

Appendix E – Watershed Modeling Procedure

The Difficult Run hydraulic and hydrologic are simulated by using two models: SWMM and HECRAS. SWMM is used to estimate flows and pollutant loads for each one of the 202 catchments (over 58 square miles in total) through over 83 miles of channels connected at 314 nodes and through over 300 on site BMPs. Flows from SWMM are used in the HECRAS model to simulate the routing of the stream flow, through the 83 miles of channel plus 90 hydraulic crossing structures. A description of the procedures that are used setting up both models follows.

The hydrologic, hydraulic, and water quality modeling for Difficult Run is performed to reproduce the current conditions and to estimate the planned conditions of future development. The County of Fairfax Department of Public Works and Environmental Services Stormwater Planning Division provided *Technical Memorandum No. 3, Stormwater Model and GIS Interface Guidelines*, June 2003 that were followed in the SWMM setup process. Water quality modeling is based on the report prepared by AMEC Earth & Environmental, Inc. and Limno-Tech, Inc., *Development of SWMM Water Quality Model Inputs for Fairfax County, Virginia*, March 2004. The objectives of both the present and the future conditions models are to evaluate the following:

- Existing conditions in the watershed,
- Impacts of development projected to occur in the watershed,
- The benefits provided by various stormwater management measures,
- Stream crossing flooding and improvements,
- Overall benefits of alternative watershed management planning alternatives.

HYDROLOGIC MODEL DEVELOPMENT

SWMM is used to develop the present and future hydrologic models including regional ponds, lakes, and future low impact development (LID) areas and best management practices (BMPs). This model shows the effect of the previously mentioned factors on runoff and water quality.

SWMM estimates flows from balancing water volumes. Evapotranspiration, depression storage and infiltration are subtracted from precipitation to estimate the direct runoff. Stream flow is estimated from the addition of ground water flow into channels to the direct runoff. Channel flows are routed through Best Management Practices (BMP) to model the effect of peak shaving.

Using GIS technology it is possible to estimate the initial input data for the SWMM RUNOFF block. Intersecting GIS layers representing catchments, land use and soil type and linking the resulting intersected layers with digital tables, it is possible to obtain an area average of the parameters describing the physical condition of the subcatchments by using an electronic spreadsheet.

Pollutant loads are modeled from build up and wash off equations. Constituents are built in during dry weather and are washed off in wet periods. Pollutant load is accounted for depending on the weighted average of the type of land use for each subcatchment. The total pollutant is routed through BMPs to account for the pollutant reduction.

Although no data was available to describe the existing BMPs, they were modeled by dividing the areas in three: areas with water quantity treatment, areas with water quantity and quality treatment and untreated areas. This concept help to develop a model such that the post developed peak is lower than the predevelop peak by routing the flow through several storage units and release structures. The structures are sized based on the pre developed runoff volume for the 2 and 10-year storm.

Additionally, 24 regional ponds were modeled using grading data taken from as-built plans. These ponds route flows and pollutants from several subcatchments. Sometimes the flows are routed from streams into other streams (In-stream ponds) and some others flow are taken from a certain area and drop into the streams (Out-of-stream ponds).

The procedures used to estimate input data used in RUNOFF block and TRANSPORT block are based on the guidelines and the scope of work as previously mentions. A description of such procedures used for estimating the input data for each model follows.

RUNOFF block. There are several lines in the input file where values of parameters describing the conditions of the watershed must be entered. The description of each one of these is done in the same order they appear on the SWMM input file. A reference to the SWMM line command is given in parenthesis following the name of the parameter or parameters.

Continuous rainfall data (D1). A 15-minute rainfall data is taken from Dulles Airport (Station number 448903). In this station, there is data available from 1984 through 2004. According to the guidelines, three consecutive years must be selected to model dry, wet and moderate precipitation (wet and dry years). Years 2001, 2002 and 2003 meet these criteria and are included in the SWMM model as dry, medium and wet years respectively.

Table E.1 Total precipitation (inches per year) Dulles Rain Gage (Sta. No. 448903)

Year	Precipitation
2001	35.06
2002	38.84
2003	63.39

Design storms (E3). Design storms are based on the SCS type II design storm for 2, 5, 10, 25, 50, 100 and 500 years. The total volume of precipitation is taken from the NOAA Atlas No. 14. These storm intensities are shown in the following table.

