APPENDIX 3

Regional Hydraulic Model Plan

November 17, 2008

Contents

Section 1
Introduction

A Regional Hydraulic Model will be developed, calibrated, verified, and applied to include the following Regional Sanitary Sewer (SS) System components:

- All Hampton Roads Sanitation District (HRSD) interceptor systems, pump stations, and pressure reducing stations
- Locality pump stations and associated force mains where the force mains directly discharge into a HRSD interceptor sewer
- The gravity sewers extending one manhole upstream from each modeled Locality pump station where the force main directly discharges to an HRSD interceptor sewer. (Note that some pump stations may receive discharge from multiple sewers; in these instances, the first upstream manhole on each line will be included.)
- Locality gravity sewers extending one manhole upstream from the point of connection with an HRSD gravity interceptor
- Locality facilities required to include significant Locality Overflow Points as identified in Appendix A

Section 3.2 of this Model Plan provides additional details on the Regional Hydraulic Model extent including the significant Locality Overflow Points to be included in the Regional Hydraulic Model.

The Regional Hydraulic Model developed as described in this Model Plan will be used to evaluate the existing Regional SS System response to dry- and wet-weather flows and potential system improvements as required to support Regional Wet Weather Management Plan (RWWMP) development. The model development goal is to provide a consistent and appropriately accurate Regional Hydraulic Model that realistically represents the modeled Specified Portions of the Regional SS System components at the level of detail and accuracy required to meet HRSD's and the Localities' planning needs.

The following provides an overview of this report:

- Section 2 documents the overall Regional Hydraulic Model objectives and model software capabilities required to support these objectives.
- Section 3 describes the Regional Hydraulic Model development, including the selected simulation software, model configuration and extent, data used to develop the model, Locality coordination, and dry- and wet-weather flow simulation procedures.
- Section 4 documents the Regional Hydraulic Model calibration and verification procedures.

- Section 5 documents the procedures for simulating long-term flows to assess peak-flow recurrence frequencies.
- Section 6 describes the report that will document model development, calibration, and verification.
- Section 7 provides the model development schedule.

Section 2
Model Objectives and Capabilities

The Regional Hydraulic Model will support the following objectives:

- Assess the modeled Specified Portions of the Regional SS System capacity
- Perform alternative evaluations and operation-scenario testing to support RWWMP development, including level-of-service analyses and impacts of peak flow reduction through system rehabilitation
- Test and optimize sewer system design

To fulfill these objectives, the calibrated Regional Hydraulic Model will have the following capabilities:

- Adequately characterize flow rates and pressure (or hydraulic grade line, as appropriate) throughout the HRSD SS System and modeled Specified Portions of the Regional SS System under an appropriate range of dry- and wet-weather conditions
- Adequately simulate the capacities and operating characteristics of all modeled pump stations and pressure reducing stations within the HRSD SS System and modeled Specified Portions of the Regional SS System under an appropriate range of dry- and wet-weather conditions
- Incorporate, interface with, and utilize output from Locality models and other Locality inputs
- Assess the Specified Portions of the Regional SS System conveyance capacity
- Support the analysis of various alternatives and scenarios during RWWMP development
- Perform long-term planning
- Support analysis of development growth and regional facilities that may be required to support this growth
- Support the analysis of force main flow re-routing scenarios

2.1 Model Software Capabilities

The Regional Hydraulic Model software will have the following capabilities:

- Provide a fully dynamic hydraulic solution (model time-varying flows and depths representing the true nature of flow attenuation and translation)
- Produce minimal volume balance errors and numerical instabilities

- Be able to model both gravity (open-channel) and pressurized flows, simultaneously including the measurement of pressures less than atmospheric pressures and siphons
- Provide a stable and robust solution for transitions between gravity and pressurized flows
- Have stable pump controls, including pump curves, switch on/off controls, variable speed pumps, and real-time control capabilities
- Be able to model surcharged manholes with storage of surcharged volume out of manhole lids and/or flow/depth in excess of manhole depth predicted to overflow manholes
- Be able to accept diurnal curves and hydrographs as flow input

Section 3
Model Development

The following sections present the selected modeling software, the model configuration and extent, the data used to develop the model, Locality coordination, and dry- and wet-weather flow simulation procedures.

3.1 Selected Model Software

The dynamic hydraulic sanitary sewer system modeling software to be used in the Regional Hydraulic Model was selected through a collaborative process. Model software selection criteria were identified and the relative importance of each criterion was weighted at model selection workshops attended by HRSD and the Locality representatives. The selection process included detailed technical evaluations and vendor presentations followed by discussion sessions with potential vendors.

DHI MIKE URBAN CS model software (using DHI's MOUSE hydraulic engine - potentially using Version 5 of the EPA Storm Water Management Model (EPA SWMM 5) to simulate hydrology) was selected for the Regional Hydraulic Model. This combination satisfies the software requirements summarized in Section 2.1. The capability to use of EPA SWMM 5 hydrology adds flexibility when coordinating with the Locality models.

HRSD has purchased this software for the Localities, many of which plan to use it to develop their hydraulic models. However, the Localities are not required to use this software as long as the selected software meets the minimum requirements and provides the outputs required for the Regional Model. Successful Regional Hydraulic Model development does not require that the Localities to use the selected software as only flow hydrographs, or the parameters used to generate these hydrographs, will be transferred from the Localities to the Regional Hydraulic Model. The flows can come from any fully dynamic hydraulic sanitary sewer system model that the Locality wishes to use. The selected MIKE URBAN software is configured to be able to use the SWMM wet-weather flow simulation features, making it compatible with many modeling programs. Regardless of the modeling tools adopted by the Localities, HRSD will work closely with all Localities to achieve reliable and compatible results.

3.2 Model Configuration and Extent

This section describes the Regional Hydraulic Model configuration and defines the Regional Hydraulic Model extent.

