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Flood Stage Forecast Maps

Upper Susquehanna River Basin
Susquehanna River Basin Commission

Final Report

Dewberry

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1 | Introduction

The high quality data developed by the Federal Emergency Management Agency (FEMA) following the June 2006 flood in the Susquehanna River Basin provided an incalculable opportunity to improve the flood forecasting and warning systems deployed by the Susquehanna River Basin Commission (SRBC). As noted in the SRBC's post-flood report, one of the shortcomings of the current warning system was the lack of emergency response tools. Flood Severity Inundation Maps developed by the National Weather Service (NWS) are the response to this need. This report describes Dewberry's approach to producing inundation maps at ten River Forecast Points (RFPs) located in the Upper Susquehanna subbasin (Figure 1), including the:

- Chenango River at Chenango Forks, NY
- Chenango River at Greene, NY
- Susquehanna River at Bainbridge, NY
- Susquehanna River at Binghamton, NY
- Susquehanna River at Conklin, NY
- Susquehanna River at Owego, NY
- Susquehanna River at Unadilla, NY
- Susquehanna River at Vestal, NY
- Susquehanna River at Windsor, NY
- Unadilla River at Rockdale, NY

Intended for emergency managers, these maps provide an important tool to protect the lives and property of Susquehanna River Basin residents.
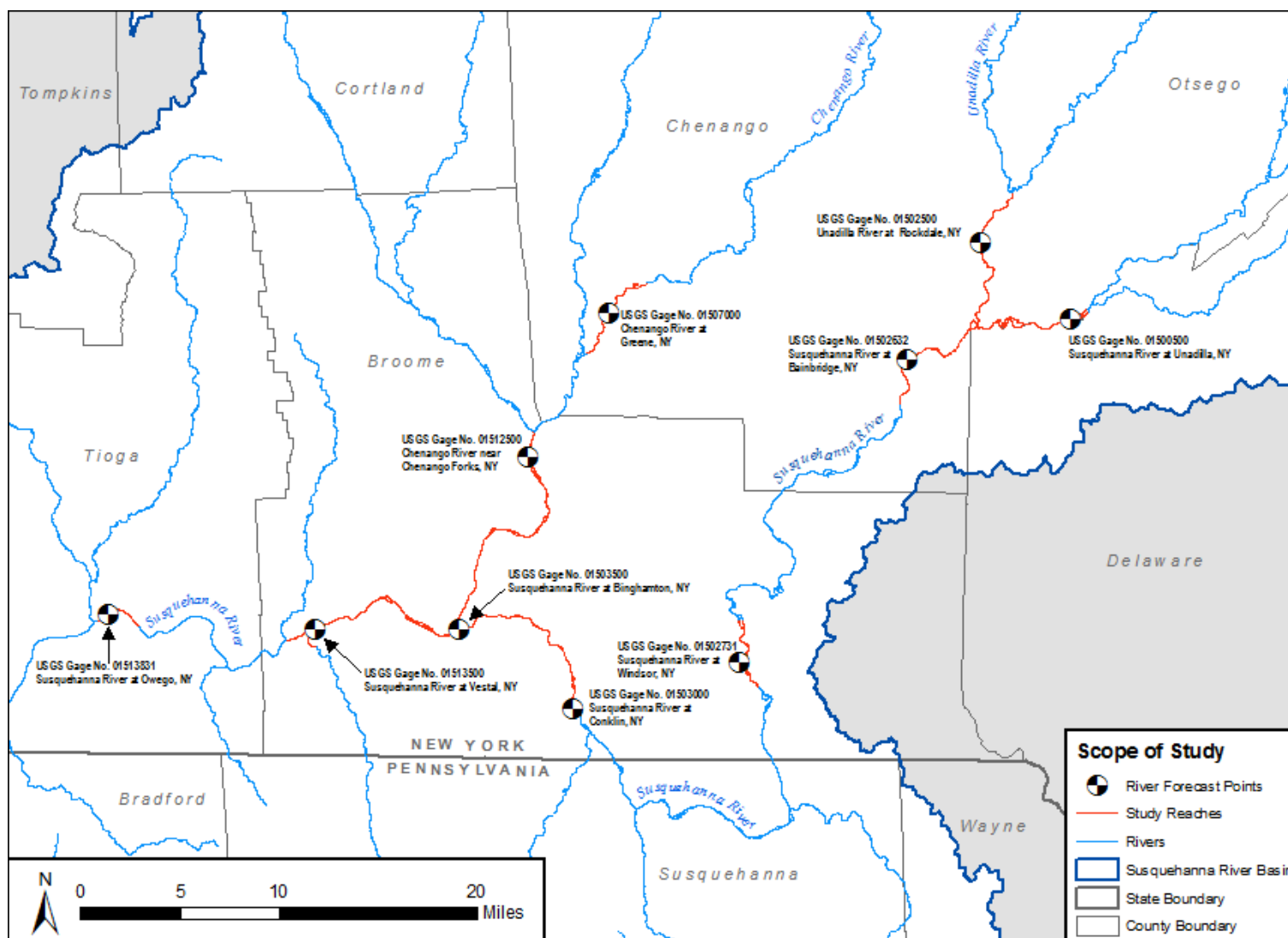
Figure 1 – River forecast points and reaches for which flood stage forecast maps were developed.

2 | Data Development

2.1 Datum Conversion

To facilitate the hydrologic and hydraulic modeling efforts, the gage elevations at all RFPs were converted from the National Geodetic Vertical Datum of 1929 (NGVD 29) to the North American Vertical Datum of 1988 (NAVD 88). This conversion was performed using the Corpscon 6.0 computer software (USACE, 2004). For display purpose, the SRBC Flood Stages in the Forecast Maps are based upon the depth of flooding (in feet) above the gage elevation. Each RFP map series includes the actual water surface elevations of each flood stage increment in both NGVD 29 and NAVD 88.

Table 1 - Summary of river forecast point gage elevations and flood forecast stages.

USGS Gage No.	Gage Name	Latitude	Longitude	Vertical Datum Conversion	Gage Height (ft)		Flood Stage (ft)		NWS Flood Stages (ft)			
					NGVD29	NAVD88	NGVD29	NAVD88	Action	Flood	Moderate	Major
1500500	Susquehanna River at Unadilla, NY	42.3217	-75.3169	-0.387	997.25	996.86	1008.25	1007.86	9.0	11.0	13.0	14.5
1502632	Susquehanna River at Bainbridge, NY	42.2914	-75.4767	-0.404	956.55	956.14	969.55	969.14	13.0	15.0	20.0	22.0
1503000	Susquehanna River at Conklin, NY	42.0353	-75.8033	-0.522	841.04	840.52	852.04	851.52	8.0	12.0	14.0	20.0
1503495	Susquehanna River at Binghamton, NY	42.0936	-75.9147	-0.466	821.49	821.02	835.49	835.02	12.0	14.0	15.0	18.0
1513500	Susquehanna River at Vestal, NY	42.0908	-76.0564	-0.469	799.19	798.72	817.19	816.72	15.0	18.0	21.0	27.0
1513831	Susquehanna River at Owego, NY	42.0972	-76.29	-0.535	776.64	776.105	806.6	806.1	29.0	30.0	32.0	33.0
1502731	Susquehanna River at Windsor, NY	42.0747	-75.6381	-0.466	900	899.53	917.0	916.5	13.0	17.0	19.0	20.5
1502500	Unadilla River at Rockdale, NY	42.3778	-75.4064	-0.338	992.25	991.91	1003.25	1002.91	8.0	11.0	12.0	13.0
1507000	Chenango River at Greene, NY	42.3244	-75.7717	-0.42	892.58	892.16	905.58	905.16	11.0	13.0	17.0	22.0
1512500	Chenango River near Chenango Forks, NY	42.2181	-75.8486	-0.449	871.63	871.18	881.63	881.18	8.0	10.0	12.6	20.3

2.2   Terrain

Light Detection And Ranging (LiDAR) data was used in this project, specifically for the cross-section geometry of the three hydraulic models, the resultant floodplain delineation, and the depth grid production. LiDAR was obtained through the post-disaster flood hazard data effort conducted by FEMA under the Hazard Mitigation Technical Assistance Program (HMTAP) 1650 contract, which included data covering 3-mile buffers around each of the three river studies in the Susquehanna basin. As a result, three different terrain databases were needed for this project. Under this task, terrains were newly built for the Unadilla and Susquehanna Rivers; whereas terrain for the Chenango River was already delivered under the HMTAP project. Depending on the size of the datasets, a selection was made for the storage type: a file geodatabase (FGDB) was used for Unadilla, the smaller dataset; while a spatial database environment (SDE) was used for the larger datasets, in Chenango and Susquehanna.

2.4   Study Reach Data Development

2.4.1   Determine Target Reach

As per the proposal, the target reach lengths were initially defined based on pending data for population centers around the gage. The reach determination was based on two criteria: maximizing the inclusion of nearby population centers respective to the gage, while ensuring that the hydrologic analyses results produced remain valid. The following steps were taken for this target reach determination:

- Visually inspect the areas around the gage to see where the surrounding population centers exist and try to maximize the target reach length.
- Determine which two cross sections from the HEC-RAS model define the boundaries of the target reach.
- Compute the change in 100-yr discharge between the two bounding sections and make sure that the change is not greater than 5%.
- Assess the change in Water Surface Elevation (WSEL) between the two bounding sections in HEC-RAS, ensuring that there are no sudden drops in the elevations within the target reach.
- If the results do not appear valid from a discharge or WSEL perspective, iterate the process with smaller bounds.

2.4.2   Determine Stage Increments/Water Surface Elevations

The theme of this section is to describe the process for determining the stage increment. The stage increment is then used to produce at least six depths between the minor and major flood stages (or maximum flood stage record). For example, at the Susquehanna River at Bainbridge, the stages ranged between 11 ft and 27 ft respectively (during a 2006 flood not reported by NWS). At 2ft increments, 9 stage values were needed between these two values. The resulting stage values at the gage used are provided in the tables in Appendix B.

3 | Hydrologic and Hydraulic Modeling

The hydrologic and hydraulic models used to develop flood stage forecast maps for the 10 RFPs in the Upper Susquehanna River Basin were adapted from models developed under the FEMA HMTAP 1650 contract. For more information regarding the model parameters and methodology, consult the final hydrology and hydraulics reports for that contract (Appendix A).

