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IMPROVING FLOOD FORECASTING AND WATER CONTROL VIA HEC-HMS AND HEC-RAS CALIBRATION

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ABSTRACT

This thesis will revolve around the successful calibration of a hydrologic and hydraulic analysis model for the West Branch of the Susquehanna River. The model will be developed using a combination of HEC-HMS and HEC-RAS, two traditional water resources programs that model a watershed’s response to precipitation events. The main focus will revolve around using previously modeled HMS and RAS events and river reaches to come up with a comprehensive, accurate model that can be used for future forecasting and modeling in the area. The accuracy of the results obtained will be evaluated by comparing them to the National Weather Service (NWS) expected outputs for similar events at those locations.

The intended outcome of the thesis is a successfully calibrated model for the West Branch. A successfully calibrated model can be used by government and state authorities to provide more accurate, up to date information for dam design and flood inundation studies.

TABLE OF CONTENTS

LIST OF FIGURES……………………………………………………………………..iii

LIST OF TABLES………………………………………………………………………iv

ACKNOWLEDGEMENTS…………………………………………………………...v

Chapter 1 Background and Introduction to HEC Programs…………………………........1

Chapter 2 Previous Modeling…………………………………………………………...5

Chapter 3 Calibration Techniques……………………………………………………..12

Chapter 4 Conclusions and Recommendations……………………………………......19

Appendix A References…………………………………………………………………..20

LIST OF FIGURES

Figure 1-1 Susquehanna Basin with West Branch………………………………………...1

Figure 1-2 Area of Study………………………………………………………………..1

Figure 1-3 HMS Model of the West Branch of the Susquehanna Basin……………………..3

Figure 1-4 Summary of Geometric Cross Sections of the West Branch in HEC-RAS……....4

Figure 1-5 Sample Cross Sectional View from HEC-RAS…………………………………...4

Figure 2-1 West Branch sub-basins developed using HEC-GeoHMS…………….…………9

LIST OF TABLES

Table 1 24 hour precipitation depths for Clearfield, PA……………………………………6

Table 2 Sub-basin characteristic for use in HEC-HMS……………………………………10

Table 3 Muskingum routing parameters for West Branch…………………………………11

Table 4 West Branch land uses……………………………………………………………12

Table 5 Curve numbers for corresponding soil types based on land usage………………..13

Table 6 New West Branch CNs compared to old CNs……………………………………14

Table 7 Pre-calibration values for West Branch………..…………………………………15

Table 8 New West Branch Muskingum (K) values………………………………………..16

Table 9 Post-calibration figures for West Branch………………………………………….17

Table 10 HEC-RAS calibration Storms…………………………………………….…...18

Table 11 HEC-RAS results……………………………………………………….…..18

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1 Background and Introduction to HEC Programs

1.1 Site Background

The Susquehanna River Basin drains 27,510 square miles of water, supplying water for nearly 4 million people. It covers half of Pennsylvania, as well as portions of Maryland and New York. It is also one of the most flood prone watersheds in the country, experiencing a “devastating flood” on average every 14 years with damages totaling $150 million annually (Susquehanna).

The West Branch of the Susquehanna (from now on referred to as the “West Branch”) is focused primarily in the center of Pennsylvania (see figure 1-1). It flows northeast through the Allegheny Mountains, turning southeast at Renovo and cutting through a series of valleys and ridges. The area is covered mainly by forests, with the western portions more covered by coal mining and the eastern and southern portions being covered more by agricultural and urban lands. The area primarily being focused on in this study reaches from the Curwensville Dam to Karthaus (see figure 1-2). The watershed in question was delineated using USGS Stream Stats in Pennsylvania (PA Stream Stats).

Figure 1-1 Susquehanna Basin With West Branch (http://www.srbc.net/atlas/westbr.asp)

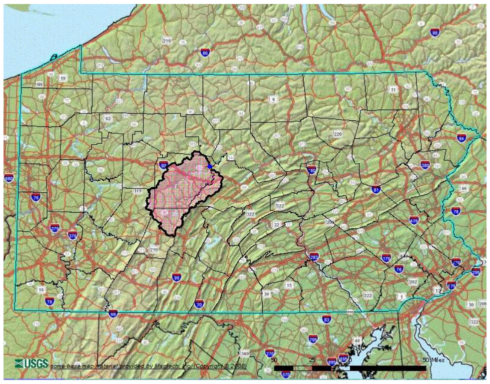

Figure 1-2 Area of Study

Using PA Stream Stats, it was determined that watershed being studied covers approximately 1464 mi^2. This area includes 2572 miles of streams and receives an average annual precipitation of approximately 41.937 inches. Glendale Lake and Curwensville Lake are the two main reservoirs within the watershed.

