Storm Water Management Model

Pocaty River Watershed MDP

Master Drainage Plan

April 2008
Revised November 13, 2009

US Army Corps of Engineers
Norfolk District

Chesapeake VIRGINIA
Department of Public Works

URS
URS Corporation

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Pocaty River Watershed MDP

Chesapeake, VA

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Executive Summary

Engineers from the U.S. Army Corps of Engineers, City of Chesapeake and URS Corporation have completed a drainage study of the Pocaty River Watershed which includes the Pocaty River Subwatershed (North) and Pocaty River Subwatershed (South) using the Storm Water Management Model (SWMM) computer program.

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, the engineering team has identified six specific projects that can alleviate future flooding in the subject watershed. One of the six projects is not considered Master Drainage Facilities (MDF's) because its contributing drainage area is not greater than 320 acres. Preliminary cost opinion computations, provided in a separate Cost Appendix, indicate that the five Master Drainage Facilities are financially feasible. These projects can be carried forward as Capital Improvements Projects with some assurance that the impacts on the watershed as a whole have already been adequately considered. Portions of some projects can potentially be constructed as part of private development initiatives with little or no cost to the City. For example, the Carter Road Drainage Improvements project could be constructed by the City, or could be done as part of future development

proffers. This project may not be needed for a very long time, depending on how development occurs near Fentress Airfield.

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.

Portions of this watershed associated with roadway or development projects have been evaluated by the City over the past several years. Some studies have been completed to address specific problems as described elsewhere in this report. The modeling conducted as part of this Master Drainage Plan incorporates the previously prescribed improvements where possible, either directly or with modifications.

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 and the U.S. Army Corps of Engineers to conduct a study on the area of Pocaty River Watershed covering approximately 14,834 acres.

The Pocaty River Watershed is located in eastern Chesapeake and is bordered on the east by the city of Virginia Beach. The runoff discharges into the eastern part of the watershed through Pocaty River to the North Landing River, which flows to the Currituck Sound in North Carolina.

The subject watershed was delineated into 215 subbasins in order to distribute runoff throughout the entire watershed. The Pocaty River Watershed consists mostly of rural property and contains large, undeveloped tracts of land, 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 400 nodes and over 400 links, making it a large and complicated model for this region.

Two drainage studies, Green Haven/Murray Drive Drainage Study and King James Colony Drainage Study, were previously completed within the watershed. The following is a brief description of each of the two studies.

In December of 1999, the City of Chesapeake concluded a study of the Green Haven subdivision along Murray Drive. This study was in response to hurricanes, tropical storms, and other thunderstorms that caused flooding during the months of September and October in 1999. Green Haven contains seven parallel storm drainage systems that drain to a large ditch located along the north side of the subdivision.

Also, three of the drainage systems deliver runoff to the crop field south of Green Haven. The large outfall ditch drains through four parallel pipe culverts under Whittamore Road and eventually drains to the Pocaty River. The City proposed improvements to the drainage systems in three phases.

Phase I

-clean and lower outfall ditch located on the north side of the subdivision
-clean and clear all cross ditches to the outfall ditch
-clean all pipes in Green Haven drainage system
-lower invert of outfall to drain all cross ditches and pipes

Phase II

-clean and clear second outfall ditch located on the south side of the subdivision
-re-clean all cross ditches and pipes in Green Haven
-remove and replace 54" pipe culverts

Phase III

-enlarge all outfall ditches
-clear outfall ditch past the four 48" parallel pipe culverts under Whittamore Road
-install additional 48" pipe under Whittamore Road
-install additional 54" pipe in northern outfall ditch
-re-clean all pipes and ditches

Although this study was completed in 1999, none of the recommendations were implemented.

King James Colony is located in the northeastern portion of the Pocaty River Watershed. It is bordered to the north by North Landing Estates, Blackwater Road to the east, Pocaty Road to the south, and Fentress Airfield Road to the west. The previous study focused on the two channels: North Ditch and Herring Run. Approximately 960 acres drain into these channels before being released into Pocaty River. During the course of the previous study several deficiencies were discovered throughout the channel system. The City recommended the following improvements: increasing the bottom width to 20 feet and creating 2H:1V side slopes for Herring Run, and increasing the bottom width to 8 feet and creating 2H:1V side slopes for the North Ditch.