The Regional Hydraulic Model will include the following facilities:

- HRSD force mains
- HRSD gravity sewers
- HRSD pressure reducing stations

- HRSD pressure control valves
- HRSD pump stations
- Locality terminal pump stations and force mains where the force mains connect directly into HRSD force mains or gravity sewers
- Private terminal pump stations and force mains where the force mains connect to a HRSD interceptor and the flows are significant relative to the capacity of modeled downstream facilities
- Locality gravity sewers to include the first sewer segment and manhole upstream from modeled terminal pump stations
- Locality gravity sewers to include the first sewer segment and manhole upstream from the point of connection to a HRSD gravity sewer
- Locality facilities required to include significant Locality Overflow Points listed in Appendix A. Locality Overflow Points located further upstream within the Locality systems will be addressed in the Locality models.

The Regional Hydraulic Model will be developed as two hydraulically independent models as these systems are not connected: North Shore and South Shore.

3.3 Regional Hydraulic Model Development

The following sections describe hydraulic model input data, data sources, and data validation for the Regional Hydraulic Model.

3.3.1 Hydraulic Model Input Data

Data to be collected and input to the Regional Hydraulic model to represent the modeled portions of the physical SS system are listed below.

Force Main Segments

- Force main segment identifier
- Nominal diameter
- Length
- Upstream and downstream junctions
- Material
- Condition from HRSD's condition assessments
- Location and configuration of valves and other control features that may be operated during normal system operations. The valve configuration is not changed

often or in response to conditions for individual wet-weather flow events. The configuration may change for system maintenance or as system conditions change. HRSD is developing automated procedures to document valve configuration and changes to this configuration. This information will be used to properly configure the models for the calibration and verification. System capacity evaluations will use valve settings representative of standard system operating procedures.

- Age as determined by the year constructed
- Hazen Williams roughness coefficients will initially be developed though procedures that relate the roughness coefficient to the pipe material, age, and condition using values from standard engineering references. These coefficients will be refined as necessary during model calibration and verification, but the calibrated values will remain within the documented expected ranges for the pipe material and estimated condition.

Force Main Junctions

- Force main junction identifier
- Location
- Invert elevation
- Ground elevation

Gravity Sewer Segments

- Gravity sewer segment identifier
- Nominal diameter
- Shape and dimensions (if not circular)
- Length
- Upstream invert elevation
- Downstream invert elevation
- Upstream and downstream manholes
- Material
- Location and configuration of pressure sewers, siphons, and control or diversion structures
- A Mannings roughness coefficient of 0.013 will be used for all gravity sewers as is standard practice for most sewer system modeling and capacity evaluation studies

Gravity Sewer Manholes and Junction Chambers

- Manhole or junction chamber identifier
- Location
- Invert and rim elevation
- Diameter/size
- Location and placement of weirs, gates, orifices, or other control features
- Other pertinent information

Terminal Pump Stations

Pump stations where the force mains deliver wastewater directly an HRSD interceptor are referred to as terminal pump stations. The following data will be collected and input to the model for HRSD and Locality terminal pump stations:

- Terminal pump station identifier and description
- Location
- Wet-well dimensions and shape as required to develop storage volume relationships
- Required net positive suction head. This information will be collected for suction lift pump stations and other pump stations where cavitation due to excessive suction head could be an issue.
- Number of pumps
- Type of pump (suction lift, dry pit, submersible, etc.)
- Type of drive (variable or constant-speed)
- Flow vs. total head pump curves, including maximum-speed and minimum-speed curves for variable-speed pumps
- Pump control logic (wet-well start/stop elevations, set-point elevation). The control logic and set-point elevations for the terminal pump stations are not changed often or in response to conditions for specific wet-weather flow events. The controls may be modified for system maintenance or as system conditions change as noted on the operator logs maintained at the pump stations. These logs will be obtained and reviewed during model calibration and verification if the model cannot represent observed conditions. Capacity evaluations will use pump control logic representative of standard system operating procedures.

- Location and elevation of manhole rim or other feature where an overflow would first occur should the peak flows exceed the pumping capacity or the pump station fail to operate as designed.

Pressure Reducing Stations

Pressure reducing stations reduce the upstream hydraulic grade line elevation. The following data will be collected and input to the model for pressure reducing stations:

- Pressure reducing station identifier and description
- Location
- Number of pumps
- Type of drive (variable or constant-speed)
- Flow vs. total head pump curves, including minimum-speed and maximum-speed curves for variable-speed pumps
- Pump control logic, including on and off elevations and set-point control elevations (or pressures). The control logic and elevations for the pressure reducing stations are not changed often or in response to conditions for specific wet-weather flow events. The controls may be modified for system maintenance or as system conditions change, and these changes will be noted on the operator logs maintained at the pressure reducing stations. These logs will be obtained and reviewed during model calibration and verification if the model cannot represent observed conditions. Capacity evaluations will use pump control logic representative of standard system operating procedures.

Pressure Control Valves

Pressure control valves maintain upstream pressures or hydraulic grade line elevations above a programmed minimum value. The following data will be collected and input to the model for pressure control valves:

- Pressure control valve identifier and description
- Location
- Type of valve and diameter
- Control logic, including location and elevation of control sensor, set-point elevation or pressure, response delay, maximum rate of opening or closing, and minimum and maximum valve opening. The control logic is not changed often or in response to conditions for specific wet-weather flow events. The controls may be modified for system maintenance or as system conditions change, and these changes will be noted on the operator logs. These logs will be obtained and reviewed during model calibration and verification if the model cannot represent observed conditions.

Capacity evaluations will use pressure control valve operating logic representative of standard system operating procedures.

Other Boundary Conditions

Facilities at or near the headworks of sewage treatment plants or wastewater pump stations define the downstream boundary condition elevations for the Regional Hydraulic Model. Record drawings and other available data will be evaluated to identify the appropriate procedures for modeling the downstream boundary conditions to accurately represent the elevation or pressure over the range in expected flows. Treatment plant operation controls are static and do not change in response to conditions for specific wet-weather flow events. The controls may be modified for system maintenance or as conditions change at the plants or in the system, and these changes will be noted on operator logs. These logs will be obtained and reviewed if the model cannot represent observed conditions during calibration and verification.

3.3.2 Data Sources

The following sources will provide hydraulic input data for the Regional Hydraulic Model:

- HRSD and Locality GIS data
- HRSD and Locality record drawings
- HRSD and Locality design drawings
- Field survey data
- Pump station inspections and performance testing

The following provides details on the procedures that HRSD and the Localities are using to generate and review these data for input to the Regional Hydraulic Model and Locality models.