Table E.2 Twenty-four hour rainfall precipitation

Return Period (years)	1	2	5	10	25	50	100	500
Rain intensity (inches/24 hour)	2.7	3.2	4.5	5.2	6	7	7.7	12.06

Evapotranspiration (F1). These data are based on KCI experience in other projects located nearby the Difficult Run Watershed, in Charles County, Maryland. These values are given in inches per month and have been used in a calibrated model in that watershed. The values used are in Table E.3 below.

Table E.3 Evapotranspiration values

Month	Evapotranspiration (inches/month)
January	0.10
February	0.10
March	0.15
April	0.30
May	0.35
June	0.70
July	0.70
August	0.80
September	0.70
October	0.50
November	0.15
December	0.10

Subwatershed physical data (H1). Difficult Run watersheds are labeled following the instruction guide manual: the first two digits are letters representing the Difficult Run project (DF), the following two digits are letters representing the subwatershed (e.g. CH for Captain Hickory Run) and the following four digits are a unique numeric code within each subwatershed representing each individual subcatchment. Each subcatchment is draining to a node. The node name is, in general, the same name of the subwatershed except when two subcatchments are draining to the same node. In this case, one of them does not have the same name for the node, but the other subcatchment name for the node instead.

Area. The area is calculated from the shape file using ArcGIS subroutines and is converted to acres (SWMM requirement). This value is saved in an electronic spreadsheet to be used in further calculations.

Width. The width of each subwatershed was estimated by dividing the area by twice the channel length. The result of this operation is an estimation of the overland flow. The channel length was measured manually using GIS layers. Area is given in square feet and channel length in feet; therefore the subcatchment width is given in feet.

Imperviousness. This fraction is estimated by the ratio of impervious area inside each subcatchment and the subcatchment total area. Each impervious fraction is estimated by considering three types of impervious areas in each subcatchment: driveways, sidewalks and roofs/parking areas. The last one is referred to as polygon imperviousness. A description of each one of these three impervious areas follows.

Driveways. A randomized sample of the total driveway area for each residential land use was done on several subwatersheds around the Difficult Run watershed. The total area for each residential land use was divided by the total area of the land use giving a percent of driveways per residential land use. Results are shown in the following table.

Table E.4 Driveway Imperviousness per Residential Land Use

Residential Land Use	Fraction of imperviousness	Percent imperviousness
ESR	0.032	3.2%
LDR	0.041	4.1%
MDR	0.047	4.7%

Sidewalks. The sidewalk areas were estimated by multiplying the total length of sidewalks in each subwatershed by an assumed sidewalk width of 4 ft. The resulting area is divided by two because the sidewalk line shape had both edges included.

Polygon (roofs, parking areas and streets). These polygons were clipped with the subwatershed layer in order to get the total area per subwatershed.

Ground slope. Using ArcView 3D extension a slope grid was created from the DEM. The slope was clipped to each subwatershed and an average was calculated as a representative ground slope for each subwatershed.

Manning's roughness coefficient. Both impervious and pervious Manning's roughness coefficients are obtained by an area-weighted average based on the different land use. The following Manning's were used as representative of each land use.

Table E.5 Impervious and Pervious Manning's n Values

Land use	Impervious Manning's n	Pervious Manning's n
AVRES	0.15	0.25
ER	0.15	0.30
HDR	0.15	0.25
HIC	0.15	0.25
IND	0.15	0.25
LDR	0.15	0.25
LIC	0.15	0.25
MDR	0.15	0.25
OS	0.15	0.35
OTHER	0.15	0.25

Depression storage. A simple approach of 0.10 and 0.20 values per impervious and pervious depression storage were used for all the subwatersheds as suggested in the modeling guidelines.

Infiltration (Horton). Horton infiltration approach was used in this model. Three parameters were defined based on the soil distribution for each subwatershed: maximum infiltration, minimum infiltration and decay coefficient. The values are defined for each hydrologic soil type (A, B, C and D) according to the following table. The representative value for each subwatershed is obtained from a weighted average of the soil type areas. Missing data was filled from adjacent areas.