None of the improvements have yet been implemented from the King James Colony Drainage Study.

In addition to the previous studies, the City of Chesapeake provided URS with several plan sets for projects within the subject 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 these four main sources—past studies, plan sets, survey data, and GIS data to extract channel and infrastructure information, such as inverts, pipe type and sizes, and channel characteristics, throughout the subject watershed.

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 new nodal ponding option allows the modeler to specify a constant "ponding area" over which nodal surcharges are stored as they escape from the node, then released back into the system as water surface elevations recede. 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 storm water flows up and out of the ground, it runs down a street or hill 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. The point is that above the ground elevation, it is difficult and sometimes impossible to determine a ponding area with accuracy. 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.

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 2008. Channels are modeled using their existing (2008) 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 and studies, provided by the City, that were used in the existing conditions model (the list includes completed past studies, projects that have been constructed, as well as approved projects not yet constructed):

1. 2236 Carolina Road Subdivision Plan
2. Carriage House Commons
3. Carriage House Marketplace
4. Centerville Turnpike Park – Phase I
5. Dixon Property – Land of Promise Road
6. Emerald Lakes Estates
7. Emerald Lakes Estates – Section Three
8. Etheridge Greens
9. Etheridge Lakes – Section Five
10. Etheridge Lakes – Section Three
11. Green Haven/Murray Drive Drainage Study
12. King James Colony Drainage Study
13. Long Ridge 88 AC Subdivision Plan
14. Long Ridge Woods Subdivision
15. Ramsgate – Section One

Scenario 2 Future watershed hydrology with the drainage system configured as it existed in 2008. Channels are modeled using their existing (2008) 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 configured as envisioned by the City of Chesapeake and URS. This is the "Scenario 3" model. This scenario incorporates the drainage from Scenarios 2 along with any recommendations from the engineering team to help eliminate flooding on a master drainage facility level (i.e. areas serviced by 320 acres or greater).

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

1. Green Haven Drainage Improvements
2. Carter Road Drainage Improvements
3. Pocaty Road Outfall Improvements
4. Land of Promise – Dixon Area Drainage Improvements
5. Walnut Green Area Drainage Improvements
6. Beaver Dam Bridge Replacement

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. Cost opinions are presented in a separate Cost Appendix.

Modeling Results

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

Stable SWMM runs were obtained for all modeling scenarios. Continuity errors ranged from low to very low. URS senior engineers used PCSWMM.NET to review dynamic hydraulic grade lines, checking the hydraulic routing for potential stability problems or any type of flow anomaly. During this QA/QC procedure items were found and addressed, so the final modeling results should be reliable.

Boundary conditions (water surface elevations) at the downstream outfall were set in accordance with Chapter 5, Section Q of the City of Chesapeake Public Facilities Manual (July 2001 Edition). In all cases, for all return periods, the hydraulic boundary condition was modeled as a constant water surface elevation of 0.93 feet (NAVD88) in the Pocaty River. Due to the natural topography and wide floodplain environment of the Pocaty River, the water surface elevations in the upper portions of this watershed are not very sensitive to the downstream boundary water surface elevation used in these models.

The GIS analysis prepared in support of this modeling indicates that the Pocaty River Watershed will increase from **7.59** to **9.85** 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 storm water 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 computer models should be carefully checked.

As noted in the Background section above, maintenance is a significant issue with respect to flooding in and along the major outfall channels. During field inspections, and as attested to by local residents, trees have fallen across the outfall channel in multiple locations. These fallen trees are either catching debris or have the potential to catch debris during large storm events. These models are based on realistic assumptions as to the conditions of the existing and proposed channels—good maintenance practices must be followed to keep the system functioning properly.

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*. 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.

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 storm water 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.