HRSD FORCEMAIN Model

HRSD had a previous model of the major sanitary sewer system that operated in a proprietary software named FORCEMAIN ™. This program is based on the EPANET simulation program. The program runs only in a steady-state configuration, uses simplified assumptions for pump station operation, and is therefore not appropriate for use in the wet weather flow management program. The existing HRSD FORCEMAIN model has been converted to operate in the MIKE URBAN CS software. HRSD will use the original and converted models as interim planning tools until the Regional Hydraulic Model is developed, calibrated, and verified. Data from the converted model will not be used in the Regional Hydraulic Model as it is desirable to build the model from HRSD and Locality GIS data to simplify future updates.

HRSD and Locality GIS Data

HRSD and many Localities had gravity and pressure sewer GIS data before Regional Model development began. However, the existing GIS data accuracy is uncertain and the data sources are not documented. In many cases, these data sets did not contain all data attributes necessary for model development.

HRSD has created a new GIS that includes force mains, pump stations, and gravity sewers to be used in model development. Similarly, the Localities are creating or modifying their collection system GIS data. Procedures will be implemented to allow the model to be updated as modifications and additions are made to the HRSD and Locality GIS data.

The following sections document the procedures used by HRSD and the Localities to collect the data for the major modeled system components.

Force Main Data

HRSD force main data were obtained from HRSD construction record drawings. The force main attributes, location of valves, T-connections, and elevations from the record drawings accurately describe the system. HRSD also used pump station and pressure reducing station record drawings to obtain accurate and detailed force main data near these stations. HRSD will perform quality control checks on these data before they are used to build the Regional Hydraulic Model.

HRSD will be surveying the force main elevations at selected locations through several ongoing programs:

- Elevations will be obtained where Flow, Pressure, and Rainfall (FPR) Monitoring Plan flow meters and pressure sensors are being installed. The force main diameter will also be confirmed during meter installation.
- Elevations will be surveyed where the force mains enter and exit pressure reducing stations.
- Elevations will be surveyed at pressure control valves.

The surveyed information will be used to verify the vertical datum referenced in the record drawings and, where necessary, make wholesale adjustments to correct the elevation data from the record drawings to a standard model vertical datum (NAVD 88).

The data collection accurately describes the existing Specified Portions of the Regional SS System. It should be noted that the force main elevations are not critical to model development as the system is pressurized. Small discrepancies in force main elevations will not affect modeled hydraulic grade line elevations or system capacity.

Gravity Sewers
HRSD has obtained the services of licensed surveying firms to obtain manhole rim elevation, manhole invert elevation, pipe invert elevation, diameter, location, and other data for all HRSD operated and maintained gravity sewers.

Pump Station Information
Wet well geometry, pump information, pump curves and other information required to simulate HRSD terminal and pressure reducing pump stations have been obtained from construction record drawings and other digital data. HRSD has contracted with surveying firms to obtain accurate elevation data at all its pump stations (e.g., slab elevations, pump centerline elevations, wet well inverts) to the selected NAVD 88 model vertical datum. These data will be used to adjust, where necessary, elevation data obtained from the record drawings.

As part of a program to document the condition of all HRSD pump stations, additional data required to model the stations are being obtained and/or verified. Pump operation levels and controls will be obtained through these field inspections and pump drawdown tests. Minimum and maximum pump speeds will be documented.

Pressure Control Valves
Valve, force main, and pressure sensor elevations will be surveyed to the model datum. Specific valve operation control levels and logic will be documented through field visits and from HRSD system operations.

System Boundary Conditions
The appropriate model outlet boundary condition at the nine sewage treatment plants will be obtained from record drawings and verified through meetings with plant operations staff. Control structures will be surveyed to correct record drawing elevations to the model datum and to obtain the elevations where the primary control features are adjustable (e.g. movable weirs).

Locality Data
The Localities are undertaking similar procedures to that described above to collect data on the portions of these systems included in the Regional Hydraulic Model. The extensive coordination between HRSD and the Localities related to the Regional Hydraulic Model development is described in Section 3.4.

3.3.3 Data Accuracy and Validation

As discussed above, much of the model data will have been obtained recently by HRSD and the Localities specifically to support model development. These data will be obtained from record drawings, field inspections, and survey. Data attributes obtained from more than once source will be crosschecked, and differences will be resolved.

An extensive effort has gone into making the data sources as accurate as required because the Regional Hydraulic Model will be used to evaluate system capacity and improvement alternatives in the RWWMP development. These data also form the basis for HRSD's and the Localities' geographic information systems and will be used to develop the Locality hydraulic models as required under the Virginia Department of Environmental Quality (VDEQ) Special Order by Consent (SOC).

HRSD and the Localities will have performed quality control checks on these data before they are used for model development. Additional standard modeling and engineering validations and quality control checks will be performed on data entered into the Regional Hydraulic Model:

- Analyze critical model parameters (elevations, slopes, diameters, pipe invert offsets, conduit length, and manhole diameter) to identify, review, and correct low and high outliers where appropriate

- Compare conduit length with that computed from the locations of the end nodes and correct those that differ by a significant amount (e.g., more than 10 percent) where appropriate

- Check that gravity sewer crown is below ground level

- Review gravity mains with negative or small slopes

- Identify and review locations where a gravity sewer flows into a sewer with a smaller diameter

- Review profile plots of force main and gravity sewer segments to identify data that appears to be in error through comparison of data for upstream and downstream components

- Review hydraulic grade line slope and velocities during model calibration and verification to identify high and low outliers; review model data to identify the cause of the anomalies, and adjust when necessary system data

- Compare selected data values where appropriate with standard or expected values as listed in Table 3-1, and verify those found to be outside these ranges. HRSD may refine these parameters and standard values during model development.