3.1   Rating Curve Development and Validation

In order to validate the approach and underlying assumption of consistency between the FEMA-derived and the USGS NY Water Science Center-derived rating curves, two sets of discharges were obtained and compared under both models: the first set of discharges included annual peak flows reported by USGS while the second set of flows included randomly generated events between the 10% annual chance (10-year) and 0.2% annual chance (500-year) flood frequencies. The decision to present the results against two different flow regimes stems from the fact that the FEMA model was developed for a particular flow regime (between the 10% and 0.2% annual chance flood frequencies) and may not compare well for flows outside this range. Nonetheless, for the SRBC inundation mapping project, a range of flows is needed including flows above and below the FEMA range; therefore, it was critical to evaluate differences at the extreme flows. It is important to note that the FEMA model was calibrated using high water marks gathered following the June 2006 event.

FEMA's model of the Susquehanna River in the upper basin was developed in two pieces — labeled as the "upper basin" and the "lower basin" to differentiate the segment of the Susquehanna River upstream or downstream of the Pennsylvania–New York state border, respectively. The models were then compared to their respective rating curves (as shown in the example below).
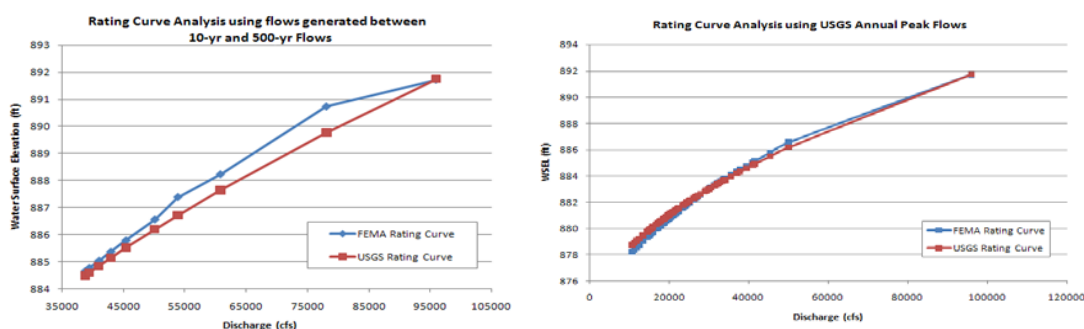
Figure 2 – USGS and FEMA Rating Curve Comparisons for *10-yr and 500-yr Flows* and *USGS Annual Peak Flows*

For all gages except Bainbridge, the average difference between the model and USGS rating curves is reasonable (below 1.5 ft), especially when the associated levels of uncertainty are considered.

However, when comparing annual peak flows, the average difference for all gages — including Bainbridge — at each stage of the rating curve is approximately 1 foot.

The consequence of this analysis is critical for understanding the engineering principles underlying the inundation mapping products. While USGS has expressed some uncertainty with the accuracy of the rating curve at higher frequencies (lower elevations), the inundation maps are

targeted from action stage to 125% of the flood of record. If the FEMA-derived rating curve is incorrect, it is either conservative or understated with respect to the relationship between discharge and elevation. If the FEMA rating curve is conservative, i.e. Susquehanna at Bainbridge, then the NWS' discharge forecast would predict a lower elevation than FEMA's model would indicate for the same flow. If the FEMA rating curve is understated, i.e. Susquehanna at Windsor, then the NWS' discharge forecast would predict a higher elevation than FEMA's model would indicate for the same flow.

For both situations, Advanced Hydrologic Prediction Service (AHPS) forecasts are presented as elevations. Because inundation map libraries are also presented as elevations, the underlying difference in the engineering analyses can be obscured.

Overall, the range of higher flows, the USGS rating curves and the FEMA rating curves are reasonable within the key target domain for the inundation mapping products — concerning flows greater than the 2% annual chance (50-year). Therefore the model rating curves are in agreement for the purpose of inundation mapping of NWS flood stages.

3.2   HEC-RAS Model Development

The following subsections provide our rating curve comparative analysis for each gage in the scope (see Section 1) under the USGS annual peak flow and the 10-yr to 500-yr flow regimes. The reason for this dual approach ensures that the models are consistent, particularly since NWS forecasts are based on the USGS rating curves. Also included in each analysis is a description of the model reach and evaluation between the 500-yr versus the 125% flow.

3.2.1   Chenango River at Chenango Forks

Model Reach Determination

The model reach for the Chenango Forks RFP is defined as the section between the most downstream station cross sections at 362.75 ft and 71,282.844 ft in the FEMA model. The model reach is approximately 13.4 miles, extending between the confluence of the Chenango and the Tioughnioga Rivers to the Susquehanna River. The reach length for this gage was extended beyond the normal parameters specified for this study, where the normal difference in drainage area between the upstream and downstream limits were within 1% of the drainage area at the gage. For this gage, the difference was approximately 8% due to the fact that there are no major tributaries entering the Chenango River through this reach. However, discharges were modified by transferring the flow at the gage downstream through the use of New York State USGS regression equations. This deviation was coordinated with the SRBC prior to mapping.

Location	Drainage Area (miles)
US from gage	1474
DS from gage	1594
At the gage	1475

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 96,000 cfs (which occurred in 1935); accordingly, 125% of this value is 120,000 cfs. The 500-yr flow model at this location — which is higher than the 2006 event — is 78,094 cfs.

- The HEC-RAS model was run by inputting the 125% flow; however, the cross sections in FEMA's model did not extend sufficiently to contain the lateral expansion of the floodplain.

- Moreover, by examining the 93 annual peak flows we can conclude that the model does not need to include the 125% of the highest peak flow, since the likelihood for such an event is very low:

  - The peak flow occurred in 1935 with 96,000 cfs; while the second highest flow is 50,100 cfs, almost half of the 1935 flood.
  - There are 93 annual recorded peaks, of which 91 are below 50,100 cfs.
  - Excluding the 1935 event, the average peak flow at this gage is 23,383 cfs — almost 1/4th of 96,000 cfs.
  - Therefore, treating the second highest flow as the maximum flood on record, the 125% flood flow would be 62,625 cfs.

- Since 62,625 cfs is less than FEMA's 500-year flow event, the model is considered sufficient. The resulting geometry in the truncated SRBC model was able to contain the 120,000 cfs required — which is also 125% of the highest recorded peak flow.

Rating Curve Comparison

The FEMA and USGS rating curves are compared by analyzing the differences between the stages (also known as water surface elevations, or WSELs) for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flows.

FEMA Flood Frequency Analysis

- A total of 10 flows were generated between the 10- yr and 500-yr FEMA model flows, and then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

- The difference between the two WSEL series was computed, recording an average of **0.364 ft.**

Figure 3 – Chenango River at Chenango Forks, FEMA Flood Frequency Analysis

Historic *Annual Peak Flow Analysis*

- USGS reported 93 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models in order to obtain their WSELs.

- The difference of the WSEL series was computed, recording an average of **0.234 ft.**

Figure 4 – Chenango River at Chenango Forks, Historic Annual Peak Flow Analysis

3.2.2   Chenango River at Greene, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Chenango Forks RFP is determined between station cross sections located at 103,784.6 ft and 136,216.09 ft. The length of the model reach is approximately 6.14 miles, extending between the confluence of the Chenango River with Genegantslet Creek and Spring Brook. The drainage areas at the upstream and downstream ends of the reach and the gage are 581.14, 595.93, and 589.5 square miles, respectively. A comparison of the drainage areas (DA) — 8.36 and 6.43 square miles — indicates that there is little change across the RFP; as a result, one can expect the discharge at the gage to be representative of the discharge throughout the entire reach.

For hydraulic modeling purposes, the model reach was extended two cross sections downstream of the downstream end of the scope reach. The extension was incorporated in order to dampen the effects of uncertainties in the boundary condition assumptions (normal depth) on the model reach. Therefore, the model starts at the cross section with station 101,764.84 ft. and the reach of interest starts at station 103,784.6 ft.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 27,100 cfs (in 2006); accordingly, 125% of this value is 33,875 cfs, a discharge value close to the model 500-yr flow, which is 32,753 cfs.

- The HEC-RAS model was successfully run with the 125% flow since the cross sections were large enough to include the lateral expansion of the floodplain, which resulted from the greater flows.

Rating Curve Comparison

The FEMA and USGS rating curves are compared by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage and sample discharges between the 10-yr and 500-yr flows.

FEMA Flood Frequency Analysis

- A total of 23 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

- The difference between the two WSEL series was computed, recording an average of **0.303 ft.**
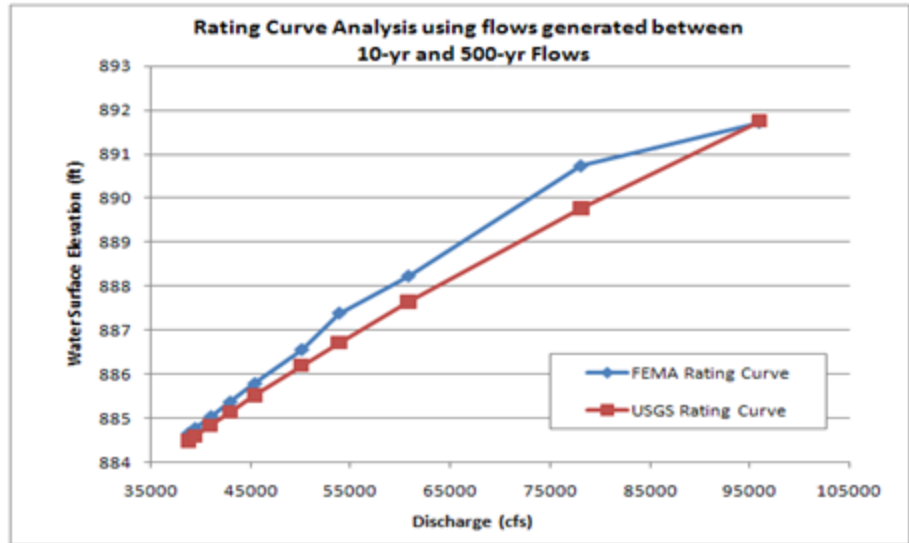
Figure 5 – Chenango River at Greene, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 71 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models in order to obtain their WSELs.

