F I N A L   R E P O R T

FLOOD MAP MODERNIZATION PROGRAM HYDROLOGY REPORT APPOQUINIMINK RIVER WATERSHED NEW CASTLE COUNTY, DELAWARE

MAPPING ACTIVITY STATEMENTS

The Delaware Department of Natural Resources and Environmental Control Division of Water and Soil Conservation

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TASK SUMMARY

INTRODUCTION

Borton-Lawson is under contract to the Delaware Department of Natural Resources and Environmental Control (DNREC), a Cooperative Technical Partner (CTP) with the Federal Emergency Management Agency (FEMA), to provide updated hydrology for a Flood Insurance Study (FIS). This Hydrologic Analyses Technical Support Data Notebook (TSDN) is intended to clearly define the scope of work, methodologies for modeling, any exceptions to the standards outlined in the scope of work, and to summarize the final results.

STATEMENT OF WORK – HYDROLOGIC ANALYSES

Scope: The Consultant shall perform hydrologic analyses for the limited detailed study reaches of drainage areas for the Appoquinimink River Watershed in New Castle County. The Consultant shall calculate peak flood discharges for the 10-, 2-, 1-, and 0.2-percent-annual-chance storm events using the appropriate hydrologic model. These flood discharges will be the basis for subsequent hydraulic analyses.

If GIS-based modeling is used, Borton-Lawson shall document automated data processing and modeling algorithms and provide them to FEMA to ensure they are consistent with the standards outlined above. Digital datasets (such as elevation, basin, or land use data) are to be documented and provided to FEMA for approval before performing the hydrologic analyses to ensure the datasets meet minimum requirements. If non-commercial (i.e., custom-developed) software is used for the analyses, then the Consultant shall provide full user documentation, technical algorithm documentation, and the software to the Client for review before performing the hydrologic analyses.

Deliverables: In accordance with the TSDN format described in described in Appendix M of *Guidelines and Specifications for Flood Hazard Mapping Partners*, the Consultant shall make the following products available to the Client:

- Digital copies of all hydrologic modeling calculations for the 10-, 2-, 1-, and 0.2-percent-annual-chance storm events;
- Digital and hardcopy versions of the Summary of Discharges Table presenting discharge data for the flooding sources for which hydrologic analyses were performed;
- Digital and hardcopy versions of draft text for Section 3.1, Hydrologic Analyses, of the FIS report; and
- Digital and hardcopy versions of all backup data used in the analyses, including work maps.

For GIS-based modeling, deliverables include all input and output data, intermediate data processing products, and GIS data layers.

STUDY AREA

The Appoquinimink River Watershed is located in the southern portion of New Castle County, Delaware. The watershed encompasses the towns of Middletown, Odessa, and Townsend, as illustrated in Map 1.

The State of Delaware has two major physiographic provinces, the Piedmont and the Coastal Plain. The Fall Line, which crosses from the northeast corner of Delaware to approximately 5 miles south of the northwest corner of the State, forms the divide between the two provinces.

New Castle County lies within the Coastal Plain physiographic province. The Coastal Plain province consists of an area of low relief adjacent to the Chesapeake and Delaware Bays, with elevations ranging from sea level to less than 100 feet. Streams in the Coastal Plain are often affected by tides for substantial distances above their mouths.

Hydrologic analyses were performed for the streams listed in Table 1. The study areas for this flood study are also shown in Map 1.

GENERAL WATERSHED DESCRIPTION

The Appoquinimink River Watershed has a total drainage area of 46.5 square miles, is approximately 16 miles long, and originates about 2 miles west of the Town of Townsend in the southwest part of the watershed. The river runs in a northeast direction towards the Town of Odessa then changes direction about 2 miles east of Odessa, where it flows in a southeast direction until it discharges into the Delaware Bay. The major tributaries to the Appoquinimink River include: Doves Nest Branch, Drawyer Creek, Deep Creek, and Hangman's Run.

The major routes in the Appoquinimink River Watershed include U.S. Routes 13 and 301 and Delaware State Routes 1, 9, 15, 71, and 299. U.S. Route 13 runs in a north-south direction for approximately 11 miles through the watershed. U.S. Route 301/DE Route 71 runs for approximately 2.8 miles and splits in the Town of Middletown. Route 301 continues to run for about 1.7 miles in a southwest direction, while Route 71 continues to run about 5.2 miles in a southeast direction through the Town of Townsend. Route 1 runs in a north-south direction, paralleling Route 13. Route 9, which crosses over Hangman's Run, only runs for about 1.5 miles through the watershed. Route 15 travels for approximately 1.5 miles in a north-south direction through the western portion of the watershed. Route 299 runs in an east-west direction for about 5.7 miles and passes through the towns of Middletown and Odessa.