Table 3-1
Expected and Standard Values for Selected Model Parameters

	North Shore Model		South Shore Model	
Parameter	Force Mains	Gravity Sewers	Force Mains	Gravity Sewers
Maximum Segment Length (Feet)	3,000	500	3,000	500
Minimum Segment Length (Feet) *	1	3	1	3
Maximum Pipe Diameter (Inches)	48	54	54	30
Minimum Pipe Diameter (Inches)	2	8	2	6
Maximum Pipe Slope (Percent)	55%	20%	15%	20%
Minimum Pipe Slope (Percent)	0%	0.013%	0%	0.013%
Maximum Invert Elevation (Feet)	125	30	80	55
Minimum Invert Elevation (Feet)	-15	-15	-15	-15
Hazen Williams (Force mains) and Mannings (Gravity Sewers) Roughness Coefficients**	80 - 145	0.013	80 - 145	0.013

* - To improve model stability and increase simulation time steps, short sewer segments will be combined with adjacent facilities where appropriate or lengthened with appropriate adjustments to roughness coefficients. The minimum pipe length desired for the Regional Hydraulic Model is approximately 30 feet.

** - Hazen Williams Roughness values will initially be set based on material and age using standard engineering references and adjusted as appropriate. Calibrated values will not be outside the ranges specified. Mannings roughness coefficient will be set to 0.013 for all sewers as is standard practice for sanitary sewer modeling and capacity evaluation studies.

The degree of data validation and verification will be targeted towards meeting Regional Hydraulic Model objectives and capabilities described in Section 2. These efforts recognize that the Regional Hydraulic Model will not be an exact representation of the existing Specified Portions of the Regional SS System but needs both to adequately simulate flows and hydraulic grade line elevations for a range in flow rates and to adequately simulate system capacity and operation. Model results are more sensitive to some system data than others. For example, nominal pipe diameter is critical to represent system conveyance capacity, whereas force main elevations are of lesser importance. Data validation and collection will focus on accurately representing the system within accepted tolerances where capacity concerns are found. Less emphasis will be placed on portions found to have sufficient capacity.

In summary, the data will be collected using force main and pump station record drawings that accurately describe the constructed facilities. Additional data will be obtained through pump station inspections and surveys. Much of the data will have been field verified. As a result, all data most critical to accurate model development will be obtained from a highly accurate data source and/or from direct field observations. Various quality control checks and crosschecks will ensure that the model's data accurately represent the existing Specified Portions of the Regional SS System.

3.4 Locality Coordination

HRSD and the Localities continue to work collaboratively towards meeting all VDEQ SOC requirements including Regional Hydraulic and Locality hydraulic model development to adequately evaluate system capacity and response to wet-weather flows and develop system improvement options to address potential capacity concerns for the appropriate level of service during RWWMP development.

HRSD has developed and maintained open communications with the Localities and collaborated with them in major decisions. Throughout this process, HRSD will provide technical guidance and review to ensure that the Hampton Roads Regional Wet Weather Management Program meets all regulatory requirements and deadlines. The following further describes the coordination of hydraulic model development and other issues by HRSD and the Localities:

1. Model software selection was a collaborative effort between HRSD and the Localities. Several model selection workshops were held in which HRSD and the Localities identified model selection criteria and weighting factors for software evaluation. Together, HRSD and the Localities selected a short-list of software vendors, attended vendor demonstrations, and voted on the selected software based on the evaluation criteria and weightings.

2. A Capacity Team that includes members from the Localities and HRSD meets regularly to discuss various issues related to the Regional Wet Weather Management Program.

3. Locality coordination meetings are held at least quarterly in which the agenda includes various wet-weather program activities, including regional and Locality hydraulic model development, data collection, information sharing, and communications. These meetings provide the primary forum for coordinating Regional Hydraulic Model data needs, data collection procedures, and processes to deliver the data to HRSD.

4. A Regional GIS Users Group has been coordinated that meets approximately quarterly to discuss and present ongoing programs related to the GIS systems being developed by HRSD and the Localities, including GIS programs that support the Regional Hydraulic Model.

5. A Regional Hydraulic Model Users Group that includes modelers and technical staff from the Localities and their consultants first met on September 17, 2008. This group will meet approximately monthly (as agreed to by the members) to coordinate and discuss detailed technical issues and procedures for model development, calibration, verification, and application. Training in specific aspects of model development, wet- and dry-weather flow procedures, flow data analysis, and other issues will be conducted through this group.

6. Through the above forums, and if needed, other meetings, HRSD and the Localities will continue to coordinate critical technical procedures, including flow data analysis, wet- and dry-weather flow modeling, interfacing the Regional Hydraulic Model and Locality models, model calibration, model verification, long-term flow simulations, peak flow frequency, identification of representative design storms, capacity analyses, and RWWMP development.

7. HRSD has purchased one copy of the MIKE URBAN CS software for each Locality and VDEQ. While MIKE URBAN CS has been selected for the Regional Hydraulic Model, the Localities may use other appropriate dynamic hydraulic modeling software that meets the requirements described in Section 2.

8. VDEQ staff have attended model selection, Locality coordination, GIS User Group, and Hydraulic Model Users Group meetings.

9. HRSD will brief EPA and VDEQ at appropriate intervals. One such meeting was held on September 4, 2008. It is anticipated that the next briefing will be in first quarter of 2009.

10. In April 2008, HRSD provided the Localities a document that describes the Locality Requirements for Sanitary Sewer System Facility Data. This report describes the data required to be developed and delivered by the Localities to support the Regional Hydraulic Model, including datums, accuracy requirements, and schedule. An ESRI geodatabase template was provided to the Localities to deliver these data to HRSD in a uniform and consistent

format. HRSD will share its system data with the Localities using same geodatabase format.

11. HRSD and the Localities are sharing other GIS information beyond that required for Regional Hydraulic Model development to support other wet-weather flow management activities.

12. HRSD and the Localities will ensure dry-weather flow estimating procedures and methodologies used by the Localities are compatible with the Regional Hydraulic Model. These results will be documented by the Localities in a Flow Evaluation Report, which will be reviewed by HRSD. The flows, or parameters used to compute these flows, will be transmitted to HRSD and included in the Regional Hydraulic Model. HRSD will work collaboratively with the Localities as necessary to adjust these flows during model calibration and verification.

13. HRSD and the Localities will ensure that the wet-weather flow simulation methodologies are compatible with the Regional Hydraulic Model. These results will be documented by the Localities in a Flow Evaluation Report, which will be reviewed by HRSD. The flows, or parameters used to compute these flows, will be transmitted to HRSD and included in the Regional Hydraulic Model. HRSD will work collaboratively with the Localities as necessary to adjust these flows to achieve model calibration and verification.