1.2 HEC-HMS and HEC-RAS

HEC-HMS and HEC-RAS are the two programs that will be used to model the watershed's response to pre-designated storm events. HEC-HMS stands for the Hydrologic Engineering Center Hydrologic Modeling System. It was developed by the Army Corps of Engineers to "simulate the precipitation-runoff processes of dendritic watershed systems" (USACE 2010 3.5). HMS produces hydrographs (graphs that show discharge of a stream vs. time) that can be used in combination with other programs to assist state and government agencies in studies involving water supply, flow forecasting, impacts of urbanization and much more.

The watershed is first represented in HMS using a basin model. Watershed characteristics such as area and baseflow are entered first, followed by the preferred methods for calculating loss and routing parameters (see sec. 2-3). Once the watershed has been successfully entered, the precipitation event is put into HMS. The National Resource Conservation Service (NRCS) provides several different options are available for the distribution of the precipitation over the watershed. Types I and IA are for Pacific, maritime regions, Type III is for the Gulf of Mexico and Atlantic regions and Type II is for the rest of the United States. In this study, Type-II storm distributions were used.

Although a couple precipitation gages are available throughout the watershed, the variance between the gages generally did not vary more than 1/10", so the precipitation events from Clearfield Creek were used uniformly across the area with no fear of inaccuracies from spatial variability. Figure 1-3 shows the previously modeled West Branch of the Susquehanna in HEC-HMS.

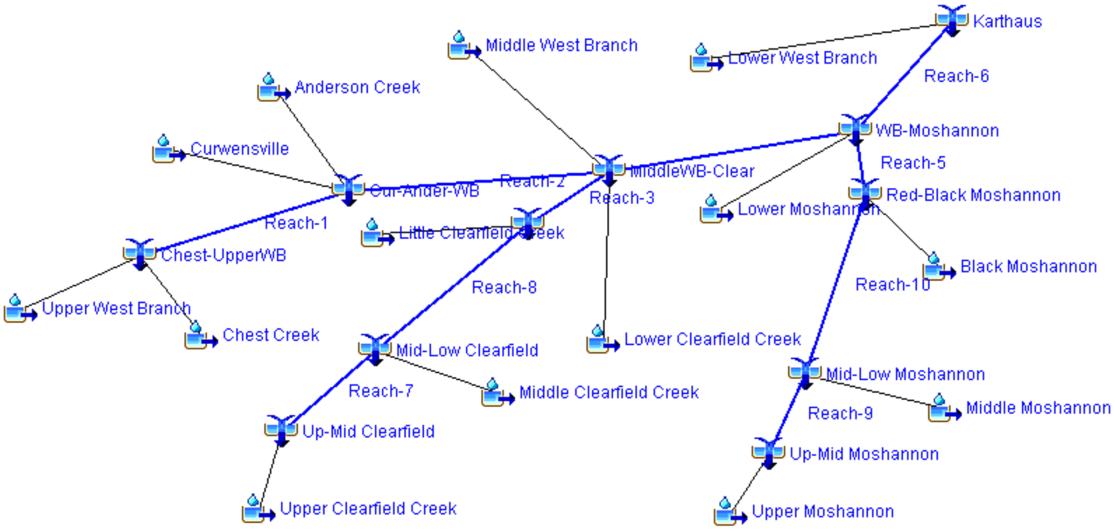

Figure 1-3 HMS Model of the West Branch of the Susquehanna Basin

Once the watershed has been modeled and the precipitation readied to be spread over the watershed, the HMS model is run and a flow resulting from the precipitation is calculated. This flow is then fed into HEC-RAS (River Analysis System). HEC-RAS "allows you to perform one-dimensional steady flow, unsteady flow calculations, sediment transport/mobile bed computations and water temperature modeling" (USACE 2010 4.1). The flow obtained from HMS is entered into RAS as a steady flow, from which point HEC-RAS will model and display how the flow would affect the water levels in the Susquehanna. Figure 1-4 shows the overview of the geometric cross sections of the

West Branch in HEC-RAS. Figure 1-5 shows a sample cross-sectional view of a flow profile calculated with a steady flow.

