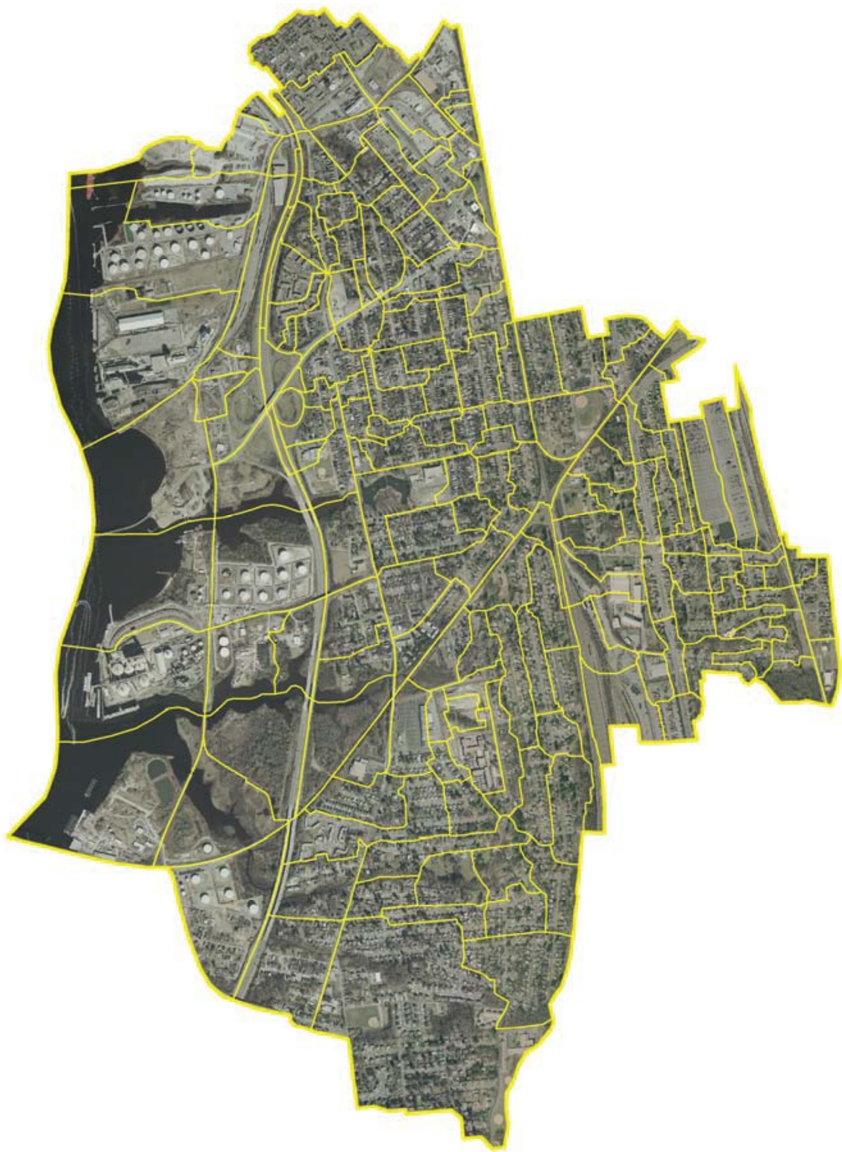
Storm Water Management Model

South Norfolk Master Drainage Study



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Chesapeake VIRGINIA
Department of Public Works

URS
URS Corporation

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Chesapeake, VA

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Executive Summary

Engineers from the City of Chesapeake and URS Corporation have completed a drainage study of the South Norfolk Watershed using the Storm Water Management Model (SWMM) computer program.

Much of the drainage and stormwater management infrastructure in South Norfolk is old, and was not well mapped or adequately inventoried prior to this study. In related work, the City undertook cleaning, surveying, and mapping of substantial lengths of stormwater pipelines and culverts, in part to facilitate the delivery of this drainage study. URS field crews, City surveyors, and Public Works engineers worked to determine how the South Norfolk drainage system is connected and configured, and produced infrastructure inventory and closed-circuit television (CCTV) inspection reports in March 2009. With the field information completed, the project team was able to complete the modeling analyses and prepare this study report.

The analytical procedure is based on computing localized flood volumes resulting from design rainfall events such as the 2-, 5-, 10-, 25-, 50- and 100-year storms. The watershed is analyzed using modeling configurations to quantify flooding associated with both existing and future watershed conditions. Drainage improvement alternatives are carefully evaluated with respect to their potential impact to the entire watershed. The improvement alternatives are then given further consideration based on construction feasibility and financing constraints, with the focus on the entire watershed rather than on a few individual components. The advantage of this approach is that the entire drainage system can be evaluated on a consistent, system-wide basis.

The process of identifying candidate drainage improvement projects is based on trial-and-error modeling techniques. The watershed is analyzed using anticipated future land use and imperviousness, and locations and volumes of computed flooding are identified in the modeling.

After analyzing existing and potential problems in this watershed, URS has identified six specific projects that can alleviate future flooding in the subject watershed. None of the six projects are considered Master Drainage Facilities (MDF's) because their contributing drainage area is not greater than 320 acres. However, the City requested that potential improvements to Outfall 8 be cost-estimated due to current construction activities in this area. Preliminary cost opinion computations, provided in Appendix E, indicate that Outfall 8 Drainage Improvements are financially feasible. The potential improvements

identified in this report are by no means exhaustive, but seem to provide a reasonable amount of flooding relief. The projects appear to be feasible from a preliminary planning standpoint, but issues such as future wetlands or stream delineations, construction costs and complexity, and the ability to successfully acquire rights-of-way or parcels of land may necessitate some modifications as these projects move forward. The South Norfolk watershed has large areas of low-lying topography, and in some locations the potential future improvements required to relieve flooding may not turn out to be cost-effective. The City requested that these potential improvements be included in this study so that those determinations can be made with specific improvements in mind.