3.5 Locality Dry-weather Flows

3.5.1 Model Subbasins

Subbasins will be developed to include the areas served by the modeled Regional SS System. These will often represent the terminal pump station service areas or other connection points and will form the basis for developing dry- and wet-weather flows for input into the modeled system. Analyses will provide consistent subbasin sewered area estimates that exclude large unsewered areas.

3.5.2 Locality Dry-weather Flows

Dry-weather flows will be estimated for model subbasins. A primary source of dry-weather flows will be the flow metering performed by the Localities as described in flow monitoring plans submitted to the VDEQ in December 2007. The following general procedures will be used to develop and validate the dry-weather flows:

- The Localities are monitoring flows at many locations within their systems during 2008 as required in the VDEQ SOC.

- The Localities will evaluate the flow data to estimate average dry-weather flow, dry-weather infiltration, base sewage flow, and dry-weather flow diurnal hydrographs. HRSD will coordinate with the Localities such that the procedures meet the Regional Hydraulic Model development needs. The EPA Sanitary Sewer Overflow Analysis and Planning (SSOAP) Toolbox (“Computer Tools for Sanitary

Sewer System Capacity Analysis and Planning, U.S. EPA, October 2007"), Sliicer.com™ by ADS Environmental Services, or similar programs will be used to analyze flow data for dry-weather flow characteristics.

- The Localities will develop flow estimates at Regional Hydraulic Model connection points. This will require that flows be estimated for unmetered basins. Again, HRSD and the Localities will coordinate on the appropriate procedures.
- The Localities will document the dry-weather flow characteristics for monitored and unmonitored basins in a Flow Evaluation Report. HRSD will review and comment on these reports.
- HRSD will provide a flow data delivery template and requirements report to the Localities to ease data transfers from the Localities to the Regional Hydraulic Model.
- Results from simulations using the Locality-provided dry-weather flows will be calibrated and verified to flow and pressure data collected within the Specified Portions of the Regional SS System under the FPR Monitoring Plan. This calibration provides efficient and independent Locality dry-weather flow data validation through direct comparisons with the FPR Monitoring Plan data. HRSD will coordinate with the Localities to modify dry-weather flow estimates to calibrate and verify the model.

3.6 Locality Wet-weather Flows

3.6.1 Wet-weather Flow Simulation Procedures

Three general methods are suitable to simulate wet-weather flows from rainfall in the Locality and Regional Hydraulic models:

- Synthetic unit hydrograph
- Rainfall/flow regression
- Hydrologic methods

HRSD has evaluated the available approaches in collaboration with the Localities and has identified the following two as best for Regional Hydraulic Model development and application.

RTK Triangular-shaped Synthetic Unit Hydrograph with SWMM Groundwater Routines

This method uses up to three triangular-shaped unit hydrographs to represent wet-weather flows from rainfall. The shape of each unit hydrograph is defined by three parameters:

- R - The ratio of the wet weather flow volume to the rainfall volume

- T – The time required for flows to increase from zero to the peak flow
- K – Defines the time required for flows to decline from the peak flow back to zero (The time from peak flow to zero flow equals T times K)

The rainfall is applied to the unit hydrographs to generate wet-weather flows. This method is contained in the SWMM 5 modeling program.

This method will be coupled with the SWMM groundwater simulation routines to represent the long-term variation in dry-weather infiltration when performing long-term simulations.

Hydrologic Method Using Calibrated HSPF Model

This method relates wet-weather flows in the sanitary sewers to those generated by a calibrated Hydrologic Simulation Program FORTRAN (HSPF) model. This procedure would use Chesapeake Bay Community Watershed Phase 5 HSPF models prepared through the Chesapeake Community Modeling Program.

HSPF simulates four components of stream flow from rainfall:

- Impervious land surface runoff (ISURO) is the rapid stream flow response produced by rain on impervious surfaces.
- Pervious land surface runoff (PSURO) is stream flow response produced by rain on pervious land.
- Pervious land interflow groundwater (PIFWO) represents rainfall that infiltrates into the shallow groundwater and then flows laterally into the stream.
- Pervious land active groundwater (PAGWO) represents rainfall that infiltrates into the deeper groundwater and then enters the stream as base flow.

To simulate wet-weather flows in sewers, linear factors are applied to relate these factors to wet-weather sanitary sewer flows using an equation similar to the following:

$$Q = ISURO * A + PSURO * B + PIFWO * C + PAGWO * D$$

A, B, C, and D are parameters calibrated to represent observed wet-weather flows. This method is applied by first running the calibrated HSPF models for the desired location with observed rainfall and then computing wet-weather flows by applying the calibration factors.

Selection of Wet-weather Flow Simulation Procedures

HRSD and several Localities have tested both methods using flow and rainfall monitoring from Virginia Beach, Suffolk, Newport News, and two HRSD wastewater treatment plants. These evaluations show that the two procedures provide similar results in simulating peak flows and volumes when calibrated and verified to a short duration of observed flows. The HSPF hydrologic method has advantages when calibrated to the several years of data available at the HRSD wastewater treatment plants. The RTK unit hydrograph method has advantages because it has been widely applied in many sanitary sewer overflow studies and requires less effort to apply. The Localities can use either method since the Regional Hydraulic Model can be set up to accommodate both methods. HRSD will provide technical guidance and tools for both methods.

3.6.2 Locality Wet-weather Flows

The following general procedures will be used to develop and validate the wet-weather flows:

- The Localities are monitoring flows at many locations during 2008 as required in the VDEQ SOC.
- The Localities will evaluate the flow data to estimate model parameters to simulate wet-weather flows from observed rainfall. These will either be RTK unit hydrograph parameters or the parameters that related HSPF model results to wet-weather flows. HRSD will coordinate with the Localities such that the procedures meet the Regional Hydraulic Model development needs. The EPA's SSOAP Toolbox, Sliicer.com™ by ADS Environmental Services, or similar programs will be used to analyze flow data for wet-weather flow characteristics.
- The Localities will develop flow estimates at Regional Hydraulic Model connection points. This will require that flows be estimated for unmetered basins. Again, HRSD and the Localities will coordinate on the appropriate procedures.
- The Localities will document the wet-weather flow characteristics for monitored and unmonitored basins in a Flow Evaluation Report. HRSD will review and comment on these reports.
- HRSD will provide a flow data delivery template and requirements report to the Localities to ease data transfers from the Localities to the Regional Hydraulic Model.
- The Regional Hydraulic Model will be calibrated and verified to flow and pressure data collected within the Specified Portions of the Regional SS System under the FPR Monitoring Plan. Due primarily to the time required to install the flow meters, the FPR Monitoring Plan calibration period is after the Locality monitoring is complete. The wet-weather flow simulation parameters developed by the Localities will be applied to radar-derived rainfall observed during selected calibration and verification events. The results of hydraulic model simulations using these estimated wet-weather flows will be compared with FPR Monitoring Plan flow and pressure data collected within the Specified Portions of the Regional SS System. This procedure will provide an efficient evaluation of flows generated by the wet-

weather flow model parameters through direct comparisons with the flow data collected within the HRSD system. HRSD will coordinate with the Localities to collaboratively modify wet-weather flow parameters to calibrate and verify the Regional Hydraulic Model.

Section 4
Model Calibration and Verification

This section describes the Regional Hydraulic Model calibration and verification procedures and protocols.

FPR Monitoring Plan flow, pressure, and rainfall monitoring document conditions within the Regional SS System. These data, after being subjected to quality assurance procedures, will be compared to the modeled response during model calibration and verification. The Locality dry- and wet-weather modeling parameters will determine the flows into the Regional Hydraulic Model, whereas the FPR Monitoring Plan data will be used to evaluate the hydraulic model's ability to simulate the modeled system's response to these flows. In this manner, the model calibration provides a direct validation of the Locality flows.

HRSD has identified 50 to 60 primary FPR Monitoring Plan flow and pressure calibration sites. These sites were selected to compare simulated pressures and flows at key points in the system to ensure overall model calibration. HRSD may delete these sites and/or select additional sites depending on data quality to further validate the model's ability to simulate observed system performance.

The model will first be calibrated to dry-weather flows and then calibrated and verified to wet-weather flows, as described in the following sections. Model input parameters will be adjusted within acceptable limits to meet the model calibration criteria.

4.1 Dry-Weather Flow Calibration

The following dry-weather flow calibration criteria will be applied for at least two dry-weather days occurring during the FPR Monitoring Plan program.

- The simulated hydrograph should match the general observed hydrograph shape.
- The simulated time of peaks and troughs will be within 1 hour of the observed data.
- The simulated peak flow will be within 10 percent of observed flow.
- The simulated flow volume over 24 hours will be within 10 percent of observed flow.

Average dry-weather flow data for input to the model will be provided by the Localities. However, dry-weather flows vary in response to dry-weather infiltration and water consumption. The flow monitoring data will be reviewed to identify periods where flows are approximately equal to the average dry-weather flows for comparison with model results.

4.2 Wet-Weather Flow Calibration

Accurate simulation of wet-weather flows and the system response to these flows are essential for evaluating conveyance system capacity and developing the RWWMP. Accurate and documented model wet-weather flow calibration and verification are key to gaining RWWMP acceptance.

The Regional Hydraulic Model will be calibrated to a minimum of two wet-weather events and verified to a single independent event. These events will be selected to address the intended model use, which is to evaluate the system response and capacity for wet weather events. Rainfall data will be evaluated to identify events that produced significant rainfall over the model area and to determine the rainfall return period for various durations. Storms that have the desired return period for durations of interest will be initially selected. Storms that produced significant power outages or other abnormal conditions that would prevent model calibration will not be used. Different storms may be used for the North Shore and South Shore models. Radar rainfall estimates will be obtained and used for the model calibration and verification.

The following wet-weather flow calibration criteria will be applied:

- Simulated time of peaks and troughs will be within one hour of the observed flow.
- Simulated peak-flow rates will be within -15 percent and +25 percent of the observed peak.
- Simulated wet-weather event volume will be within +20 percent and -10 percent of the observed volume.
- Simulated pump discharge pressure will be within 10 percent of observed pressures.
- Simulated surcharge depth in manholes or other structures will be within +1.5 feet and -0.3 foot of the observed depth.
- Simulated non-surcharged water surface elevations will be within 0.3 foot of the observed depth.
- Simulated and observed hydrographs will have the same general shape.

Other information may be used to assess the calibrated model validity, including documented overflow locations and volumes, terminal pump station performance, pressure reducing station performance, and sewage treatment plant performance and flow data.

The model development team will review cases in which calibration criteria cannot be met without adjusting parameters beyond acceptable ranges. Possible causes, including sediment accumulations in pipes, partially closed valves, pumps not operating as designed, excessive air entrainment, or inaccurate input data, will be evaluated and identified. Field investigations may be performed to further evaluate calibration anomalies. In some cases, additional flow and rainfall monitoring data may be used to assist in this effort. Unresolved discrepancies will be documented, and their impact on model applications will be assessed.

4.3 Wet-Weather Flow Verification

The response for the calibrated model will be verified to observed flow and pressure data for at least one event not used in the model calibration. The calibrated model parameters will not be changed for model verification. The wet-weather flow calibration criteria also apply to verification.

The model development team will review cases where verification criteria cannot be met without adjusting parameters beyond acceptable ranges. Unresolved discrepancies will be documented, and their impact on model applications will be assessed.

Section 5
Long-term Flow Simulations

This section documents procedures for simulating long-term flows to assess peak-flow recurrence frequencies.

Minimum peak-flow scenarios will be determined using a peak sewer flow return frequency approach rather than a rainfall return frequency approach. The peak-flow return frequency approach is more direct and accurate because it does not rely on assumptions about the relationship between the recurrence interval of the rainfall and the resulting simulated peak flow.

The calibrated and verified Regional Hydraulic Model will be applied to generate a synthetic long-term flow hydrograph at points-of-interest using representative hourly long-term rainfall records.

Initial evaluations of long-term sewage treatment plant flow data indicate that dry-weather infiltration vary significantly and may affect overall system performance. The long-term simulations will include these variations. The relatively short Locality flow monitoring period will not allow a comprehensive calibration of dry-weather infiltration modeling parameters. The following documents the procedures for long-term simulation of dry-weather flows:

- Where synthetic RTK unit hydrograph procedures are used, SWMM 5 groundwater simulation parameters will be calibrated to represent the long-term observed sewage treatment plant flows. These model parameters will then be allocated to the model subbasins for use in the long-term simulation.