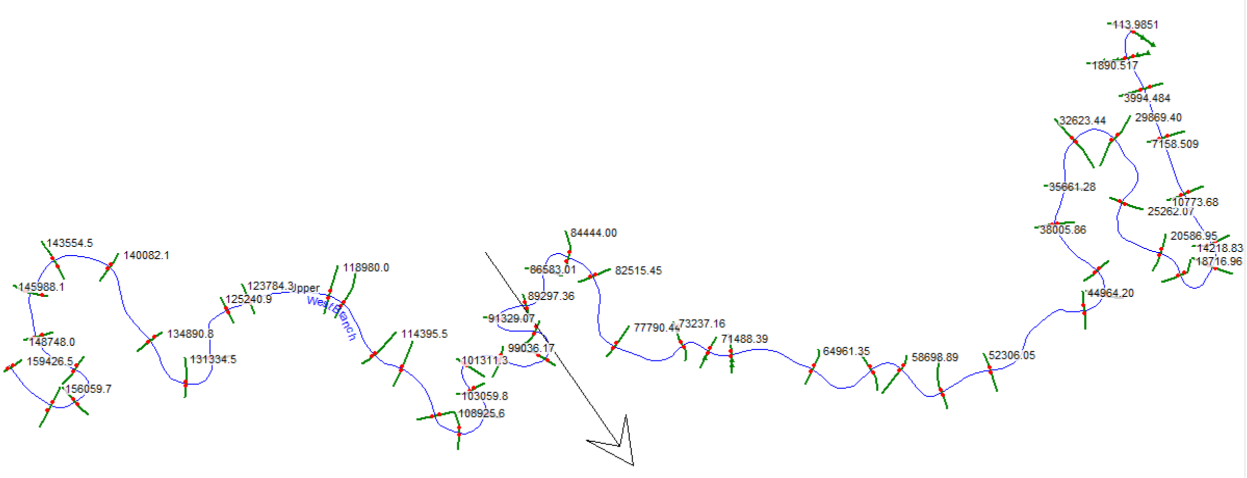

Figure 1-4 Summary of Geometric Cross Sections of the West Branch in HEC-RAS

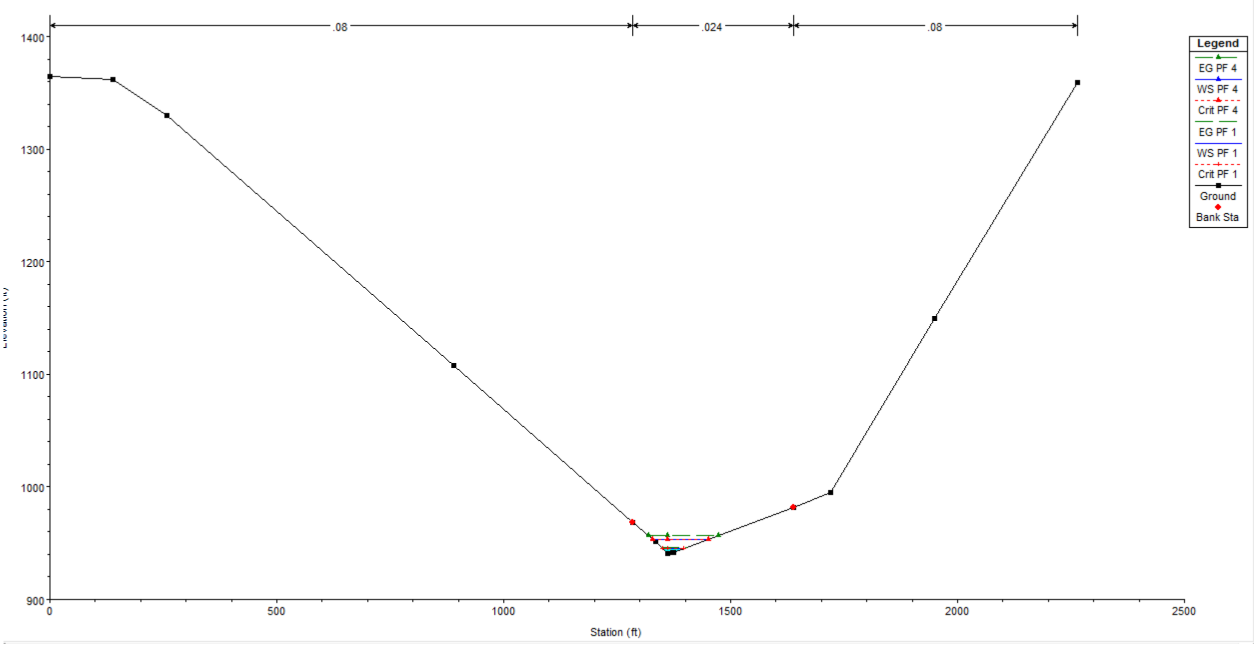

Figure 1-5 Sample Cross Sectional View from HEC-RAS

2 Previous Modeling

2-1 Overview

As part of an independent study in Spring 2011, the area in the West Branch from Curwensville Dam to Karthaus was modeled and flow calculations were started in HMS and RAS. The methods were "somewhat crude" by the authors' own admissions (Bakey), but their results were not that far off from PA Stream Stats' results for the same returns.