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, one of which will not be considered an MDF improvement due to its contributing drainage area being less than 320 acres. These projects are by no means exhaustive, but they seem to provide a reasonable amount of flooding relief at reasonable costs. All of the projects appear to be feasible from a preliminary planning standpoint, but issues such as future wetlands delineations and the ability to successfully acquire rights-of-way or parcels of land may necessitate some modifications as these projects move forward. The six projects are shown in Figure 10 and are included in the future modeling scenario. Refer to Figures 6, 7, and 10 of this report to find node and link numbers and to view the locations of improvements that are referenced in the following project summaries. In some cases, due to the tight proximity of nodes and links, it may be easier to view these links and nodes using the GIS files provided with this report.

1. Green Haven Drainage Improvements

Several field investigations by URS engineers and City surveyors verified that curb elevations at several locations along on Murray Drive are lower than the banks of the drainage channels and ditches connecting to the Greenhaven Subdivision drainage system from the south and to the north. Engineers also discovered after the original April 2008 Pocaty Creek Watershed Master Drainage Plan study that more than 120 acres of farm drainage are also connected to the Murray Drive drainage system. They also discovered that a controlling weir was constructed on private farm property after the field investigation for the April 2008 study was completed. (The City has made the owner aware that the weir should not be used to block drainage to the east.) These discoveries are now incorporated into modeling Scenarios 1, 2 and 3.

There is a shallow ditch section with very low banks at the southern end of Bonney Road. According to local residents, runoff during storms overtops the ditch banks at Bonney Road (node 554.2), creating street flooding. This flooding gets even worse when water levels rise in the outfall channels to the north.

Many of the road culverts and pipes that connect the ditches are too small for the current drainage configuration. Recommended improvements to this area include:

1. Remove or disconnect 42-in RCP between nodes **545** and **551**.
2. Node **545**: Create invert at 9.35 ft. Note that node **545** in this scenario is at beginning southern ditch, about 20 ft. south of existing location.
3. Node **546**: Lower ditch invert to 6.90 ft. from 8.56 ft.
4. Node **553**: Lower ditch invert to 6.00 ft. from 7.66 ft.
5. Node **555**: Lower ditch invert to 4.60 ft. from 6.21 ft.
6. Node **554.1**: Lower ditch invert to 4.34 ft. from 6.17 ft.
7. Node **554**: Lower ditch invert to 4.00 ft. from 6.16 ft.
8. Node **554.2**: Lower ditch invert to 3.50 ft. from 6.15 ft.
9. Node **566**: Lower ditch invert to 3.50 ft. from 6.14 ft.
10. Node **565**: Lower ditch invert to 3.50 ft. from 6.40 ft.
11. Node **563**: Lower ditch invert to 3.50 ft. from 7.00 ft.
12. Node **708**: Create invert at 3.50 ft.
13. Node **709**: Create invert at 3.50 ft.
14. Node **710**: Create invert at 2.84 ft.
15. Node **714**: Create invert at 2.79 ft.
16. Block flow from southern ditch at node **556**.
17. From Nodes **556** to **555**: Re-grade ditch for positive flow from nodes **556** to **555**.
18. From Nodes **543** to **545**: Replace existing 42-in RCP with 60-in RCP.
19. From Nodes **543** to **546**: Using existing ditch bottom as a bench, enlarge channel cross section to 10-ft. bottom width with side slope of 2H:1V.
20. From Nodes **546** to **553**: Using existing ditch bottom as a bench, enlarge channel cross section to 10-ft. bottom width with side slope of 2H:1V.
21. From Nodes **553** to **555**: Using existing ditch bottom as a bench, enlarge channel cross section to 15-ft. bottom width with side slope of 2H:1V.
22. From Nodes **555** to **554.1**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
23. From Nodes **554.1** to **554**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
24. From Nodes **554** to **554.2**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
25. From Nodes **554.2** to **566**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
26. From Nodes **566** to **565**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
27. From Nodes **565** to **563**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
28. From Nodes **563** to **708**: Using existing ditch bottom as a bench, enlarge channel cross section to 20-ft. bottom width with side slope of 2H:1V.
29. From Nodes **708** to **709**: Construct 80 ft. 4-ft x 10-ft box culverts.
30. From Nodes **709** to **710**: Construct a trapezoid channel with bottom equal to 20 ft and side slopes equal to 2H:1V.
31. From Nodes **710** to **714**: Construct 80 ft. 4-ft x 10-ft box culverts.
32. From Nodes **714** to **718**: Construct a trapezoid channel with bottom equal to 20 ft and side slopes equal to 2H:1V. This channel should be tied to existing creek at node **718**.
33. From Nodes **582** to **583**: Add one 21-in RCP parallel to existing 21-in RCP.
34. From Nodes **559** to **579**: Clean channel.
35. From Nodes **579** to **581**: Clean channel.