AERIAL PHOTOGRAPHY

The aerial photo used was obtained from the National Agriculture Imagery Program (NAIP). It was photographed in 2006 at a resolution of 1 meter rectified to a horizontal accuracy of within +/- 5 meters of reference digital ortho quarter quads (DOQQ's) from the National Digital Ortho Program (NDOP); (USDA-FSA Aerial Photography Field Office, 20050915, naip_1-

1_1n_s_dl005_2006_1.sid: USDA FSA Aerial Photography Field Office, Salt Lake City, Utah). Aerial photography of the watershed is shown in Map 2.

DIGITAL ELEVATION MODEL

A Digital Elevation Model (DEM) for the Appoquinimink River Watershed was developed from DEM data obtained from USGS. The USGS DEM was created in 1999 based on 10-meter grid cells and the Geographic coordinate system Horizontal datum of NAD83 (USGS EROS Data Center, Sioux Falls, SD 57198). Subwatersheds or subareas used in the watershed modeling process were derived from the above mentioned DEM. Drainage courses, land slopes and lengths, and drainage element lengths and slopes were all determined from the DEM as well. The DEM for the Appoquinimink River Watershed is displayed in Map 3.

WATERSHED MAP

The Geographic Information System (GIS) data of the Appoquinimink River Watershed boundary was received from the Delaware Department of Natural Resources and Environmental Control (DNREC). This watershed boundary was overlaid on USGS topographic maps to determine its accuracy.

In this project, the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) software package developed by US Corps of Engineers (USCOE) used the ten (10) meter US Geological Survey's (USGS) Digital Elevation Model (DEM) mentioned above to delineate the watershed boundary of the Appoquinimink River. This DEM based watershed boundary was then compared to the GIS data received from DNREC, the Center for Watershed Protection Assessment boundary and the USGS Hydrologic Unit Code 12-digit dataset (HUC-12) delineation. Minor adjustments to the watershed boundary were made. The final watershed boundary was edited by Borton-Lawson through the use of USGS Topographic maps and field verification. This final watershed boundary as well as major subwatersheds are provided in Map 4.

LAND COVER

The existing Land Cover data was generated by overlaying the 2002 Land Use and Land Cover data set for the State of Delaware which was compiled at a scale of 1:2400 with the 2006 Aerial Photo, and Parcel Data provided by New Castle County, Delaware. The Land Cover shapefile was then updated to incorporate any development that has occurred since 2002.

The landscapes of the Appoquinimink River Watershed vary from rural to densely suburbanized. The majority of the watershed is undeveloped, with low-density housing subdivisions found throughout the watershed and higher-density development found within the Town of Middletown. The predominant land cover in the watershed is classified as agricultural (44.7%). Approximately 20.5% of the watershed is residential land, and wetlands account for 12.6% of the land cover. Map 5 illustrates the existing land cover of the watershed while Table 1 details the land cover by category within the Appoquinimink River Watershed.

Table 1 – Land Cover in Appoquinimink River Watershed

LAND COVER	SQUARE MILES	ACRES	PERCENT AREA
Agriculture	20.9	13,368.8	44.7
Commercial	1.5	949.5	3.2
Farmstead	0.5	347.3	1.1
Forest	3.8	2,450.9	8.1
Industrial	0.2	141.2	0.5
Institutional	0.4	240.6	0.8
Meadow	0.4	239.0	0.8
Mining	0.1	70.7	0.2
Open Space	0.5	332.0	1.2
Orchard	0.2	137.1	0.5
Paved	0.6	409.4	1.4
Residential (1 – 4 acre lots size)	4.5	2,868.8	9.6
Residential (1/3 – 1 acre lot size)	3.9	2,501.2	8.4
Residential (1/8 – 1/3 acre lot size)	0.8	517.4	1.7
Residential (1/8 acre or less lot size)	0.4	229.7	0.8
Water	2.0	1,308.7	4.4
Wetlands	5.8	3,728.1	12.6
TOTAL	46.5	29,840.4	100%