2-2 Precipitation

Precipitation is the driving force of both the HEC-HMS and HEC-RAS models. There are three main categories that precipitation can be divided into. First is convective, which consists of the heating of the air at the surface and usually results in thunderstorms or flash flood events. Orographic precipitation occurs when moist air is lifted into the atmosphere (common in western United States). Finally there is cyclonic – movement of air masses in warm and cold fronts. Most of the rain events in Pennsylvania are cyclonic.

As previously mentioned, spatial variability is an important aspect to take into consideration when modeling a precipitation event. The previous calculations performed on this watershed assumed that the precipitation from the Clearfield precipitation monitoring system was representative of the precipitation across the entire watershed. Table 1 shows the 24 hour precipitation depths used to model the West Branch in HMS obtained from the National Oceanic and Atmospheric Administration's Precipitation Frequency Data Server. The return period indicates the likelihood of that storm event occurring. For example, a 5-year return period indicates a storm of that magnitude will occur on average once every five years. The precipitation values increase as the return period increases, indicating that the severe storms occur less frequently.

Table 1 24 hour precipitation depths for Clearfield, PA

Return Period	**2-year**	**5-year**	**10-year**	**50-year**	**100-year**
Precipitation (in)	2.54	3.12	3.6	4.85	5.45

Precipitation depths from gages within the region rarely varied more than 1/10". In addition, studies have shown that for "single events with a longer duration, the spatial distribution of precipitation influences less the mean catchment precipitation because differences in rainfall are more balanced" (Tetzlaff 135). Because the events being used for calibration in this model are single events with longer duration, for the scope and purpose of this thesis it will be assumed that the precipitation can be applied over the entire basin uniformly.

2-3 Runoff

Rainfall excess, or "runoff", is rainfall that is neither retained on the land surface nor infiltrated into the soil. After moving across the watershed, this runoff enters tributaries and waterways, becoming direct runoff. Simply put, the excess rainfall is calculated from the following equation:

$$\text{Excess precipitation} = \text{Storm precipitation} - \text{Hydrologic losses}$$

There are several contributing factors to hydrologic losses: interception (caught by vegetation), depression storage, infiltration and evapotranspiration (water intercepted or used by the atmosphere). Losses are primarily attributed to infiltration, with some concessions made for interception and depression storage.

There are also several methods used to calculate hydrologic losses. The most widely used method, and the method used for this study, is the NRCS Curve Number (CN) approach. By combining the ratio of actual runoff to potential runoff and principles of continuity, NRCS came up with an equation for excess precipitation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

Where: P_e = Direct runoff

P = Depth of precipitation

I_a = Initial abstraction before ponding

S = Potential maximum retention

Through empirical studies of many small watersheds, an empirical relation was discovered for I_a:

$$I_a = 0.2S$$

The aforementioned equation can now be transformed to:

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where:

$$S = \frac{1000}{CN} - 10$$

The curve number is a weighted number developed by NRCS to estimate the amount of precipitation is infiltrated into the soil of the watershed given soil types and land use. This way, the amount of runoff can be determined by subtracting the infiltration. These curve numbers can range from 0 – 100 but typically occur between 30 and 98. A higher curve number means less infiltration (leading to more runoff) and therefore leads to larger peak flows – the opposite goes for low curve numbers. The United States Department of Agriculture's TR-55 manual contains charts that shows what curve numbers result from a given land use and various soil types. Each soil type has a corresponding curve number that is dependent on the land use.

In the previous research, the curve number was developed using a combination of ArcGIS and HEC-GeoHMS. A 30-meter Digital Elevation Model (DEM) was first obtained from the Pennsylvania Spatial Data Access (PASDA) website. A DEM is a 3-dimensional projection of the terrain surface, in this case broken into 30 meter resolution. Using ArcGIS tools, a watershed was delineated from the gaging station at Karthaus. From there, the watershed was further delineated into 14 smaller sub-basins using HEC-GeoHMS. The curve numbers for each of the respective sub basins was determined by visual inspection of the satellite imagery – this is one area that will be addressed with calibration. Figure 2-1 shows the 14 sub-basins created in HEC-GeoHMS.