36. From Nodes **584** to **586**: Add one 24-in RCP parallel to existing 18-in RCP.
37. From Nodes **597** to **598**: Add one 18-in RCP parallel to existing 18-in RCP.

At the 30-percent design drawing stage in November 2009, the City's budget estimate for the Green Haven Drainage Improvements project is **$ 2.2 Million** dollars.

2. Carter Road Drainage Improvements

This area has flooding under existing conditions due to its undersized pipes and ditches. However, the area may not be experiencing frequent flooding because it is now still open fields and woods. Flooding is expected to increase significantly under future conditions if this area develops. Recommended improvements to this area include:

1. Node 692: Lower invert to 7.50 ft. (NAVD 88).
2. Node 693: Lower invert to 7.00 ft. (NAVD 88).
3. Node 694: Lower invert to 6.95 ft. (NAVD 88).
4. Node 695: Lower invert to 6.25 ft. (NAVD 88).
5. Node 696: Lower invert to 6.20 ft. (NAVD 88).
6. Node 697: Lower invert to 5.45 ft. (NAVD 88).
7. Node 699: Lower invert to 5.40 ft. (NAVD 88).
8. Node 703: Lower invert to 3.00 ft. (NAVD 88).
9. Node 705: Lower invert to 2.95 ft. (NAVD 88).
10. Node 707: Lower invert to 1.35 ft. (NAVD 88).
11. From Nodes 692 to 693; Re-grade and widen channel bottom to 10 ft with side slopes equal to 2H:1V.
12. From Nodes 693 to 694: Replace existing 18-in RCP by double 4-ft x 4-ft box culvert.
13. From Nodes 694 to 695: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
14. From Nodes 695 to 696: Replace existing 18-in RCP by double 4-ft x 4-ft box culvert.
15. From Nodes 696 to 697: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
16. From Nodes 697 to 699: Replace existing 18-in RCP by double 4-ft x 4-ft box culvert.
17. From Nodes 699 to 703: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
18. From Nodes 703 to 705: Replace existing 18-in RCP by double 4-ft x 4-ft box culvert.
19. From Nodes 705 to 707: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.

The City could mitigate the increase in flooding by requiring on-site storm water management for future development projects.

The estimated cost for the Carter Road Drainage Improvements project is **$ 1,309,763** in 2008 dollars, as summarized in the separate Pocaty River MDP Cost Appendix.

3. Pocaty Road Outfall Improvements

The vicinity between node 743 and 753 has a lower ground elevation that will flood when improvements 1 and 2 above are in place. Therefore, improvements at this channel section need to done to accommodate the increased flows that would result from upstream improvements. The recommended improvement to this area is:

1. From Nodes 743 to 761: Clean out wet channel from bank to bank. This will improve storm water conveyance.

Due to stream perenniality issues, it is unlikely that this channel can be widened without substantial impact fees being assessed by state and federal permit writers. For this reason, this project is limited to simply "maintaining" the channel conveyance by cutting brush to Manning n=0.035. If either of the two preceding projects are constructed, the Pocaty Road Outfall Improvements project must be completed.

The estimated cost for the Pocaty Road Outfall Improvements project is **$ 296,416** in 2008 dollars, as summarized in the separate Pocaty River MDP Cost Appendix.

