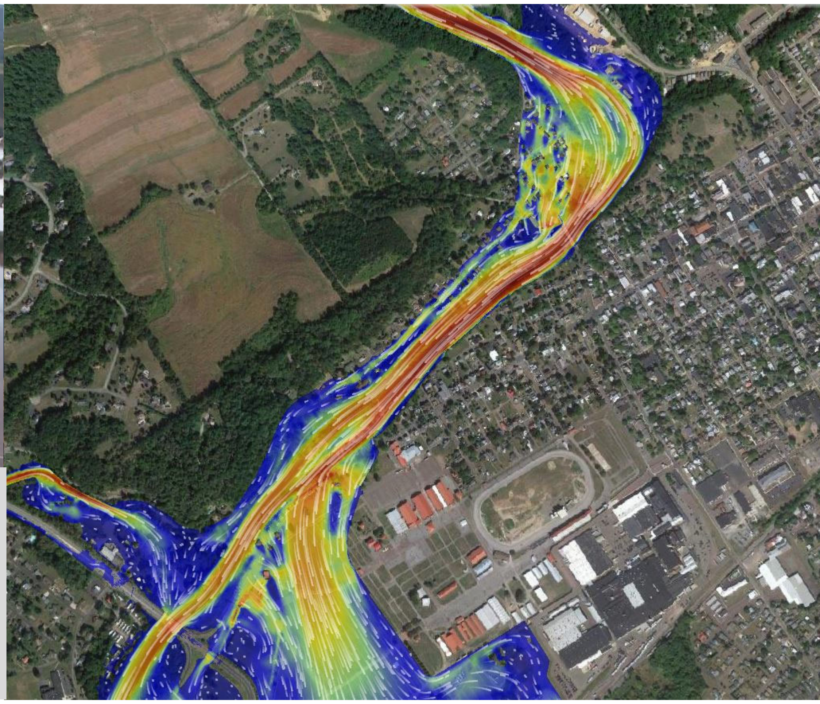
COLUMBIA COUNTY

West End Flood Mitigation Study

ADDENDUM NO. 1

2-DIMENSIONAL HYDRAULIC MODELING ANALYSIS

November 2022



FINAL REPORT

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BL Project #: 2021-5134-001

Executive Summary

Columbia County West End Flood Mitigation Study
Addendum No. 1
2- Dimensional Hydraulic Modeling Analysis of Fishing Creek

This supplemental report is an addendum to the Final Report for the West End Flood Mitigation Study published in June 2022. The Final Report outlined the recommendations for a levee system to mitigate flooding risks from Fishing Creek and the Susquehanna River. The purpose of this supplemental hydraulic study was to determine the impacts of a proposed levee more accurately during the Base Flood (100-Year flood flows) on Fishing Creek and the neighboring municipalities and residents. Based on the impacts determined in the Two-Dimensional (2D) hydraulic modeling analyses, the viability of various proposed mitigation solutions was assessed to minimize or eliminate any induced flooding impacts.

In the initial phase of the West End Flood Study, it became evident that the complexity of the Fishing Creek hydraulics exceeded the capability of One-Dimensional (1D) analysis. Due to the size and breadth of the floodplain/floodway, multiple occurrences of split flow and flow junctions, density of development in the floodplain/floodway, and superelevated water surfaces around channel bends, a 2D hydraulic model was determined to be required for analysis of existing and proposed Fishing Creek hydraulic conditions related to the recommended flood mitigation project for the West End of the Town of Bloomsburg. Advanced hydraulic modeling with 2D software offers powerful computational methods to better understand the behavior of flows under existing conditions and to predict flows under the proposed conditions with a levee system.

Fishing Creek has a large floodway within the study area and is situated such that any proposed levee system would be constructed entirely within the regulatory floodway. Results of the 2D proposed conditions modeling (with levee system) performed for this supplemental study show that the water surface elevation (WSEL) of the Base Flood increases approximately 2.1 feet when a levee is constructed along the left bank of Fishing Creek. Residential areas across the stream and upstream of the proposed levee in Hemlock Township would experience a higher level of flooding due to the levee system's encroachment into the Floodway. See attached Figure 7.5 WSEL Profiles - Existing, Proposed, and Mitigation Alternative No. 7.

A number of mitigation alternatives were evaluated with the goal of eliminating all induced flooding to structures (homes) from a proposed levee. Mitigation Alternative No. 7 was chosen as the preferred mitigation alternative and is shown on attached Figure 7.4. This proposed alternative includes a benched floodplain along the Hemlock Township side of Fishing Creek to increase flow capacity from Railroad Street to just upstream of PA Route 42 and a series of seven (7) culverts under US Route 11 to encourage flow back into the existing floodway west of the proposed levee alignment. The culverts are proposed in an area along US Route 11 where several homes were destroyed by the overbank flows during the record Lee Flood of 2011. Eleven homes in this area were eventually bought and demolished by the Town of Bloomsburg. The 2D hydraulic model output verified the extremely high creek velocities at this location, which affirms the natural tendency of the creek to send more flow through this area of the floodway.

The supplemental 2D analysis of the proposed mitigation features included in Mitigation Alternative 7, showed induced flooding levels were eliminated in most of the creek length studied except for a limited reach of the creek in Hemlock Township where two (2) homes would be impacted by approximately four (4) inches of induced flooding (see Figure 7.5). It is likely that further refinement of the selected mitigation features during the preliminary stages of the proposed project design could eliminate all residual induced flooding. If residual induced flooding cannot be eliminated entirely, acquisition/demolition or elevation of impacted structures remain as options that would be acceptable to both the Federal Emergency Management Agency (FEMA) and the Pennsylvania Department of Environmental Protection (PADEP). This approach could be considered if the cost of further structural mitigation to eliminate all induced flooding is higher than the costs of elevating or acquiring the structures.

Meetings were held during the study on May 31, 2022 and October 24, 2022 with FEMA, the United States Army Corps of Engineers (USACE), and PADEP to review the proposed project and permitting requirements. The agencies provided guidance on the viability of successfully permitting the proposed levee system and mitigation features. The final guidance provided indicated the entire project could be submitted for a Conditional Letter of Map Revision (CLOMR) if induced flooding were eliminated and/or all impacted structures mitigated. Following CLOMR approval by FEMA and completion of final design, a PADEP Chapter 105 Water Obstruction and Encroachment Permit / USACE Section 404 Authorization (i.e., Joint Permit) could be obtained for the proposed project (levee and mitigation features). Municipal floodplain consistency approvals would also be required from each impacted municipality and submitted with the PADEP permit application.

Due to the land-use and need for a partnership, meetings with the effected municipalities, (Hemlock Township and the Town of Bloomsburg) were held to discuss the findings and proposed mitigation of any impacts.

The cost for the preferred mitigation features ranges from $3.4 to $4.4 million dollars (this does <u>not</u> include the proposed levee costs). Initial estimates in the Final Report for mitigation were $3 million dollars. If the project proceeds to preliminary design, additional geotechnical investigations in the proposed benched floodplain area and refinement of the proposed culvert system under US Route 11 could lead to cost savings resulting in a total cost at the lower end of this range.

The recommended next steps toward implementation of the project include the below key items.

1. Eliminate or Mitigate Induced Flooding (from proposed levee)

    a. Continue refinement of the proposed levee alignment and mitigation concepts with the goal to eliminate the 4-inches of induced flooding impacting two (2) residential structures on Drinker Street in Hemlock Township. ***This evaluation would occur during the preliminary design phase of the proposed project.***

b. Verify the lowest finished floor elevations in the two (2) residential structures impacted by induced flooding and identify mitigation concepts such as elevations or floodproofing.

c. Coordinate with Hemlock Township and the impacted property owners to determine the preferred approach to mitigate residual induced flooding impacts for the two (2) residential structures. In this case, feasible mitigation options include Elevation, Mitigation Reconstruction or Acquisition/Demolition. This type of mitigation is **only required if** the elimination of induced flooding is not feasible with refinement of the proposed levee alignment and mitigation concepts (Item 1.a).

2. Property Acquisition/ Rights of Way

a. Coordinate with the Town of Bloomsburg and impacted property owners to review acquisition requirements of three to four residential structures and several garages/sheds needed for the proposed levee footprint.

b. There is also one additional residential structure in Bloomsburg located on US Route 11 (West Main Street) outside of the proposed levee, west of the Bloomsburg University parcel, that will not be a required acquisition to accommodate the proposed levee footprint; however, this residential structure is recommended for acquisition due to the extremely high creek velocities during flood events that impact this home. Early coordination with this property owner is recommended.