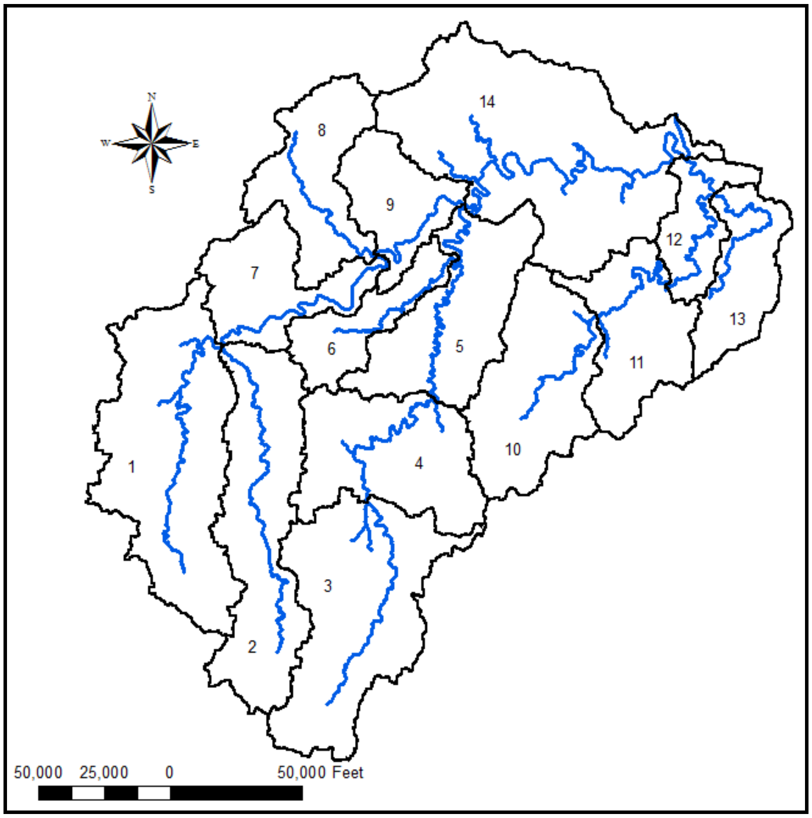

Figure 2-1 West Branch sub-basins developed using HEC-GeoHMS

Another important factor in determining the rainfall-runoff relationship is the lag time of a watershed. The lag time is defined as the amount of time, in hours, that it takes to get from the peak of the precipitation event to the peak amount of discharge due to said event. There are several methods used to calculate lag time, the most popular being the NRCS lag equation, the segmental approach, and the Folmar/Miller equation. The previous research relied on the Folmar/Miller equation, due to its reliance on the main limiting factor: the longest hydraulic length. The basin lag time was determined using:

$$T_L = \frac{L^{0.65}}{83.4}$$ (Folmar and Miller)

Where: L = Longest hydraulic length (m)

T_L = Lag time

Table 2 shows the summary of each sub-basin's area, lag time and curve number. The sub-basin numbers refer to the numbers in figure 2-1.

Table 2 Sub-basin characteristics for use in HEC-HMS

Designation	Sub-Basin Name	Sub-Basin Area (mi^2)	Sub-Basin Lag Time (hr)	Sub-Basin Curve Number
1	Upper West Branch	180.97	15.79	72
2	Chest Creek	137.88	16.75	72
3	Upper Clearfield Creek	156.89	13.41	69
4	Middle Clearfield Creek	109.09	11.75	72
5	Lower Clearfield Creek	105.39	14.46	70
6	Little Clearfield Creek	47.46	11.37	72
7	Curwensville	73.94	12.69	74
8	Anderson Creek	83.27	12.32	71
9	Middle West Branch	58.56	9.10	75
10	Upper Moshannon Creek	111.12	11.94	72
11	Middle Moshannon Creek	81.41	12.69	73
12	Lower Moshannon Creek	42.44	11.17	67
13	Black Moshannon Creek	59.63	12.32	68
14	Lower West Branch	238.72	18.74	72

After the curve numbers and lag times were entered, a routing method had to be chosen. Muskingum routing, the most widely used method, was chosen. Muskingum routing requires two parameters: the Muskingum (X) parameter is weighting factor that depends on the shape of the modeled wedge storage (Mays) and the Muskingum (K) is a coefficient that is approximately equivalent to the travel time of through a given reach. The Muskingum (X) was assumed to be 0.25 (to represent a natural channel), and the Muskingum (K) was calculated using an assumed velocity of 7 ft/s through each reach. This value was chosen without any stream data, nor is it likely to occur uniformly throughout each reach – this will also be addressed in calibration. Table 3 shows the Muskingum parameters used in the previous calculations. The reach numbers refer to the reaches in figure 1-3.