4. Land of Promise–Dixon Area Drainage Improvements

This project is not considered a master drainage improvement project because the contributing drainage area is less than 320 acres. It is considered for improvement because flooding will overtop the road during large rainfall events. The recommended improvement to this area is:

1. Replace the existing 12-in RCP with 30-in RCP between nodes 472 and 473.

A cost opinion has not been developed for this project because its contributing drainage area is less than 320 acres.

5. Walnut Green Area Drainage Improvements

Modeling scenarios 1 and 2 (exiting hydrology and drainage, and future hydrology and existing drainage) show significant flooding at the culvert under Land Of Promise Road during a 50-year rainstorm. Recommended improvements, which will increase the conveyance of storm water, include:

1. From Nodes 393 to 395: Replace existing 30-in RCP with 42-in RCP.
2. From Nodes 409 to 411: Add one 36-in RCP parallel to existing 36-in RCP.
3. From Nodes 411 to 413: Widen channel bottom to 3 ft with side slopes equal to 2H:1V.
4. From Nodes 413 to 415: Add one 36-in RCP parallel to existing 36-in RCP.

The estimated cost for the Walnut Green Area Drainage Improvements project is **$ 255,120** in 2008 dollars, as summarized in the separate Pocaty River MDP Cost Appendix.

6. Beaver Dam Bridge Replacement

Modeling scenarios 1 and 2 show flooding at nodes 149 and 181. Relieving flooding at these culverts will cause flooding downstream at Beaver Dam Bridge. Replacing the bridge with culverts is the best option.

The City is considering, or has previously considered, replacing the bridge from Node 185 to 187.

Recommended improvements to this area include:

1. From Nodes 149 to 151: Add one 54-in RCP parallel to existing 54-in and existing 48-in RCPs and adjust the relay these existing pipes to create positive flow.
2. Node 183: Lower invert to -0.07 ft. (NAVD 88).
3. Node 185: Lower invert to -0.12 ft. (NAVD 88).
4. From Nodes 151 to 183: Re-grade and widen channel bottom to 25 ft with side slopes equal to 2H:1V.
5. From Nodes 181 to 183: Replace double 36-in RCPs with double 48-in RCPs.
6. From Nodes 183 to 185: Re-grade and widen channel bottom to 25 ft with side slopes equal to 2H:1V.
7. From Nodes 185 to 187: Replace bridge with three 6-ft x 8-ft box Culverts.
8. Node 211: Lower invert to 0.10 ft. (NAVD 88).
9. From Nodes 187 to 211: Re-grade and widen channel bottom to 25 ft with side slopes equal to 2H:1V.
10. From Nodes 211 to 215: Clean and re-grade channel.

The estimated cost for the Beaver Dam Bridge Replacement project is **$ 815,214** in 2008 dollars, as summarized in the separate Pocaty River MDP Cost Appendix.

Other Design Options Considered

The City asked URS to consider and document other options and alternative drainage routes, which were prepared and reviewed prior to selecting the configuration contained in the *Murray Drive-Greenhaven Subdivision Drainage Improvements* project (AC #08-1049-06), which was originally "Option 2A" before being incorporated into Scenario 3 (i.e. the "Future Improvements" scenario) as "Improvement 1."

Three other options were modeled and considered, as documented below and depicted in Figures 10a-10c. The preferred alternative was Option 2A, which is described as Improvement 1 above and depicted in detail in Figure 10d. PCSWMM.NET computer files for all of these options are provided on the DVD for November 13, 2009 submittal.

Option 1—Green Haven Drainage Improvements

1. Block flow from southern ditch at node **556**.
2. Node **555**: Lower ditch invert to 5.87 ft. from 6.21 ft.
3. From Nodes **556** to **555**: Re-grade ditch for positive flow from nodes 556 to 555.
4. Node **554.1**: Lower ditch invert to 5.51 ft. from 6.17 ft.
5. Node **554**: Lower ditch invert to 4.94 ft. from 6.16 ft.
6. Node **554.2**: Lower ditch invert to 4.00 ft. from 6.15 ft.
7. Node **565**: Lower ditch invert to 4.70 ft. from 6.40 ft.
8. Node **566**: Lower ditch invert to 3.00 ft. from 6.14 ft.
9. From Nodes **546** to **553**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
10. From Nodes **553** to **555**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
11. From Nodes **555** to **554.1:** Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.