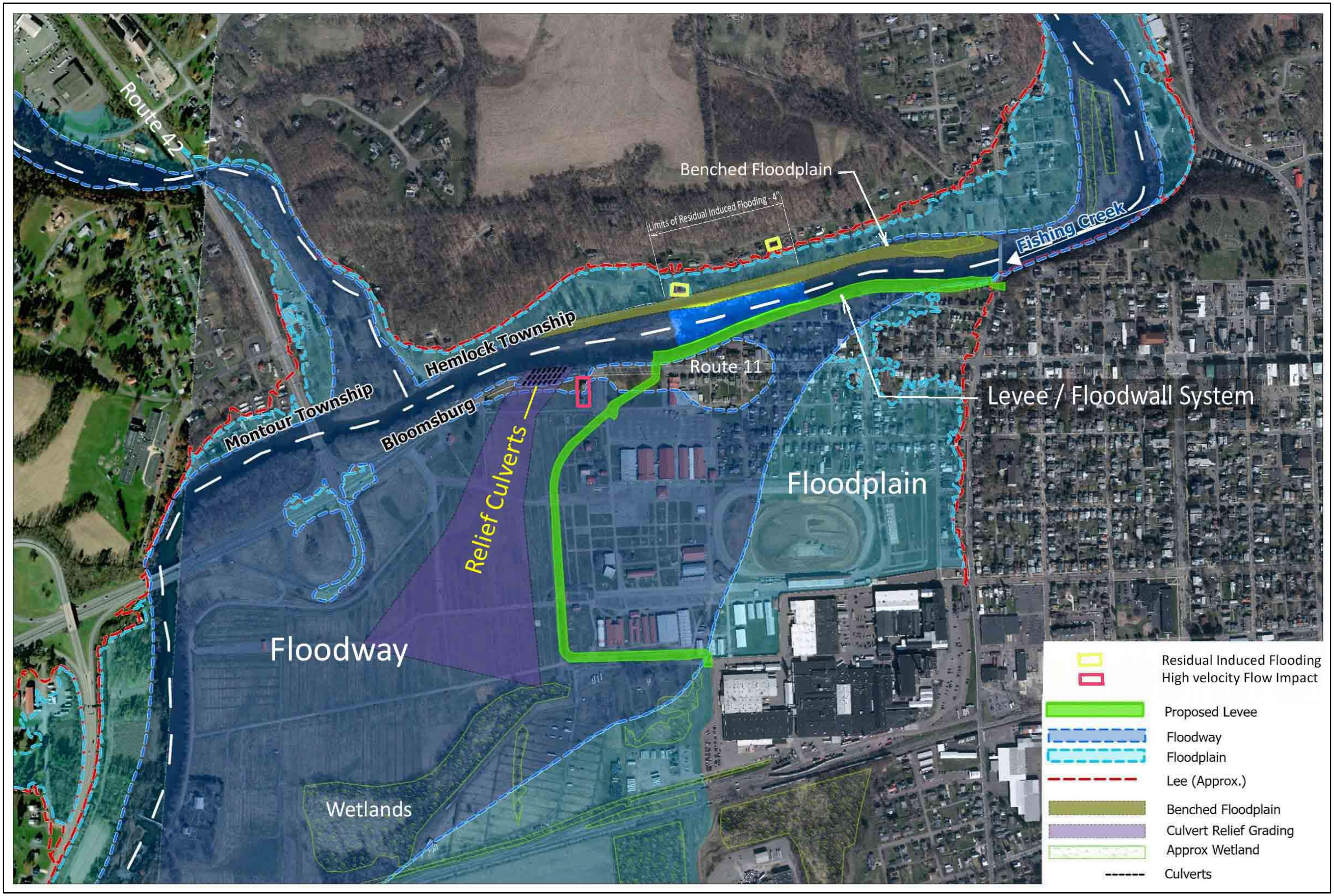

Figure 7.4 – Final Proposed Levee Alignment with Mitigation Features

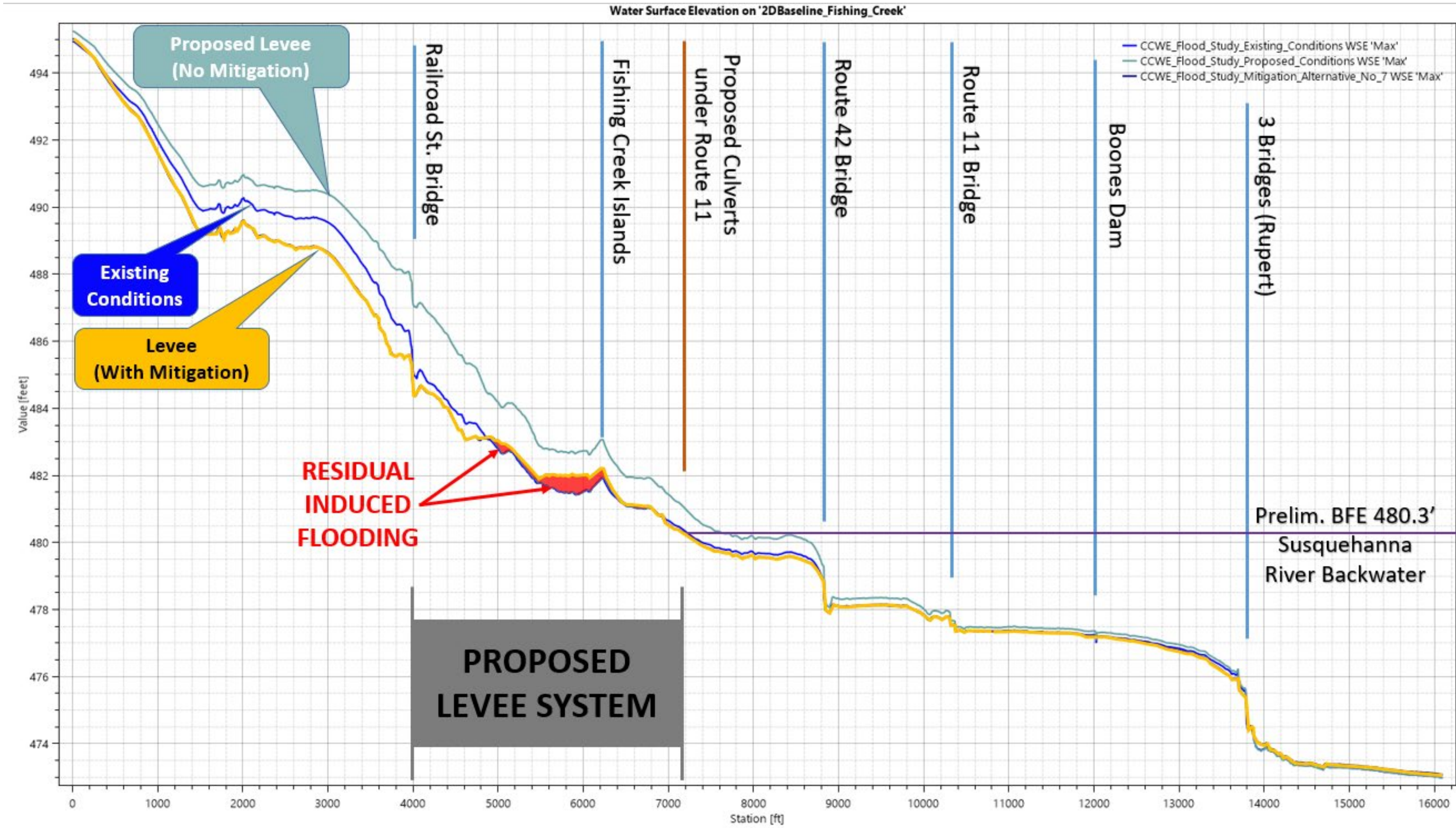

Figure 7.5 – WSEL Profiles - Existing, Proposed, and Mitigation Alternative No. 7
2D Modeled Base Flood Flows (100-Yr)

COLUMBIA COUNTY
WEST END FLOOD MITIGATION STUDY
FINAL REPORT

ADDENDUM NO. 1
2-DIMENSIONAL HYDRAULIC MODELING ANALYSIS

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SECTION 1 – INTRODUCTION

1.1. Purpose and Goals

The overall purpose and goals of the West End Flood Mitigation Study are described in Section 1.3 of the Columbia County West End Flood Mitigation Study Final Report, Volume I, dated June 2022 hereinafter referred to as the Final Report.

This hydrologic and hydraulic (H&H) report is an addendum to the Final Report. In the initial phase of the study, Fishing Creek hydraulics were evaluated utilizing a 1-Dimensional (1D) hydraulic analysis. During that study, it became evident that the complexity of the hydraulics exceeded the capability of 1D analysis. Due to the size and breadth of the floodplain including the regulated floodway, multiple occurrences of split flow and flow junctions, density of development in the floodplain, and superelevated water surfaces around channel bends, a 2-Dimensional (2D) model was created for analysis of existing and proposed hydraulic conditions related to the recommended flood mitigation project for the West End of the Town of Bloomsburg.

The Final Report outlines the recommendations for a levee/floodwall system to mitigate flood risk from Fishing Creek and the Susquehanna River. The purpose of this supplemental 2D hydraulic analysis of Fishing Creek was to accurately determine the hydraulic impacts of a proposed levee on neighboring municipalities and residents and to evaluate the viability of various solutions to minimize or eliminate those impacts. The 2D hydraulic analysis included:

1) Model Development
2) Model Calibration
3) Existing Conditions Analysis
4) Proposed Conditions Analysis
5) Induced Flooding Mitigation Alternatives Analysis

1.2. Project Area & Description

The study area and description are presented in Section 1.2 of the Final Report. Refer to Figure 1.1 on the following page for a map of the study area.

The study area is comprised of approximately five hundred (500) parcels and three hundred fifty (350) structures.

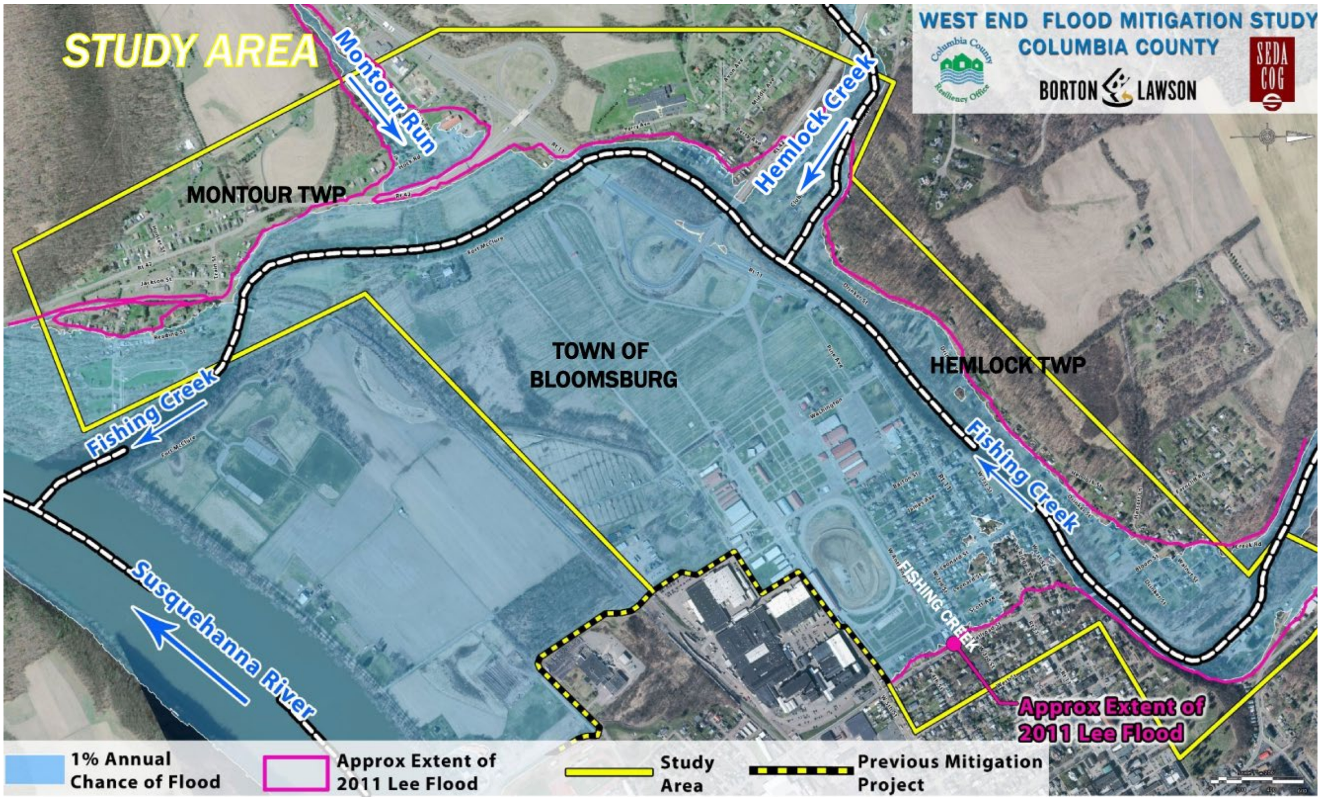

Figure 1.1 – Study Area Map

SECTION 2 – HYDROLOGIC ANALYSIS

The 1D hydraulic analysis performed as part of the West End Flood Mitigation Study assumed a constant flow in Fishing Creek with no flow changes along the studied reach of the creek. When creating the 2D model for this supplemental study in the same manner, the nature of the output appeared incomplete with tributaries within the study area not producing flow. To model Hemlock Creek and Montour Run, flows were added to these tributaries. Fishing Creek flows were then adjusted accordingly to ensure the peak discharge at the confluence with the Susquehanna River remained consistent. This action resulted in a reduction in peak flows on Fishing Creek upstream of Hemlock Creek relative to the 1D model.

The coincident recurrence intervals for Hemlock Creek, Montour Run, and the Susquehanna River corresponding to the base flood (100-Yr flood) on Fishing Creek were determined by applying drainage area ratios per Figure 2.1 for determining relationships between tributaries and a main stem.

	50-year design		100-year design	
	main stream	tributary	main stream	tributary
10,000:1	2	50	2	100
	50	2	100	2
1,000:1	5	50	10	100
	50	5	100	10
100:1	10	50	25	100
	50	10	100	25
10:1	25	50	50	100
	50	25	100	50
1:1	50	50	100	100
	50	50	100	100

Figure 2.1 – Frequencies of Coincidental Occurrence
Pennsylvania Department of Transportation (PennDOT) Publication 584, Chapter 7

Brief hydrologic summaries are provided below for each watercourse within the study area. Tables 3.1 and 3.2 summarize the design flows used for each condition relative to the original 1D hydraulic model.

Fishing Creek

Fishing Creek is a major tributary to the Susquehanna River within Columbia County and has a total drainage area of 385 square miles above its confluence with the Susquehanna River. Fishing Creek discharges were obtained using a combination of a United States Army Corps of Engineers (USACE) Study, dated June 2012, which incorporated data from the Tropical Storm Lee event of 2011 and the United States Geological Survey (USGS) Scientific Investigations Report (SIR) 2019-5094 for estimation of flood flows at ungauged sites.

The 2012 USACE study determined flows at the project site by applying a ratio of the drainage area to the gauged flow. USGS SIR 2019-5094 presents a newer method for transposing flows from a nearby stream gauge to a project site using a drainage area characteristic exponent in the regional regression equation. Applying the USGS method to the Tropical Storm Lee event results in a lower flow rate compared to the method utilized in the USACE report, 72,500 cubic feet per second (CFS) vs. 78,700 CFS. The lesser flow is within the standard 90% confidence interval for an event with a 350-year recurrence interval.

To calibrate the model for the Tropical Storm Lee Event, the flows calculated following the USGS method were chosen as the target flows at the Susquehanna River confluence and adjusted to the upper boundary of Fishing Creek by subtracting the tributary inflows at Hemlock Creek and Montour Run.

Hemlock Creek

Hemlock Creek is a tributary to Fishing Creek with a drainage area of 16.6 square miles; the confluence occurs within the study area immediately upstream of the US Route 11 and PA Route 42 Interchange. Hemlock Creek is a Federal Emergency Management Agency (FEMA) detailed study watercourse with a regulatory floodway. Water surface elevations (WSELs) and peak discharges on Hemlock Creek were obtained from the Preliminary Flood Insurance Study (FIS) dated August 28, 2020.

Montour Run

Montour Run is a tributary to Fishing Creek with a drainage area of 4.6 square miles. The confluence occurs downstream of US Route 11 within the Township of Montour. Montour Run is an approximate study stream with no predetermined WSELs or peak discharges. Because no peak discharges are available from FEMA, PA StreamStats was used to obtain peak flows for various recurrence interval events. StreamStats is a web-based application created and managed by USGS and utilizes hydrologic regression equations to estimate flows. StreamStats data for Montour Run is included in Appendix A.

Susquehanna River

Susquehanna River flows used in modeling the base flood on Fishing Creek were taken from the 2020 Preliminary FEMA Flood Insurance Study (FIS). When calibrating the model for Tropical Storm Lee, the coincident discharge recorded by the USGS Susquehanna River gauge at Bloomsburg coinciding with the peak flow recorded on the USGS Fishing Creek gauge was used. These flows are recorded in Tables 3.1 and 3.2.

SECTION 3 – 2D HYDRAULIC MODEL DEVELOPMENT

3.1. Model Selection & Justification

The Hydrologic Engineering Center-River Analysis System (HEC-RAS) version 6.2 program, developed by the U.S. Army Corps of Engineers, was used to perform the hydraulic analysis of the study area using the Two-Dimensional modeling capabilities of the software. Two-Dimensional modeling produces detailed and accurate representations of complex flow path conditions including wide floodplains, sinuous channels, multiple channels, bends and confluences, bridge/roadway crossings, lateral hydraulic structures, roadway overtopping, levees, and heavily developed urban settings among other conditions. The West End of the Town of Bloomsburg contains several of these features in existing conditions and several more are introduced in proposed conditions and for mitigation. The complex nature of the study area justifies using 2D analysis which is critical to support the decision making of engineers, stakeholders, and local elected officials.

Two-Dimensional models can enhance communication with stakeholders and the public with presentation of realistic, easy to interpret graphics and videos produced by the model. These models also provide more accurate representations of flow and velocity distribution, water surface elevation, backwater, velocity magnitude and direction, flow depth, shear stress and many other parameters which may be of interest to the modeler or stakeholders.