Open channels and ditches in this watershed provide vital floodplain storage that must be carefully protected. The maintenance of floodplain storage along open channels and in low-lying areas is strongly recommended. If floodplain storage is lost through filling or poor maintenance, property and street flooding will increase. The City can protect these areas by enforcing the existing floodplain ordinance and through the acquisition of impoundment easements.

There are many combinations of drainage improvements that can be evaluated in any watershed. While a substantial effort has been applied to develop this study, it is by no means exhaustive. The intent of this undertaking was not only to develop sound alternatives for watershed improvements, but also to leave the underlying data files and computer models so that they can be used in a straightforward manner in the future.

The maximum computed water surface elevation at each modeled node, and peak computed discharge at each modeled link are presented in Appendices C and D, respectively, for existing and future conditions.

FEMA flood insurance studies and rate maps are the definitive source of floodplain limits and elevations. The SWMM models developed for this drainage study are specific design scenarios based on 2-, 5-, 10-, 25-, 50-, and 100-year rainfall events—THEY ARE NOT TO BE CONSTRUED AS INDICATIVE OF EXPECTED WATER SURFACE ELEVATIONS FOR THE PURPOSES OF FLOODPLAIN MANAGEMENT AND/OR INSURANCE REQUIREMENTS. The SWMM models developed for this study could be adapted for use in the National Flood Insurance Program and submitted to FEMA for approval, but until they are subjected to that process the published flood insurance studies and rate maps remain fully in effect.

Background

URS was directed by the City of Chesapeake to conduct a study in the South Norfolk watershed covering approximately 2,250 acres. The South Norfolk watershed is located in northern Chesapeake and is bordered on the north by the City of Norfolk. The majority of runoff from this watershed discharges into the Southern Branch of the Elizabeth River to the west, while a portion of the runoff discharges eastward into Indian River.

The age of the existing stormwater and drainage infrastructure (much of which was previously unmapped), the degree of urbanization, and the extent of low-lying ground having tidally influenced outfalls, makes this a particularly challenging watershed for analysis, planning, and design of potential future stormwater improvements.

The watershed was delineated into 179 subbasins in order to adequately distribute point sources for inflow. The South Norfolk watershed consists mostly of highly developed land areas, very few of which are targeted for future land use modification. This study addresses existing drainage and storm water issues, as well as expected future conditions. The entire SWMM model has over 320 nodes and more than 350 links, resulting in a high level of detail and discretization for a regional model.

No Master Drainage Plan (MDP) study had been performed previously, and very little data existed for the storm infrastructure prior to this effort. This study commenced in early 2008 but it became clear early on that additional data would be needed in order to successfully complete a SWMM analysis and report. Therefore, the study was placed on hold while the South Norfolk inventory and CCTV inspections were completed. Due to the age of the South Norfolk drainage system, accurate data on the existing drainage infrastructure was largely unavailable; therefore the collection of field information to develop an inventory of the drainage infrastructure was necessary. The inventory consisted of field inspections of previously identified storm structures. Data for each structure was obtained that included pipe connectivity, downs, and sizes as well as an overall condition assessment of the structure. The inventory and CCTV work was completed in early 2009 and the data that was gathered during this project was of great value to the overall integrity of the SWMM analysis. During the inventory process, much of the infrastructure was found to be heavily filled with sediment and debris.

Although a Master Drainage Plan study has not previously been conducted for this watershed, a smaller study entitled *Halifax Street Preliminary Drainage Study* was completed in the northwest portion of the watershed in January of 2005 by Rummel, Klepper & Kahl, LLP (RK&K). The current 36-inch pipe that drains Outfall 1, under the railroad tracks and traveling without an easement on the U.S. Gypsum property, was determined to be undersized. Additionally this pipe was found to be collapsed and heavily filled with sediment and debris. Due to the blockage created by the poor condition of the 36-inch pipe, low velocities caused sediment deposits in the 96-inch culverts upstream. It was a goal of this current study to replace the drainage outfall with a system that would satisfy the 10-year storm event as well as meet Norfolk Southern's design criteria for the 100-year storm event. RK&K recommended that the 36-in pipe be replaced with a 72-inch pipe under the railroad track. The 72-inch railroad culvert would then drain south into a new trapezoidal channel, to be constructed along the west side of the railroad track, and then back into a 72-inch pipe before discharging to its new location in the Western Branch of the Elizabeth River.

During the RK&K study an environmental site assessment (ESA) revealed multiple instances of petroleum contamination and underground storage tanks in this area. Soil contamination has been reported in several locations and it is quite possible that contaminated soils could be encountered during construction in this area.

The City of Chesapeake provided URS with several plan sets for projects within the watershed, some of which have been approved for construction but have not yet been completed. As directed by the City, URS modeled these as 'existing' conditions. While some of these developments were not expected to be complete by the end of this study, they were considered existing conditions because the approval of the project assures its near-future development.

The City of Chesapeake surveyed selected points in the subject watershed at the request of URS. These selected survey points are presented in Appendix B. The City also provided URS with GIS-related topographic data. URS utilized the plan sets, survey data, and GIS data as well as the data retrieved during the inventory and CCTV inspections in order to extract channel and infrastructure information, such as pipe inverts, type and sizes, and channel characteristics, throughout the watershed.