12. From Nodes **554.1** to **554**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
13. From Nodes **554** to **554.2**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
14. From Nodes **554.2** to **556**: Re-grade and widen channel bottom to 15 ft with side slopes equal to 2H:1V.
15. From Nodes **563** to **565**: Re-grade and widen channel bottom to 5 ft with side slopes equal to 2H:1V.
16. From Nodes **565** to **566**: Re-grade and widen channel bottom to 5 ft with side slopes equal to 2H:1V.
17. Node **568**: Lower ditch invert to 2.17 ft. from 5.01 ft.
18. Node **569**: Lower ditch invert to 2.00 ft. from 4.81 ft.
19. Node **572**: Lower ditch invert to 1.70 ft. from 4.05 ft.
20. Node **574.1**: Lower ditch invert to 1.40 ft.
21. Node **579**: Lower ditch invert to 2.93 ft. from 3.35 ft.
22. Node **581**: Lower ditch invert to 2.00 ft. from 2.35 ft.
23. Node **581.1**: Lower ditch invert to 1.20 ft.
24. Node **585**: Lower ditch invert to 1.00 ft. from 1.50 ft.
25. Node **587**: Smooth channel flow line to fill hole to 0.82 ft. from 0.10 ft.
26. Node **589**: Smooth channel flow line to fill hole to 0.75 ft. from 0.39 ft.
27. From Nodes **582** to **583**: Add one 21-in RCP parallel to existing 21-in RCP.
28. From Nodes **583** to **577**: Clean channel.
29. From Nodes **584** to **586**: Add one 24-in RCP parallel to existing 18-in RCP.
30. From Nodes **586** to **576**: Clean channel.
31. From Nodes **597** to **598**: Add one 18-in RCP parallel to existing 18-in RCP.
32. From Nodes **559** to **579**: Clean channel.
33. From Nodes **566** to **568**: Remove existing 30-in RCP. Re-grade, extend and widen existing channel to a trapezoid channel with bottom equal to 15 ft and side slopes equal to 2H:1V. This channel should stop 30 ft. from Murray Drive.
34. From Nodes **568** to **569**: Remove existing double 19 in. x 30 in elliptical pipes. Construct 90 ft. double 4-ft x 10-ft box culverts crossing Murray Drive.
35. From Nodes **569** to **572**: Remove existing 34 in. x 53 in. elliptical pipe. Re-grade, extend and widen existing channel to a trapezoid channel with bottom equal to 15 ft and side slopes equal to 2H:1V. This channel should begin 30 ft. from Murray Drive.
36. From Nodes **572** to **574.1**: Re-grade and widen channel bottom to 10 ft with side slopes equal to 2H:1V.
37. From Nodes **576** to **574.1**: Clean channel.
38. From Nodes **576** to **581**: Clean and re-grade channel.
39. From Nodes **577** to **579**: Clean and re-grade channel.
40. From Nodes **579** to **581**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
41. From Nodes **581** to **581.1**: Clean and re-grade channel.
42. From Nodes **574.1** to **581.1**: Re-grade and create a 15-ft bench on the east bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
43. From Nodes **581.1** to **585**: Re-grade and create a 15-ft bench on the east bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
44. From Nodes **585** to **587**: Re-grade and create a 10-ft bench on the south bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.

45. From Nodes **587** to **589**: Relay all three existing pipes to new inverts and add two 54-in RCPs parallel to existing triple 54-in RCPs.
46. From Nodes **589** to **599**: Clean and smooth channel.
47. From Nodes **599** to **601**: Add two 54-in RCPs parallel to existing four 48-in RCPs. **Note:** To create positive slope for the new double 54-in RCPs, lay pipes with upside invert equal to ditch invert (0.52 ft. NAVD 88) and downside invert equal to 0.40 ft.