3.2. Assumptions & Limitations

The current limitations of the HEC-RAS 2D hydraulic modeling software includes an inability to perform water quality modeling in 2D flow areas, account for steep slopes above 10% inside the model, or allow a straightforward coupling to an 2D dynamic stormwater analysis. None of these current software limitations are present or relevant to the objectives of this study.

3.3. 2D Model Domain

The HEC-RAS 2D model domain was defined to encompass the extent of the Preliminary FEMA 500-Year floodplain and include the upstream and downstream boundaries of all modeled watercourses a sufficient distance from the study area to stabilize the computations.

A single HEC-RAS 2D flow area was created for the entire domain, and a 2D computational mesh was generated at a nominal grid cell spacing of 40' X 40'.

The final computational mesh contains approximately 177,300 cells with an average cell size of about 5,370 square feet. The model domain covers approximately 16,095 linear feet (3.0 miles) of Fishing Creek and approximately 1,063.5 acres of floodplain.

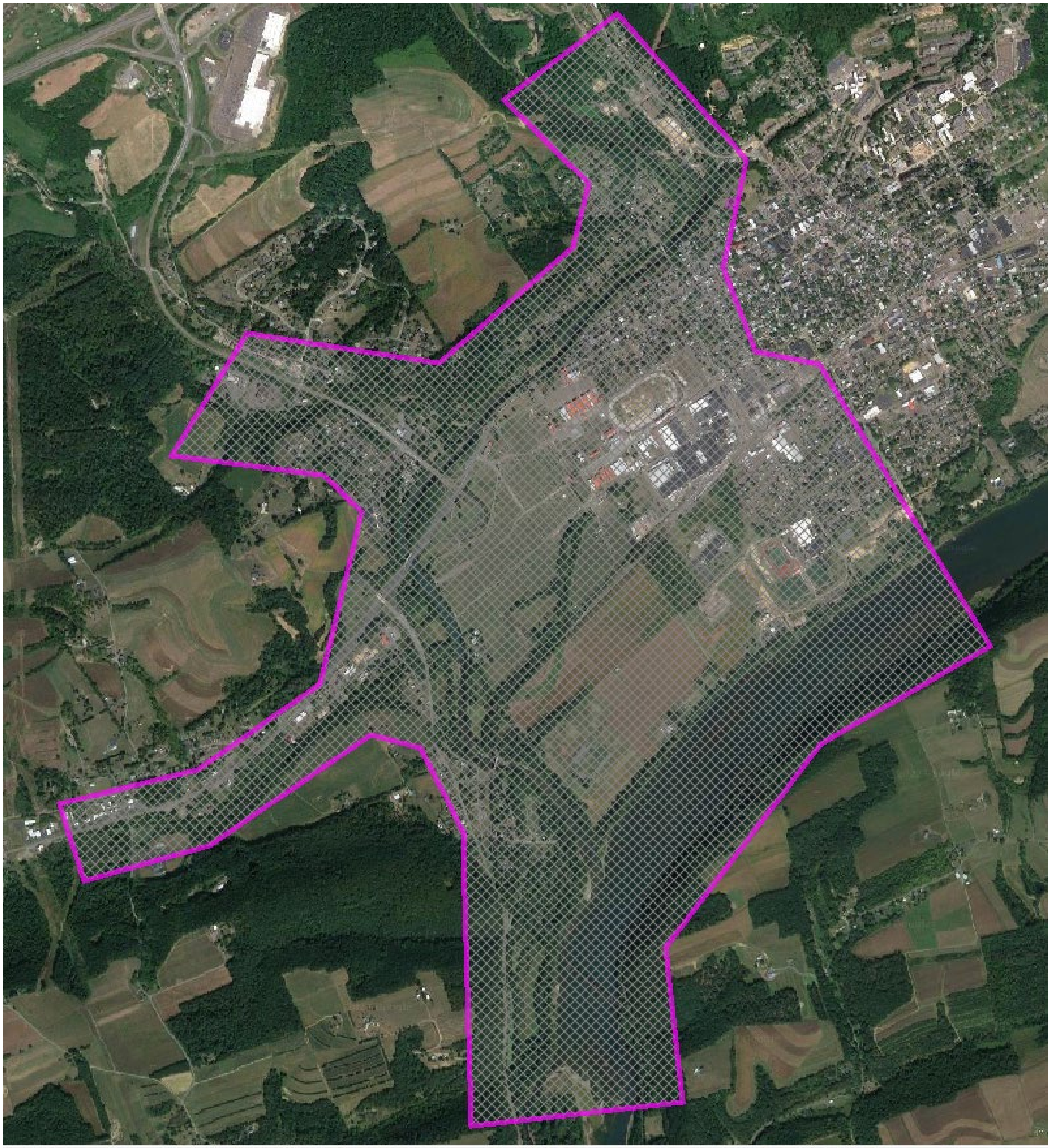

Figure 3.1 – 2D Hydraulic Model Domain Limits

3.4. Terrain Data Sources

Horizontal projection and Vertical Datum

The horizontal coordinate system is set to Pennsylvania Sate Plane North American Datum of 1983 (NAD83) North FIPS 3701 Feet. The vertical datum is referenced to the North American Vertical Datum of 1988 (NAVD88).

Data Sources

The surface terrain data used in the modeling effort is a combination of topographic data from the following sources:

- PA State LIDAR (Light Detecting and Ranging) – Obtained from Pennsylvania Spatial Data Access (PASDA) and collected under the Pennsylvania Department of Conservation and Natural Resources (DCNR) PAMAP Program in 2008.
- Detailed topographic survey - performed by The Thrasher Group in the Spring of 2021 via airplane and LIDAR.
- Bathymetric Survey of Fishing Creek - Performed by Borton-Lawson, May/June 2022.
- Supplemental topographic survey – Performed by Borton-Lawson, May/June 2022.
- Bathymetry data segments from the upstream boundary for Fishing Creek to the beginning of the bathymetry field survey, and from the end of the bathymetric field survey to the mouth of the Susquehanna River were generated from FEMA cross sections.
- Bathymetric data for Hemlock Creek were generated from FEMA cross sections.
- Bathymetry data for Susquehanna River derived from 2013 HEC-RAS Model developed by the USACE.
- As-Built survey and design surface data for formerly completed Phase 1 and Phase 2 Levee systems.

Considering the density of development present within the floodplain, building footprint data was extruded 20 feet above existing grade and made part of the final merged terrain. The initial building footprint Geographic Information Systems (GIS) shape file was obtained from Columbia County, GIS Department.

In areas where data sources overlap, sources were layered in order from lowest precision to highest precision when merging the final terrain file.

3.5. Boundary Conditions

The boundary conditions for the hydraulic models are summarized in Table 3.1 and Table 3.2 for the 1% annual exceedance probability (AEP) Base Flood and for the 2011 Lee Flood Event, respectively. The boundary values for the 2011 Lee Flood Event were used to calibrate the model for the Existing Conditions, Proposed Conditions, and Mitigation Alternatives analyses.

Table 3.1
Boundary Conditions for 1% AEP Base Flood

Boundary	Type	Peak Value (CFS)	Return Period (Years)	Reference/Source
Inflow Fishing Creek	Inflow Hydrograph	54,363	100	2012 USACE Report
Inflow Susquehanna River	Inflow Hydrograph	155,100	10	Preliminary FIS 2020
Inflow Hemlock Creek	Inflow Hydrograph	3,800	25	Interpolated from Preliminary FIS 2020
Inflow Montour Run	Inflow Hydrograph	737	25	USGS PA StreamStats
Downstream Susquehanna River	Normal Depth	0.001	-	(100-Year) Flow gradient @ FEMA Cross-section: BH

Table 3.2
Boundary Conditions for 2011 Lee Flood Event

Boundary	Type	Peak Value (CFS)	Return Period (Years)	Reference/Source
Inflow Fishing Creek	Inflow Hydrograph	63,064	350	USGS SIR 2019-5094 & 2012 USACE Report
Inflow Susquehanna River	Inflow Hydrograph	141,501	10	Susquehanna River Gauge at Bloomsburg
Inflow Hemlock Creek	Inflow Hydrograph	8,500	100	Preliminary FIS 2020

Inflow Montour Run	Inflow Hydrograph	935	50	USGS PA StreamStats
Downstream Susquehanna River	Normal Depth	0.001	-	(100-Year) Flow gradient FEMA @ Cross-section: BH

The return period for tributaries was determined according to PennDOT Pub584/ Frequencies for Coincidental Occurrence.

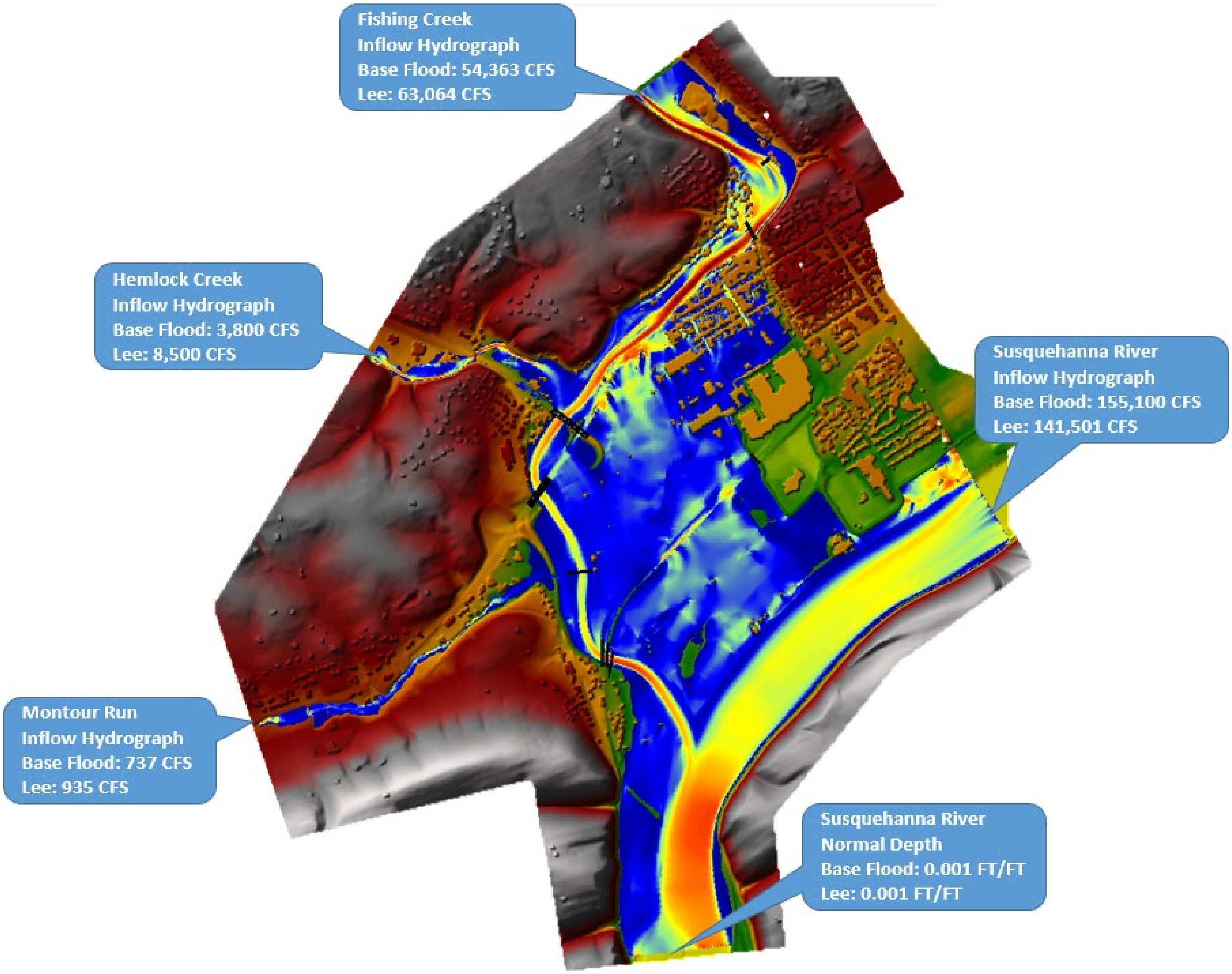

Figure 3.2 - Annotated Plot of Boundary Conditions

3.6. Breaklines and Refinement Regions

The 2D domain mesh was adjusted extensively using refinement regions and 2D breaklines in areas with complex topography and along elevated terrain features that would otherwise be missed by the uniform rectilinear grid.

Breaklines were created along channels, riverbanks, roadways, levees, and other areas of high ground. These breaklines and refinement regions were enforced within the 2D flow area at a nominal grid cell spacing of 20' x 20'. The breaklines along levees alignments were enforced with 10'x10' grid spacing. The SA/2D connections at dams and bridges were enforced as breaklines with 10'x10' spacing.

3.7. Hydraulic Structures

Multiple structures exist along Fishing Creek within the model domain including eight (8) bridges and two (2) dams. The modeled structures are listed in Table 3.3 below.

Table 3.3 – Existing Structures

Station (ft)	Designation
2366.2	Dam_1 (Near water authority plant)
3986.3	Railroad Street Bridge
8826.0	SR42 Mall Blvd Bridge over Fishing Creek
8826.0	SR42 Mall Blvd Bridge over SR 11
10308.6	US Route 11 Bridge North Bound over Fishing Creek
10365.1	US Route 11 Bridge South Bound over Fishing Creek
12020.3	Dam_2 (Boone's Dam)
13696.9	Railroad Bridge (abandoned)
13786.6	Railroad Bridge
13862.8	Covered Bridge #56

3.8. Manning's Roughness Coefficients

Manning's roughness coefficients are used to quantify a surface's resistance to flow. The assignment of these values to channels and floodplain is critical in determining channel and overbank velocities and is a crucial step in successful implementation of the hydraulic model. Manning's roughness coefficients are typically denoted by the variable "n."