There have been several recent, concurrent work efforts in the South Norfolk watershed. Field crews from URS were sent out to collect inventory information, URS CCTV crews collected video data and made condition assessments, City surveying crews collected field data, and engineers continued to work on computer models and data processing. To accommodate this work, several nomenclatures were used to refer to node locations. This reality is brought about because field crews need to be able to assign data labels on-the-fly, as structures are discovered in the field. A match-key is presented in Appendix B that ties the labeling systems together. The following naming convention is used for nodes throughout this modeling effort:

#I**** (Node Label)

where:

refers to the outfall number,
I indicates the Inventory status of the data [‘C’ came from the South Norfolk Inventory, ‘D’ was added after the Inventory, and ‘F’ is a future node (for Scenario 3)], and
**** is the sequential number label.

For example, ‘6C3710’ refers to node 3710 in outfall 6, which is contained in the South Norfolk Inventory. ‘8F537’ refers to future node 537 in outfall 8.

Methodology

The engineering methodology applied in this study is summarized in a separate document, submitted by URS to the City of Chesapeake in April of 2005, entitled *Master Drainage Plan Methodology*. SWMM modeling is typically used for relatively large-scale studies. It is not generally intended to be used as a design tool for individual projects, due to its complexity and data requirements. Its strength lies in the application of very advanced hydrologic and hydraulic routing computational routines, fed with data from a geographic information system (GIS) and from plans for future roadway and parcel development projects.

This Master Drainage Plan Report presents the findings of the application of this methodology to the subject watershed.

Treatment of Nodal Flooding

The issue of how to handle nodal flooding is important when using or interpreting any rainfall-runoff model, including SWMM. Loosely speaking, nodal flooding occurs when a computed water surface elevation exceeds the maximum defined depth at a point in the system (referred to as a “node”).

In previous versions of SWMM (Versions 4.x and earlier), the water leaving the node was treated as an “escape” from the system. However, the treatment of nodal flooding was enhanced in SWMM Version 5 by introducing “nodal ponding” and “nodal surcharge” capabilities. The nodal ponding option allows the modeler to specify a constant “ponding area” over which <u>nodal surcharges are stored as they escape from the node, then released back into the system as water surface elevations recede</u>. This nodal ponding capability can produce more reliable water surface elevation computations due to the re-introduction of nodal flooding volumes and their continued downstream routing through the drainage system.

The option to compute nodal ponding in SWMM necessitates an approach to treat or develop the ponding area for each node, subject to two considerable limitations. First, the ponding area increases with depth, and in fact at some depth the ponded volume will actually combine with other nearby nodes such that deciding which node has what portion of the surface flooding becomes arbitrary at best. Secondly, it is not feasible to spend the time performing elaborate delineations at each node to compute a constant ponding area that is approximate at best, requires judgment regarding how much area to assign to which node, and ultimately varies with depth. In many locations, the situation is further complicated—when stormwater flows up and out of the ground, it runs down a gutter or downhill flow path to some other location.

SWMM is a one-dimensional model—it can only compute flow depth, discharge and related properties along one-dimensional lines through the drainage network. It cannot compute lateral variations in the flow (such as can be accomplished with two-dimensional surface-flow models). Even if it were possible to precisely compute the ponding area at each node, we are still limited by the use of a one-dimensional model. It is difficult to determine a ponding area with accuracy when the computed water surface elevation exceeds the ground elevation. The problem is further complicated by the difficulty in determining the nominal "ground elevation" in a one-dimensional model.

URS has developed an approach to handle nodal flooding using SWMM Version 5, which we are using on many similar studies. The approach used is to divide the total watershed area by the number of modeling nodes to develop an average ponding area, which is then applied to all nodes that are not directly modeled as storage nodes. This approach is simple, but effective, and because the surface flooding is re-introduced into the drainage system as flood levels decrease, it gives a reliable basis upon which to compute water surface elevations in these models. In some locations, storage nodes are used to make the hydraulic routing results stable, and the nodal ponding area is a function of the storage node characteristics (rather than the average ponding area as described above). For most nodes, the average ponding area is applied in the SWMM models created for this study.

Vertical Datum

Unless specifically stated otherwise, the **North American Vertical Datum of 1988 (NAVD88)** was used throughout this study.

Modeling Configurations

Three modeling configurations—Existing Hydraulics with Existing Hydrology (Scenario 1), Existing Hydraulics with Future Hydrology (Scenario 2), and Future Hydraulics with Future Hydrology (Scenario 3)—were developed for this study as described below.

Scenario 1 Existing watershed hydrology with the drainage system configured as it existed in 2009. Channels are modeled using their existing (2009) conditions as well. This is the "Scenario 1" model. The City of Chesapeake requested certain plan sets be considered as 'existing' because they have been approved prior to the start of this study. The following is a list of plan sets, provided by the City that was used in the existing conditions model (the list includes projects that have been constructed as well as approved projects not yet constructed):

1. Ohio Street Drainage Improvements
2. Atlantic Ave. Outfall
3. Proposal from S. Main St. to Poindexter St.
4. Strawberry Lane Neighborhood Development Area Improvements
5. Sheridan Heights Drainage Project
6. South Norfolk / Oakdale Drainage Improvement
7. Southgate Plaza Tidal Mitigation Site