Option 1A—Green Haven Drainage Improvements

1. Block flow from southern ditch at node **556**.
2. Node **555**: Lower ditch invert to 5.73 ft. from 6.21 ft.
3. From Nodes **556** to **555**: Re-grade ditch for positive flow from nodes 556 to 555.
4. Node **554.1**: Lower ditch invert to 5.37 ft. from 6.17 ft.
5. Node **554**: Lower ditch invert to 4.80 ft. from 6.16 ft.
6. Node **554.2**: Lower ditch invert to 4.00 ft. from 6.15 ft.
7. Node **565**: Lower ditch invert to 5.46 ft. from 6.40 ft.
8. Node **566**: Lower ditch invert to 4.96 ft. from 6.14 ft.
9. From Nodes **546** to **553**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
10. From Nodes **553** to **555**: Re-grade and widen channel bottom to 8 ft with side slopes equal to 2H:1V.
11. From Nodes **555** to **554.1:** Re-grade and widen channel bottom to 12 ft with side slopes equal to 2H:1V.
12. From Nodes **554.1** to **554**: Re-grade and widen channel bottom to 12 ft with side slopes equal to 2H:1V.
13. From Nodes **554** to **554.2**: Re-grade and widen channel bottom to 12 ft with side slopes equal to 2H:1V.
14. From Nodes **563** to **565**: Re-grade and widen channel bottom to 5 ft with side slopes equal to 2H:1V.
15. From Nodes **565** to **566**: Re-grade and widen channel bottom to 5 ft with side slopes equal to 2H:1V.
16. From Nodes **566** to **554.2**: Re-grade and widen channel bottom to 5 ft with side slopes equal to 2H:1V.
17. Node **574**: Lower ditch invert to 3.09 ft.
18. Node **574.1**: Lower ditch invert to 2.89 ft.
19. Node **576**: Lower ditch invert to 2.60 ft. from 2.85 ft.
20. Node **579**: Lower ditch invert to 2.93 ft. from 3.35 ft.
21. Node **581**: Lower ditch invert to 2.00 ft. from 2.35 ft.
22. Node **581.1**: Lower ditch invert to 1.18 ft.
23. Node **585**: Lower ditch invert to 0.60 ft. from 1.50 ft.
24. From Nodes **582** to **583**: Add one 21-in RCP parallel to existing 21-in RCP.
25. From Nodes **583** to **577**: Clean channel.
26. From Nodes **584** to **586**: Add one 24-in RCP parallel to existing 18-in RCP.
27. From Nodes **586** to **576**: Clean channel.
28. From Nodes **597** to **598**: Add one 18-in RCP parallel to existing 18-in RCP.
29. From Nodes **554.2** to **574**: Construct 835 ft. double 4-ft x 10-ft box culverts.
30. From Nodes **559** to **579**: Clean channel.
31. From Nodes **577** to **579**: Clean and re-grade channel.
32. From Nodes **572** to **574**: Clean and re-grade channel.
33. From Nodes **574.1** to **576**: Clean and re-grade channel.
34. From Nodes **576** to **581**: Clean and re-grade channel.

35. From Nodes **574** to **574.1**: Re-grade and create a 10-ft bench on the north bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
36. From Nodes **574.1** to **581.1**: Re-grade and create a 16-ft bench on the east bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
37. From Nodes **579** to **581**: Re-grade and create a 10-ft bench on the south bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
38. From Nodes **581** to **581.1**: Clean and re-grade channel.
39. From Nodes **581.1** to **585**: Re-grade and create a 15-ft bench on the east bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
40. From Nodes **585** to **587**: Re-grade and create a 10-ft bench on the south bank at elevation of 1 foot from the bottom of channel. Also create a side slope of 2H:1V at the end of bench to tie into existing grade.
41. From Nodes **587** to **589**: Add two 54-in RCPs parallel to existing triple 54-in RCPs.
42. From Nodes **589** to **599**: Clean channel.
43. From Nodes **599** to **601**: Add two 48-in RCPs parallel to existing four 48-in RCPs.