- The difference of the WSEL series was computed, recording an average of **1.233 ft.**
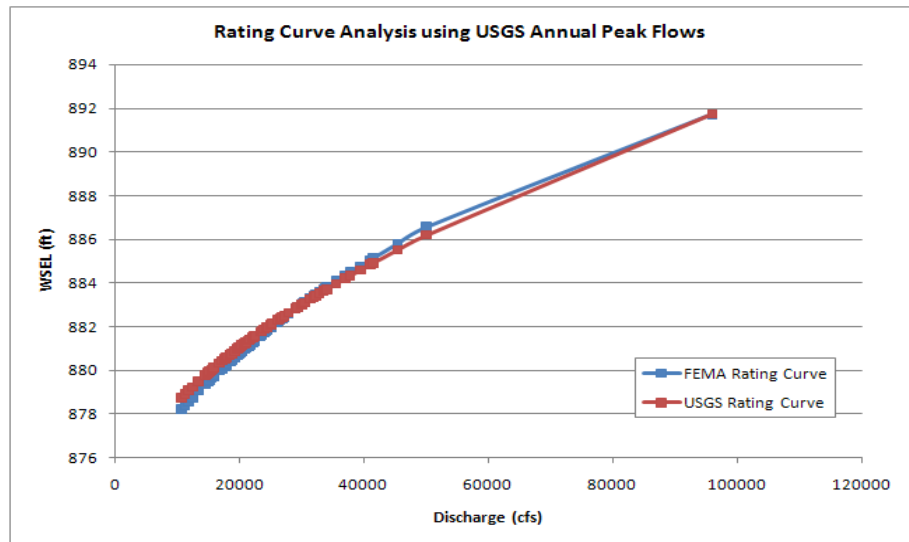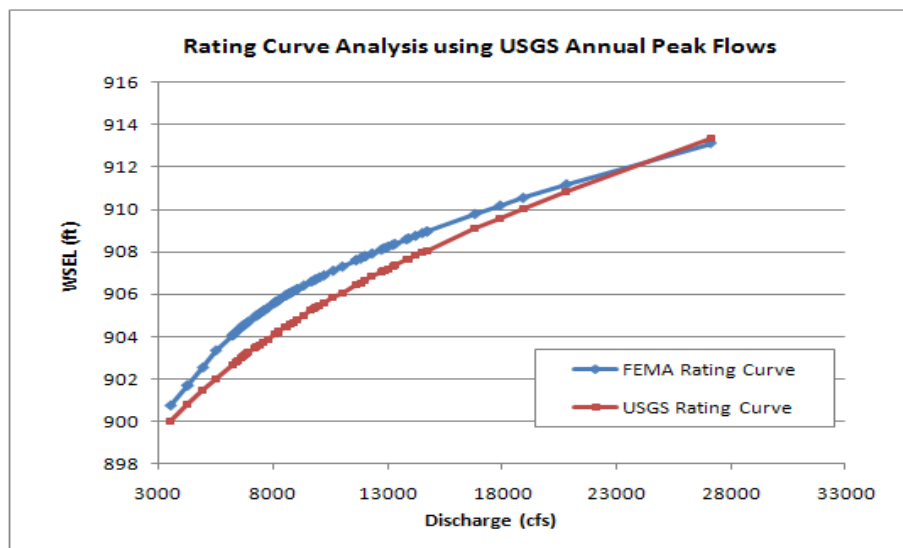

Figure 6 – Chenango River at Greene, NY, Historic Annual Peak Flow Analysis

3.2.3 Susquehanna River at Bainbridge, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Bainbridge RFP is determined between station cross sections located at 187,865 ft and 166,095 ft. The length of the model reach is approximately 4.1 miles, extending downstream of the Unadilla River confluence to Bennetsville Creek. The drainage areas at the upstream and downstream limits of the reach and at the gage are 1593, 1623, and 1621 square miles, respectively. A comparison of the DAs indicate that the model reach is uniform, based upon the small areal differences (of 28 and 2 square miles, or approximately 1%) between each end and the gage.

For hydraulic modeling purposes, the model reach was extended two cross sections downstream of the downstream end of the scope reach. The extension was incorporated in order to dampen the effects of uncertainties in the boundary condition assumptions (normal depth) on the model reach. Therefore, the model starts at the cross section with station 158,948.3 ft.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 58,700 cfs (recorded in 2006); accordingly, 125% of this value is 73,375 cfs.

- The HEC-RAS model was successfully run with the 125% flow since the cross sections were large enough to include the lateral expansion of the floodplain, which resulted from the greater flows.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage and sample discharges between the 10-yr and 500-yr flow.

FEMA Flood Frequency Analysis

- A total of 30 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

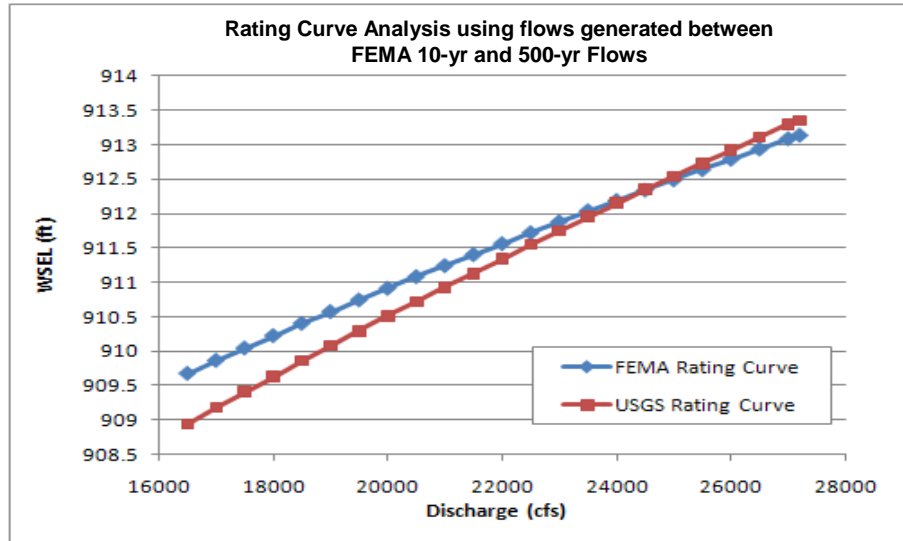- The difference between the two WSEL series was computed, recording an average of **1.05 ft.**
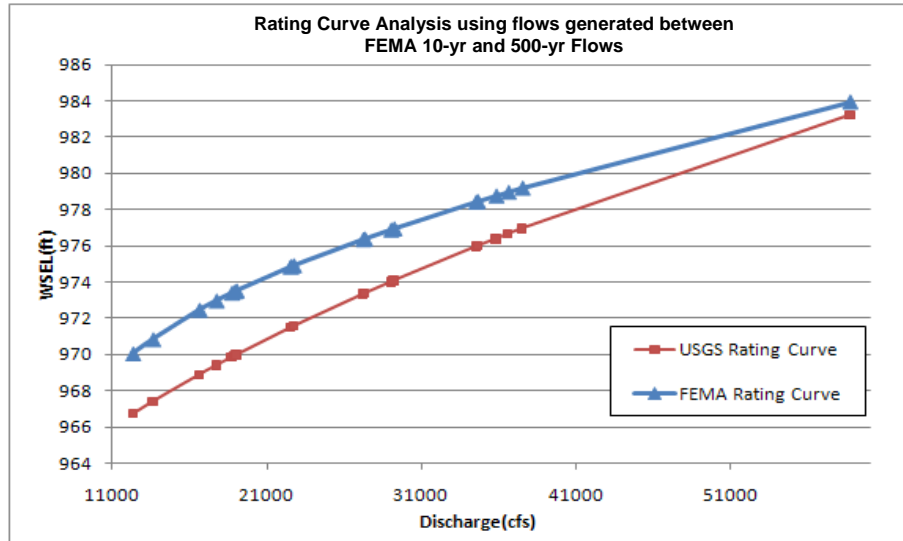
Figure 7 –Susquehanna River at Bainbridge, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 20 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to obtain their WSELs.

- The difference of the WSEL series was computed, recording an average of **2.94 ft.**
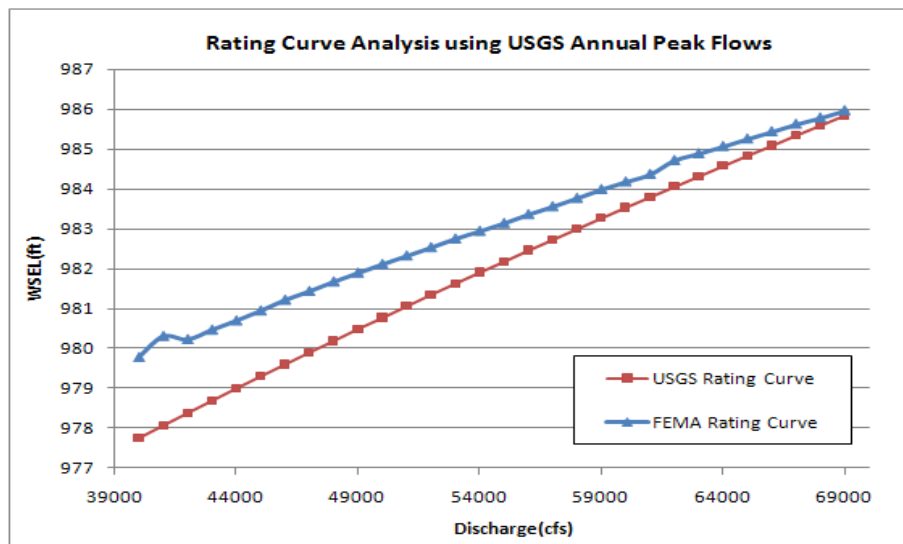
Figure 8 – Susquehanna River at Bainbridge, NY, Historic Annual Peak Flow Analysis

3.2.4 Susquehanna River at Binghamton, NY

The model for the RFP at Binghamton varies from the other RFP model methodologies due to a complex hydraulic system located near the gage. This includes the presence of the confluence with the Chenango River just downstream of the USGS staff gage at Tompkins Street, as well as numerous levees on both sides of the river.

To account for the influence of the Chenango River in the model — which is not assumed to have a coincident peak with the Susquehanna River — the downstream boundary conditions of the Binghamton reach use the most upstream discharges for the RFP at Vestal, NY.

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Binghamton RFP is determined between station cross sections located at 203,961 ft and 237,033 ft. The length of the model reach is approximately 6.3 miles. The model reach extends downstream of the confluence with the Chenango River. The drainage areas at the upstream and downstream ends of the reach and the gage are 2,265 square miles, 3,890 square miles, and 2,283 square miles, respectively. This downstream difference is addressed with the Vestal flow.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 78,128 cfs (in 2006); accordingly, 125% of this value is 97,660 cfs.

- The HEC-RAS model was successfully run with the 125% flow since the cross sections were large enough to include the lateral expansion of the floodplain that resulted from the greater flows.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stage/WSEL(s) for a given discharge set. A graphic is unavailable for the randomized FEMA (10-yr to 500-yr) flows since the Binghamton gage is not used for discharge calculation in the FEMA model. As a result, only an analysis of the historic annual peak flows is available.

Historic Annual Peak Flow Analysis

- USGS reported 73 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models in order to obtain their WSELs.