As an initial approach, land cover information was extracted from the 2019 National Land Cover Database. The land cover polygons were verified using Columbia County parcel data and land use depicted on the ortho-imagery to create Manning's n polygons.

The Manning's n values were based on land cover descriptions and defined within recommended ranges from the USACE Hydrologic Engineering Center (HEC).

The land cover descriptions and corresponding initial Manning's N value are shown in Table 3.4.

Table 3.4 - Land Coverages & Initial Manning's n Values

Reference Identifier	Description	Manning's n Values
0	No Data	
1	Water	0.035
2	Deciduous	0.15
3	Shrub	0.12
4	Developed Open Space	0.04
5	Low Intensity Developed	0.09
8	Medium Intensity Developed	0.12
9	High Intensity Developed	0.16
7	Roads	0.025
6	Cultivated Land	0.035
10	Bare Land	0.027

3.9. Computation and Run Control Parameters

The following computation & run control parameters used in the hydraulic model are as follows:

- Computation Equation SW-ELM, Variable Time Step, Initial value = 5 seconds
- Run Time = 24 hours
- Simulation Time
    - Start Date & Time: 01JAN2023 00:00:00
    - End Date & Time: 01JAN2023 24:00:00
- Computation Settings:
    - Computation Interval: 5 seconds
    - Hydrograph Output Interval: 30 minutes
    - Mapping Output Interval: 30 minutes
    - Detailed Output Interval: 30 minutes

The model was reviewed for mesh quality and other errors and troubleshooted to ensure that the model did not experience mathematical instability where significant oscillations or mass balance errors could occur.

SECTION 4 – MODEL CALIBRATION

Calibration is performed to establish the accuracy of a model, typically by simulating a historic flow with well-established high-water marks.

4.1. Historical Event Selection

The West End Flood Mitigation model was calibrated to the 2011 Tropical Storm Lee flood event. This historical event was selected for it being the flood of record and for the quantity of high-water marks (HWMs) recorded after the event. The majority of HWMs for the 2011 Lee event were recorded by USGS. Detailed information on location, type, and quality of the HWMs are provided in Table 4.1 below and in Appendix B.

Multiple HWMs shown in the study area on Figure 4.1 (not labeled) were set by backwater from the Susquehanna River the day after Fishing Creek crested. These HWMs are not useful for calibration of Fishing Creek.

One additional HWM was collected from a tree along the left bank of Fishing Creek. While not displayed on the USGS map below, it is included in the comparison provided in Table 4.5.

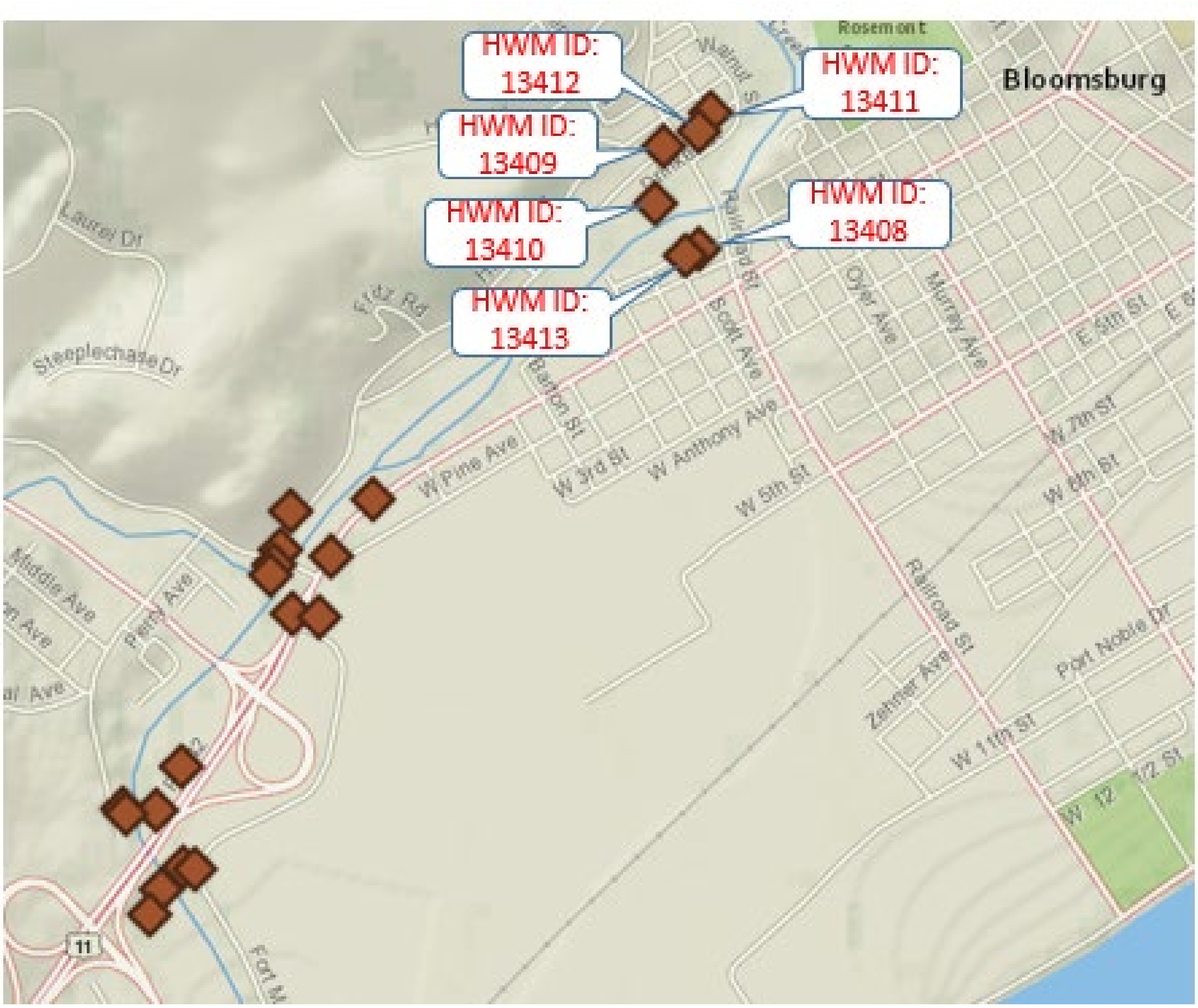

Figure 4.1. – USGS High Water Mark Locations

Table 4.1. – USGS High Water Marks

HWM ID	Site ID	HWM Type	HWM Quality	LOCATION	Survey Date	Elevation (feet NAVD88)
13408	16098	Mud	Good: +/- 0.10 ft	HWM transferred from small garage with grey vinyl siding at 435 West First St. Transferred to telephone pole 63 ft bankward across street and 65 ft upstream.	5/31/2012	485.8
13409	16098	Debris	Fair: +/- 0.20 ft	HWM is debris in shrubs just downstream of house number 139. Mark was transferred to telephone pole ID 35479/N30746 49 ft upstream on same roadside.	5/31/2012	486.4
13410	16098	Seed Line	Fair: +/- 0.20 ft	HWM was seed line on door jamb of garage. Mark transferred to tree 90 ft streamward.	5/31/2012	483.5*
13411	16098	Mud	Fair: +/- 0.20 ft	Located at house address 49 Drinker St. Transferred HWM to telephone pole from door 75 ft downstream on same side of road. Pole Id 35520/N30772	5/31/2012	488.4
13412	16098	Mud	Fair: +/- 0.20 ft	HWM found on siding of house number 87 on Drinker St. Transferred to telephone pole ID N30759/35510 downstream and across road from house.	5/31/2012	487.9
13413	16098	Mud	Good: +/- 0.10 ft	HWM is transferred from house #441 on West First St to telephone pole directly across street, distance from house to telephone pole =36 ft.	5/31/2012	484.9*

*No elevation given. Height Above Ground was provided and used to approximate elevation.

4.2. Discharge Flows

The discharge flows used for the 2011 Tropical Storm Lee event conditions were developed in similar fashion as the flows used for the base flood event modeling. The June 2012 USACE report titled *Bloomsburg, PA Flood Risk Management Study (FMRS) Update of Hydrology and Hydraulics for Inclusion of Tropical Storm Lee Event* (Appendix C) analyzed a full range of recurrence intervals from 99% to 0.2% annual exceedance probabilities. Following Tropical Storm Lee, the USGS determined the peak discharge of Fishing Creek at the confluence with the Susquehanna River to be 78,700 CFS. USACE used this discharge value and calculated 90% confidence limits between approximately 63,000 and 100,000 CFS. This corresponds to a recurrence interval of 350 years or an annual exceedance probability of 0.3% for Tropical Storm Lee. The flows applied to the calibration model were calculated using an updated USGS procedure outlined in SIR 2019-5094 as covered in the hydrologic section of this report.

Coincident tributary flows on Hemlock Creek and Montour Run were set to 100-year and 50-year recurrence intervals, respectively. Tributary flows were determined in the same manner as for modeling of the Base Flood condition using drainage area ratios to make assumptions for lagging peak discharges.

Coincident flow on the Susquehanna River was determined by identifying the time at which peak flow occurred at the USGS Fishing Creek gauge 01539000 located on the Bowman's Mill Bridge 5.5 miles north of Bloomsburg and retrieving the concurrent flow at the USGS Susquehanna River gage 01538700 located immediately upstream of the SR 0487 Bridge in Bloomsburg. Some uncertainty exists in this approach because of the lag time required for flow to travel 5.5 miles from the Fishing Creek gauge to the study area and because the gauge on Fishing Creek failed near the peak of the event.

Peak discharges applied to the Tropical Storm Lee calibration model are provided in Table 3.2.

4.3. Terrain Data Adjustments

In order to recreate the topographic conditions at the time of the 2011 Tropical Storm Lee Event, several modifications were made to the final terrain file. Several property acquisition/demolition projects have occurred within the floodplain since Tropical Storm Lee. With this knowledge, historical imagery was used to add structures to the terrain surface which do not currently exist or appear in the Columbia County GIS dataset.

Additionally, neither the Phase 1 levee system around Autoneum nor the Phase 2 levee system around the Bloomsburg High School existed in 2011. These features were removed from the 2011 calibration terrain file.

Some factors are either impossible or exceedingly difficult to replicate for the 2011 event such as bathymetric data, geomorphology of stream banks, and conditions which developed mid-event which would have impacted peak WSELs (i.e., debris jams, erosion, structure movement).

4.4. Hydraulic Structures

The structures listed in Table 4.2 were modeled under 2011 Storm Lee flood event conditions. Notably included in the calibration model is the Red Mill Road Bridge which once connected Red Mill Road to US Route 11. The structure was erected in 1923 and demolished in 2012; a photo of the structure during the Tropical Storm Lee event is shown in Figure 4.2. Due to the age of the structure, little information was available for coding the bridge into the calibration model except for a 1937 sketch of the bridge and the 2011 PennDOT demolition plan, both provided in Appendix D.

Table 4.2 – 2011 Tropical Storm Lee Hydraulic Structures

Rank	Station (ft)	Designation
1	2366.2	Dam_1
2	3986.3	Railroad Street Bridge
3	7947.0	Red Mill Road Bridge
4	8826.0	SR42 Mall Blvd over Fishing Creek
5	8826.0	SR42 Mall Blvd over SR 11
6	10308.6	US Route 11 Bridge North Bound over Fishing Creek
7	10365.1	US Route 11 Bridge South Bound over Fishing Creek
8	12020.3	Dam_2 (Boone's Dam)
9	13696.9	Railroad BR (abandoned)
10	13786.6	Railroad Bridge
11	13862.8	Covered Bridge #56

Figure 4.2 – Red Mill Road Bridge (2011 Event Facing Upstream)

4.5. Manning's Roughness Coefficients

The initial Manning's n roughness values were further refined through model calibration to result in closer agreement between calculated WSELs and recorded HWMs set during the 2011 Tropical Storm Lee event. It is important to understand that general descriptions are given to land uses that are comprised of subsets of smaller land uses; for example, a manning's value for high intensity residential land use considers a proportion of lawn, impervious area, and physical obstructions inherent to that weighted roughness value.

When creating the hydraulic model, the physical obstructions in the floodplain were integrated into the terrain itself; therefore, it would be considered a form of "double counting" to also account for these obstructions in the Manning's coefficient. Likewise, roadways and other large impervious areas were assigned unique Manning's coefficients and should not factor into the weighted value assigned to high intensity residential values.

When these areas are accounted for elsewhere in the model parameters for low, medium, and high intensity residential land uses, the primary land use remaining may be considered as developed open space. This was the logic applied in determining the Manning's n values reflected in Table 4.3.

Table 4.3 - Final Manning's n Values Derived from Calibration

Reference Identifier	Description	Manning's n Values
0	No Data	
1	Water	0.027
2	Deciduous	0.10
3	Shrub	0.08
4	Developed Open Space	0.03
5	Low Intensity Residential	0.03
8	Medium Intensity Residential	0.03
9	High Intensity Residential	0.03
7	Roads	0.02
6	Cultivated Land	0.03
10	Bare Land	0.03

4.6. Calibration Results

The calibration model run consisted of performing a simulation of the hydraulic model with known variables to ensure the accuracy of subsequent model runs. For this project, the model was calibrated using information from the 2011 Tropical Storm Lee Flood. This was a record flood event that is well documented with many sources of information available for reference.