Table 3 Muskingum routing parameters for West Branch

Reach	**Muskingum (K) (hr)**	**Muskingum (X)**
Reach 1	4.66	0.25
Reach 2	2.65	0.25
Reach 3	3.97	0.25
Reach 4	4.49	0.25
Reach 5	1.96	0.25
Reach 6	9.28	0.25
Reach 7	3.24	0.25
Reach 8	3.40	0.25
Reach 9	1.20	0.25
Reach 10	0.70	0.25

3 Calibration Techniques

3-1 Curve Number and Lag Time

The first step in calibrating the previously modeled work involves fine tuning each sub-basin's curve number and lag time. The first step in improving the accuracy of the curve numbers is to determine the land use for each sub-basin. The land use is important to understand because it affects the amount of runoff in a given watershed – as such, it's integrally related to the curve number. After delineating the entire watershed using PA Stream Stats (see figure 1-2), the watershed's land use was calculated using the website's built-in tools. As the website is unable to delineate sub-basins within a watershed, the land use for the watershed is assumed to be uniformly representative of each sub-basin. Table 4 shows the land uses that were determined using PA Stream Stats.

Table 4 West Branch land uses

Land Use	**% of Watershed**
Forest	80.51
Impervious	0.74
Residential (1/4 acre)	7.19
Meadow	11.56

The next step is to determine the soil type for each of the sub-basins. The United States Department of Agriculture (USDA) has a Web Soil Survey online that separates an inputted Area of Interest (AOI) into its respective soil groups. This site separates the soil types into four classifications developed by the NRCS. These types are referred to as type A, B, C, and D. Type A soils (sands) have very high infiltration rates and drain very well. As a result, runoff is generally fairly low with type A soils. Infiltration rates decrease from A to D. Type D soils (clays) drain poorly or not at all and have very low infiltration rates – this leads to higher runoff rates. Because the AOI is limited to 10,000 acres, occasionally smaller samples of the sub-basins were inputted into the Web Soil Survey as a representative sample of the larger sub-basin. Once the percentages for respective soils are found for each sub-basin, they are multiplied by the corresponding CNs for the previously determined land uses to determine an average weighted curve number for each land use. The curve numbers for the land uses in West Branch are shown in table 5 (TR-55):

Table 5 Curve numbers for corresponding soil types based on land usage

Land Use	**Soil Type**			
	A	**B**	**C**	**D**
Forest	36	60	73	79
Impervious	98	98	98	98
Residential (1/4 acre)	61	75	83	87
Meadow	30	58	71	78

The weighted curve numbers are then multiplied by the percentage of the watershed that the land use covers (see table 4) to come up with a final weighted curve number for the sub-basin in question.

The lag time was not addressed in calibration for several reasons. First, the Folmar/Miller equation has shown that the longest hydraulic length is the main limiting factor in determining the lag time of a watershed – “the inclusion of other watershed characteristics in the equation did not improve its ability to predict the lag time” (Folmar and Miller). Although the previous research was not able to empirically determine the CN via HEC-GeoHMS, the program is very accurate when analyzing DEMs to determine the longest hydraulic length. To this end, the previously calculated lag time was assumed to be an accurate calculation. Table 6 shows the new curve numbers for each sub-basin and how they compare to the previously calculated CNs and lag times.

Table 6 New West Branch CNs compared to old CNs

Designation	Sub-Basin Name	Area (mi^2)	Old CN	New CN	Sub-Basin Lag Time (hr)
1	Upper West Branch	180.97	72	75.11	15.79
2	Chest Creek	137.88	72	70.30	16.75
3	Upper Clearfield Creek	156.89	69	74.83	13.41
4	Middle Clearfield Creek	109.09	72	70.34	11.75
5	Lower Clearfield Creek	105.39	70	68.22	14.46
6	Little Clearfield Creek	47.46	72	69.63	11.37
7	Curwensville	73.94	74	70.48	12.69
8	Anderson Creek	83.27	71	72.09	12.32
9	Middle West Branch	58.56	75	69.64	9.1
10	Upper Moshannon Creek	111.12	72	68.54	11.94
11	Middle Moshannon Creek	81.41	73	63.09	12.69
12	Lower Moshannon Creek	42.44	67	68.95	11.17
13	Black Moshannon Creek	59.63	68	64.88	12.32
14	Lower West Branch	238.72	72	67.75	18.74

3-2 Muskingum (K) and Hydrograph Optimization

From section 2-3, it is known that the Muskingum (K) parameter used for routing was calculated very crudely. In order to more effectively model the West Branch’s response to designated rainfall events, the Muskingum (K) will be optimized using hydrographs from designated storm events. To best perform this optimization of the West Branch, hydrographs were obtained for the USGS for several sites within the region for two base storm events (see appendix). The storm events were chosen due to their longer duration and higher outputs. Data was restricted to storms over the past 37 years, as the USGS does not have digital data prior to 1985. The storm events chosen were entered in HEC-HMS as SCS Type-II storms with precipitation amounts gathered from precipitation gages at Clearfield. The precipitation was assumed to be uniform over the entire basin.