- The difference of the WSEL series was computed, recording an average of **3.72 ft.**

Figure 9 – Susquehanna River at Binghamton, NY, Historic Annual Peak Flow Analysis

3.2.5 Susquehanna River at Conklin, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Conklin RFP is determined between station cross sections located at 237,033 ft and 265,189 ft. The length of the model reach is approximately 6.1 miles, starting immediately downstream of the confluence of Snake Creek to the upstream section of Stanley Hollow Creek. The drainage areas at the upstream and downstream ends of the reach and the gage are 2,232 sq mi., 2,249 sq mi., and 2,232 sq. mi., respectively. A comparison of the DAs indicate that the model reach is uniform, based upon the small areal differences (of 0 and 17 square miles, or less than 1%) between each end and the gage.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 78,000 cfs (in 2006); accordingly, 125% of this value is 96,000 cfs.

- The HEC-RAS model was successfully run with the 125% flow since the cross sections were large enough to include the lateral expansion of the floodplain that resulted from the greater flows.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flow.

FEMA Flood Frequency Analysis

- A total of 35 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

- The difference between the two WSEL series was computed, recording an average of **0.43 ft.**

Figure 10 – Susquehanna River at Conklin, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 93 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **1.20 ft.**
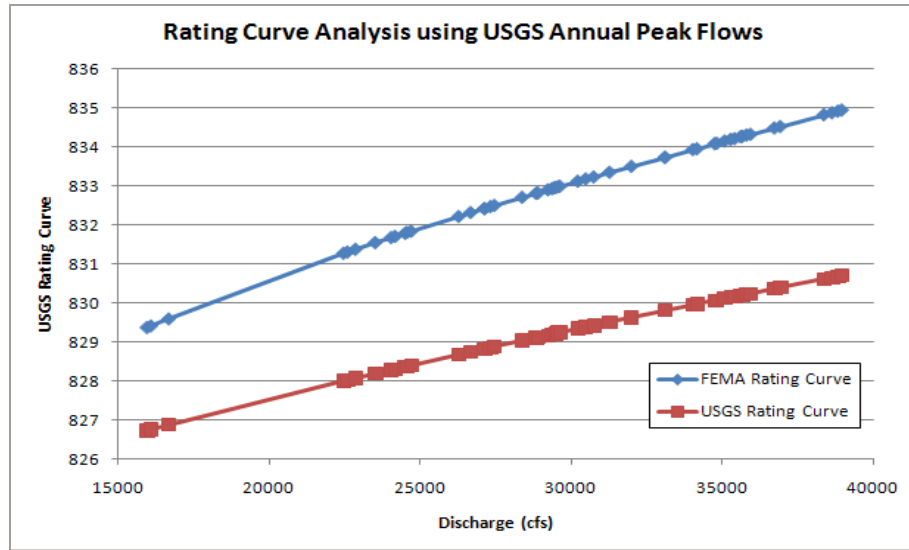

Figure 11 – Susquehanna River at Conklin, NY, Historic Annual Peak Flow Analysis

3.2.6   Susquehanna River at Owego, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Owego RFP is determined between station cross sections located at 97,737 ft and 83,995 ft. The length of the model reach is approximately 2.6 miles, extending between the confluence of Little Nanticoke Creek and Pumpelly Creek. The drainage areas (DAs) at the upstream and downstream ends of the reach and at the gage are 4,214, 4,226, and 4,217 square miles, respectively. A comparison of the DAs indicate that the model reach is uniform, based upon the small areal differences (of 9 and 3 square miles, or less than 1%) between each end and the gage.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFC is 127,000 cfs (in 2006); 125% of this value is 158,750 cfs.

- The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flow.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage and sample discharges between the 10-yr and 500-yr flow.

FEMA Flood Frequency Analysis

- A total of 37 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

- The difference between the two WSEL series was computed, recording an average of **0.83 ft.**
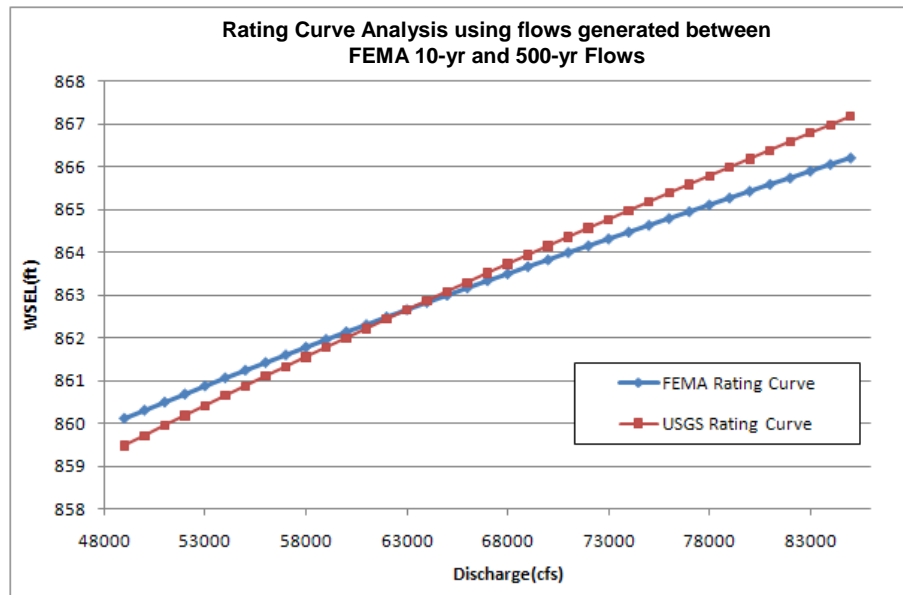
Figure 12 – Susquehanna River at Owego, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 17 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **1.32 ft.**
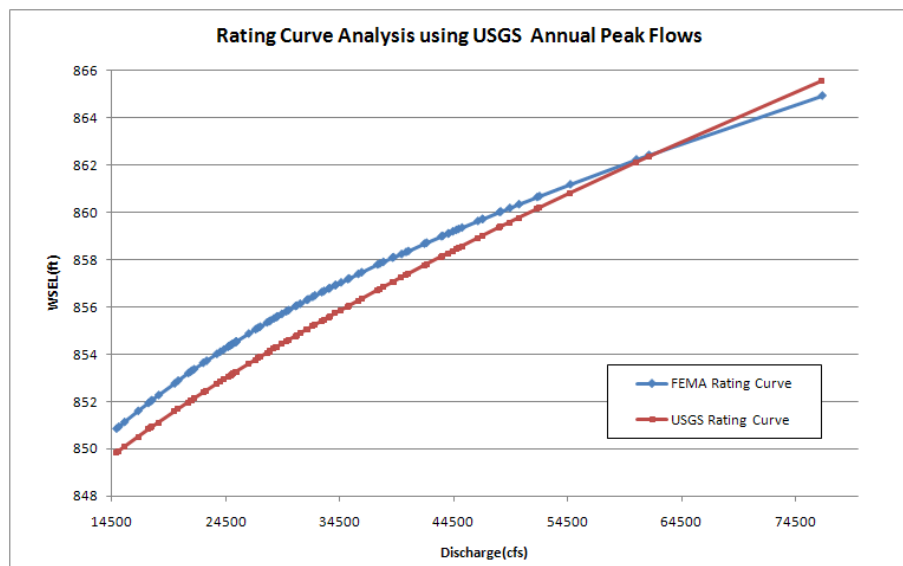

Figure 13 – Susquehanna River at Owego, NY, Historic Annual Peak Flow Analysis

3.2.7   Susquehanna River at Unadilla, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Unadilla RFP is determined between station cross sections located at 187,678 ft and 235,685ft. The drainage area for the upstream reach length and downstream reach length are approximately 979 and 1,030 sq. miles, respectively. The drainage area at the gage is approximately 984 sq. miles. The reach length for this gage was extended beyond the normal parameters specified for this study, where the normal difference in drainage area between the upstream and downstream limits were within approximately 1% of the drainage area at the gage. For this gage, the difference was approximately 4% due to the fact there are no major tributaries entering the Susquehanna River through this reach. Discharges were however modified by transferring the flow at the gage downstream through the use of New York State USGS regression equations. This deviation was coordinated with the SRBC prior to mapping.

Evaluate 500-yr Flow vs. 125% Flow

- The highest peak flow recorded at this RFP is 35,100 cfs (in 1935); 125% of this value is 43,875 cfs. The 500-year flow model, which is higher than the 2006 event, is 38,745 cfs.

- The HEC-RAS model was successfully run with the 125% flow, as shown by the cross sections' capacity to include the larger floodplain.

- All but two cross sections — at stations 229,100, and 229,620 — were considered sufficient to carry the flow.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flow.

> **FEMA Flood Frequency Analysis**
>
> - A total of 19 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.
>
> - The difference between the two WSEL series was computed, recording an average of **0.55 ft.**
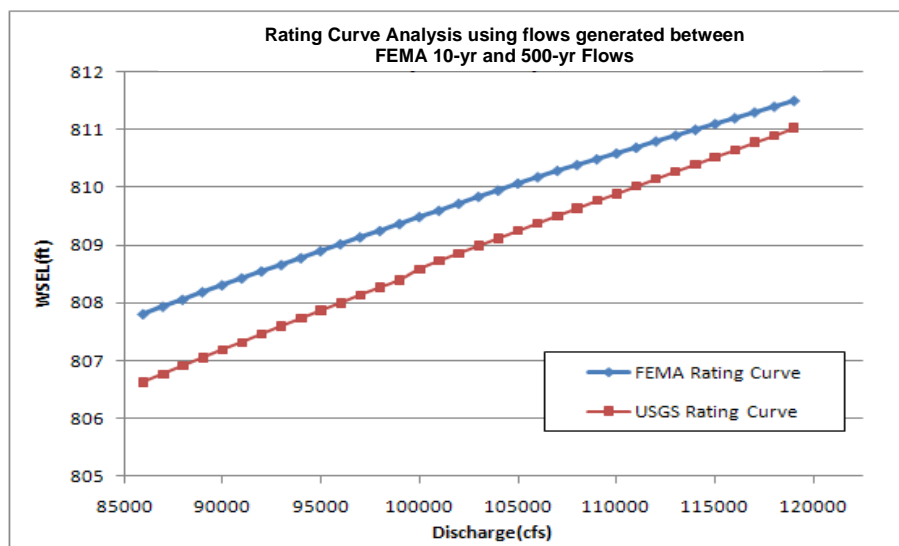
Figure 14 – Susquehanna River at Unadilla, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 72 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **0.44 ft.**
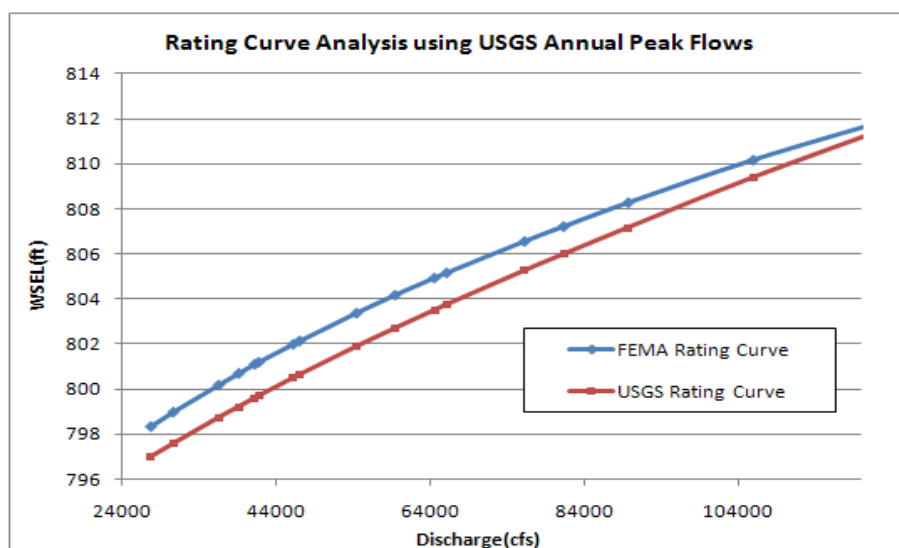