Results of the initial run showed that the model was significantly overestimating WSELs relative to recorded HWMs throughout the study area. In subsequent calibration runs, the initial roughness values were adjusted incrementally lower until reaching the values recorded in Table 4.3. During calibration, it was clear that adjusting Manning's coefficients alone would not bring the model into agreement with the recorded HWMs. Other parameters altered include boundary condition inflows and the bridge modeling approach at the Railroad Street Bridge.

Boundary condition inflows on Fishing Creek were adjusted lower by increasing the coincident recurrence interval of Hemlock Creek and Montour Run to 100-year peak discharges as discussed in Section 4.2. The peak discharge at the confluence with the Susquehanna River remained constant through all calibration runs.

Calculated WSELs in the Fernville area of Hemlock Township remained particularly high relative to surveyed HWMs. Because the Railroad Street Bridge is a major structure in this reach of Fishing Creek, further evaluation of the modeling approach at the structure occurred and led to switching the high flow modeling approach from pressure/weir to energy only. Although the flow does hit the low chord of the bridge, the parapet and bridge deck are not overtopped and the ratio of the hydraulic open area to the area obstructed by the bridge deck is relatively small.

Table 4.4. presents the calibration results by comparing the predicted WSELs against the high-water marks from the September 2011 Lee flood Event. The results show close agreement between the model and the surveyed values generally within 0.6 feet with two outliers. The differences, while not large, are likely due to a combination of three factors. First, the exact location of the surveyed high-water mark is difficult to pinpoint based on the available information. Second, the slope of the water surface profile is steep for a distance of approximately 1,000 feet upstream of the Railroad Street Bridge, changing by more than 3.5 feet between Station 2900 and STA 3950. Lastly, because this study area is in an ungauged location, flow values are statistical estimates based upon a stream gauge located 5.5 miles upstream which malfunctioned near the peak of the 2011 event. As a result, the location of the reading and the selected boundary condition flows will influence the water surface elevation value retrieved from the model.

Table 4.4 - Comparison of HWMs to Modeled WSELs

HWM ID	2011 High Water Marks (Feet NAVD88)	Model Elevation* (Feet NAVD88)	Difference (feet)
13408	485.8	485.45	-0.35
13409	486.4	487.00	0.60
13410	483.5**	485.32	1.82
13411	488.4	489.42	1.02
13412	487.9	488.09	0.19
13413	484.9**	485.21	0.31
Surveyed HWM on Tree (2006 – 482.19')	483.23	482.63	-0.60

*Elevation taken at approximate location of HWM as described in Table 4.1.
**No elevation given. Height Above Ground was provided and used to approximate elevation.

SECTION 5 – EXISTING CONDITIONS HYDRAULIC ANALYSIS

Upon completion of the model calibration, the final parameters were copied to the existing conditions model to be evaluated under a 100-year (Base Flood) condition. The results of the existing conditions model run were used as a base for comparison to the proposed levee condition and mitigation alternative runs.

The 100-year base flood discharge flows used in the existing conditions model are shown in Table 3.1 in Section 3.5. The terrain and structure footprint data included in the existing conditions surface reflect the conditions at the time this study was completed.

SECTION 6 – PROPOSED CONDITIONS HYDRAULIC ANALYSIS

The proposed conditions model was derived from the existing conditions model with identical discharge flows, hydraulic structures, and Manning's n roughness values. The only change from the existing conditions model was the incorporation of the proposed levee system shown in Figure 6.1 into the terrain surface. The proposed levee system is discussed in greater detail in the Final Report.

Minor terrain modifications were required on the proposed levee surface to correct model output/data issues resulting from conflict between the terrain and the mesh grid. These corrections were primarily required where the levee type transitions or where the surface is much narrower than the mesh grid spacing. In these locations, the terrain was widened toward the protected side of the levee to ensure model results are not influenced.

The large floodway of Fishing Creek in the West End study area is situated such that a proposed levee system would be constructed entirely within the regulatory floodway. Results of the 2D proposed conditions modeling show that the WSELs of the base flood increase with the proposed levee shown in Figure 6.1, creating what is referred to as induced flooding. The induced flooding with the proposed levee causes a WSEL increase of the base flood on Fishing Creek up to 2.1 feet. The residential areas in Hemlock Township adjacent to and upstream of the proposed levee would experience a greater risk of flooding because these areas would not be protected by the proposed levee. Figure 6.2 presents the WSEL profiles of the base flood on Fishing Creek with existing conditions as compared to the proposed condition with a levee.

A comparison of Fishing Creek Existing Conditions WSELs and Proposed Conditions WSELs for the base flood is also presented in Table 6.1.

Figure 6.1 – Proposed Conditions Levee Alignment

Table 6.1 - Existing & Proposed Conditions - WSEL Comparisons

2D Modeled Base Flood Flows (100-yr)

#	Designation/Location	Station/ River Feet	WSEL Existing	WSEL Proposed	Change in WSEL (Feet)
1	Dam_1 - Upstream	2330	489.84	490.61	0.77
2	Dam_1 - Centerline	2370	489.80	490.59	0.79
3	Dam_1 - Downstream	2400	489.84	490.62	0.78
4	Railroad Street - Upstream	3950	486.32	488.08	1.76
5	Railroad Street - Centerline	3985	485.75	487.72	1.97
6	Railroad Street - Downstream	4025	484.96	487.04	2.08
7	Leonard Street	4900	483.07	484.45	1.38
8	Barton Street	5800	481.51	482.70	1.19
9	Hemlock Creek	8160	479.67	480.15	0.48
10	SR 42 Mall Blvd - Upstream	8760	479.21	479.65	0.44
11	SR 42 Mall Blvd - Centerline	8840	478.79	479.16	0.37
12	SR 42 Mall Blvd - Downstream	8900	477.95	478.14	0.19
13	SR 11 - Upstream	10240	477.74	477.92	0.18
14	SR 11 - Centerline	10320	477.56	477.70	0.14
15	SR 11 - Downstream	10400	477.38	477.49	0.11
16	Dam_2_: Fishing - Upstream	11980	477.24	477.36	0.12
17	Dam_2_: Fishing - Centerline	12020	477.21	477.33	0.12
18	Dam_2_: Fishing - Downstream	12060	477.20	477.32	0.12
19	Railroad BR Abandoned - Upstream	13650	476.08	476.17	0.07
20	Railroad BR Abandoned - Centerline	13700	475.85	475.93	0.08
21	Railroad BR Abandoned - Downstream	13730	475.67	475.74	0.07
22	Railroad Bridge - Upstream	13750	475.61	475.68	0.07
23	Railroad Bridge - Centerline	13790	475.18	475.23	0.05
24	Railroad Bridge - Downstream	13810	474.44	474.46	0.02
25	Covered BR #56 - Upstream	13840	474.50	474.52	0.02
26	Covered BR #56 - Centerline	13860	474.38	474.39	0.01
27	Covered BR #56 - Downstream	13900	473.95	473.94	-0.01

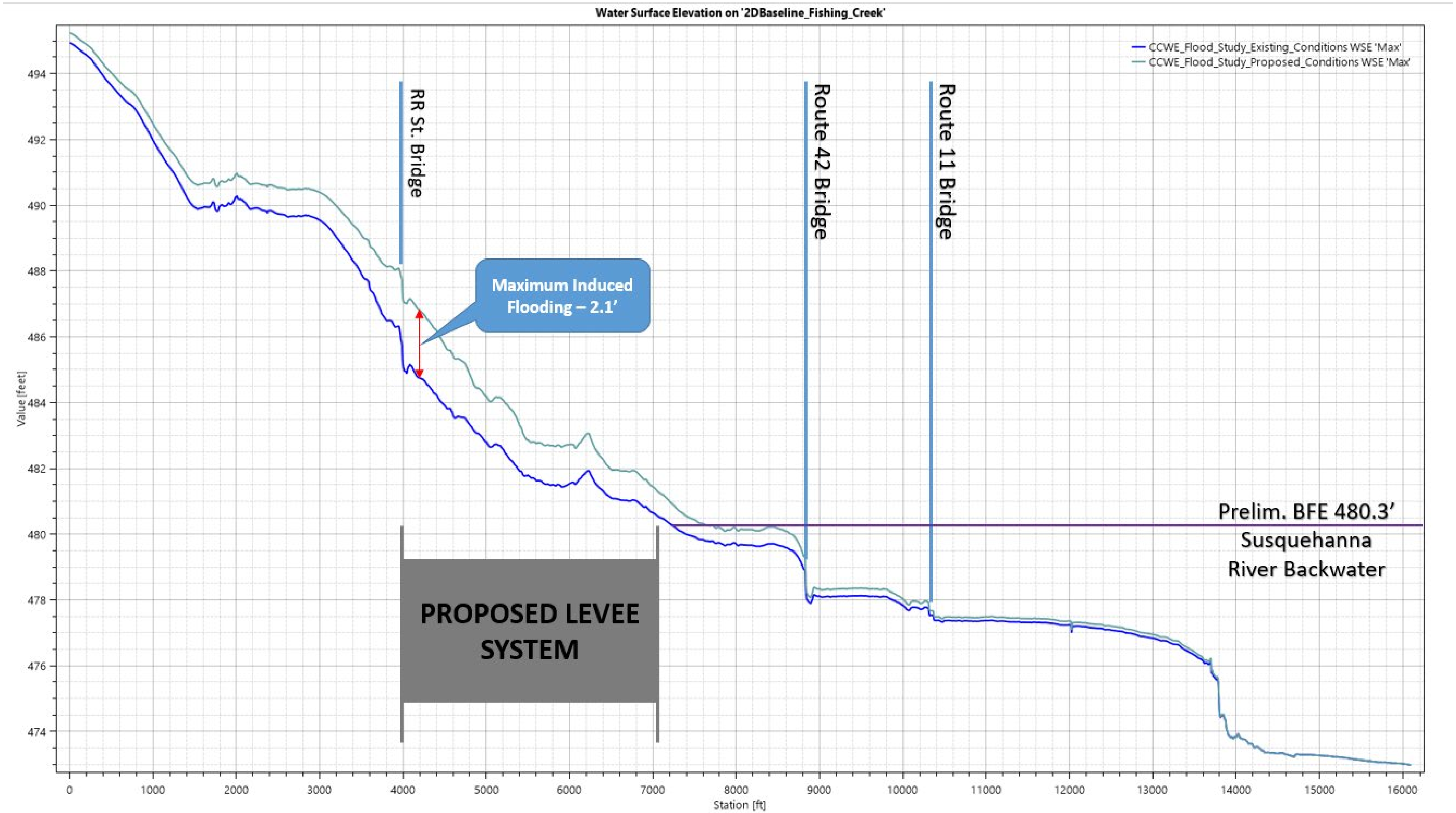

Figure 6.2 – WSEL Profiles of Existing & Proposed Conditions, 2D Modeled Base Flood Flows (100-yr)

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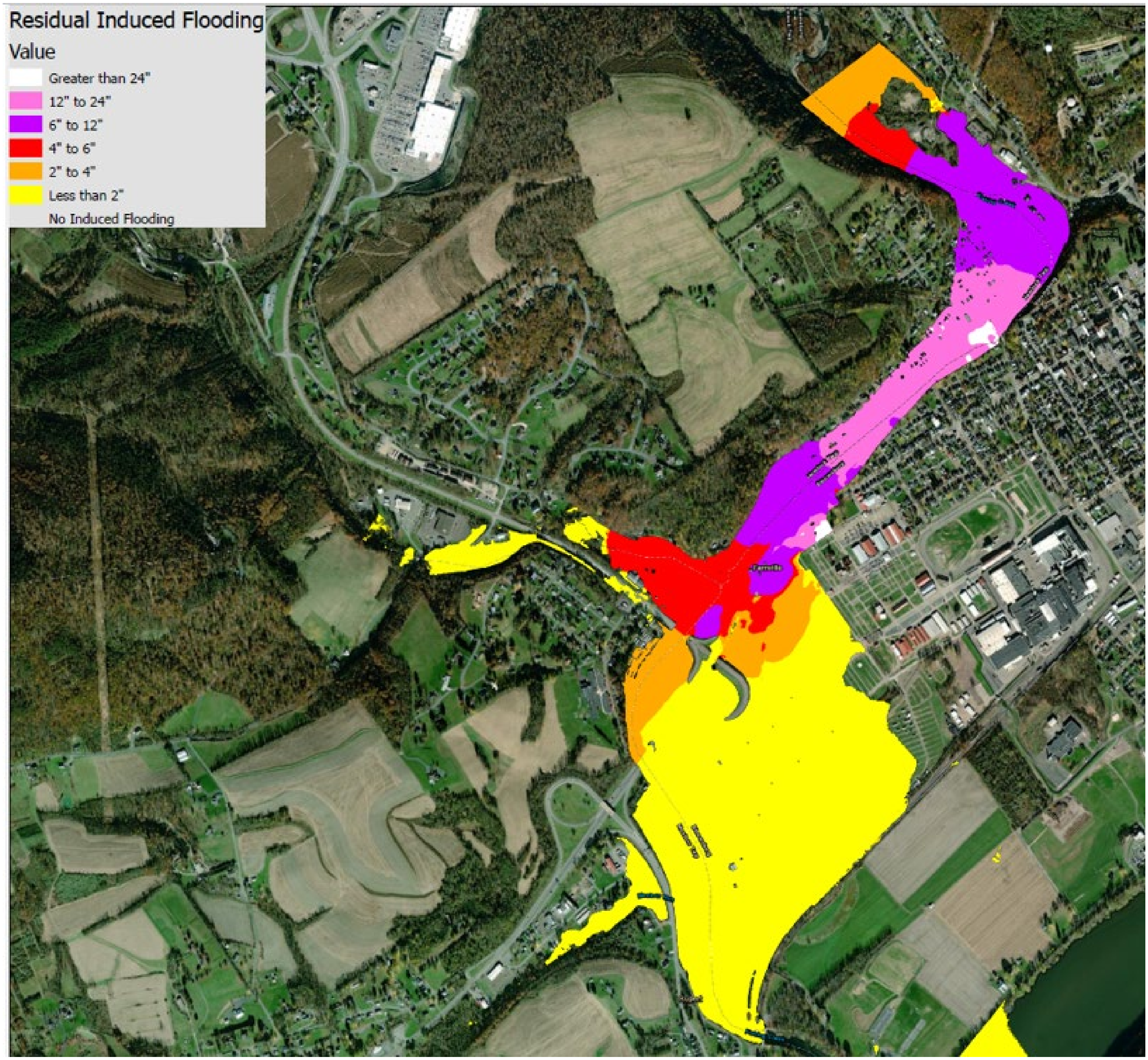

Figure 6.3 – Induced Flooding (Without Mitigation)

SECTION 7 – MITIGATION ALTERNATIVES

In order to analyze mitigation actions required to lower the induced flooding to zero, several alternatives were simulated.