HYDROLOGIC SOIL GROUPS

Soil properties influence the runoff generation process. NRCS has established a criterion determining how soils will affect runoff by placing all soils into four Hydrologic Soil Groups (HSGs) – A through D, based on infiltration rate and depth. There are no group A soils, which have a high infiltration rate and low runoff potential, found within the Appoquinimink River Watershed. The majority of soils within the watershed fall within group B. Group B is characterized as having moderate infiltration rates, and it consists primarily of moderately deep to deep, moderately well to well drained soils that exhibit a moderate rate of water transmission. Group C soils, found sporadically throughout the watershed, have slow infiltration rates when thoroughly wetted and contain fragipans, a layer that impedes downward movement of water and produces a slow rate of water transmission. Located mainly within floodplain areas, D soils are tight, low permeable soils with high runoff potential and are typically clay soils. This information was incorporated into the GIS and, from this, the watershed HSG map was developed as shown in Map 6.

TOPOGRAPHY DATA

The digital USGS 7.5-minute topographic quadrangle map (DRG) was obtained from the USGS. It was edited in 1993 at a scale of 1:24,000 and the National Geodetic Vertical Datum of 1929 (NGVD 29). The topography of the watershed is relatively flat. The highest point is found along the watershed boundary, about a half mile north of the southwest tip of the watershed, with an elevation of 88 feet above sea level using the USGS datum. The lowest elevation, 3 feet below sea level, is found at the western part of Silver Lake, and much of the area near the confluence of the Appoquinimink River and the Delaware Bay is at sea level. Map 7 displays the topography of the watershed.

OBSTRUCTION DATA

Locations of significant waterway obstructions (i.e., culverts, bridges, etc.) were obtained from Delaware Department of Transportation (DelDOT), and are supplemented with field measurements. The obstruction flow capacities were then computed. Locations were identified through the use of USGS DRG topographic maps and field verified by Borton-Lawson on November 12, 2007. The locations of all obstructions can be found on Map 8. The obstruction data that was obtained and the calculated flow capacity of the obstructions are found in Appendix B.

METHODOLOGY

The following table is the list of study streams included in this TSDN. This table shows the type of study that was performed for each stream and the methodology selected.

Table 2 – Hydrologic Methods Used and Study Type

Study Stream Name	Study Type	Hydrologic Method Used
Appoquinimink River	Limited Detail Study	HEC-HMS[1]
Deep Creek	Limited Detail Study	HEC-HMS
Doves Nest Branch	Limited Detail Study	HEC-HMS
Drawyer Creek	Limited Detail Study	HEC-HMS
Hangman's Run	Limited Detail Study	HEC-HMS

PROCESSING

Subwatershed Delineation

Delineation of the subwatersheds is based on points of interest (POI) and was accomplished through the use Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) (1) software package version 1.1 developed by U.S. Corps of Engineers. The delineated subwatersheds are illustrated in Map 9.

The HEC-GeoHMS is a software package for use with the ArcMap Geographic Information System (GIS). GeoHMS uses ArcMap and Spatial Analyst to develop a number of hydrologic modeling inputs for HEC-HMS. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities of HEC-GeoHMS also include the development of; grid-based data for linear quasi-distributed runoff transformation, the HEC-HMS basin model, physical watershed and stream characteristics, and the background map file. The hydrologic results from HEC-GeoHMS were then imported into the Hydrologic Modeling System (HEC-HMS), where a hydrologic analysis was performed (2).

The main considerations in the subdivision process were the location of obstructions, problem areas, changes in existing FEMA flows, and tributary confluences. The most downstream point of each of these areas is considered as a Point of Interest (POI) where increased runoff was analyzed for its potential impact. POIs were sent to FEMA's consultant, URS, for concurrence with the hydraulic modeling they would be performing.

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[1] U.S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System

Some of the POIs used to delineate the subwatersheds were evaluated in StreamStats to determine peak flow rates at these locations. StreamStats is a web based application used for determining peak flows, and is based on a regression equation outlined in the USGS Scientific Investigations Report 2006-5146 (USGS SIR 2006-5146) "Magnitude and Frequency of Floods on Nontidal Streams in Delaware" (3). Map 9 shows the location of the POIs that were evaluated in StreamStats, and the subareas that were delineated in HEC-GeoHMS which were input into the HEC-HMS model.