Figure 15 – Susquehanna River at Unadilla, NY, Historic Annual Peak Flow Analysis

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Bainbridge RFP is determined between station cross sections located at 48,104 ft and 25,660 ft. The length of the model reach is approximately 4.2 miles, starting downstream of Sage Creek to the upstream section of Tuscarora Creek. The drainage areas at the upstream and downstream ends of the reach and the gage are 1,836, 1,863, and 1,854 square miles, respectively. A comparison of the DAs indicate that the model reach is uniform, based upon the small areal differences (of 18 and 9 square miles, or approximately 1%) between each end and the gage.

For hydraulic modeling purposes, the model reach was extended two cross sections downstream of the downstream end of the scope reach. The extension was incorporated to dampen the effects of uncertainties in the boundary condition assumptions (normal depth) on the model reach. Therefore, the model starts at the cross section with station 17,153.418 ft.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flow.

> **FEMA Flood Frequency Analysis**
>
> - A total of 20 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.
>
> - The difference between the two WSEL series was computed, recording an average of **0.64 ft.**

Figure 16 – Susquehanna River at Windsor, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 32 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **0.49 ft.**
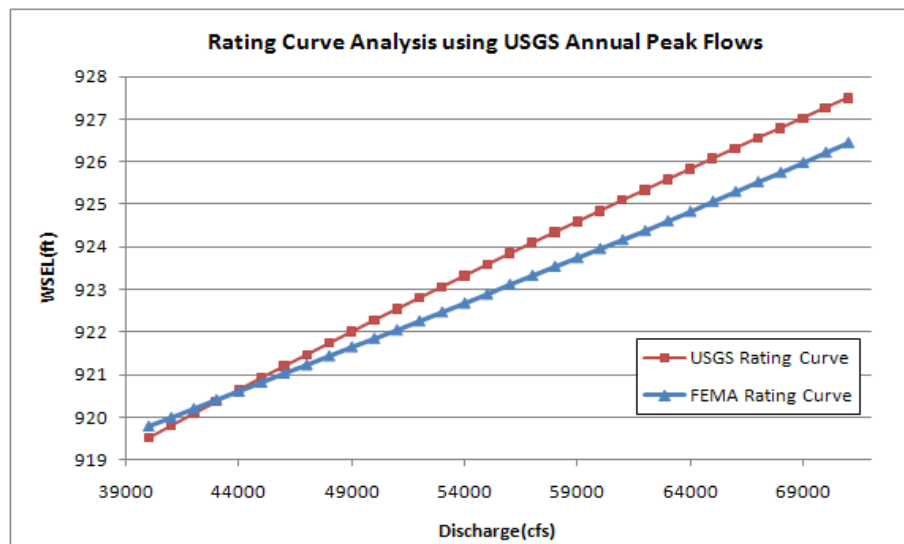
Figure 17 – Susquehanna River at Windsor, Historic Annual Peak Flow Analysis

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Susquehanna River at the Bainbridge RFP is determined between station cross sections located at 203,961 ft and 155,753 ft. The length of the model reach is approximately 9.2 miles, extending between the confluence at the Chenango River and near Anson Road. The drainage areas at the upstream and downstream ends of the reach and the gage are 3,884, 3,993, and 3,934 square miles, respectively. A comparison of the DAs indicates that the model reach is uniform, based upon the small areal differences (of 50 and 59 square miles, or approximately 1%) between each end and the gage. An additional flow change location is added near cross section at river station 184,015 ft to account for the difference in drainage areas.

Evaluate 500-yr Flow vs. 125% Flow

- ▪ The highest peak flow recorded at this RFC is 119,000 cfs (in 2006); accordingly, 125% of this value is 148,750 cfs.

- • The HEC-RAS model was successfully run with the 125% flow, as shown by the cross sections' capacity to include the larger floodplain.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage and sample discharges between the 10-yr and 500-yr flow.

FEMA Flood Frequency Analysis

- • A total of 34 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

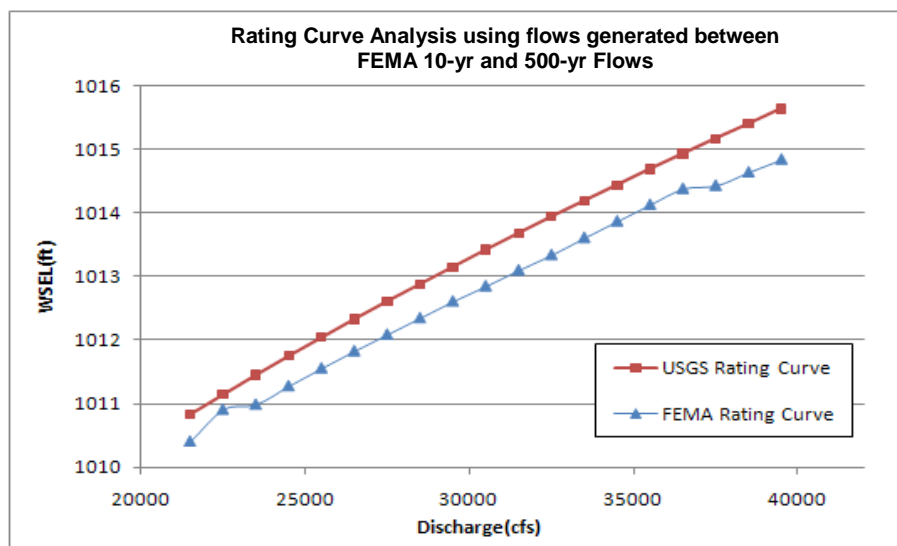- • The difference between the two WSEL series was computed, recording an average of **1.07 ft.**
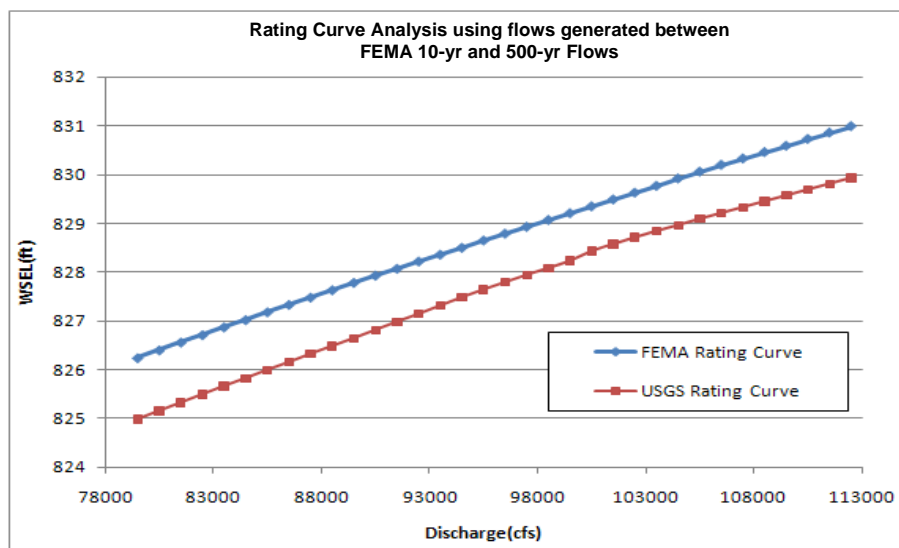
Figure 18 – Susquehanna River at Vestal, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 70 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **1.45 ft.**
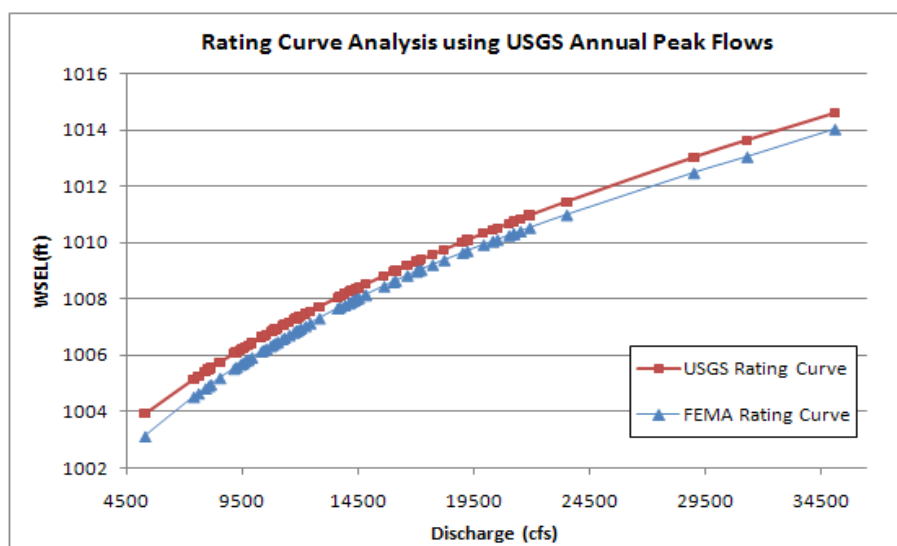

Figure 19 – Susquehanna River at Vestal, NY, Historic Annual Peak Flow Analysis

3.2.10 Unadilla River at Rockdale, NY

Model Reach Determination

Based on the requirement to optimize the inclusion of population centers while maintaining accurate recordings, the model reach for the Unadilla River at the Rockdale RFP is determined between station cross sections located at 152 ft and 46,912 ft. The length of the model reach is approximately 8.8 miles. The model reach extends between the confluence of Unadilla with the Susquehanna River and Butternut Creek. The drainage areas at the upstream and downstream ends of the reach and the gage are 581.14, 595.93, and 589.5 square miles, respectively. A comparison of the DAs indicate that the model reach is uniform, based upon the small areal differences (of 8.36 and 6.43 square miles, or approximately 1%) between each end and the gage.