Table E.6 Horton Parameters per Hydrologic Soil Type

Hydrologic Soil Type	Horton Parameter			
	A	B	C	D
WLMAX	6.0	4.0	3.0	2.0
WLMIN	0.25	0.10	0.05	0.03
DECAY	0.0009	0.0009	0.0009	0.0009

Ground Elevations (H2). Three parameters are required in this section: ground elevation, bottom of aquifer and bottom of channel. The ground elevation was estimated from the outlet DEM elevation. The bottom of the aquifer was estimated to be 75 ft. below ground elevation. The channels are assumed to be 5 ft deep as an average.

Groundwater coefficients (H3). Following the Dupit-Foreheimer approach for flows into channels, the groundwater coefficients are defined by:

$A1 = A3 = 4K/L^2$, $A2 = 0$ and $B1=2$. The value of K (saturated hydraulic conductivity) is obtained from the soil layer and L is the overland flow.

Other groundwater parameters (H3). Porosity, wilting point, field capacity and saturated hydraulic conductivity are obtained from the soil layer as a weighted area average for each subwatershed.

More groundwater parameters (H4). HCO, PCO, CET, DP and DET were left as the SWMM manual default values. These parameters are mostly used for calibration.

Land use distribution (L1/L2). The land use fractions are taken from the intersection of the land use and subcatchment GIS layers. SWMM requirement is that the fractions must add exactly 1.0; therefore an adjustment was made to the largest fraction to round the figures to two decimal points.

Pollutant modeling (JJ - J3). Following Limno-Tech technical memo, pollutant build up is modeled with an exponential equation. In the same way pollutant wash off is modeled with a power equation. QFACT1, QFACT2, WASPO and RCOEF are given values for each pollutant.

TRANSPORT BLOCKS IN SWMM

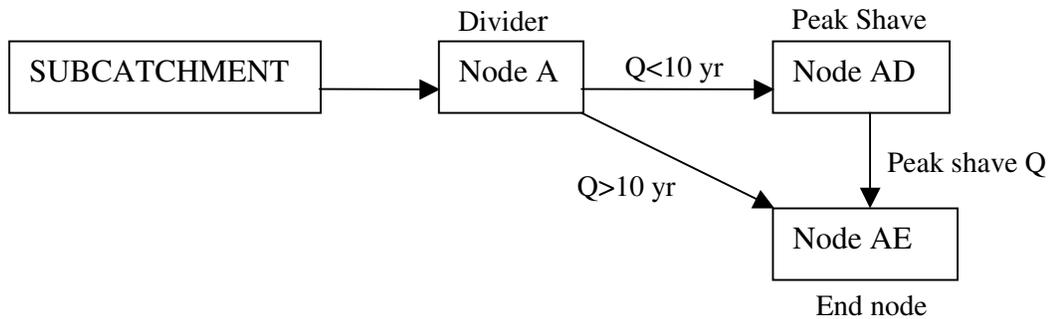
TRANSPORT block. Transport model is divided in two blocks: one with the channels and on-site peak shaving and another one with regional ponds and stream network. Splitting the model in these two sections give more control about the different results that are required. Also it separates the channel hydraulics to be used in HECRAS from the one to be used in the pollutant analysis.

TRANSPORT BLOCK onsite modeling. Peak shavings and septic loads were modeled in this transport block.

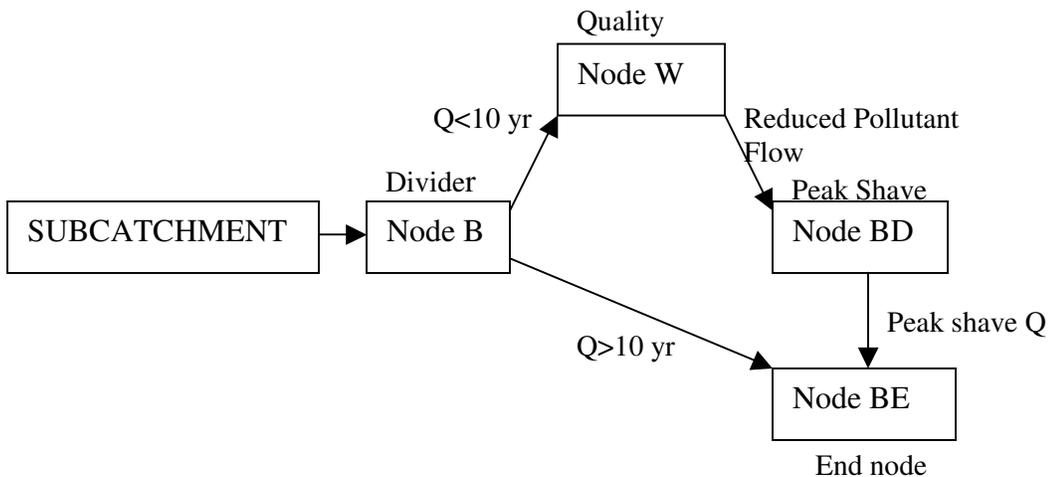
Nodes (E1). Node naming convention is to name the nodes with the same name from the catchment draining to it followed by a letter or series of letters. These letters identify the type of element (node or link) that is used. First, catchments