The Coastal Plain regression equations listed in USGS SIR 2006-5146 are as follows:

$$PK10 = 210 DRNAREA^{0.709} BSLDEM10M^{0.289} (SOILA+1)^{-0.316}$$

$$PK50 = 353 DRNAREA^{0.712} BSLDEM10M^{0.297} (SOILA+1)^{-0.328}$$

$$PK100 = 425 DRNAREA^{0.715} BSLDEM10M^{0.303} (SOILA+1)^{-0.332}$$

$$PK500 = 623 DRNAREA^{0.720} BSLDEM10M^{0.320} (SOILA+1)^{-0.344}$$

Where,

PK10, *PK50*, *PK100*, and *PK500* are the peak discharges for floods with recurrence intervals of 10 years, 50 years, 100 years, and 500 years;

DRNAREA is the drainage area, in square miles;

BSLDEM10M is mean basin slope determined from a 10-meter DEM, in percent, and;

SOILA is hydrologic soil type A, in percent, high-infiltration-rate soils.

Rainfall

The rainfall depths of various return frequencies used in the HEC-HMS model were supplied by DNREC. Table 3 lists the NRCS Type II, 24-hour duration rainfall depth of various return frequencies for New Castle County, Delaware[2] where the Appoquinimink River Watershed is located. Those 24-hour rainfall depths were derived from National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Volume 2, Version 3.

Table 3 – Design Rainfall of Various Return Frequencies

24-hour Rainfall Depths				
Return Frequency (year)	10	50	100	500
Depth (in)	4.8	6.9	8.0	10.9

Hydrology

Within the Appoquinimink River Watershed, there are six USGS stream gauges (cited from USGS Surface Water website) (4). Table 4 lists the gage number, location and years of record available for those six stream gages. Ideally, a hydrologic model should be calibrated against stream gage data from actual storm events. Unfortunately, the Appoquinimink River does not have enough gage data or years of record to be able to calibrate against actual storms, or develop statistical frequency curves as recommended on the FEMA document, "FEMA Map Modernization, Guidelines and Specifications for Flood Hazard Mapping Partners." For instance, for gage No. 01483153 (Noxontown Lake Outlet near Middletown, DE), there are only 6 years of record and a gap between years 1994 and 2000, therefore no recurrence interval peak flows could be computed. For gage No. 01483170 (Dove Nest Branch near Odessa, DE), there are only three peak flow events. Others are short of data or have no data available.

[2] Latitude 39.547 N, Longitude 75.681 W

Table 4 – USGS Stream Gage Located in the Appoquinimink River Watershed (cited February, 2008)

USGS Gauge No.	Location	Years of Record
01483153	Noxontown Lake Outlet Near Middletown, DE	1993-2003
01483155	Silver Lake Tributary at Middletown, DE	2001-2006**
01483160	Drawyer Creek Near Mount Pleasant, DE	N/A*
01483165	Spring Mill Branch Near Armstrong, DE	2001-2004
01483170	Dove Nest Branch Near Odessa, DE	1979-2004***
01483175	Drawyer Creek at Odessa, DE	N/A*

*N/A: Not Available.
**Discharge affected by Regulation or Diversion and only has 6 counts of peak streamflow.
***Only three counts of peak flow available.

The USGS along with the Delaware Department of Transportation (DelDOT), and the Delaware Geological Survey (DGS) present methods (a regression equation) for estimating the magnitude and frequency of floods on nontidal streams in Delaware at locations where stream gaging stations monitor streamflow continuously, and at ungaged sites. This methodology is presented in the USGS Scientific Investigations Report 2006-5146 (USGS SIR 2006-5146). Stream gage data was utilized to develop the regression equations which predict peak flows, the next most reliable method to determine recurrence interval peak flows in the absence of reliable gage data. Stations were not used in the analysis if they had less than 10 years of annual peak flow data, or if peak flows were substantially affected by dam regulation or reservoirs that provide flood control. Therefore, SIR 2006-5146 should not be used to obtain flows for model comparison downstream of reservoirs in the Appoquinimink River Watershed. The SIR 2006-5146 equations were incorporated into an online USGS application, "StreamStats."