For hydraulic modeling purposes, the model reach was extended two cross sections downstream of the downstream end of the scope reach. The extension was incorporated in order to dampen the effects of uncertainties in the boundary condition assumptions (normal depth) on the model reach. Therefore, the model starts at the cross section with station 101,764.84 ft.

Evaluate 500-yr Flow vs. 125% Flow

- For the current gage, the 125% flow is 28,875 cfs — a value greater than both the 500-yr and 2006 event flow, recorded at 24,208 cfs and 23,100 cfs, respectively.

- Since the discharge is greater than the maximum flow model, this flow needs to be input into the model and checked for water containment within the extent of the cross section.

- If the discharge is less than the largest of the 500-yr and 2006 event flows, further steps are not required and the model is deemed sufficient.

Rating Curve Comparison

The FEMA rating curve was compared to the USGS rating curve by analyzing the differences between the stages for a given discharge set. Two types of discharge data are used for this purpose: historic annual peak discharges published by USGS at the gage, and sample discharges between the 10-yr and 500-yr flow.

FEMA Flood Frequency Analysis

- A total of 34 flows were generated between the 10-yr and 500-yr FEMA model flows, which were then inputted into the FEMA and USGS models to obtain the respective WSELs at each stage.

- The difference between the two WSEL series was computed, recording an average of **1.07 ft.**
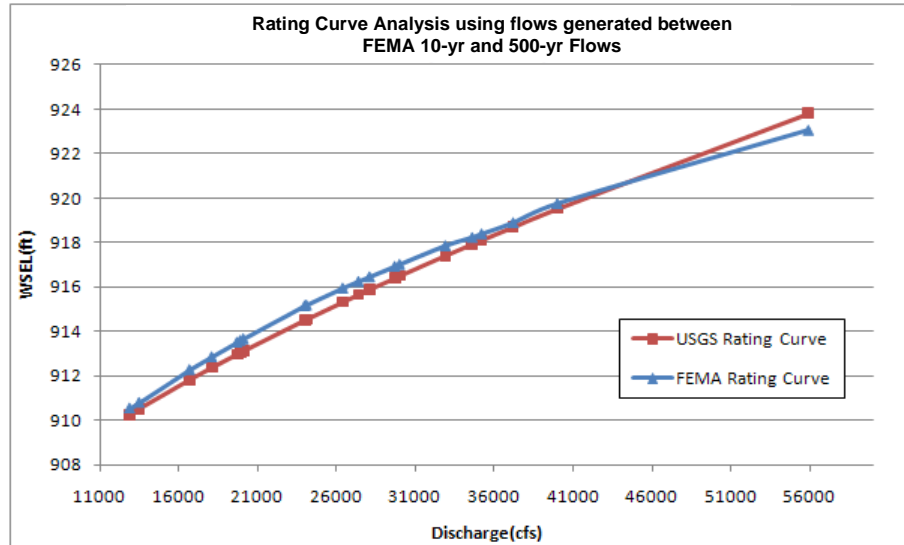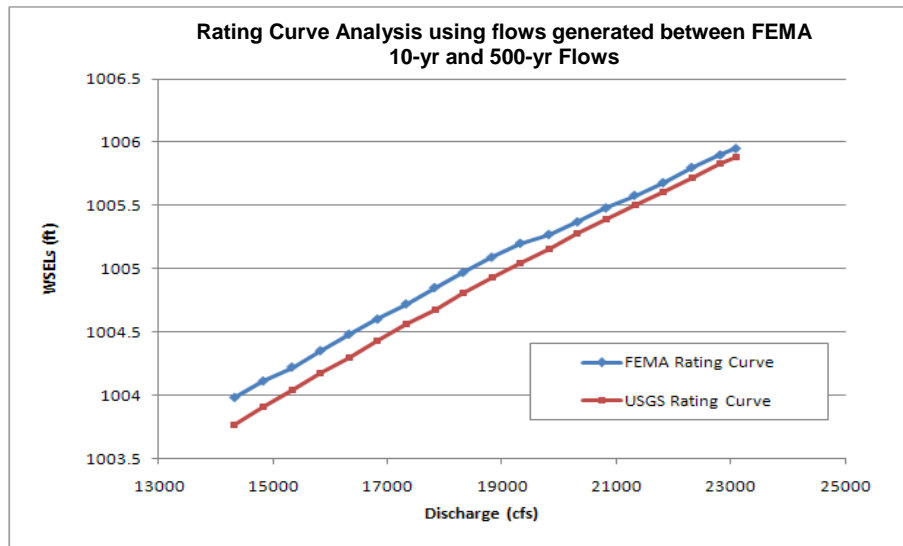
Figure 20 – Unadilla River at Rockdale, NY, FEMA Flood Frequency Analysis

Historic Annual Peak Flow Analysis

- USGS reported 70 annual peak flows for this gage, which were then inputted into the FEMA and USGS rating curve models to provide their respective WSELs.

- The difference of the WSEL series was computed, recording an average of **0.14 ft.**

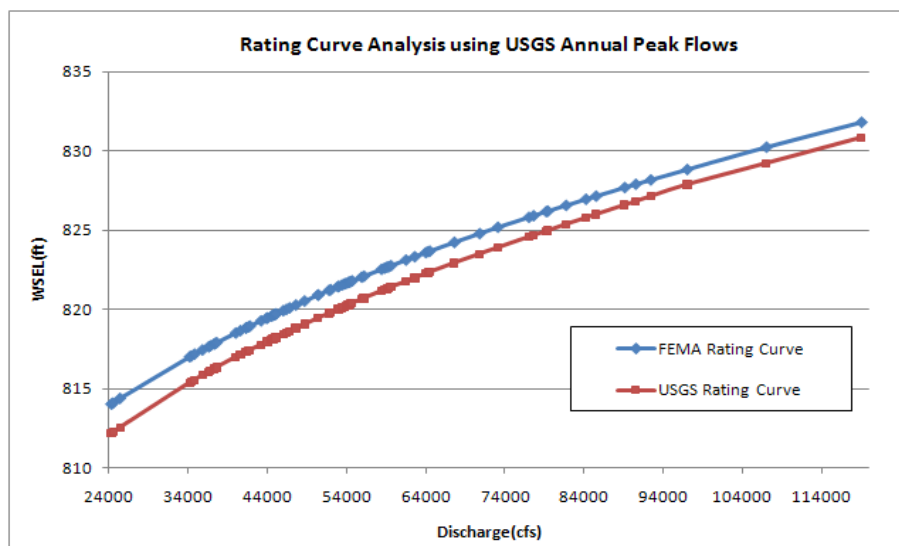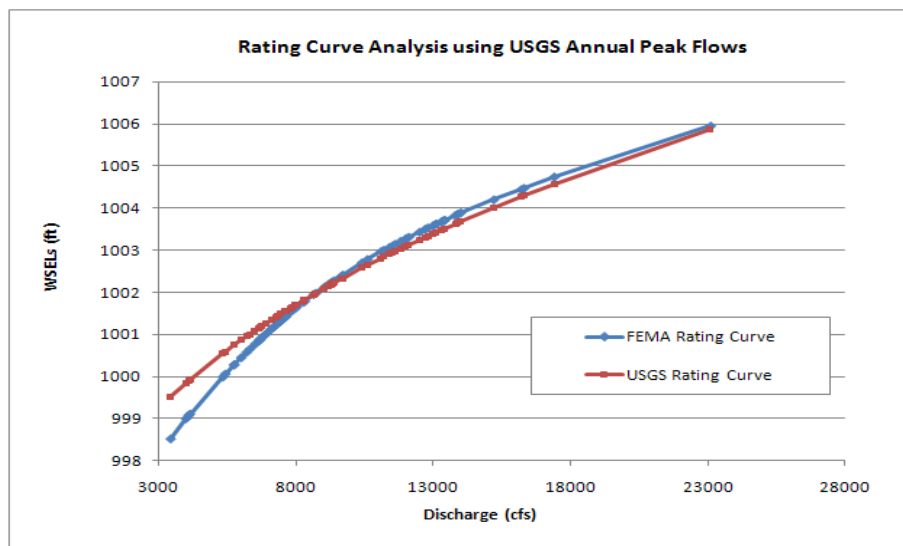**Figure 21 – Unadilla River at Rockdale, NY, Historic Annual Peak Flow Analysis**

3.2.11 Statistical Analysis

The following table shows the results from the Rating Curve Comparison: the FEMA Flood Frequency Analysis and the Historic Annual Peak Flow Analysis. The minimum, maximum and average are obtained for each River Forecasting Point, from which the average parameters are determined (bottom row).

It is important to note that under both analyses, there is a one-foot average difference between the FEMA and USGS Rating Curves. These two values — of 1.32 ft and 0.70 ft — comply within Dewberry's range of acceptability, therefore validating our approach in this Task 3 study.

Table 2 – Summary statistics for rating curve comparison. All values in feet.

RFP	River	USGS Peaks			FEMA Flow		
		Min	Max	Avg	Min	Max	Avg
Chenango Forks, NY	Chenango River	0.00	0.52	0.23	0.03	0.96	0.36
Greene, NY	Chenango River	0.22	1.50	1.23	0.01	0.73	0.30
Bainbridge, NY	Susquehanna River	0.73	3.57	2.94	0.12	2.23	1.05
Binghamton, NY	Susquehanna River	2.66	4.24	3.73	-	-	-
Conklin, NY	Susquehanna River	0.61	1.86	1.20	0.00	0.96	0.43
Owego, NY	Susquehanna River	0.30	1.51	1.32	0.41	1.15	0.83
Unadilla, NY	Susquehanna River	0.34	0.79	0.44	0.23	0.80	0.55
Vestal, NY	Susquehanna River	0.99	1.87	1.45	0.92	1.26	1.07
Windsor, NY	Susquehanna River	0.22	0.73	0.49	0.03	1.05	0.64
Rockdale, NY	Unadilla River	0.07	0.21	0.14	0.92	1.26	1.07
Average		0.61	1.68	1.32	0.30	1.16	0.70

4 | Flood Inundation Extent and Depth Grid Development

4.1   Inundation Mapping

After the hydraulic modeling was completed, the final water surface elevations were exported to a GIS using Dewberry's GeoFIRM suite of tools. This process populates hydraulic model cross sections with the water surface elevations for all calculated flood stages. The cross sections are then imported into Dewberry's GeoTerrain tool. GeoTerrain enables the creation of water surface elevation Triangulated Irregular Networks (TINs) that can be evaluated against a ground elevation surface to develop a floodplain. The tool leverages an ESRI *terrain* dataset to develop a floodplain that is based on the full range of available LiDAR data, rather than averaging many points together and reporting it as a cell value in a digital elevation model (DEM) in raster format. This process was used to develop inundation areas for all 10 RFPs.