are classified in A, B or C depending on the water control. A stands for having water quantity control, B for water quantity and quality control and C for not having any control. This classification was done based on the year of building for each parcel. Parcels built before 1970 were assumed to have no water control (C), parcels build after 1985 were assumed to have both water quantity and quality control (B) and the rest, parcels built between 1970 and before 1985, were assumed to have water quantity control (A).

According to the water control classification, the node name extension was some how different. Nodes A are split flow nodes, all discharges above the estimated maximum flow were diverted to end nodes (ending in AE), flows below this maximum flow go to peak shaving nodes (ending in AD) which once peak shave go to the end node (AE).



The model is different for nodes with water quantity and quality included. An additional node (W) is included to reduce the pollutant loads from node B. same structure for excess flow (overtopping) is similar to the water quantity control nodes. Nodes with no control end in C and are used to connect downstream nodes AD and BD and are used as the final outlet of each subcatchment.



On-sites. There are two types of peak shaving (on-site BMPs): water quantity and water quantity and quality. This classification is based on the year of construction of the parcels. It was assumed that parcels with date prior 1970 had no control; parcels between 1970 and 1985 had water quantity control and parcels from 1985 and on had both water quantity and quality.

The peak shaving is done by sizing a pond and a drainage pipe such that the 2-year peak discharge for undeveloped conditions is maintain up to a 10-yr storm event. An electronic spreadsheet was designed to run the DOS SWMM model and help the designers to model the detention and release structures. The results are summarized in a digital table that is used to model each peak shaving in the first TRANSPORT block.

Septic system modeling (R1). Septic loads are based on an average discharge per capita of 200 liter per day and a concentration of 1 mg/l and 12 mg/l for phosphorus and nitrogen respectively. Based on an average of 2.5 people per household. Dwelling units are calculated from the residential land use estimation. No septic wells are modeled in the commercial or industrial land uses.

STREAMS AND REGIONAL PONDS IN SWMM

Transport Block stream and regional ponds. The second Transport block models the stream network (natural channels) and the regional ponds. Nodes from the catchment outlet (ending in C) are connected to channel nodes and to other catchment nodes. Some culverts are included in the model due to the significant effect they have on the downstream conditions.

Nodes (E1). Nodes identify the outlet from catchments, stream connection nodes and the regional ponds. Outlet from catchments and stream junctions are manhole type nodes (19), while regional ponds are storage nodes (22). Ponds. Similar tables were copied and completed from the as-built plans for the existing 24 ponds. They are included in the second TRANSPORT block in the form of Stage-Storage-Area-Discharge tables. The naming convention for these ponds was based using the regional pond name or the subshed location.

Links. Natural channels and culvert pipes are identified with numbers 16 or 2 respectively. Natural channels, stream lengths and slopes were measured from GIS layers but the culvert length and slope are taken from survey data. In the same way, natural cross section data is obtained from running HEC Geo RAS so they correspond to the same location and data used in the HECRAS model. Culvert dimensioning is taken from survey data.

Cross-sections. Cross sections were drawn in ArcView to be able to use them in the HEC GeoRAS extension. Some of these cross sections are used in the representation of the natural streams in SWMM. The base for the cross sections is the field surveyed ones; additional cross sections were drawn to make a hydraulic model more representative. Manning's roughness coefficients are consisting with HECRAS model input for natural cross section.