StreamStats was used to obtain the estimated peak flow at various Points of Interest (POIs). Table 5 lists the peak flows for various POIs for different frequencies developed through StreamStats. Some of the POIs in Table 5 were selected as calibration points or target values for use in the HEC-HMS model. These POIs are highlighted in blue in the summary table presented in Appendix C. The map ID number that corresponds to the POIs labeled in Map 9, for each of the calibration points are also found in this summary table. Appendix C also contains the results of the StreamStats analysis for the selected POIs.

It should be noted that not all of the POIs correspond exactly to the "elements" in the HEC-HMS model ("elements" represents subwatersheds, stream junctions, and stream reaches). This results in minor discrepancies in the drainage areas between StreamStats and the HEC-HMS model, and is evidenced in the summary table contained in Appendix C. However, flow comparisons by relative drainage area could still be made.

Table 5 – Peak Flow at Various Points of Interest as Developed from StreamStats

Map ID	Peak Flow, (cfs)			
	10-yr	50-yr	100-yr	500-yr
0	890	1510	1830	2730
1	308	519	627	925
2	451	761	920	1360
3	2370	4040	4940	7440
4	1840	3140	3830	5760
5	3610	6160	7530	11400
6	3670	6260	7650	11600
7	73	121	145	207
8	1050	1780	2170	3250
9	1740	2970	3630	5460
10	612	1040	1250	1860
11	237	398	479	703
12	1050	1790	2180	3270
13	2020	3450	4210	6350
14	2260	3860	4710	7100
15	321	543	656	969
16	680	1150	1400	2080
17	667	1130	1370	2030
18	247	415	500	730
19	151	253	303	439
20	835	1420	1720	2560
21	872	1480	1800	2680
22	345	584	707	1050
23	345	584	707	1050
24	513	868	1050	1570
25	962	1640	1990	2980
26	452	765	925	1370
27	1330	2260	2750	4140
28	978	1660	2020	3010

Comparison to FEMA Flow

The FEMA Flood Insurance Study (FIS) of New Castle County, Delaware, January, 2007 (5) lists the drainage area-peak discharge relationships for the streams studied by detailed methods in the FIS Table 2, "Summary of Discharges". In this table, peak discharges at various Shallcross Lake branches were reported. FEMA continuously updates the FIRM (Flood Insurance Rate Map) through the Letter of Map Revision (LOMR) process. There was one LOMR (case No. 07-03-0823, dated Oct. 19, 2007) published after the FIS was published. The flow for Spring Mill Branch at a point approximately 2,500 feet upstream of Cedar Land Road was obtained from this LOMR. Table 6 lists the peak discharges reported in the FIS and the above mentioned LOMR. The FIS maps with locations for the various tributaries, the above mentioned LOMR and a LOMR dated August 16, 2004 along with the TR-20 modeling results for tributaries within the vicinity of Shallcross Lake are found in Appendix D.

Table 6 – FEMA FIS Reported Peak Discharge at Various Shallcross Lake Branches

Flood Location and Sources	Drainage Area (mi2)	Peak Discharge (cfs)			
		10-year	50-yr	100-yr	500-yr
BRANCH NO. 1 at confluence with Shallcross Lake	1.9	*	*	2,200	*
BRANCH NO.2 at confluence with Shallcross Lake Branch No.1	0.2	*	*	200	*
BRANCH NO.3 at confluence with Shallcross Lake Branch No.1	0.2	*	*	420	*
BRANCH NO.4 at confluence with Shallcross Lake	0.2	*	*	300	*
BRANCH NO.5 at confluence with Shallcross Lake	1.2	*	*	1,200	*
BRANCH NO.6 at confluence with Shallcross Lake Branch No. 5	0.5	*	*	450	*
SPRING MILL BRANCH at the confluence with Shallcross Lake	0.4**	*	*	449	*
SPRING MILL BRANCH at a point approximately 2,500 feet upstream of Cedar Lane Road***	1.4	*	*	1,116	*

* – Data not available
**This drainage area appears to be incorrect. The drainage area should be greater than 1.4 square miles since this location is downstream of Cedar Lane.
***LOMR Case No. 07-03-0823, dated Oct. 19, 2007

There are discrepancies between the peak discharges calculated by the HEC-HMS model and the values reported by the FIS. These discrepancies were pointed out in an interim hydrologic report entitled, *Appoquinimink River Watershed FEMA Review*, dated August 12, 2008, which was submitted to URS and DNREC. URS concurred with the conclusions in the report that the newly developed HEC-HMS flows are the most appropriate for the new FIS. A detailed comparison can be found in Appendix E.