- The HSPF model pervious land active groundwater (PAGWO) represents rainfall that infiltrates into the deeper groundwater and enters the stream as base flow, and therefore represents the dry-weather flow variation. However, the calibration to the relatively short Locality monitoring data may not accurately represent long-term flow characteristics. Model parameters will be evaluated against long-term flow data at the sewage treatment plants and adjusted in collaboration with the Localities as necessary before being used in the long-term flow simulations.

Since the peak flows from model subbasins are the primary concern for this analysis, the long-term simulations will be performed with only the hydrologic models. With this approach, approximately 60 years of rainfall data will be applied to the calibrated hydrologic model to generate a long-term flow record that will be analyzed to provide statistically accurate estimates of 2-, 5-, and 10-year peak flows. It simply will not be possible to perform 60-year duration simulations using the large and complex MIKE URBAN CS MOUSE hydraulic model.

The specific application procedures are not defined and will be developed collaboratively by HRSD and the Localities. While it will be possible to determine the flow frequency for the more than 1,000 connection points to the Regional Hydraulic

Model, it will likely be appropriate to group these connection points into regions in the final analysis.

5.1 Historical Precipitation Records

A long-term record of hourly rainfall data is necessary to prepare the simulated flow records. Norfolk International Airport has digital hourly rainfall data from August 1948 through the present. Reviews indicate these data are mostly complete.

Newport News/Williamsburg International Airport has digital hourly data starting in 2001 and daily data starting in 1948. Other National Oceanic and Atmospheric Administration rainfall gauges in the area have only daily data, which are of limited use in the long-term simulations.

Based on these reviews, the 60 years of hourly data for Norfolk Airport will be used for the long-term hydrologic simulations for both the North Shore and South Shore models.

5.2 Minimum Peak-flow Events

Probabilistic analysis will be used to establish peak flows for selected peak-flow recurrence frequency (2-, 5-, and 10-year, at a minimum) using the simulated wastewater flows for selected locations or regions.

The long-term simulations and statistical analysis provides peak flows with the defined recurrence interval. It is not appropriate to enter these values directly into the model for the following reasons:

- The peak flows typically occur over a short duration.
- Differences in basin size and inflow and infiltration characteristics cause peak flows to occur at different times and therefore not coincide.
- Regional SS System response to wet-weather flows is expected to be complex such that peak flow timing differences between basins close to sewage treatment plants and those far away may be important.

HRSD expects it will be necessary to identify historical rainfall events that generate the peak flows of interest. This work will not be performed during model development, calibration, and verification but will be performed in the initial stages of the capacity analysis and RWWMP development. Though specific details will not be finalized until after model development, we expect rainfall record and synthetic flow data will be analyzed to identify a suite of observed rainfall events that generate peak flows of interest. These rainfall events will be used in the Regional Hydraulic Model to evaluate system operation and potential system improvements.

HRSD and the Localities will coordinate to identify the specific analyses to be performed to select the rainfall events. The selection will consider both peak flows and flow volumes. It will also recognize that events appropriate when evaluating the capacity of small-diameter Locality systems may differ from the events appropriate to evaluate the response of major Specified Portions of the Regional SS System components.

Section 6
Regional Hydraulic Model Documentation

The Regional Hydraulic Model Report will document the following aspects of model development, calibration, and verification:

- Project definition and purpose
- Data description, sources, and reliability
- Assumptions and simplifications
- Naming conventions for manholes, pipes, structures, etc.
- Flow estimation methodology
- Calibration records, including initial parameter assumptions and justifications for parameter adjustments
- Regional Hydraulic Model extents
- Attribute and model input data sources and validity
- Model integration with Locality system models
- Calibration results, including graphical displays of HRSD SS System flows, hydraulic grade lines, and pressure values
- Metrics indicating the Regional Hydraulic Model's compliance with verification standards
- Graphs comparing predicted to observed flow and pressure for calibration and verification events
- Comments on the model's suitability for the intended use, specifically where the model response does not meet one or more verification criteria
- Model limitations

Section 7
Regional Hydraulic Model Development Schedule

Collection and analysis of data from the FPR Monitoring System is the critical path item for calibration and verification of the Regional Hydraulic Model. As presented in the FPR Monitoring Plan, installation of this network is expected to be complete in January 2010. HRSD plans to use the initial 6 months of data collected to perform an initial model calibration. This initial calibration will be provided in a report to VDEQ and EPA by November 30, 2010. HRSD would then complete the 12 months of data collection through January 2011 and complete the Regional Hydraulic Model calibration. These results will be summarized in a Model Report which will be submitted to VDEQ and EPA by July 31, 2011.

Appendix A

Locality Overflow Points to be Included in the Regional Hydraulic Model

Appendix A
Locality Overflow Points for Inclusion in the
Regional Hydraulic Model
November 13, 2008

Locality Overflow Number	**Locality**
2	Suffolk
22	Chesapeake
23	Chesapeake
30	Williamsburg
35	Portsmouth
49	James City
51	Poquoson
53	Suffolk
57	James City
58	James City
65	Portsmouth
66	Portsmouth
70	Williamsburg
72	Portsmouth
76	Hampton
84	Chesapeake
85	Chesapeake

1436 Air Rail Avenue
Virginia Beach, VA 23455
(757) 460-2261

Regional Hydraulic Model Plan
Addendum No. 1

April 15, 2009

Regional Hydraulic Model Plan Addendum No. 1

1. Introduction

This Addendum No. 1 to the Hampton Roads Sanitation District (HRSD) Regional Hydraulic Model Plan (last submitted on November 17, 2008) addresses the comments submitted by e-mail by Mr. Mark Zolandz on February 25, 2009.

2. Question Regarding Flow Parameters

> *In Section 3.1 Paragraph 3, HRSD states that Localities will transfer "flow hydrographs, or the parameters used to generate these hydrographs" to the model. HRSD should provide a more detailed discussion about why provision of "model parameters" by the Localities would allow HRSD to exactly replicate the hydrographs that the Locality itself would generate. This discussion should include access to and use of the same rainfall record, access to all of each Locality's system attribute data, the "parameters" in question and how the model uses them to generate flow data.*

The Localities are providing the dry and wet weather flow parameters needed to fully describe the flows at the Regional Hydraulic Model (RHM) loading points. Since HRSD and the Localities are using the same simulation software, the flow hydrographs generated in the RHM are exact duplications of the flow hydrographs that the Locality itself would generate.