After analyzing the data and running the storm events through HMS, it was determined that the Muskingum (K) would be optimized against hydrograph data from the Clearfield Creek and Karthaus gaging stations. Clearfield and Karthaus are two of the more prominent gaging stations within the West Branch – Karthaus is located at the outlet of the watershed and Clearfield towards the middle (note: because of Karthaus' location, measured flow at that station will be considered the overall watershed flow).

Before the model could be calibrated, though, base conditions had to be set. Table 7 shows the resulting flow from pre-calibration CNs and Muskingum parameters for the West Branch and how they compare to values obtained from PA Stream Stats. Flows are shown from the two calibration stations as well as three other stations located throughout the watershed for thoroughness.

Table 7 Pre-calibration figures for West Branch

Precip (in)	Precip Significance	Upper West Branch (cfs)	Black Moshannon (cfs)	Curwensville (cfs)	Clearfield Creek (cfs)	Karthaus (cfs)	Stream Stats (cfs)
2.54	2-year	2,752	804	1,536	6,455	16,630	24,100
3.12	5-year	4,429	1,379	2,416	10,351	26,800	34,800
3.6	10-year	5,990	1,931	3,227	13,966	36,253	42,300
4.85	50-year	10,578	3,608	5,582	24,588	64,008	59,300
5.45	100-year	12,975	4,505	6,802	30,081	78,504	67,000
2.9	11/9/1997	3,763	1,148	2,068	11130*	23728*	
4.55	9/18/2004	9,231	3,109	4,894	14668*	54395*	

*USGS stream gage values

After the base calculations were performed, the known hydrographs obtained from the USGS were imported into HEC-HMS. The observed flows were then compared to the output derived from HMS and an “optimization trial” was run for each storm event gathered. An optimization run is a tool HMS utilizes that assists users in generating more realistic results. After an optimization run is performed, a suggested value for the parameter being optimized is suggested and the user has the option of running another optimization run with this suggested value. As expected, the more optimization iterations run, the more closely the HMS output will agree with the observed flow. In this case, the Muskingum (K) was the parameter being optimized. After many optimization runs using multiple storms, new numbers were obtained for Muskingum (K) values – these results can be seen in table 8.

Table 8 New West Branch Muskingum (K) values

Reach	Muskingum (K) (hr)	New Muskingum (K) (hr)	Muskingum (X)
Reach 1	4.66	4.45	0.25
Reach 2	2.65	2.3	0.25
Reach 3	1.96	1.6	0.25
Reach 4	9.29	9.95	0.25
Reach 5	1.2	0.9	0.25
Reach 6	0.7	0.3	0.25
Reach 7	3.97	3.9	0.25
Reach 8	4.49	4.2	0.25
Reach 9	3.24	3.75	0.25
Reach 10	3.4	3.1	0.25

After the new Muskingum (K) values were calculated, the five design storms were run through the West Branch model again with the new K values and the new curve numbers. The new flow values obtained from HMS can be seen in table 9.

Table 9 Post-calibration figures for West Branch

Precip (in)	Precip Significance	Upper West Branch (cfs)	Black Moshannon (cfs)	Curwensville (cfs)	Clearfield Creek (cfs)	Karthaus (cfs)	Stream Stats (cfs)
2.54	2-year	3,411	610	1,189	6,859	14,577	24,100
3.12	5-year	5,286	1,107	1,962	10,930	23,961	34,800
3.6	10-year	6,990	1,598	2,689	14,455	32,807	42,300
4.85	50-year	11,902	3,129	4,856	25,274	59,179	59,300
5.45	100-year	14,228	3,964	6,000	30,906	73,106	67,000
2.9	11/9/1997	4,541	905	1,653	11130*	23728*	
4.55	9/18/2004	10,472	2,669	4,216	14668*	54395*	

*USGS stream gage values

As can be seen from the results, the newly calibrated curve numbers and Muskingum (K) values assisted more in making the larger storms match up with the results from PA Stream Stats than the smaller storms. The smaller storms HMS output remained smaller than the PA Stream Stats output. The 50-year and 100-year storms, though, converged more towards the known output (the 50-year storm was within 0.2%). The convergence of the higher intensity storm events towards their real world equivalents was most likely due to larger intensity storm events being used to calibrate the model.