8. VDH&T 0.332 Mile North of Park Ave, to 0.205 Mile North of S. Main St.
9. VDH&T 0.217 Mile South of Park Ave. to 0.322 Mile North of Park Ave.
10. Bainbridge Boulevard
11. Atlantic Ave. and Campostella Rd.
12. Jones Creek Outfall Study
13. Holly Point Apartments (Section 7)
14. Park Ave. and Stewart St. New Drainage
15. Norfolk Southern Railway
16. Poindexter Streetscape Improvements (Preliminary Drainage Calculation)
17. Replacement School for Oscar F. Smith Middle
18. Gateway at SoNo
19. Chesapeake Ave
20. Chesapeake-Rodgers Intersection
21. Lakeside Park
22. Richmond-Byrd Ave
23. Technico
24. VDH&T 0.217 Mile South of Park Ave. to 0.322 Mile North of Park Ave.
25. Poindexter Street Storm Drainage Outfall Improvements Phase 1-A
26. Poindexter Street Storm Drainage Outfall Improvements Phases 3 & 4
27. Stewart Street #1321 Erosion Repair Project
28. Portlock Drainage Phase II
29. Stewart Street and Park Avenue Outfall

Scenario 2 Future watershed hydrology with the drainage system configured as it existed in 2009. Channels are modeled using their existing (2009) conditions as well. This is the "Scenario 2" model. This scenario will show the flooding effects of the existing drainage system due to future land use development. In other words, if no improvements are made to the current drainage system and the remainder of the watershed is constructed as described by the City's 2005 Adopted Land Use Plan, these are the locations and volumes of flooding that can be expected.

Scenario 3 Future watershed hydrology with the future drainage system configuration as envisioned by the City of Chesapeake and URS. This is the "Scenario 3" model. This scenario incorporates the drainage from Scenarios 1 and 2 along with any future plans previously identified by the City. In addition, this scenario includes recommendations from URS to help eliminate flooding on a master drainage facility level (i.e. areas of flooding serviced by 320 acres or greater). The following is a list of plan sets, provided by the City, that were added to the future conditions model:

1. Halifax Street Preliminary Drainage Study
2. SONO Condominiums

The future improvements should largely reduce flooding at key locations, where feasible, in the future conditions. The improvements developed during this study, are highlighted in Figure 10, and specifically include the following projects:

1. Outfalls 1 & 2 Drainage Improvements
2. Outfall 4 Drainage Improvements

3. Outfall 5 Drainage Improvements
4. Outfall 7 Drainage Improvements
5. Outfall 8 Drainage Improvements
6. Outfall 9 Drainage Improvements

This scenario depicts future conditions with strategic drainage and storm water improvements in place. Additional details and descriptions regarding the improvements are presented elsewhere in this report. A cost opinion is presented in Appendix E.

Modeling Results

Stable RUNOFF and FLOW ROUTING runs were obtained for all modeling scenarios. ROUTING continuity errors ranged from low to very low.

The boundary condition (water surface elevations) for Outfalls 1 through 4 and 6 through 9 (see Figure 10 for outfall labels) were set in accordance with Chapter 5, Section Q of the *City of Chesapeake Public Facilities Manual* (July 2005 Edition, 9/08 Revision). In all cases, for all return periods, the hydraulic boundary condition was modeled as a constant water surface elevation of 3.60 feet (NAVD88) in the Elizabeth River. The Boundary condition for Outfall 5 was set to normal flow. Due to the topographic relief in Outfall 5 as well as the distance to the nearest body of water, this portion of the model is not particularly sensitive to the hydraulic boundary conditions. Therefore Outfall 5 was computed based on a boundary condition of normal depth (i.e. the slope of the energy grade line is generally equal to the channel slope).

The GIS analysis prepared in support of this modeling indicates that the South Norfolk Watershed will increase from **57.72** to **59.92** percent imperviousness in the future, as indicated in Figures 3 and 4. The procedures used to determine this increase are explained in the *Master Drainage Plan Methodology* (April 2005) report submitted previously. This increase in impervious cover produces greater volumes of stormwater runoff, which have been incorporated into the future conditions models.

Figures 8, 9, and 11 depict street and property flooding volumes for the 10- and 50-year design storm events. The histograms are not drawn to any scale, but they are proportional, and serve to graphically identify where flooding can be expected under each modeling configuration.

The City does not have to 'fix' all of the flooding represented by the histograms in the figures. Areas such as woodlands, deep ravines, large open spaces, ball fields and parks, and along railroad rights of way often do not require improvements unless there is a specific reason to construct them. It is also important to bear in mind that a 50-year design storm is an extreme event, and that neighborhood drainage systems are typically not required to accommodate 50-year storms.

Flooding complaints, particularly those in residential neighborhoods, often result from maintenance problems such as a clogged pipe or debris in a ditch. In considering whether or not drainage improvements might be required to correct an *existing* deficiency, the model results should indicate a flooding problem, and there should be some flooding history to support the need for improvements. If both of these conditions are not met, then the system maintenance should be reviewed or the preliminary computer models should be carefully scrutinized.

It is also important to understand when reviewing these results that there can be low-lying structures in the watershed that have finished floor elevations below the maximum water surface elevations computed in the SWMM models. In order to estimate whether or not a particular structure will be subject to flooding for a given storm condition, maximum hydraulic grade line elevations in the vicinity should be checked against the finished floor elevation.

As with all models of this size and complexity there is a great deal of detailed information required. Because it is not feasible to collect *all* of the required data, in some locations it is necessary to make educated guesses about inverts and pipe and channel dimensions and geometries. Where future designs and studies will be based on these models, engineers are strongly encouraged to field-verify all items that may critically impact their designs.