A brief description of each mitigation alternative is provided below.

Mitigation Alternative No. 1

Alternative 1 includes a benched floodplain along the right bank of Fishing Creek and an additional span on the Railroad Street Bridge matching the width of the benched floodplain through the structure. This alternative consists of several sub-alternatives ranging from Alternatives 1B-1F which were created to gauge sensitivity of the model to changes in bridge span length and benched floodplain extents.

A benched floodplain is a term used to describe an area where an elevated streambank has been excavated to provide a bench closer to the channel bottom that will flood more frequently. This feature provides more channel conveyance during flood events and can reduce impacts to the developed floodplain. Figure 7.1 includes an example of a typical benched floodplain and a cross section of Fishing Creek showing proposed conditions grading. The location and extents of the benched floodplain are depicted in Figure 7.4.

Initial iterations of Alternative 1 demonstrated a sizable reduction in induced flooding in the area adjacent to the levee system and significant reduction (up to 1') below existing conditions upstream of the Railroad Street Bridge. Later iterations of Alternative 1 revealed that expansion of the Railroad Street Bridge is not required because presence of the benched floodplain downstream of the Railroad Street Bridge is sufficient in mitigating induced flooding in the vicinity of and upstream of Railroad Street.

Typical Benched Floodplain

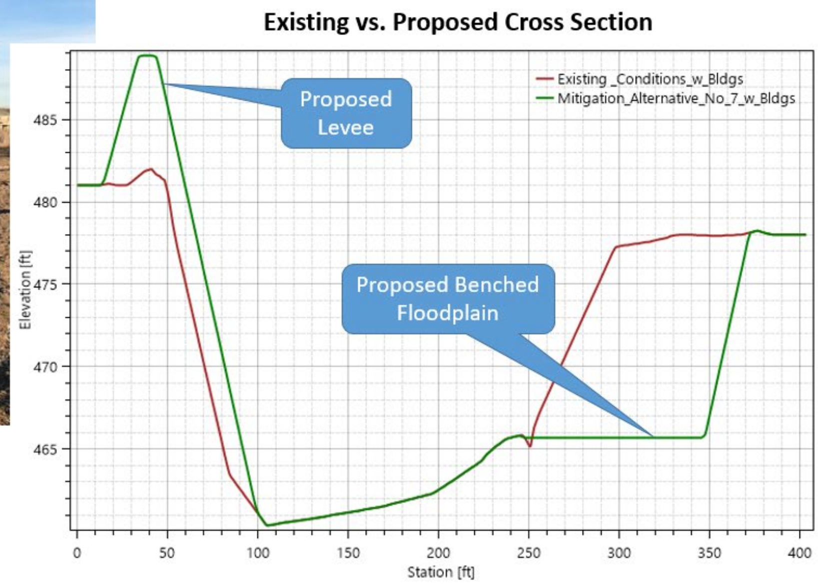

Figure 7.1 – Benched Floodplain

Mitigation Alternative No. 2

Alternative 2 was modeled to determine the effects of minimizing encroachment into the regulated floodway by replacing the 90 degree turn in the alignment of the proposed levee with a smoothed radius alignment. Other minor modifications to the levee alignment were also evaluated as Alternative 2A.

Alternative 2A produces a modest decrease in induced flooding with a correspondingly small cost of implementation. A simple change in the proposed levee alignment, while negatively impacting a portion of fairgrounds, aids in meeting the ultimate goal of no induced flooding. Comparison of the alternative alignment vs. the proposed alignment presented in the Final Report is provided in Figure 7.2.

Figure 7.2 – Levee Alignment Modifications

Mitigation Alternative No. 3

Alternative 3 was created to evaluate the benefit of constructing culverts under US Route 11 to reconnect Fishing Creek flows to the floodplain. Alternative 3 consists of seven (7) 4'x30' low-profile concrete arch culverts oriented to the direction of overbank flow. The final shape, span, and configuration of the structures beneath US Route 11 will likely be modified during design to balance hydraulic effectiveness vs. cost vs. reduction in induced flooding.

US Route 11 parallels Fishing Creek downstream of where the proposed levee along the left bank of Fishing Creek turns inland. The location of the culverts was chosen based on the high velocities in this area predicted by the model and because of the historical damages that occurred to homes at this location during Tropical Storm Lee which led to their demolition in 2012. This Alternative serves to mitigate induced flooding between benched floodplain and the PA Route 42 Bridge by increasing conveyance from Fishing Creek to the floodplain. See Figure 7.3 below.

The concept employed by Mitigation 3 has been used in flood mitigation projects elsewhere in the United States, notably the USACE Old River Control Structure on the Mississippi River in Louisiana and the Yolo Bypass on the Sacramento River in California.

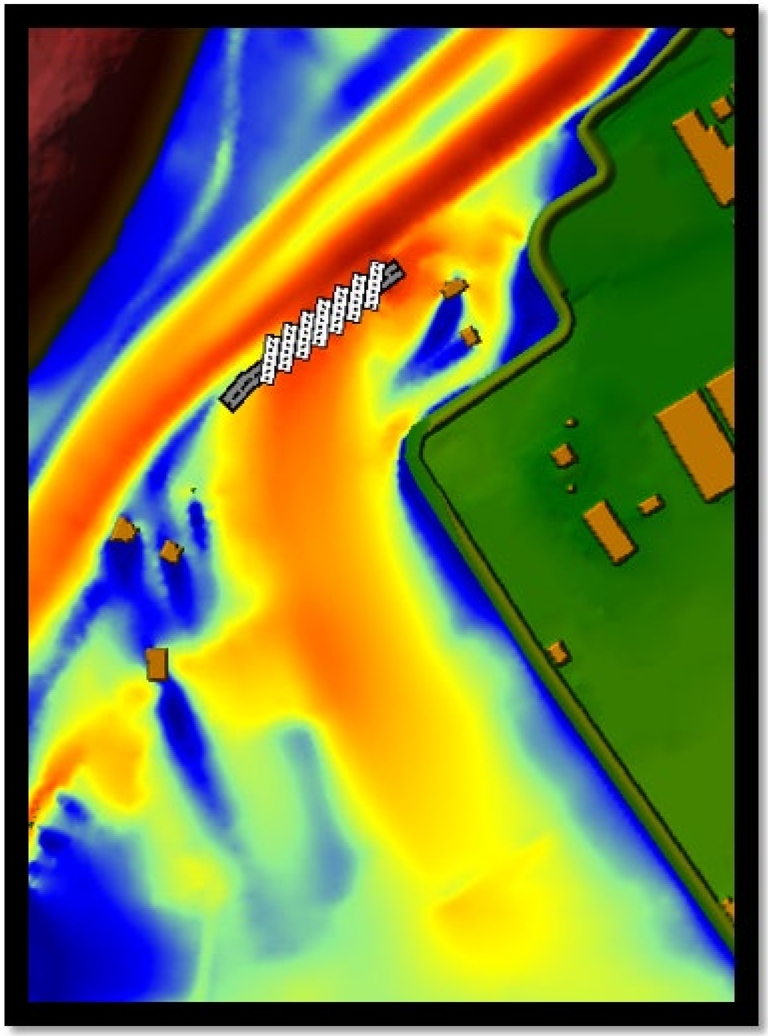

Figure 7.3 – Relief Culverts Beneath Route 11

Mitigation Alternative No. 4

Mitigation Alternative 4 consists of combining Alternatives 1, 2, & 3 to determine potential compounding benefits of mitigation features.

The benched floodplain and floodplain reconnection utilizing relief culverts under US Route 11 operate in tandem to largely mitigate induced flooding to homes and structures in Hemlock Township. The benched floodplain increases conveyance capacity of Fishing Creek in the area where the Creek overtops its bank into the West End of Bloomsburg; this flow is then conveyed downstream to be released back into the floodplain by the proposed relief culverts described in Mitigation Alternative 3.

Upon review of Alternative 4 results, several structures in Hemlock Township remained impacted by induced flooding. Additional evaluation of mitigation alternatives was performed.

Mitigation Alternative No. 5

Alternative 5 evaluated the impact of adding an additional span on the left side of the PA Route 42 Bridge. Alternative 5A evaluated additional spans on both sides of the structure and included a benched floodplain beginning upstream of the bridge and extending downstream through the structure past the existing mobile home park. Alternative 5A produced noticeably more reduction in induced flooding compared to Alternative 5. Significant increases in water surface elevation downstream at the US Route 11 Bridge together with the excessive cost and scheduling implications of modifying a large state bridge prevented further consideration of this alternative.

Mitigation Alternative No. 6

Alternative 6 is a refinement of Alternative 4 created by including the least restrictive levee alignment from Alternative 2A, eliminating the additional span on the Railroad Street Bridge (Alt 1F), and improving the transitional grading from the relief culverts into the floodplain. Results of this alternative were positive and offered confirmation that the mitigation concepts were heading in the right direction. Six (6) structures, all located along Drinker Street in Hemlock Township, remained impacted by induced flooding of between 2" to 6" under base flood conditions. Note that existing structures scheduled for acquisition/demolition are not included in this number.

Mitigation Alternative No. 7

Alternative 7 is the final alternative completed under the scope of this study and builds upon Alternative 6 by including adjustments to the proposed levee alignment along West 1st Street which runs parallel to the left bank of Fishing Creek and by lowering and widening the benched floodplain along the right bank (opposite the proposed levee). The purpose of this alternative is to reduce channel constrictions and maximize conveyance capacity within the channel of Fishing Creek.

Alternative 7 provides the most promising results of all those evaluated resulting in just two (2) structures with residual induced flooding of approximately 4" under base flood conditions. Both structures are located along Drinker Street which runs parallel to Fishing Creek in Hemlock Township. Figures 7.4 through 7.6 include graphics of the final proposed levee and mitigation features, water surface elevation profiles along Fishing Creek, and graphical extents of expected residual induced flooding in Hemlock Township for the base flood. Figures 7.7 and 7.8 illustrate modeled velocities in Fishing Creek main channel and floodplains under existing conditions and proposed (with Mitigation Alternative 7 conditions) for the base flood. Velocities are slightly reduced in Fishing Creek's channel with proposed conditions, as compared to existing conditions, likely due to the proposed benched floodplain. Velocities are slightly increased down gradient of the proposed relief culverts in the open field area of the Bloomsburg Fairgrounds; this is due to intentional diversion of flows to this area from Fishing Creek under high flow/flood conditions on the creek.

No additional alternatives were modeled as part of this flood mitigation study. Additional sensitivity analysis can be completed during the design phase of a future project. Successful mitigation of the residual induced flooding is likely with refinement of the levee alignment along the left bank of Fishing Creek and with final design of a culvert system beneath US Route 11.