After completing the GeoTerrain floodplain delineation, the process of creating the flood stage polygons begins. Following the modeling process, there were artifacts in the inundation polygons which had to be removed manually. These artifacts are results of LiDAR producing nodes that create triangulated imperfections from the floodplain. Once the features were removed from each flood stage, the smoothing process could begin. Each flood stage was smoothed using ESRI's Polynomial Approximation and Exponential Kernel (PAEK) algorithm with a 10-foot offset. ESRI defines the PAEK method as *a weighted average of the coordinates of all points of the source line. The weights of each point decrease with the distance along the line to the current point. In addition to averaging, approximation with polynomials of the second degree is used*.

After the smoothing process, all extra polygons not connected to the main channel were removed, except in the case of the four most populated RFPs in the study.

In the cases of Chenango River near Chenango Forks, Susquehanna River at Conklin, Susquehanna River at Binghamton, and Susquehanna River at Vestal, the methodology was altered to better reflect the risk in the populated areas. In these four RFPs, each flood stage was examined to determine if any flood area polygons were hydraulically connected through conduits, such as a culvert. If the decision was made that there was a hydraulic connection between the two polygons that was not apparent from the imagery, a manual edit to the polygon was made to show the possible flooding of additional areas and structures in these populated river reaches. Once these connections were made, the remaining polygons not connected to the channel were removed.

To ensure quality, the flood stages should not overlap each other, nor should they intersect or obscure any subsequent flood stages. If such instances are present, they should be removed manually. This also serves as an additional check for isolated, not hydraulically-linked polygons outside of the main floodplain. After this process, special cases are addressed before the polygons are finalized.

4.2   Special Cases

4.2.1   Bridges

Given the emergency management objectives of the inundation mapping product, bridges must be manually evaluated to determine if they are passable. Route accessibility during flood events is crucial, and transportation by bridge is a key need." There are three possible outcomes from this evaluation: deck flooding, approach flooding, and no flooding. First, the model output is examined for each flood stage, and if the deck is in any way flooded at any given stage, the inundation polygon is not modified, and the deck is shown as flooded and not passable. If the evaluation shows the deck is not flooded, but the approach to the bridge is flooded, again the inundation polygon is not modified, and the bridge is shown as not passable. Finally, if the model output shows the deck and approach are not flooded at a flood stage, the inundation polygon is modified to show the bridge is passable. In other words, the bridge is shown as having no water on the surface, and the bridge is passable to emergency personnel.

4.2.2   Levees

Levee systems exist throughout the Susquehanna River Basin. In the Upper Basin, levee systems are in place along the Susquehanna River and tributaries in the vicinities of Binghamton and Conklin. Analyses were conducted under FEMA's HMTAP to assess the available freeboard for these levees.

The HMTAP analysis yielded the information that most levees were not candidates for accreditation with respect to providing protection against the 1% annual chance event based on the criteria presented in NFIP Regulations (44 CFR, Section 65.10).

To address this finding, the hydraulic analyses for the Susquehanna River included the following scenarios:

1. With levees on both sides of the stream
2. With levee only on the left side of the stream but not on the right side
3. With levee only on the right side of the stream but not on the left side
4. With no levee on either side.

Since the inundation map product is not a FEMA product, a decision was made on how, for a particular flood stage, the various scenarios should be employed to produce a useful product for the objectives of the inundation mapping project. A discussion was held between the SRBC and NWS about whether the lack of 3 feet freeboard or a simple elevation exceedance criterion be employed as the mode of failure.

Based on the discussions, Dewberry and the SRBC decided to use the simple exceedance criteria for this project. Then, the following criteria would be used to guide the choice of model scenario from which to extract water surface elevations:

- If a WSEL computed for a particular stage does not exceed the levee crest at every inflection point on both the levees, Scenario 1 above would be used.
- If a WSEL computed for a particular stage exceeds even one inflection point on the right side levee and passes for all the inflection points on the left side levee, Scenario 2 above would be used.

- If a WSEL computed for a particular stage fails for even one inflection point on the left side levee and passes for all the inflection points on the right side levee, Scenario 3 would be used.
- If a WSEL computed for a particular stage fails for even one inflection point on both the levees, Scenario 4 would be used.

Once the appropriate model was chosen, mapping criteria was required. Here, based on previous discussions with SRBC staff, Dewberry and SRBC agreed that for any water surface that overtops the levee, the area inundated by the highest calculated elevation should be shown as a "Levee Risk Area."

Working in cooperation with the NWS, we used either the 500-yr floodplain, 125% of record flow, or the highest modeled flood stage as the basis for determining the levee risk area. In determining the longitudinal extent of the risk area, however, we used the natural contour at the upstream and downstream ends of the levee as the limits of the risk area. This method limits the area at risk of levee failure as the area immediately behind the levee, rather than extending the area upstream and downstream of the levee. The figure below demonstrates this method.
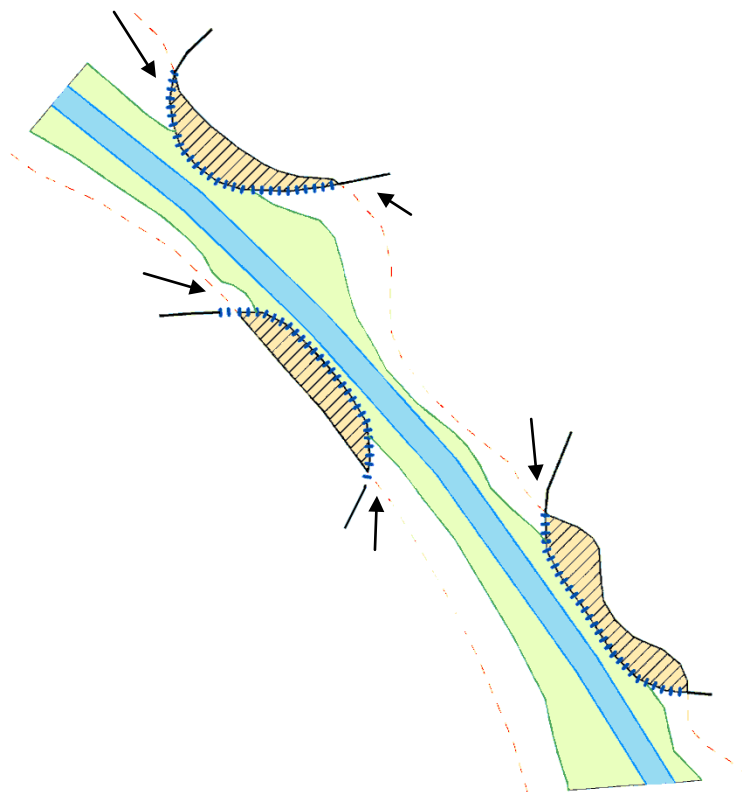
Figure 22 – Conceptual model of development of levee risk areas.

In this example, the black lines extending from the ends of each levee (blue hashed line) are the natural contours that tie into the upstream and downstream ends of each levee. Generally, these contours will extend landward from the levee and the intersection of this area with the 500-yr (or 125% of maximum) floodplain (red dashed line) behind the levee will represent the Levee Risk Area. Based on this methodology, there could be areas where there is abrupt change in the shape of the flood inundation areas (green shading) compared to the levee risk areas (tan hatch, see arrows in graphic above). However,

when comparing the 500-yr/125% of maximum floodplain polygon, the levee risk area will appear hydraulically consistent with the floodplain. The results of a levee failure are therefore limited to the area directly behind the levee.

Below is an example of a case along the Chenango River and how the methodology is applied.
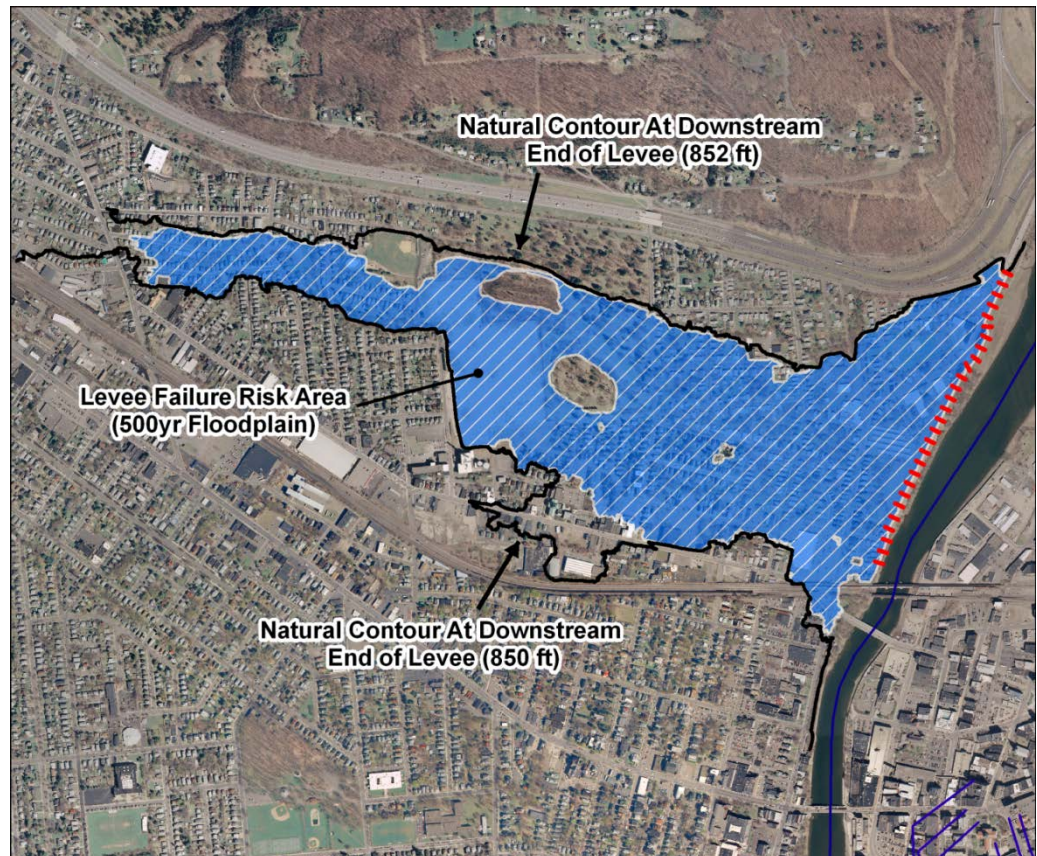
Figure 23 – Production mockup of a levee risk area overlaid on aerial imagery for the Chenango River at Chenango Forks, NY.

A levee risk area was delivered for each levee where overtopping was predicted by the HEC-RAS model. Depth information was not provided for these areas. The approach used a mask composed of each levee risk area to "clip" the standard depth grid produced for each gage elevation.