HEC-HMS Model

An initial step in the preparation of this stormwater management plan was the selection of a stormwater simulation model to be utilized. It was necessary to select a model which:

- Modeled design storms of various durations and frequencies to produce routed hydrographs which could be combined.
- Was adaptable to the size of subwatersheds in this study.
- Could evaluate specific physical characteristics of the rainfall-runoff process.
- Did not require an excessive amount of input data yet yielded reliable results.
- Could model the attenuation effect (routing) of dams, lakes and/or reservoirs.

The model decided upon was the U. S. Army Corps of Engineers, Hydrologic Engineering Center, Hydrologic Modeling System (HEC-HMS) for the following reasons:

- It had been developed at the Hydrologic Engineering Center specifically for the analysis of the timing of surface flow contributions to peak rates at various locations in a watershed.
- Although originally developed as an urban runoff simulation model, data requirements make it easily adaptable to a rural situation.
- Input parameters provide a flexible calibration process.
- It has the ability to analyze reservoir or detention basin routing effects and location in the watershed.
- It is accepted by the Federal Emergency Management Agency (FEMA) and Delaware Department of Natural Resources and Environmental Control (DNREC).

The HEC-HMS model generates runoff flows for selected subareas along the drainage course, it creates hydrographs, and routes flows through the watershed. The model generates runoff quantities for a specified design storm based upon the physical characteristics of the subarea, and routes the runoff flow through the drainage system in relation to the hydraulic characteristics of the stream. The amount of runoff generated from each subarea is a function of its slope, soil type or permeability, percent of the subwatershed that is developed, and its vegetative cover.

Model Parameters

Model parameters including runoff curve number, initial loss, basin transformation lag method, routing method and storage parameters are described below. The parameters were adjusted as described below in order to calibrate the model so that flows at POIs matched flows determined from StreamStats. The comparison of target flows and flows generated in the HEC-HMS model are found in Appendix C.

Runoff Curve Number

Composite runoff curve numbers were generated by overlaying the land use map with the subarea and hydrologic soil group maps within the GIS. The generated curve numbers were then used for input into the hydrologic model of the watershed. The NRCS curve number of each subwatershed as used in the HEC-HMS model is listed in Table 9. The location of each subwatershed is illustrated in Map 9.

Table 7 – NRCS Curve Numbers of Each Subwatershed

Subwatershed ID	Curve Number	Subwatershed ID	Curve Number
W1000	77.0	W590	71.2
W1010	82.4	W610	75.7
W1020	78.9	W620	70.7
W1030	71.3	W630	71.5
W1040	72.6	W650	70.7
W1050	74.3	W660	69.1
W1070	70.2	W670	75.0
W1080	71.1	W680	75.1
W1090	75.0	W710	74.6
W1100	73.2	W720	84.3
W1110	71.0	W730	69.2
W1120	71.4	W750	92.8
W1130	71.9	W760	79.6
W1140	71.9	W770	76.3
W1150	73.3	W780	82.8
W1160	71.6	W790	70.1
W1170	78.4	W800	84.3
W1210	70.2	W810	78.2
W1220	78.8	W820	90.5
W1260	70.3	W830	73.7
W1270	74.7	W840	98.9
W1310	84.0	W850	75.6
W1320	81.2	W860	97.5
W1360	89.0	W870	81.8
W1370	82.2	W880	74.8
W1410	80.1	W890	90.4
W1420	75.3	W900	74.6
W1460	79.4	W910	76.2
W1470	74.9	W920	76.2
W1510	71.6	W950	82.3
W1520	81.0	W970a	75.0
W1570	75.8	w970b	79.0
W1620	75.9	W980	77.8
W1660	88.6	W990	78.7
W1670	78.5		

Initial Loss

In the HEC-HMS model, a NRCS Curve Number Loss Method was used to estimate initial abstraction and the NRCS Unit Hydrograph method was used to simulate the process of direct runoff of excess precipitation. The estimated initial abstraction was then adjusted during calibration process to obtain flows that more closely matched the flows at the calibration points also known as the target flows. The initial abstraction was adjusted to account for the topography and additional storage from wetlands. The initial abstraction values of each subwatershed used in the HEC-HMS model, and the original pre-calibration values are contained in Appendix F.