The maximum computed water surface elevations at each model node are presented in Appendix C for both existing and future condition scenarios. The blue shading in Tables C-1 and C-2 indicates locations where the maximum computed water surface meets or exceeds the ground elevation for that node. Many of these nodal flooding locations are very small quantity or short duration events. In these SWMM 5 models, the volume of water leaving the node during flooding is computed and summarized for continuity purposes (which allows for a reasonable accounting of flood volume at the node) *and the flooded water is re-introduced into the model for subsequent downstream routing*, as explained in the Treatment of Nodal Flooding section above. If flooding occurs at a choke point in the system, downstream (or nearby) nodes may have computed maximum water surface elevations less than what can actually be expected due to the volume of water being 'held' upstream. With the introduction of Nodal Ponding in SWMM 5, this phenomenon is of less concern than it was in older versions of SWMM. Where computed water surface elevations exceed the ground elevation in these models, water surface elevations in the vicinity should be considered 'approximate'. The main purpose of this ponding approach is to account for local flooding volumes and re-introduce stored water back into the drainage system as water surface elevations recede.

The *figures* that indicate nodal flood volumes in this report have been filtered so that nodal flood volumes less than 10,000 cubic feet are not represented (because less than 10,000 cubic feet of flooding cannot be practically discerned on the ground—it simply appears as heavy runoff or sheet flow in most cases). *Tables* C-1 and C-2 have not been filtered at all; where nodal flooding is indicated in many cases the duration and quantity of flooding can be very minor.

The PCSWMM.NET modeling platform contains a very helpful dynamic hydraulic grade line tool that allows the user to view animations of the computed water surface elevations. This dynamic hydraulic grade line tool takes input from a digital interface file at *a specified sampling interval*, for example every 3 minutes in these models. The SWMM routing computations are performed at one-second (or so) intervals, and the output file contains summary information based on *every* time step. If the dynamic hydraulic grade line tool is used to view the results the user should bear in mind that it is based on a sample (one out of every 180 seconds), and therefore the 'peak' values listed by the dynamic hydraulic grade line tool are peaks as sampled using a three-minute interval. The SWMM output data on the other hand contains a summary of the *exact* peak values. The SWMM output file summaries were used to prepare Tables C-1, C-2, D-1, and D-2, as well as the flooding figures in this report.

The modeling results presented in this report are based on the assumption that the drainage and stormwater systems will be well maintained. If debris builds up to block drainage structures, or channels are allowed to fill with silt, flooding will likely be more severe than computed and represented in this report. Debris can be a significant problem in natural channel outfall systems, and should be monitored carefully to ensure that these systems function properly. Sediment and debris, and other maintenance issues have been highly problematic in the South Norfolk watershed, to the point that investigations of flooding complaints should begin with a review of the maintenance and condition of the pipes, culverts, basins, channels and ditches. Maintenance issues were documented in the stormwater inventory reports delivered to the City in March 2009. These models in effect depict scenario flooding due to capacity and configuration issues rather than flooding that results from maintenance problems.

FEMA flood insurance studies and rate maps are the definitive source of floodplain limits and elevations in all cases. The SWMM models developed for this drainage study are specific design scenarios based on 2-, 5-, 10-, 25-, 50-, and 100-year rainfall events—THEY ARE NOT TO BE CONSTRUED AS INDICATIVE OF EXPECTED WATER SURFACE ELEVATIONS FOR THE PURPOSES OF FLOODPLAIN MANAGEMENT AND/OR INSURANCE REQUIREMENTS. The SWMM models developed for this study could be adapted for use in the National Flood Insurance Program and submitted to FEMA for approval, but until they are subjected to that process, the published flood insurance studies and rate maps remain fully in effect.

Master Drainage Plan Improvements

The City of Chesapeake utilizes a 320-acre threshold for candidate Master Drainage Facility (MDF) improvements. If a project services less than 320 acres, it will generally not be constructed as part of the City's Master Drainage Plan.

Six specific projects were conceived and incorporated into the modeling during the course of this study, none of which are considered MDF improvements because their contributing drainage area is less than 320 acres. However, the City requested that potential improvements to Outfall 8 be cost-estimated due to current construction activities in this area. Preliminary cost opinion computations, provided in Appendix E, indicate that the Outfall 8 Drainage Improvements are financially feasible. The potential improvements identified in this report are by no means exhaustive, but seem to provide a reasonable amount of flooding relief. The projects appear to be feasible from a preliminary planning standpoint, but issues such as future wetlands or stream delineations, construction costs and complexity, and the ability to successfully acquire rights-of-way or parcels of land may necessitate some modifications as these projects move forward. The South Norfolk watershed has large areas of low-lying topography, and in some locations the potential future improvements required to relieve flooding may not turn out to be cost-effective. The City requested that these potential improvements be included in this study so that those determinations can be made with specific improvements in mind.

The six projects are shown in Figure 10 and are included in the future modeling scenario. Refer to Figures 6, 7, 10 and 10a of this report to find node and link numbers and to view the locations of improvements that are referenced in the following project summaries.