WATER QUALITY MODEL DEVELOPMENT

The water quality pollutants that are modeled for both current and future conditions include:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)
- Dissolved Phosphorus (DP)
- Total Phosphorus (TP)
- Total Kjeldahl Nitrogen (TKN)
- Total Nitrogen (TN)
- Total Cadmium (TCd)
- Total Copper (TCu)
- Total Lead (TPb)
- Total Zinc (TZn)

To model the buildup and wash-off of pollutants from the land surface, Limno-Tech, Inc provided an article, *Development of SWMM Water Quality Model Inputs for Fairfax County, Virginia*, in March 2004. This document gives four parameters: two for buildup, two for wash-off.

The two parameters given for pollutant buildup are:

QFACT(1). Given in pounds/acre, this is a maximum pollutant buildup rate by land use and pollutant type, given in Table 1.1 of Limno-Tech, Inc.'s report.

QFACT(2). This is given as a constant value of 0.15/day. QFACT(2) is an exponential factor that determines the accumulation rate and surface pollutant recovery after a storm.

The parameters that describe the pollutant wash-off are:

RCOEFF. This is a wash-off coefficient, set at 4.6/inch.

WASHPO. Set at 1.0, this is an exponential rate factor applied to the calculated surface runoff rate.

HYDRAULIC MODEL DEVELOPMENT

The goals of HEC-RAS are:

- Evaluate road crossing overtopping
- Evaluate structure flooding
- Delineate existing and future conditions 100-year flood limit.

The 100-year flood limit was delineated using HECRAS model results with the pre and post processing modules of HEC GeoRAS. The HECRAS model included 83 miles of stream network (a total 184 individual streams), 90 crossing structures and over 1,370 cross sections including the crossings. Cross section were cut at points were it was considered to have different reaches (significant changes in slope, flood limit elevation, crossings).

Input data. Most of the input data was drawn manually. Digital information was manipulated to obtain a representative model of the physical conditions of the terrain. Some other data had to be created (cross sections and flow path) by looking at the contours and other additional information. A description of the most relevant data procedure follows.

TIN. HEC GeoRAS was setup using a TIN created from the 5-foot contours. TIN. Generated from contour lines. The TIN provided by the county was very coarse and did not provide good detail on the flood limit; therefore a finer TIN was created to cut channel flood limit.

Field survey. Selected cross sections were surveyed to model the structures and stream reaches in HECRAS. Both cross sections on either end of each one of the 90 structures were surveyed and one cross section along each reach. These sections were digitally extended to get a better model including the flood limit. And the final data is complemented by the low flow channel sections from the survey report, using a specially design spreadsheet.

Stream layer. The stream centerlines were taken by cleaning the hydrology shape file. The cleaning process included: elimination of loops, double streams, combining multiple polylines into single ones for each reach, setting up direction to be downstream for all streams and naming all of them.

Flow paths. These lines were manually drawn for all modeled streams considering a high event (100 year flood). They are used in the HEC GeoRAS model to model the bends of the streamline.

Import geometry. Raw geometry was created from a TIN by using HEC GeoRAS. This software uses cross section stream and flow path shape files and intersect them with the TIN (Triangulate Irregular Network) to create a table with station and elevation for each cross section. This data is exported directly into HECRAS and can be edited and modified.

Manning's roughness coefficient (n). A very important parameter for estimating the channel flow is the roughness of the channel and the flood limits. This was estimated from the photographs taken during the fieldwork. This is very subject estimation; therefore two people were in charge to estimate this parameter to keep consistency across the watershed.

Banks. From the fieldwork, the banks were identified and marked down in the fieldwork books. This values were input into the model assuring a good representation of these features.

Structures. 90 structures were surveyed and the data was process and prepared to be input in HECRAS by using Excel. Review of errors was done and some parameters were changed, more data was collected from digital data based on an individual approach and analysis. Special modeling considerations were done for some of the structures (Westwood Country Club culverts) requiring a more extensive data development.

Output analysis. Once the HECRAS model was revised and executed, the results were exported into a GIS file. This file can be read by HEC GeoRAS post processing module and used to generate a flood limit shape. Minor corrections must be made to this file by eliminating and merging polygons to obtain smooth and representative flood limit delineation.