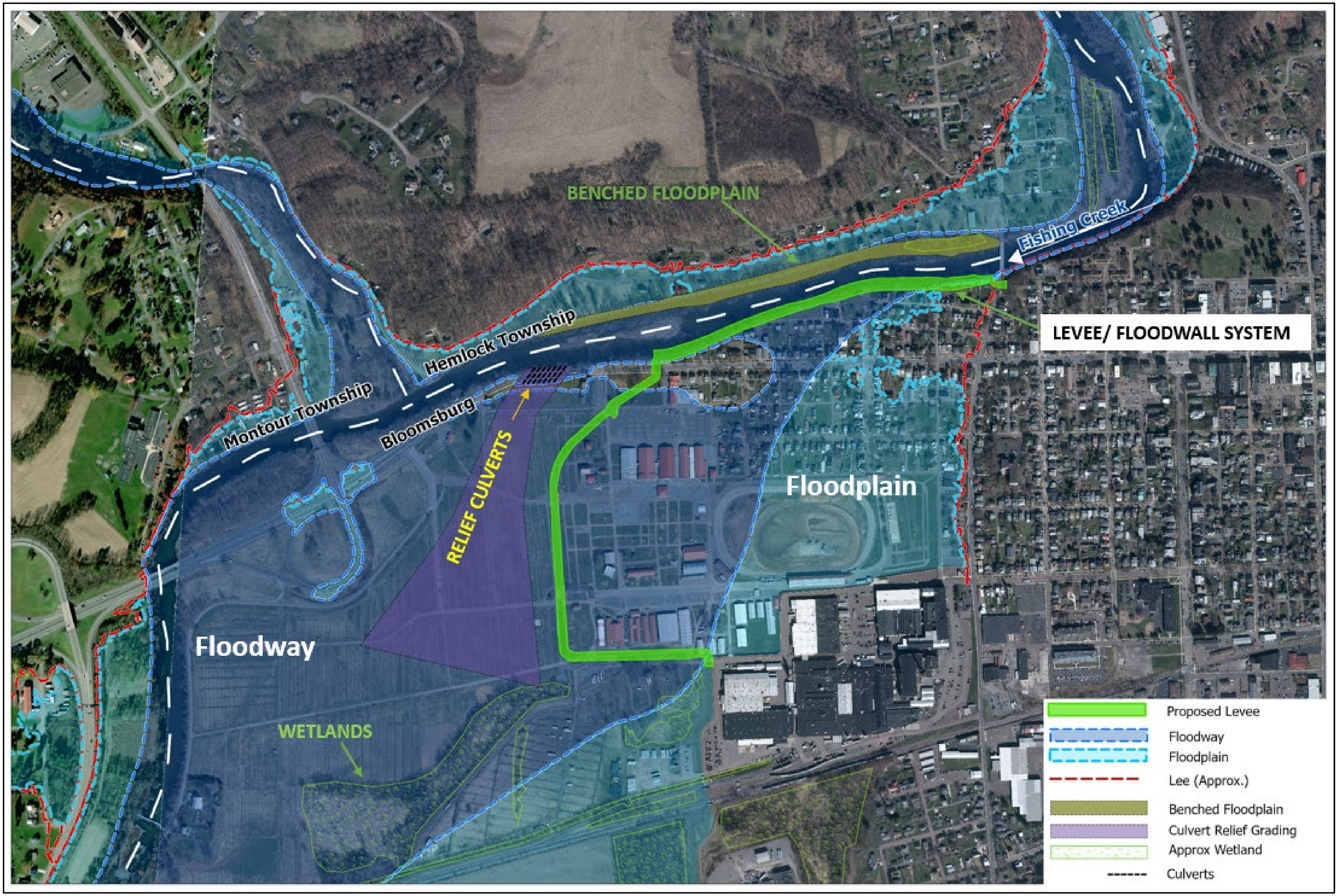

Figure 7.4 – Final Proposed Levee Alignment with Mitigation Features (Mitigation Alternative 7)

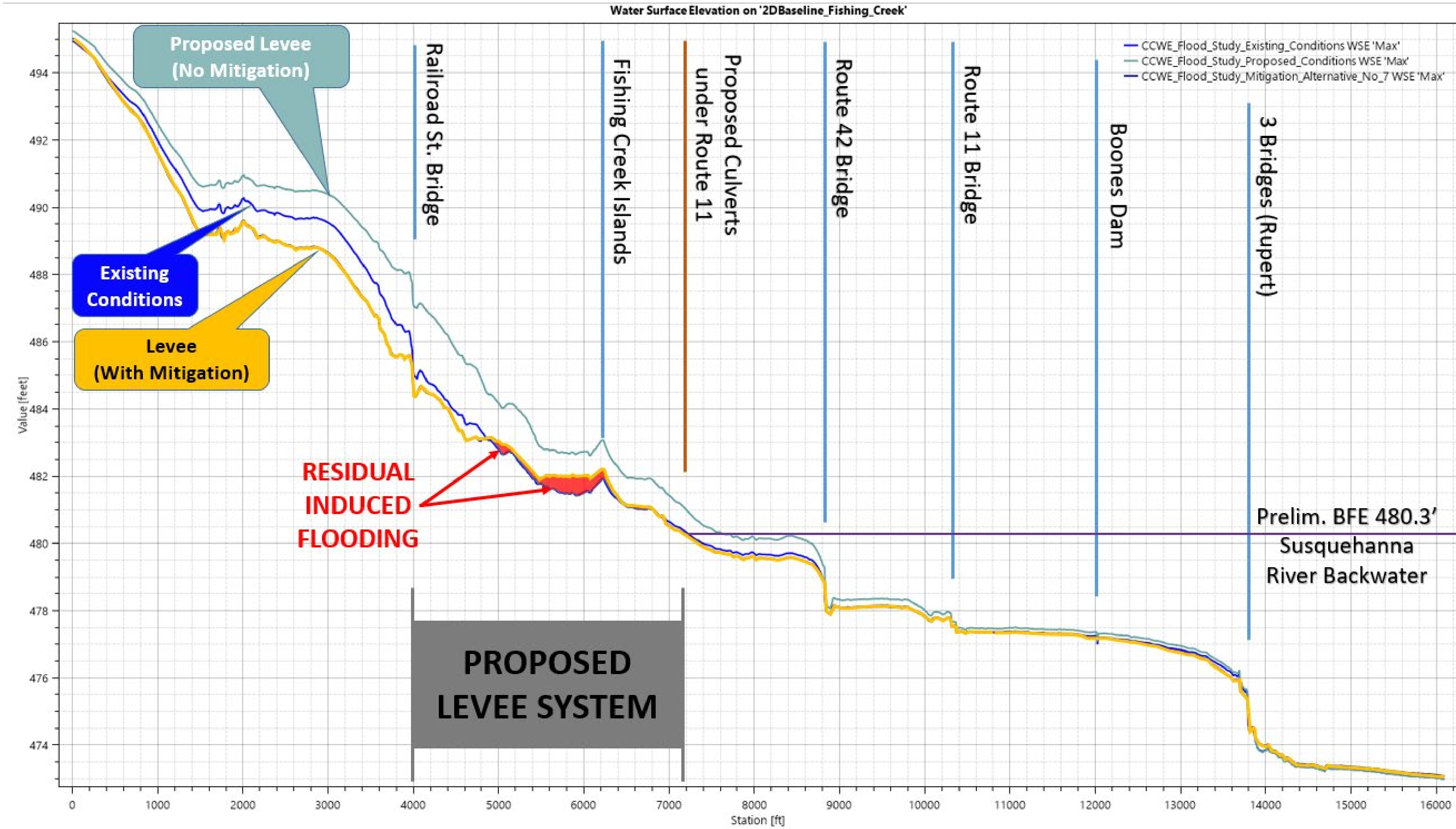

Figure 7.5 – WSEL Profiles - Existing, Proposed, and Mitigation Alternative 7

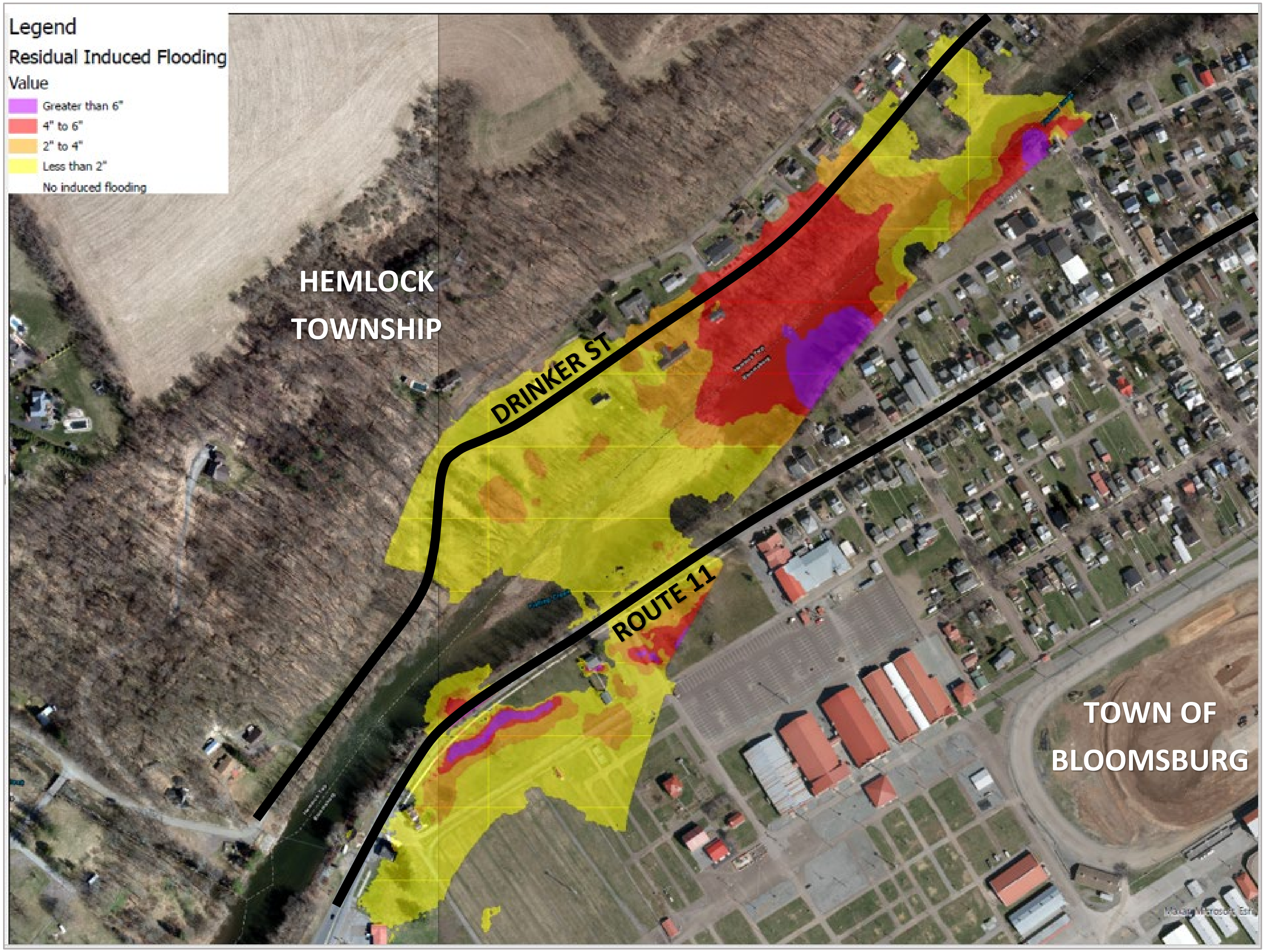

Figure 7.6 – Residual Induced Flooding (After Mitigation)

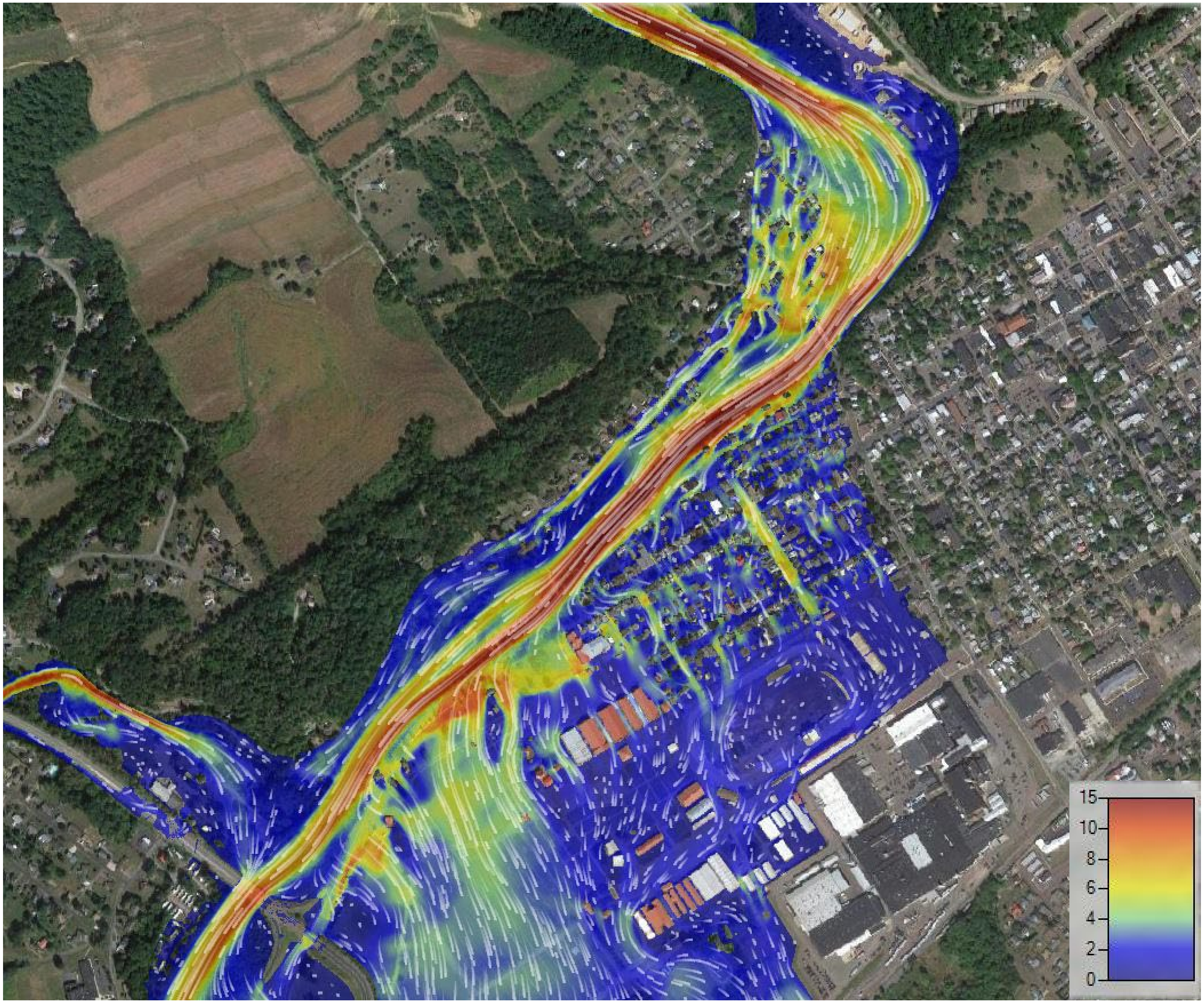

Figure 7.7 – Modeled Velocities (feet per second) along Fishing Creek, Base Flood - *Existing Conditions*