1. Outfalls 1 & 2 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. For this reason, a cost opinion is not provided. However, URS evaluated this improvement to support the City's continuing efforts to relieve flooding in upstream areas, and to determine whether improving flow through the railroad embankment project would cause flooding problems at downstream locations. The purpose of these improvements is to increase stormwater conveyance in Outfalls 1 and 2, under the railroad track near Interstate 464, adjacent to the U.S. Gypsum site. Currently, the 36-in pipe (which crosses the U.S. Gypsum property and is at the downstream end of Outfall 1) is collapsed. A previous study was completed in 2005 entitled, "Halifax Street Preliminary Drainage Study." While the recommended improvements in the Halifax study did meet hydraulic requirements for stormwater flows as well as pipe cover requirements, the recommended 72-inch culvert under the railroad may not satisfy railroad company requirements for the 100-year storm event—specifically that the inlet control conditions be limited to a headwater divided by barrel depth less than 1.5 (HW/D ≤ 1.5). However, these future improvements constitute a retrofit, and greatly improve the existing hydraulic situation by lowering all headwater depths at this culvert crossing.

A 24-inch pipe, (nodes 2C205 to 2C215) 680 feet south of the existing 36-inch pipe crossing under the railroad, is the sole relief conduit for Outfall 2. This 24-inch pipe is not sufficient to hydraulically handle the runoff flows from Outfall 2. Flooding upstream, along Bainbridge Boulevard is a direct result of the undersized railroad culvert. Due to a low grade elevation of 8.0 feet along the railroad tracks at this crossing, it is not feasible to place an additional pipe larger than 54 inches and still meet the railroad pipe cover requirements. However, if a 54-inch pipe is laid parallel to the existing 24-inch pipe, this does not allow enough flow area in order to meet HW/D requirements for the 100-year storm.

The City of Chesapeake expressed interest in combining Outfalls 1 and 2 in an effort to minimize the number of future railroad crossing projects. While the railroad may have requirements for the HW/D, these limits could be adjusted for special field conditions. The City of Chesapeake is limited by topographic constraints in this area, and replacing the collapsed 36-inch pipe with a 72-inch pipe will greatly improve the flooding situation.

Several routing alternatives for connecting Outfalls 1 and 2 were considered, such as within the I-464 median and along the west side of the I-464 embankment, but due to topography and other limiting factors URS modeled the system between Interstate 464 and the railroad track. The buildings on this property are railroad switching stations, and must remain in place. The connection would need to be placed on either side of the buildings. Space is very limited, and construction will be problematic due to the proximity of the buildings. The City asked that these outfalls be linked, as modeled in Scenario 3, so that other important issues can be addressed, such as downstream routing impacts. The City is well aware that making this connection will be difficult and costly and that other alternatives are possible and should be considered.

Flooding in the area upstream of D Street (nodes 1C435 and 1D235) is relieved due to the proposed enlarged outfall under the railroad, however, the existing single 36-inch pipe under D Street creates a constriction that drive up water surface elevations upstream, particularly at B Street (nodes 1C475 and 1C495). Increasing the capacity under D Street lowers the WSEs upstream and eliminates the flooding at B Street.

The *Halifax Street Preliminary Drainage Study* (Halifax Study) recommendations, the connection between Outfalls 1 and 2 along with additional recommendations (documented below), will help to convey stormwater flows through a new and enlarged outfall that will ultimately alleviate flooding in the upper portions of Outfalls 1 and 2.

Modeled improvements to this area include:

1. From nodes 1C435 to 1C195: Place additional 36-in RCP parallel to the existing 36-in pipe.
2. From nodes 1C225 to 1D226: Remove or abandon in place existing 36” pipe.
3. From nodes 1C225 to 1F226: Place new 72-in RCP (Halifax Study).
4. From nodes 1F226 to 1F227: Place new 72-in pipe through the railroad embankment. Pipe material will depend upon construction techniques (tunnel, jack-and-bore, etc.). (Halifax Study).
5. From nodes 1F227 to 1F228: Construct Trapezoidal channel with 4-ft bottom and 2(H):1(V) side slopes (Halifax Study).
6. From nodes 1F228 to 2C215: Place new 72-in RCP (Halifax Study).

7. From nodes 2C135 to 2C125: Replace 24-in pipe with a 36-in RCP. If rights-of-way/easements and construction details allow, a parallel 30-in pipe could be used as an alternate design.
8. From nodes 2C205 to 1F226: Place new 72-in RCP.

2. Outfall 4 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. For this reason, a cost opinion is not provided. However, URS evaluated this improvement to support the City's continuing efforts to relieve excessive flooding and to determine whether implementing the project would cause flooding at downstream locations. The purpose of these improvements is to increase stormwater conveyance in Outfall 4. Due to very low elevations at Bainbridge Boulevard (where pavement elevations are approximately 4.0 feet—refer to Figures 8, 9 and 11 for low topography), alleviating flooding in this area will require costly measures, such as multiple box culverts under the roadway.

The crest elevations for the two weirs in the Lakeside Park Lake are 2.57 and 2.87 which are below the boundary condition elevation of 3.60 feet. Both weirs therefore start out submerged and remain submerged through the entire model simulation. The City is aware that low ground is the key factor and that one alternative is to raise Bainbridge Boulevard, which would be very expensive and problematic. The potential improvements modeled in this study do not include raising Bainbridge Boulevard—instead the storm system has been modeled to determine the extent of required improvements to relieve flooding at this location. The expected cost-benefit ratio would be high for the anticipated amount of flood relief, but the value of keeping Bainbridge Boulevard open to traffic during more severe storm events could become sufficiently large to justify the expected costs.

Rights-of-way in this vicinity are tight, and the infrastructure is old, so the smaller lines should be replaced rather than supplemented with parallel pipes.