3-3 HEC-RAS Modeling

In order to show the resulting river response to the flow resulting from HEC-HMS, cross sections of the West Branch basin had to be taken. Previous modelers first took Light Direction and Radar (LiDAR) data and gathered data regarding the centerline of the channel, flow paths, bank stations and cross-sections. 16 LiDAR data tiles were put into ArcGIS and placed together so that the whole basin was represented. Overall, however, the LiDAR data was not very accurate in modeling the representative cross-sections as it is less accurate at lower flow rates. The LiDAR data was then imported to HEC-RAS for hydraulic modeling. There were 56 cross-sections modeled from HEC-GeoRAS that were then imported to HEC-RAS. After the importation, the channels were calibrated using eight known flows over the last 74 years and the 50 and 100-year

year values from PA Stream Stats. The gage heights generated from HEC-RAS were compared to the known gage heights resulting from the calibration storm events. The known flows used for calibration are shown in table 10, and the resulting flows from HEC-RAS are seen in table 11.

Table 10 HEC-RAS Calibration Storms

Event Name	Q (CFS)	Gauge Height (ft)
1	1000	2.18
2	6000	5.43
3	10500	7.05
4	12000	7.49
14-Mar-2010	25400	10.56
18-Sep-2004	55200	15.22
10-Mar-1964	63500	15.98
23-Jun-1972	84300	18.57
50 Year	59300	15.59
100 Year	67000	16.41

Table 11 HEC-RAS Results

Revision 12: Station 113.9851, n=0.024								
Profile	Q Total	Min Ch El	W.S. Elev	Vel Chnl	Flow Area	Top Width	Gauge HT	RAS HT
	(cfs)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(ft)
PF 1	1000	832.66	835.87	4	250.07	100.07	2.18	3.21
PF 2	6000	832.66	840.74	6.67	899.44	166.5	5.43	8.08
PF 3	10500	832.66	843.23	7.74	1355.74	200.41	7.05	10.57
PF 4	12000	832.66	843.91	8.02	1496.09	209.74	7.49	11.25
PF 5	25400	832.66	848.52	9.75	2605.89	272.49	10.56	15.86
PF 6	55200	832.66	854.24	12.92	4389.96	350.55	15.22	21.58
PF 7	63500	832.66	855.5	13.66	4843.13	367.75	15.98	22.84
PF 8	84300	832.66	858.38	15.26	5959.12	407.01	18.57	25.72
50 yr	59300	832.66	854.88	13.96	4615.09	359.2	15.59	22.22
100 yr	67000	832.66	856.01	13.96	5031.29	374.66	16.41	23.35

4 Conclusion and Recommendations

Overall, the calibration attempts made at HEC-HMS were moderately successful. The new curve numbers provided the model with some real-world input that had previously only been speculated about. Similarly, improving the Muskingum (K) values through optimization using known discharge hydrographs allows the user to more confidently model real-world storm events in the West Branch of the Susquehanna basin. Although the higher frequency storm outputs were slightly lower than previously (most likely due to the calibration with bigger storm events), the lower frequency storm events converged more towards real world values. These storms are more important to model accuracy due to their propensity to cause more damage than higher frequency (and thus lower intensity) storms.

The HEC-RAS component was largely left alone for several reasons. The primary reason was that previous modelers had performed exhaustive iterations of calibration on the model, varying the Manning’s n values and other parameters until flow matched the known outputs fairly well. Another reason involves the accuracy of the LiDAR data modeled in HEC-GeoRAS then imported to HEC-RAS. The LiDAR data did not really provide high enough resolution data to provide accurate estimations for lower flow data.

It is thereby recommended that future modeling work on the West Branch focus primarily on improving the accuracy of the data obtained and modeled with HEC-GeoHMS and HEC-RAS. If properly utilized, HEC-GeoHMS can provide a far more accurate curve number and lag time for each sub-basin than the methods described previously. In addition, more work would need to be done regarding the accuracy of the Manning’s n values found through LiDAR data.

APPENDIX A

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Bachelor of Science in Civil Engineering
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Professional Experience

Intern May 2011-July 2011
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- Worked 40 hrs/wk assisting senior engineers in CAD and GIS water projects. Also proofread reports and proposals, created charts, gathered data and updated cost analyses

Sales Associate September 2008-January 2009
Circuit City, Wilmington, DE

- Provided customer service and answered questions about a variety of small electronics

Educational Experience

Analyst September 2010-December 2011
Honors Projects

- Performed testing and research on Fiber Reinforced Polymer's effect on cylindrical and rectangular concrete slabs
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Designer January 2010-May 2010
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- Co-designed a prosthetic leg and transportable food cart with students from EAFIT University in Colombia and Coventry University in England
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Activities & Awards

- Computer skills: Hec-HMS, Hec-RAS, AutoCAD, ArcGIS, ArcMAP, Solid Works, Matlab, Microsoft Office
- One of fifteen freshman published in Penn State's "Best of Freshman Writing" Magazine
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References available upon request