1.75	0.75	0.94	1.14	100	5.09	10.00	11.38	Circular	15	0.013	3.09%	69.0	9.27	0.12			0.00%	0.00	0.00	RCP	
		B1-22		27.04		0.00	17.52	100	7.19	9.70	169.97	Circular	36	0.013	6.51%	119.0	24.04	0.08			0.00%	0.00	0.00	RCP	
		B23	1.42	1.42	0.60	0.85	0.85	100	5.00	10.00	8.52	Circular	24	0.013	0.14%	159.0	2.71	0.98			0.00%	0.00	0.00	RCP	
		B24	0.17	0.17	0.90	0.15	0.15	100	5.00	10.00	1.53	Circular	15	0.013	0.06%	55.0	1.25	0.74			0.00%	0.00	0.00	RCP	
		B23-24		1.59		0.00	1.01	100	5.98	9.90	9.95	Circular	24	0.013	0.19%	82.0	3.17	0.43			0.00%	0.00	0.00	RCP	
		B25	0.18	0.18	0.80	0.14	0.14	100	5.00	10.00	1.44	Circular	12	0.013	0.16%	18.0	1.83	0.16			0.00%	0.00	0.00	RCP	
		B23-25		1.77		0.00	1.15	100	6.41	9.80	11.26	Circular	36	0.013	0.03%	82.0	1.59	0.86			0.00%	0.00	0.00	RCP	
		B1-25		**28.81**		0.00	18.67	100	7.27	9.70	**181.12**	Circular	36	0.013	7.40%	26.0	25.62	0.02			0.00%	0.00	0.00	RCP	
DRAINAGE AREA C																									
		C1	0.38	0.38	0.35	0.13	0.13	100	5.00	10.00	1.33	Circular	18	0.013	0.02%	164.0	0.75	3.63			0.00%	0.00	0.00	RCP	
		C2	0.62	0.62	0.35	0.22	0.22	100	5.00	10.00	2.17	Circular	12	0.013	0.37%	22.0	2.76	0.13			0.00%	0.00	0.00	RCP	
		C1-2		1.00		0.00	0.35	100	8.63	9.35	3.27	Circular	24	0.013	0.02%	116.0	1.04	1.86			0.00%	0.00	0.00	RCP	
		C3	4.20	4.20	0.35	1.47	1.47	100	5.00	10.00	14.70	Circular	12	0.013	16.96%	25.0	18.73	0.02			0.00%	0.00	0.00	RCP	
		C1-3		5.20		0.00	1.82	100	10.49	9.10	16.56	Circular	24	0.013	0.54%	21.0	5.27	0.07			0.00%	0.00	0.00	RCP	
		C4	0.33	0.33	0.65	0.21	0.21	100	5.00	10.00	2.15	Circular	15	0.013	0.11%	42.0	1.75	0.40			0.00%	0.00	0.00	RCP	
`		C5	0.79	1.12	0.60	0.47	0.69	100	5.40	10.00	6.89	Circular	15	0.013	1.13%	50.0	5.61	0.15			0.00%	0.00	0.00	RCP	
		C6	2.61	2.61	0.55	1.44	1.44	100	5.00	10.00	14.36	Circular	15	0.013	4.92%	6.0	11.70	0.01			0.00%	0.00	0.00	RCP	
		C4-6		3.73		0.00	2.12	100	5.55	10.00	21.24	Circular	24	0.013	0.88%	195.0	6.76	0.48			0.00%	0.00	0.00	RCP	
		C7	0.66	0.66	0.80	0.53	0.53	100	5.00	10.00	5.28	Circular	18	0.013	0.25%	64.0	2.99	0.36			0.00%	0.00	0.00	RCP	
		C4-7		4.39		0.00	2.65	100	6.03	9.90	26.25	Circular	24	0.013	1.35%	32.0	8.36	0.06			0.00%	0.00	0.00	RCP	

Whitney, Bailey, Cox & Magnani, LLC
849 Fairmount Ave, Suite 100
Baltimore, MD 21286
Phone: (410) 512 - 4500
Fax: (410) 324 - 4100
Consulting Engineers

STORM SEWER DESIGN

Job No. 20090150.00.0
Sheet

PROJECT: *Annapolis See Level Rise Study*
LOCATION:
CATEGORY: *Storm Drain - 100yr storm event*

	By	Date
Computed	JP	10/07/09
Checked		

STRUCT. NO		DRAINAGE AREA			RUNOFF							PIPE													REMARKS
			A	ΣA	C	CA	ΣCA		T_c	I	Q		D	n	S_f	L	V_f	TIME	INVERT ELEVATION		S	V	Q		
FROM	TO	AREA NO.	AREA (AC)	TOTAL AREA (AC)	RUNOFF COEF.			DESIGN STORM (YRS)	TIME OF CONC. (MIN)	RAINFALL INTENS (IN/HR)	QUANTITY (CFS)	TYPE	SIZE (IN)	MANN-INGS COEF	FRICTION SLOPE (%)	LENGTH (FT)	VELOC (FT/SEC)	IN PIPE (MIN)	UPPER (FT)	LOWER (FT)	ACTUAL SLOPE (%)	FULL FLOW VELOCITY (FT/SEC)	CAPACITY (CFS)	PIPE TYPE	
		C8	1.91	**11.50**	0.55	1.05	5.52	100	10.55	9.10	**50.25**	Circular	60	0.013	0.04%	74.0	2.56	0.48			0.00%	0.00	0.00	RCP	
DRAINAGE AREA D																									
		D1	0.54	0.54	0.65	0.35	0.35	100	5.00	10.00	3.51	Circular	18	0.013	0.11%	60.0	1.99	0.50			0.00%	0.00	0.00	RCP	
		D2	0.41	0.41	0.90	0.37	0.37	100	5.00	10.00	3.69	Circular	24	0.013	0.03%	27.0	1.17	0.38			0.00%	0.00	0.00	RCP	
		D3	0.16	**1.11**	0.85	0.14	0.86	100	5.50	10.00	**8.56**	Circular	24	0.013	0.14%	31.0	2.72	0.19			0.00%	0.00	0.00	RCP	

TOTAL DISCHARGE ON 100-YEAR STORM EVENT

AREA A	Q_{100} =	147	cfs	=	3,962,435	gph	=	66,041	gpm
AREA B	Q_{100} =	181	cfs	=	4,877,156	gph	=	81,286	gpm
AREA C	Q_{100} =	50	cfs	=	1,353,260	gph	=	22,554	gpm
AREA D	Q_{100} =	9	cfs	=	230,504	gph	=	3,842	gpm
AREA E	Q_{100} =	52	cfs	=	1,400,256	gph	=	23,338	gpm
TOTAL	Q_{100} =	439	cfs	=	11,823,611	gph	=	197,060	gpm