Option 2—Green Haven Drainage Improvements

1. Remove or disconnect 42-in RCP between nodes **545** and **551**.
2. Node **545**: Create invert at 9.80 ft. **Note:** node **545** in this scenario is at beginning southern ditch, about 20 ft. south of existing location.
3. Node **546**: Lower ditch invert to 6.90 ft. from 8.56 ft.
4. Node **553**: Lower ditch invert to 6.00 ft. from 7.66 ft.
5. Node **555**: Lower ditch invert to 4.60 ft. from 6.21 ft.
6. Node **554.1**: Lower ditch invert to 4.34 ft. from 6.17 ft.
7. Node **554**: Lower ditch invert to 4.00 ft. from 6.16 ft.
8. Node **554.2**: Lower ditch invert to 3.50 ft. from 6.15 ft.
9. Node **566**: Lower ditch invert to 3.50 ft. from 6.14 ft.
10. Node **565**: Lower ditch invert to 3.50 ft. from 6.40 ft.
11. Node **563**: Lower ditch invert to 3.50 ft. from 7.00 ft.
12. Node **708**: Create invert at 3.50 ft.
13. Node **709**: Create invert at 3.30 ft.
14. Node **715**: Lower ditch invert to 2.50 ft. from 5.67 ft.
15. Node **716**: Lower ditch invert to 1.50 ft. from 5.00 ft.
16. Node **717**: Lower ditch invert to 0.80 ft. from 4.70 ft.
17. Node **719**: Lower ditch invert to 0.70 ft. from 4.60 ft.
18. Block flow from southern ditch at node **556**.
19. From Nodes **556** to **555**: Re-grade ditch for positive flow from nodes **556** to **555**.
20. From Nodes **543** to **545**: Replace existing 42-in RCP with 60-in RCP.
21. From Nodes **545** to **546**: Re-grade and widen channel bottom to 10 ft with side slopes equal to 2H:1V.
22. From Nodes **546** to **553**: Re-grade and widen channel bottom to 10 ft with side slopes equal to 2H:1V.
23. From Nodes **553** to **555**: Re-grade and widen channel bottom to 15 ft with side slopes equal to 2H:1V.
24. From Nodes **555** to **554.1**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.

25. From Nodes **554.1** to **554**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
26. From Nodes **554** to **554.2**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
27. From Nodes **554.2** to **566**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
28. From Nodes **566** to **565**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
29. From Nodes **565** to **563**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
30. From Nodes **563** to **708**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
31. From Nodes **708** to **709**: Construct 80 ft. triple 4-ft x 4-ft box culverts.
32. From Nodes **709** to **715**: Construct a trapezoid channel with bottom equal to 20 ft and side slopes equal to 2H:1V.
33. From Nodes **715** to **716**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
34. From Nodes **716** to **717**: Re-grade and widen channel bottom to 20 ft with side slopes equal to 2H:1V.
35. From Nodes **717** to **719**: Re-lay existing 42-in RCPs (guessed size) to new inverts and add one 48-in RCP parallel to existing pipes.
36. From Nodes **719** to **721**: Clean and re-grade channel.
37. From Nodes **582** to **583**: Add one 21-in RCP parallel to existing 21-in RCP.
38. From Nodes **559** to **579**: Clean channel.
39. From Nodes **579** to **581**: Clean channel.
40. From Nodes **584** to **586**: Add one 24-in RCP parallel to existing 18-in RCP.
41. From Nodes **597** to **598**: Add one 18-in RCP parallel to existing 18-in RCP.

Master Drainage Plan Caveat

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.

Contact Information

Mr. Sam Sawan, PE (757.382.6101) served as the project manager for the City of Chesapeake on this project. Mr. Mark Mansfield, Chief Planning and Policy Branch, and Mr. Walter Trinkala, Engineering Technical Specialist (757.201.7610) represented the Corps of Engineers, Norfolk District on the original April 2008 study. Mr. John Paine, PE, PH, CFM was the project manager for URS. The modeling evaluations and report were produced by Hai Tran, EIT and Jeremy Morazo, EIT. QA/QC and production assistance was provided by Stephanie Hood, EIT, Sean Bradberry, and Carol Wilkinson (757.873.0559).