Potential improvements to this area include:

1. From nodes 4C525 to 4C265: Place one-way valves on two of the three lake outfall pipes.
2. From nodes 4C265 to 4C235: Replace 30-in pipe with a 48-in RCP.
3. From nodes 4C235 to 4C305: Replace 30-in pipe with a 54-in RCP.
4. From nodes 4C305 to 4C528: Replace 36-in pipe with a 54-in RCP.
5. From nodes 4D528 to 4C295: Replace single 4-ft x 6-ft box culvert with four (4) 5-ft x 6-ft box culverts. Lower pipe invert at node 4D529 to elevation -3.7, to eliminate existing adverse grade.

3. Outfall 5 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. For this reason, a cost opinion is not provided. However, URS evaluated this improvement to support the City's continuing efforts to relieve excessive flooding and to determine whether implementing the project would cause flooding at downstream locations. The purpose of these improvements is to increase stormwater conveyance in Outfall 5, under the railroad tracks near the intersection of Strawberry Lane and Vicker Avenue. The City has already retained funding for improvements to this outfall and is waiting for recommendations and a design. Currently the pipe under the railroad is an 18-inch RCP and has an elevated invert on the upstream end. Flooding in this area occurs on the upstream side of the railroad embankment. By replacing the 18-inch pipe with a 48-inch pipe and lowering the invert in, the "flooding" problems will subsequently move downstream and therefore require the downstream pipes to be replaced with larger pipes as well. In addition to the outfall, nodes 5C1550 and 5D1591 are of concern to the City and flooding in this area must be eliminated. Scenario 3 was modeled with a larger pipe under the railroad as well as the replacement of the downstream pipes with larger pipe diameters. These improvements meet the hydraulic requirements for stormwater flows. The proposed 48-inch pipe under the railroad also meets the railroad requirements for ground cover and satisfies the requirement that HW/D for the 100-year storm event is limited to HW/D $\leq$ 1.5.

These recommendations will help to convey stormwater flow through a new and enlarged outfall that will ultimately alleviate flooding in the upper portions of Outfall 5, including nodes 5C1550 and 5D1591.

Rights-of-way in this vicinity are tight, and the infrastructure is old, so the smaller lines should be replaced rather than supplemented with parallel pipes.

Recommended improvements to this area include:

1. From nodes 5C815 to 5C350: Replace 18-in pipe with a 48-in pipe through railroad embankment. Pipe material will depend upon construction techniques (tunnel, jack-and-bore, etc.). Lower existing pipe invert at node 5C815 to elevation 10.9 to provide positive drainage.
2. From nodes 5C350 to 5C340: Replace 27-in pipe with a 60-in RCP.
3. From nodes 5C340 to 5C370: Replace 30-in pipe with a 60-in RCP.
4. From nodes 5C370 to 5C685: Replace 30-in pipe with a 66-in RCP.
5. From nodes 5C685 to 5C675: Replace 36-in pipe with a 66-in RCP.

4. Outfall 7 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. For this reason, a cost opinion is not provided. However, URS evaluated this improvement to support the City's continuing efforts to relieve excessive flooding and to determine whether implementing the project would cause flooding at downstream locations. The purpose of these improvements is to increase stormwater conveyance in Outfall 7.

Plans for the future SONO Condominiums, near the intersection of Chesapeake Drive and Rodgers Street, are in process and therefore the planned stormwater system was added to the Scenario 3 model. In addition to the SONO Condominium system, the existing storm system required some improvements. Pipes in this outfall are undersized and in order to convey the existing and future condition stormwater flows some of the smaller pipes need to be replaced with larger ones, specifically to eliminate the flooding at nodes 7C295 and 7C315.

Recommended improvements to this area include:

1. From nodes 7C235 to 7F227: Place new 24-in RCP (SONO Condominiums).
2. From nodes 7F227 to 7F226: Place new 27-in RCP (SONO Condominiums).
3. From nodes 7F230 to 7F229: Place new 42-in RCP (SONO Condominiums).
4. From nodes 7F229 to 7F228: Place new 42-in RCP (SONO Condominiums).
5. From nodes 7F228 to 7F226: Place new 12-in RCP (SONO Condominiums).
6. From nodes 7F226 to 7C225: Place new 30-in RCP (SONO Condominiums).
7. From nodes 7C315 to 7C295: Replace 24-in pipe with a 48-in RCP. If rights-of-way/easements and construction details allow, a parallel 42-in pipe could be used as an alternate design.

8. From nodes 7C295 to 7C135: Replace 24-in pipe with a 54-in RCP. If rights-of-way/easements and construction details allow, a parallel 48-in pipe could be used as an alternate design.

5. Outfall 8 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. However, URS evaluated this improvement to support the City's continuing efforts to relieve excessive flooding and to determine whether implementing the project would cause flooding at downstream locations. The City requested that URS provide a cost opinion for this improvement due to the amount of construction activity that is currently taking place to remedy the stormwater issues in this area. The purpose of the improvements is to increase stormwater conveyance under Rodgers Street and under the Oscar F. Smith Middle School grounds.

Currently the City has a project underway to slip-line the existing single 54-inch pipe currently running through the school's newly constructed parking lot (nodes 8C535 to 8C435). This process will reduce the effective flow diameter in the pipe from 54 to 48 inches. This reduction in flow area was considered when analyzing the improvements for this outfall; ie, the existing 54-inch pipe was modeled as an existing 48-inch pipe. The 54-inch pipe (48-inch effective pipe) is currently the sole source of conveyance for stormwater coming from upstream of Rodgers Street.