4.3 Depth Grid Construction

Once the vector flood stages for the RFP are complete, the construction of depth grids begins. A tool was created to produce depth TINs. Three inputs into the tool are the elevation terrain, water surface TIN and the finished vector flood stage. The elevation terrain used for any given flood stage should cover the entire area of the flood stage. Both the water surface TIN and the floodplain should correspond to the same flood stage. The elevation terrain is subtracted from the water surface TIN to produce a depth of flooding. The output is then clipped to the vector flood stage. The output of the tool will be a depth TIN, which is the depth of flooding at that given flood stage, in meters. This TIN is the first step to creating the depth surfaces. Next, all erroneous TIN nodes are removed from within the channel. To do this, the depth TIN is converted to TIN nodes,

erroneous TIN nodes are removed, and the remaining nodes are loaded into a new TIN, which is clipped to the extent of the flood stage vector. Finally, the TIN is converted to a raster with a 5 foot by 5 foot cell size, and the depths are converted into feet as well. In the completed depth raster, each cell has the depth, in feet, of flooding at that given location and flood stage.

4.4   Development of Flood Stage Forecast Maps

The final step in production was the creation of flood stage forecast maps. The maps are designed for portable use by floodplain and emergency managers to help protect human life and property within the basin.

Flood stage vectors were classified and dissolved into inundation vectors, which correspond to NWS flood stage levels. These inundation vectors were subsequently overlaid upon digital orthophotography along with political boundaries, hydrologic and transportation data. The extent of flooding for each river forecast point was divided into panels, then exported from ArcMap into PDF format using the MapBook extension. (See Appendix C.)

Flood inundation as presented on the maps involves many assumptions that may introduce relative error during calculation of flood profiles. The assumptions are made around accepted hydraulic engineering practice, and SRBC believes the maps are an accurate representation of what to expect during high flow events. However, the user should never assume complete accuracy and always use caution when using maps to make decisions that involve risk to human life and property.

Areas that are protected by levees or other structural flood damage reduction systems are shown as "high hazard areas" on the maps and represent those areas that are determined to be at risk due to structural failure. The inundation depicted in no way predicts where or when a structure will fail but implies the entire area is at flood risk from a failure anywhere within the structural system.

Flood stage forecast maps are only relevant to extreme hydrologic events that occur with no ice present in the stream channel. Ice cover represents an unpredictable risk that manifests in ice jams and flooding. These maps should never be used to make decisions that affect human life and property during ice jam flooding.

APPENDIX

Appendix A: References

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Appendix B: Flood Stage Forecast Tables

Chenango River at Chenango Forks, NY
USGS Gage No. 01512500

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
8	12800	879.08	7.899	0.101
9	16600	880.16	8.979	0.021
10	20550	881.17	9.989	0.011
11	24600	882.19	11.009	0.009
12	29050	883.18	11.999	0.001
13	34000	884.18	12.999	0.001
14	39500	885.19	14.009	0.009
15	45000	886.18	14.999	0.001
16	50900	887.18	15.999	0.001
17	57000	888.18	16.999	0.001
18	63350	889.18	17.999	0.001
19	70000	890.19	19.009	0.009
20	86500	891.22	20.039	0.039
21	94600	892.17	20.989	0.011
125 PCT	120000	894.9	23.719	-
			Average Difference	**0.016**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Chenango River at Greene, NY

USGS Gage No. 01507000

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
11	5345	903.09	10.930	0.070
12	6300	904.14	11.980	0.020
13	7473	905.15	12.990	0.010
14	8892	906.15	13.990	0.010
15	10720	907.16	15.000	0.000
16	12825	908.15	15.990	0.010
17	15212	909.16	17.000	0.000
18	17845	910.15	17.990	0.010
19	20741	911.13	18.970	0.030
20	23982	912.14	19.980	0.020
21	27230	913.09	20.930	0.070
22	31200	914.18	22.020	0.020
125PCT	33875	914.88	22.720	-
			Average Difference	**0.020**

Key to NWS Flood Categories

No Flooding	Moderate Flood Stage
Action Stage	Major Flood Stage
Flood Stage	125% of Record Flow

Susquehanna River at Bainbridge, NY

USGS Gage No. 01502632

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
11	9107	967.14	10.996	0.004
12	10250	968.18	12.036	0.036
13	11373	969.23	13.086	0.086
14	12440	970.16	14.016	0.016
15	14163	971.17	15.026	0.026
16	16015	972.18	16.036	0.036
17	18105	973.17	17.026	0.026
18	20655	974.18	18.036	0.036
19	23431	975.16	19.016	0.016
20	26556	976.16	20.016	0.016
21	29936	977.17	21.026	0.026
22	33541	978.17	22.026	0.026
23	37359	979.17	23.026	0.026
24	41812	980.2	24.056	0.056
25	45700	981.16	25.016	0.016
26	50000	982.13	25.986	0.014
27	55229	983.22	27.076	0.076
125PCT	73375	986.72	30.576	-
			Average Difference	**0.032**

Key to NWS Flood Categories

No Flooding	Moderate Flood Stage
Action Stage	Major Flood Stage
Flood Stage	125% of Record Flow

Susquehanna River at Binghamton, NY
USGS Gage No. 01503500

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
12	20070	833.04	12.016	-0.016
13	23064	834.05	13.026	-0.026
14	26262	835.05	14.026	-0.026
15	29538	836.05	15.026	-0.026
16	33154	836.94	15.916	0.084
17	36745	837.93	16.906	0.094
18	40731	838.92	17.896	0.104
19	44962	839.87	18.846	0.154
20	50078	840.91	19.886	0.114
21	54728	841.91	20.886	0.114
22	59597	842.91	21.886	0.114
23	64668	843.91	22.886	0.114
24	70045	844.93	23.906	0.094
25	75421	845.94	24.916	0.084
125PCT	97879	850.04	29.016	-
			Average Difference	**0.083**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Susquehanna River at Conklin, NY

USGS Gage No. 01503000

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
8	9900	848.53	8.012	0.012
9	12070	849.53	9.012	0.012
10	14070	850.45	9.932	0.068
11	16591	851.52	11.002	-0.002
12	19309	852.52	12.002	-0.002
13	22168	853.52	13.002	-0.002
14	25360	854.52	14.002	-0.002
15	28732	855.52	15.002	-0.002
16	32463	856.52	16.002	-0.002
17	36646	857.52	17.002	-0.002
18	41214	858.52	18.002	-0.002
19	46040	859.52	19.002	-0.002
20	51149	860.52	20.002	-0.002
21	56567	861.52	21.002	-0.002
22	62193	862.52	22.002	-0.002
23	68249	863.54	23.022	-0.022
24	74305	864.53	24.012	-0.012
25	80361	865.5	24.982	0.018
125 PCT	96000	867.91	27.392	-
			Average Difference	**0.003**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Susquehanna River at Owego, NY

USGS Gage No. 01513831

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
29	62105	805.1	28.995	0.005
30	68901	806.07	29.965	0.035
31	76626	807.12	31.015	0.015
32	84371	808.11	32.005	0.005
33	92748	809.13	33.025	0.025
34	101291	810.13	34.025	0.025
35	110427	811.12	35.015	0.015
36	120664	812.16	36.055	0.055
125PCT	152586	815.38	39.275	-
			Average Difference	**0.0225**

Key to NWS Flood Categories

No Flooding	Moderate Flood Stage
Action Stage	Major Flood Stage
Flood Stage	125% of Record Flow

Susquehanna River at Unadilla, NY
USGS Gage No. 01500500

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
9	9720	1005.88	9.020	0.020
10	11775	1006.88	10.020	0.020
11	13999	1007.87	11.010	0.010
12	16600	1008.87	12.010	0.010
13	19609	1009.88	13.020	0.020
14	22900	1010.87	14.010	0.010
15	26478	1011.88	15.020	0.020
16	30373	1012.88	16.020	0.020
17	34279	1013.89	17.030	0.030
18	39510	1014.88	18.020	0.020
125PCT	43875	1015.67	18.810	-
			Average Difference	**0.018**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Susquehanna River at Vestal, NY

USGS Gage No. 01513500

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
15	23900	813.7	14.979	0.021
16	26445	814.74	16.019	-0.019
17	29803	815.76	17.039	-0.039
18	33162	816.75	18.029	-0.029
19	36804	817.74	19.019	-0.019
20	40769	818.74	20.019	-0.019
21	45005	819.74	21.019	-0.019
22	49465	820.76	22.039	-0.039
23	54205	821.74	23.019	-0.019
24	59255	822.75	24.029	-0.029
25	64616	823.75	25.029	-0.029
26	70234	824.75	26.029	-0.029
27	76275	825.75	27.029	-0.029
28	82540	826.75	28.029	-0.029
29	89107	827.75	29.029	-0.029
30	96031	828.76	30.039	-0.039
31	103356	829.76	31.039	-0.039
32	110739	830.77	32.049	-0.049
33	118121	831.76	33.039	-0.039
34	125504	832.75	34.029	-0.029
125PCT	148750	835.84	37.119	-
			Average Difference	**-0.03**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Susquehanna River at Windsor, NY
USGS Gage No. 01502731

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
10	10744	909.53	9.996	0.004
11	12752	910.49	10.956	0.044
12	14940	911.51	11.976	0.024
13	17301	912.55	13.016	0.016
14	19794	913.58	14.046	0.046
15	22411	914.56	15.026	0.026
16	24956	915.5	15.966	0.034
17	28259	916.53	16.996	0.004
18	31700	917.53	17.996	0.004
19	35951	918.58	19.046	0.046
20	39304	919.56	20.026	0.026
21	43563	920.51	20.976	0.024
22	48727	921.57	22.036	0.036
23	53396	922.55	23.016	0.016
24	57863	923.5	23.966	0.034
25	62881	924.57	25.036	0.036
125PCT	69875	926.17	26.636	-
			Average Difference	**0.026**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Unadilla River at Rockdale, NY
USGS Gage No. 01502500

Assumed Stage Value (ft)	USGS Rating Curve Discharge (cfs)	Computed FEMA Model WSEL (ft)	Computed FEMA Model Stage (ft)	Difference in Assumed Stage and Computed Stage (ft)
8	5039	999.89	7.978	0.022
9	6509	1000.89	8.978	0.022
10	8284	1001.90	9.988	0.012
11	10703	1002.94	11.028	0.028
12	13543	1003.88	11.968	0.032
13	17550	1004.91	12.998	0.002
14	22046	1005.87	13.958	0.042
125PCT	28875	1007.19	15.278	-
			Average Difference	**0.023**

Key to NWS Flood Categories

	No Flooding		Moderate Flood Stage
	Action Stage		Major Flood Stage
	Flood Stage		125% of Record Flow

Appendix C: Example Flood Stage Forecast Map