The Localities calibrated their models to events observed during 2008 and those records will be part of the Flow Evaluation Report Submittal to VDEQ on May 26, 2009. The RHM will be calibrated to events that occurred in the 2010 monitoring period using data collected under the HRSD Flow, Pressure, and Rainfall (FPR) monitoring program. HRSD will calibrate and verify events using radar data collected during the period for RHM calibration and verification. The radar data will be calibrated using HRSD's rainfall gauge network.

HRSD has been collecting attribute data for the portions of the Localities systems that are in the RHM in a database format. These data are being checked as they are delivered as part of the RHM development process.

The Locality-provided flow parameters will be used in combination with this radar rainfall data to estimate the flows entering the RHM. Calibration to the FPR data will verify that the flows are accurate. Throughout model calibration, HRSD and the Localities will coordinate parameter adjustments and similar adjustments will be made to the Locality models and the RHM.

HRSD supplied a Locality Flow Parameter Database template for the Localities to use to transmit their flow parameters to HRSD. This database will be used to update the RHM as the Localities update these parameters.

HRSD also provided the Localities a RHM Dry Weather and Wet Weather Flow Parameters Report that documents the parameters required to simulate the flow hydrographs directly.

Dry weather parameters include:

- Existing Dry Weather Average Daily Flow
- Existing Average Daily Base Sewage Flow
- Dry Weather Infiltration
- Existing Average Daily Base Sewage Flow During Peak Season (where applicable)
- Time Period Corresponding to Peak Base Sewage Flow
- Weekday and Weekend Diurnal Hydrograph Patterns

The hydrologic model applies the average dry weather flow to the weekday/ weekend diurnal hydrograph patterns to simulate the dry weather flows in the RHM.

Parameters will be provided for one of the two recommended wet weather flow models (RTK and HSPF). The parameters associated with these models are identified below.

RTK Triangular Shaped Unit Hydrograph Model

The RTK triangular shaped unit hydrograph wet weather flow model uses as many as three triangular-shaped unit hydrographs to represent wet weather flows from rainfall. The shape of each unit hydrograph is defined by three parameters:

- **R** - Ratio of wet weather flow volume to rainfall volume
- **T** – Time in hours required for flows to increase from zero to the peak flow
- **K** – Recession ratio required for flows to decline from the peak flow back to zero (the time from peak flow to zero flow equals T times K)

Nine parameters comprise the model parameters representing the R, T and K values for the three unit hydrographs: R1, T1, K1, R2, T2, K2, R3, T3 and K3.

R and K do not have units; T has units of hours.

The maximum initial abstraction corresponds to the maximum depth of rainfall that can occur over the catchment without producing a flow response. The initial abstraction recovery rate describes the recovery of the initial abstraction during a dry weather period. The model parameters are calibrated to observed flow and rainfall data.

The hydrologic model applies the unit hydrograph to the observed rainfall to simulate the wet weather flows. The wet weather flows are then added to the dry weather flows to generate the total flow.

HSPF Model

The HSPF Model relates wet weather flows in the sanitary sewers to those generated by a calibrated Hydrologic Simulation Program FORTRAN (HSPF) model. For the RHM, Chesapeake Bay Community Watershed Phase 5 (CBCWP5) HSPF model datasets prepared through the Chesapeake Community Modeling Program are used to generate simulated flows from observed rainfall. The HSPF model outputs four flow components:

- Impervious land surface runoff (ISURO): The rapid flow response produced by rain on impervious surface
- Pervious land surface runoff (PSURO): The flow response produced by rain on pervious land
- Pervious land interflow groundwater (PIFWO): Rainfall that infiltrates into the shallow groundwater and then flows laterally into the sewer
- Pervious land active groundwater (PAGWO): Rainfall that infiltrates into the deeper groundwater and then enters the sewer

To simulate wet weather flows in sanitary sewers, four factors relate the HSPF output flows to wet weather sanitary sewer flow (Q):

Q = ISURO * AC_ISRUO + PSURO * AC_PSURO + PIFWO * AC_PIFWO + PAGWO * AC_PAGWO

AC_ISURO, AC_PSURO, AC_PIFWO, and AC_PAGWO are the watershed area in acres that contribute each of the flow components to the sanitary sewer and are calibrated using observed flow and rainfall data. The above equation is applied to convert the HSPF flows to wet weather flows using conversion factors to convert from acre-inches per hour to the appropriate flow units for input to the model. The wet weather flows are added to the dry weather flows to generate the total flow.

3. Question Regarding Seasonal Variability

In Section 3.5.2, HRSD describes how it will estimate dry weather flows for the model. HRSD should provide more specificity of how it intends to ensure that seasonal variability is taken into account when looking at long-term flow recurrence, as was explained to EPA at the meeting on 2/3. For example, HRSD should note its intent to conservatively use "in-season" dry weather flow rates for tourist areas, and high-groundwater season baseline flows for other areas.

The Localities are providing both average annual and peak season base sewage flow in tourist areas and other areas where seasonality is observed. The appropriate values will be used during model calibration. Peak season base sewage flows will be used during capacity evaluations.

HRSD will calibrate SWMM groundwater model parameters and HSPF PAGWO parameters to simulate groundwater infiltration flows using flow monitoring data from the nine HRSD sewage treatment plants from 2000 through 2008 and regional rainfall data. The sewage treatment plants provide the only comprehensive long-term flow data for the HRSD system.

The groundwater models will be used in the long-term simulations to determine the peak flow events of interest and to select the rainfall events to be used to simulate these peak flows, as described in Section 5 of the Regional Hydraulic Model Plan. Event selection will consider the appropriate combination of peak wet weather flows, wet weather flow response volumes, groundwater infiltration, and base sewage flows to generate flow commensurate with the peak flow events of interest to be evaluated.

1436 Air Rail Avenue
Virginia Beach, VA 23455
(757) 460-2261