The City had originally expressed interest in acquiring the stormwater basin on school grounds, to possibly enlarge the basin, discharge additional flows into it, and treat it as a regional BMP. Upon further evaluation of this concept, Public Works staff determined that acquiring the basin would place additional burden on the City for very little benefit. During a meeting with the Chesapeake City Schools staff, the City was asked to route any addition storm pipes on the south side of the new parking lot, through the future ball fields (nodes 8F536 to 8F537 to 8F538 to 8C435). This area has not yet been redeveloped and routing the storm pipe here will reduce the amount of disturbance to new construction. URS worked with the City to develop a proposed system that will not only better convey the flows upstream of Rodgers Street, but also minimize utility conflicts.

Figure 10a shows the Scenario 3 configuration selected by the City. Recommended improvements to this area include:

1. From nodes 8C435 to 8C455: Remove existing 54-in pipe.
2. At node 8C435: Remove existing structure and place headwall with wing walls.
3. At node 8F536: Place new manhole structure.
4. At node 8F538: Place new manhole structure
5. From nodes 8F536 to 8F537: Place new 54-in RCP.
6. From nodes 8F537 to 8F538: Place new 54-in RCP.
7. From nodes 8F538 to 8C435: Place new 54-in RCP.
8. From nodes 8C435 to 8C445: Construct Trapezoidal channel with 8-ft bottom and 2(H):1(V) side slopes.
9. From nodes 8C425 to 8C435: Place new emergency spillway from the existing pond.
10. From nodes 8C2470 to 8C2390: Place additional 48-in RCP.

The estimated cost for the Outfall 8 Drainage Improvements project is **$ 481,565** in 2009 dollars, as summarized in Appendix E. This cost could be reduced if constructed as part of adjacent development projects or through negotiations with future developers.

6. Outfall 9 Drainage Improvements

This project is not considered a master drainage facility project because the contributing drainage area is less than 320 acres. For this reason, a cost opinion is not provided. However, URS evaluated this improvement to support the City's continuing efforts to relieve excessive flooding and to determine whether implementing the project would cause flooding at downstream locations. The purpose of these improvements is to increase stormwater conveyance in Outfall 9. The City identified the storm system near the intersection of Edgewood Avenue and Walden Street that is currently in need of replacement per the City's condition assessment report. The existing pipes between nodes 9C250B and 9C615, and nodes 9C240 and 9C250 are currently not adequate to handle the 10- and 50- year storm event. In addition, flooding for the 50-year storm event is present at Bainbridge Boulevard due to an undersized crossing at this location. The models for Scenarios 1 and 2 show node 9D710 flooding. This is due to a low-lying ground elevation of 4.0. Although this node is still showing 'flooding' in Scenario 3, the crossing at this location, Bainbridge Boulevard, is at a higher elevation of 6.0 and is not targeted to flood for the 50-year storm event.

Rights-of-way in this vicinity are tight, and the infrastructure is old, so the smaller lines should be replaced rather than supplemented with parallel pipes.

Recommended improvements to this area include:

1. From nodes 9C250B to 9C250: Replace single 18-in pipe with double 36-in RCPs.
2. From nodes 9C240 to 9C250: Replace 24-in pipe with a 36-in RCP.
3. From nodes 9C250 to 9C605: Replace single 24-in pipe with double 36-in RCPs.
4. From nodes 9C605 to 9C615: Place additional 42-in RCP parallel to existing 42-in pipe.
5. From nodes 9C535 to 9C360: Place additional 48-in RCP parallel to existing 48-in pipe.
6. From nodes 9C360 to 9C545: Replace single elliptical pipe with double 48-in RCPs.

System Notes

The Gateway at SoNo is a new development community off Poindexter Street in Outfall 3. The plans for this development call for a temporary dry pond which will be turned into a landscape area after construction is complete. The City was concerned that the discontinued use of this pond will increase flooding along Poindexter Street. An analysis was done without the pond in place, and the removal of the temporary pond after construction does not impact the drainage system along Poindexter Street, however, the absence of the pond will increase flooding within the Gateway at SoNo community.

Recent stormwater improvements were done in the vicinity of Poindexter Street and the I-464 ramp. All model scenarios show flooding at nodes 3C185 and 3C505. While these recent improvements are hydraulically adequate, nodes 3C185 and 3C505 have low rim elevation and therefore flooding localized and is represented at these locations.

It is important to note that open channels modeled in this watershed are an important aspect in the entire outlook of the watershed as a whole. The protection of floodplain area along open channels is strongly encouraged due to the storage volume provided by these areas to attenuate the stormwater flow. The City can protect these areas by enforcing the existing floodplain ordinance and/or the acquisition of impoundment easements.

The goal of this type of study is not to relieve *all* flooding, but rather to identify Master Drainage Facility improvements that can be feasibly constructed. It is also important to consider that neighborhood and commercial parcel drainage and storm water systems are neither required nor designed to accommodate flooding from extreme events such as the 50-year storm.

There is an area near node 6C445 along Outfall 6 where the ditch shoulder is very low compared to the culvert and pipe depths. According to these models, there will be significant flooding in this low area. URS discussed this situation with City staff, which could not recall reports of actual flooding in this vicinity. The topography is such that this localized flooding has relief flow paths along a roadside ditch behind an industrial warehouse (that has an elevated loading dock floor) along Narrow Street. The City is aware of this situation, and will address it if needed in the future.

Contact Information

Mr. Sam Sawan, PE (757.382.6101) served as the project manager for the City of Chesapeake on this project. Mr. John Paine, PE, PH, CFM was the project manager for URS. The modeling evaluations and report were produced by Stephanie Hood, PE, Hai Tran, EIT and Jeremy Morazo, EIT. Cost opinion, QA/QC, and additional production assistance was provided by Sean Bradberry, and Carol Wilkinson (757.873.0559).