Basin Transformation Lag Time

Basin lag time is estimated using a two step process. First the basin slope is determined. Then, the basin slope is used in determining the lag time by using the curve number method described in the NEH Section 4. The basin lag time was estimated by the HEC-GeoHMS GIS with a basin slope obtained using the DEM, and curve number derived from land cover and hydrologic soil group (HSG) data. The estimated lag times were then adjusted during calibration to obtain flows that more closely match the target flows. The lag times were increased to account for flat areas, wetland storage, and also additional storage from lakes and reservoirs that would act to increase the lag time. The lag times of each subwatershed used in the HEC-HMS model, and the original pre-calibration values are contained in Appendix F.

Routing Method

The Muskingum routing method was used to simulate attenuation of the flow for storage as it is routed through the channel. The Muskingum routing method computes a downstream hydrograph, given an upstream hydrograph as a boundary condition. The Muskingum method utilizes a K value which is storage constant expressing the lag or travel time through the reach and is usually expressed in hours. The dimensionless parameter x is indicative of the relative importance of inflow and outflow to channel and floodplain storage within the reach and varies from 0 (100% storage) to 0.5 (no storage). For Muskingum K values less than 5 minutes, due to unstable HMS model calculations using the Muskingum method, the lag model, which uses a straight time translation and no storage attenuation, was used in its place, which is sufficient for short reaches. The estimated parameters of the Muskingum routing model were then adjusted during calibration to match target flows. The Muskingum routing parameters used in the HEC-HMS model for each of the subwatersheds, and the original pre-calibration values are contained in Appendix F.

Dams and Lakes

There are five lakes within the watershed which provide storage areas large enough to be included in the HEC-HMS model. They are Noxontown Pond Dam, Shallcross Lake, Silver Lake Dam, Wiggins Mill Pond, and Hangman's Run Reservoir. Hangman's Run Reservoir is privately owned and not regulated. DNREC could find no data for it, and therefore was not included in the HEC-HMS model. The elevation-area curves for Noxontown Pond Dam, Silver Lake Dam, and Wiggins Mill Pond were determined using contours derived from the 10m DEM obtained from the USGS in ArcGIS, and were used as the storage parameter in the HEC-HMS model. Outlet structure data was based on survey data obtained by URS for DNREC, and input into the HEC-HMS model for Noxontown Pond Dam, Silver Lake Dam, and Wiggins Mill Pond. Storage-Discharge and elevation-storage data for Shallcross Lake were obtained from the latest hydrologic model (TR-20) used to determine the flows for tributaries upstream of the lake and flows at the lake. The elevation-area data and outflow structure data that was input into the HEC-HMS model for the Noxontown Pond Dam, Silver Lake Dam, and Wiggins Mill Pond are shown below. The storage-discharge and elevation-storage data that was input in the HEC-HMS model for Shallcross Lake is also shown below. The elevation-area curve dam data obtained from DNREC, and data from the TR-20 model from the FEMA FIS and the LOMR dated October 19, 2007 for Shallcross Lake are found in Appendix G.

Noxontown Pond Dam

Storage Method – Elevation-Area

*Elevation (ft)	Surface Area (ac)
0.0	192.24
5.0	226.85
10.0	280.94
15.0	341.78
20.0	435.94
25.0	506.15
30.0	595.93

Outflow Structure	*Broad Crested Spillway*
*Elevation (ft)	0.00
Length (ft)	56
Coefficient	3.1
# of gates	0

Silver Lake Dam

Storage Method – Elevation-Area

*Elevation (ft)	Surface Area (ac)
0.0	47.03
5.0	55.29
10.0	65.19
15.0	81.29
20.0	101.08
25.0	145.31
30.0	195.07

Outflow Structures	*Broad Crested Spillway #1*	*Broad Crested Spillway #2*
*Elevation (ft)	0.71	0.08
Length (ft)	24	19
Coefficient	3.1	3.1
# of gates	0	0

Outlet	
Method	Culvert Outlet
Solution Method	Inlet Control
Shape	Box
Chart	10: 90 degree headwall; chamfered or beveled
Scale	1: Inlet edges chamfered ¾ in

Length (ft)	39.9
Rise (ft)	5
Span (ft)	8.4
*Inlet Elevation (ft)	-0.38
*Outlet Elevation (ft)	-0.88
Entrance Coefficient	0.2
Exit Coefficient	1
Manning's "n"	0.012

Wiggins Mill Pond

Storage Method – Elevation-Area

*Elevation (ft)	Surface Area (ac)
21.12	22.87
30.00	53.37
35.00	99.43
40.00	170.15
45.00	264.55
50.00	430.13

Outflow Structures	*Broad Crested Spillway #1*	*Broad Crested Spillway #2*
*Elevation (ft)	21.12	21.35
Length (ft)	24	5
Coefficient	3.1	3.1
# of gates	0	0

Shallcross Lake

Storage Method - Elevation-Storage (TR-20)

*Elevation (ft)	Storage (ac-ft)
9.6	0.00
10.0	50.00
11.0	107.25
12.0	167.50
13.0	231.25
14.0	298.50
15.0	369.25

Storage-Discharge (TR-20)

Storage (ac-ft)	Discharge (cfs)
0.00	0.00
50.00	85.00
107.25	667.00
167.50	1725.00
231.25	3219.00
298.50	5409.00
369.25	7000.00

*Some of the reservoirs are below sea level and HEC-HMS cannot route flow through negative elevations. Therefore, a constant of 20' was added to all elevations.

Results of Reservoir Routing

The attenuation results of the lakes and dams for the 100-year storm runs are summarized in Table 8.

Table 8 – Results of 100-year Storm Attenuation by Lakes

Lake/Pond/Dam	Inflow, cfs	Outflow, cfs
Noxontown Pond	6,916	2,529
Shallcross Lake	1,887	1,812
Silver Lake Dam	2,228	1,957
Wiggins Mill Pond	3,992	2,396

CONCLUSIONS

DISCHARGE COMPARISON

The hydrologic analyses results (restudy) were compared with the existing FIS effective discharges. Shallcross Lake Branch and Spring Mill Branch had effective data for comparison in the New Castle County, DE, FIS. Please refer to Table 9 below.

Table 9 – Discharge Comparison Table

Flooding Source and Location **Restudy vs.** **Effective Study**	**Restudy** / *[1]Effective New Castle County, DE FIS (2007)*	
	Drainage Area (sq. miles)	**100-year Peak Discharges (cfs)**
Shall Lake Branch No. 1 at confluence with Shallcross Lake	1.4 / *[1]1.9*	1,116 / *[1]2,200*
Shall Lake Branch No. 5 at confluence with Shallcross Lake	1.0 / *[1]1.20*	612 / *[1]1,200*
Spring Mill Branch at the confluence with Shallcross Lake	1.98 / *[1]0.41*	892 / *[1]449*

The new 100-year discharges at Shallcross Lake Branch No. 1 at the confluence with Shallcross Lake and at Shallcross Lake Branch No. 5 at the confluence with Shallcross Lake differ from the effective discharges. The new 100-year discharges at Spring Mill Branch at the confluence with Shallcross Lake also differ from the effective discharges. These discrepancies were pointed out in an interim hydrologic report entitled, "Appoquinimink River Watershed FEMA Review", dated August 12, 2008, which was submitted to URS and DNREC. The comparison can be found in Appendix E.

FINAL DISCHARGES

The peak flow estimates determined for this study differ from those in the previous flood studies. In the effective FIS, a drainage area is not correctly reported. The TR-20 model was used to compute the peak discharges reported in FIS. In the TR-20 model, the 100-year 24-hour rainfall amount (7.5 inches) utilized was different from the rainfall amount (8.0 inches) used in this study. Additionally, in analyzing the TR-20 model parameters, the determination of the curve numbers and lag times could not be verified. The lag time used was fairly short compared to the lag time calculated based on the National Engineering Handbook (NEH) Section 4 Chapter 15. There was also no evidence that the TR-20 model had been calibrated. These discrepancies were pointed out in an interim hydrologic report entitled, Appoquinimink River Watershed FEMA Review, dated August 12, 2008, which was submitted to URS and DNREC. URS concurred with the conclusions in the report that the newly developed HEC-HMS flows are the most appropriate for the new FIS.

Supporting computations for the peak discharges for this study are presented in Appendix B to Appendix G for reference, and the schematic of the HEC-HMS basin is found in Appendix H. Appendix I lists the final discharges that will be used for this flood study. The supporting digital data including HEC-HMS model and the GIS data that was used to develop the HEC-HMS basin model is provided in digital format in Appendix J.

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