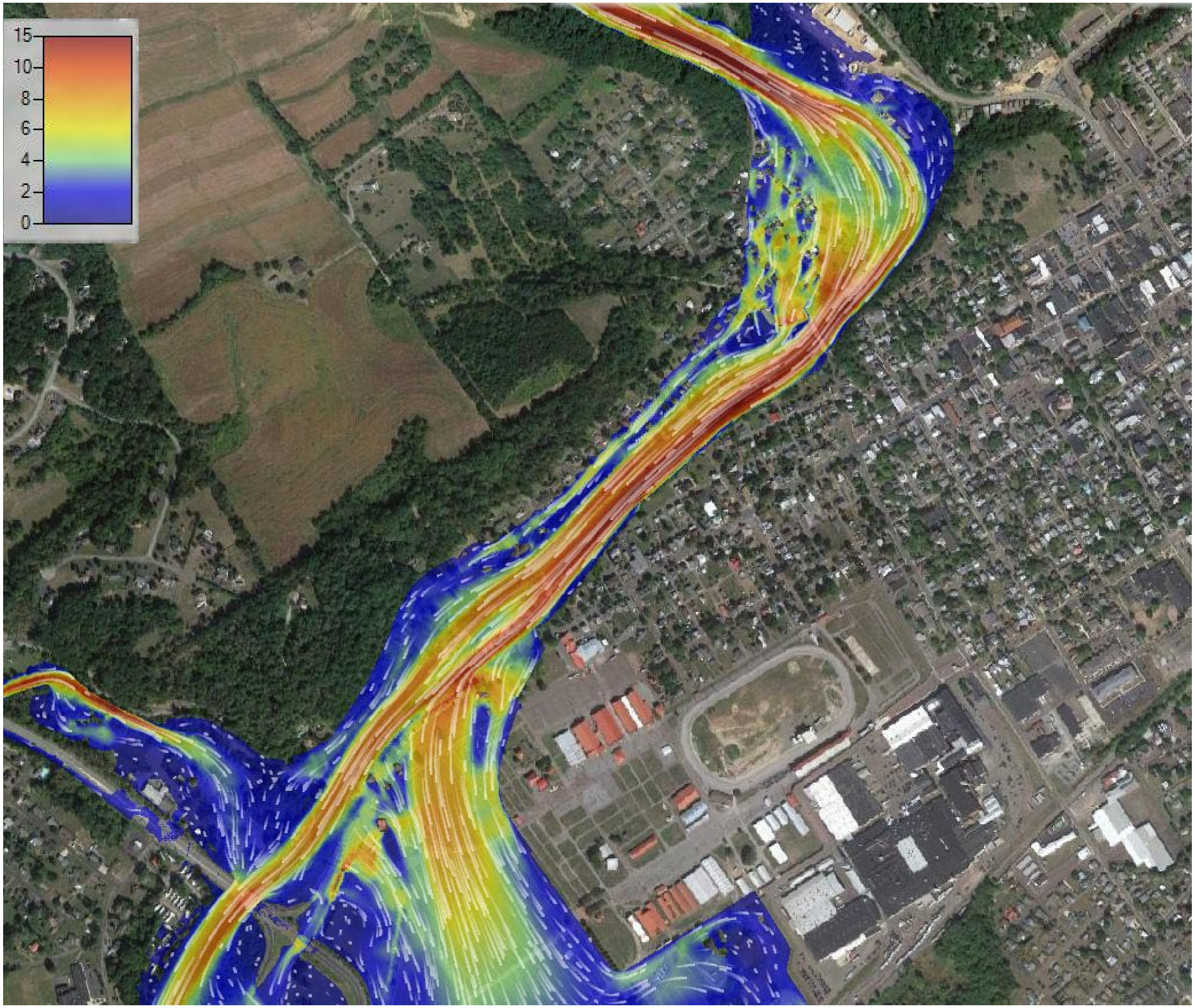

Figure 7.8 – Modeled Velocities (feet per second) along Fishing Creek, Base Flood
Final Proposed Conditions – Mitigation Alternative 7 (Levee, Benched Floodplain, Relief Culverts)

The WSEL comparisons for Mitigation Alternatives are shown in Table 7.1.

Table 7.1 - WSEL Comparisons for Mitigation Alternatives

#	Designation/Location	Station / River Feet	WSEL (feet NAVD 88)						
			Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	Alt. 6	Alt. 7
1	Dam_1 - Upstream	2330	489.32	488.82	490.50	488.76	490.59	489.24	489.01
2	Dam_1 - Centerline	2370	489.26	488.74	490.47	488.70	490.56	489.20	488.97
3	Dam_1 - Downstream	2400	489.31	488.80	490.50	488.75	490.60	489.22	488.99
4	Railroad Street - Upstream	3950	486.42	486.24	487.90	486.09	488.03	486.24	485.53
5	Railroad Street - Centerline	3985	486.19	486.09	487.68	485.87	487.76	486.08	485.21
6	Railroad Street - Downstream	4025	485.33	485.31	486.89	485.17	486.96	485.04	484.30
7	Leonard Street	4900	483.15	482.95	484.24	482.77	484.36	482.60	483.08
8	Barton Street	5800	482.58	482.33	482.29	482.05	482.58	481.90	481.90
9	Hemlock Creek	8160	480.14	479.99	479.79	479.75	479.74	479.54	479.49
10	SR42 Mall Blvd - Upstream	8760	479.77	479.64	479.44	479.41	479.49	479.18	479.14
11	SR42 Mall Blvd - Centerline	8840	478.31	478.34	478.15	478.22	478.67	478.01	478.02
12	SR42 Mall Blvd - Downstream	8900	478.17	478.19	478.02	478.06	478.66	477.94	477.95
13	US Route 11 BR - Upstream	10240	477.95	477.93	477.86	477.89	478.00	477.73	477.75
14	US Route 11 BR - Centerline	10320	477.72	477.70	477.66	477.69	477.72	477.53	477.55
15	US Route 11 BR - Downstream	10400	477.53	477.53	477.48	477.51	477.49	477.35	477.38
16	Dam_2_: Fishing– Upstream*	11980	477.39	477.38	477.31	477.37	477.37	477.15	477.20
17	Dam_2_: Fishing– Centerline*	12020	477.38	477.38	477.31	477.36	477.28	477.15	477.20
18	Dam_2_: Fishing– Downstream*	12060	477.38	477.38	477.31	477.36	477.33	477.15	477.19
19	Railroad BR Abandoned - US	13650	476.32	476.32	476.16	476.29	476.19	475.84	475.93
20	Railroad BR Abandoned - CL	13700	476.14	476.15	475.96	476.11	476.02	475.72	475.90
21	Railroad BR Abandoned - DS	13730	475.94	475.94	475.74	475.92	475.80	475.50	475.52
22	Railroad Bridge - Upstream	13750	475.87	475.88	475.68	475.85	475.76	475.41	475.46
23	Railroad Bridge - Centerline	13790	475.47	475.48	475.26	475.44	475.56	475.02	474.98
24	Railroad Bridge - Downstream	13810	474.69	474.73	474.48	474.71	474.57	474.45	474.46
25	Covered BR #56 - Upstream	13840	474.74	474.74	474.53	474.74	474.57	474.57	474.53
26	Covered BR #56 - Centerline	13860	474.62	474.62	474.40	474.62	474.45	474.56	474.51
27	Covered BR #56 - Downstream	13900	474.21	474.23	473.96	474.24	473.98	474.18	474.14

*Dam 2 (Boone's Dam) is scheduled for removal and was not included in the mitigation analyses.
**WSELs given are from the most favorable iteration of each individual alternative.
***All WSELs are taken along

SECTION 8 - OPINION OF PROBABLE CONSTRUCTION COST

Alternative 7 involves construction of a benched floodplain along the right descending bank of Fishing Creek in Hemlock Township, a system of culverts under US Route 11 just upstream of the PA Route 42 Bridge in Bloomsburg, and grading of a portion of the Fairgrounds parking area in Bloomsburg to provide an efficient flow path for higher level floods which flow through this area under existing conditions.

An opinion of probable construction costs for the mitigation features was developed utilizing cost data from recent levee construction projects in Bloomsburg, PA. The detailed construction cost estimate is included in Appendix E.

A cost summary is provided below:

1.	General Grading	$200,000
2.	Benched Floodplain	$1,800,000
3.	Culverts under US Route 11	$2,000,000
	TOTAL	**$4,000,000**

SECTION 9 – ANALYSIS SUMMARY

Fishing Creek in the West End of the Town of Bloomsburg is a hydraulically complex stream. Hydraulic modeling with 2D software offers powerful computational methods to better understand the behavior of flows under existing conditions and to predict flows under proposed conditions. This facilitates a better understanding of the movement of floodwaters in Fishing Creek and adjacent floodplains.

The large floodway of Fishing Creek in the West End study area is situated such that a proposed levee system would be constructed entirely within the regulatory floodway. Results of the 2D proposed conditions modeling show that the water surface elevation (WSEL) of the base flood increases by a maximum of 2.1 feet when a levee is constructed along the bank of Fishing Creek. The residential areas in Hemlock Township adjacent to and upstream of the proposed levee would experience a greater risk of flooding because these areas would not be protected by the proposed levee.

Several mitigation alternatives were evaluated with the goal of eliminating all induced flooding to structures/homes. Mitigation alternative 7 was chosen as the preferred alternate. It includes a benched floodplain to increase conveyance capacity parallel to the levee and a series of culverts under US Route 11 to encourage flow back into the floodplain west of the proposed levee alignment. The proposed culverts are located in the floodway in an area where, during the Tropical Storm Lee Flood of 2011, several homes were destroyed by overbank flows. The intent of this mitigation alternative is to return the flow where it originally went in existing conditions as efficiently as possible.

At the conclusion of this study, the initial 2.1 feet of induced flooding was mitigated to just 4 inches of residual induced flooding realized by two (2) structures along Drinker Street in Hemlock Township. It is possible that further refinement of the selected mitigation features during design could eliminate all the residual induced flooding; however, if not, acquisition/demolition or structure elevations at these properties remain as options that would be acceptable to both FEMA and the Pennsylvania Department of Environmental Protection (PADEP). In fact, the cost of further structural mitigation may outweigh the cost of elevating or acquiring the structures which remain impacted by induced flooding.

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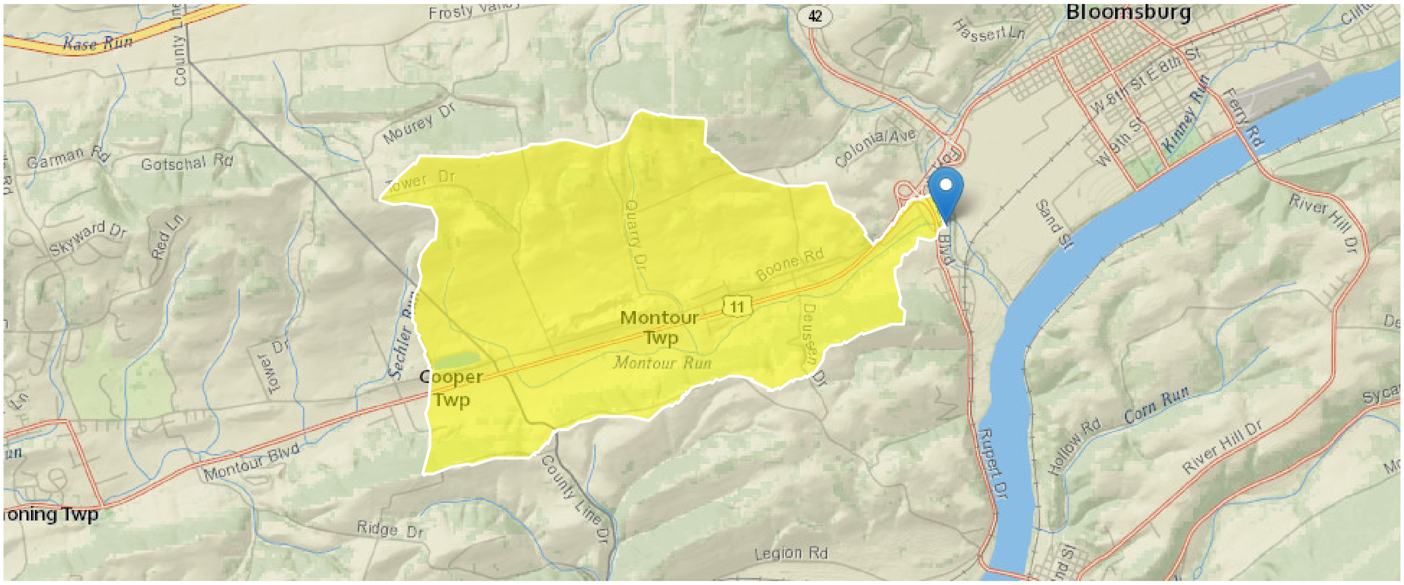
Appendix A

PA STREAMSTATS REPORT – MONTOUR RUN

StreamStats Report

Region ID: PA
Workspace ID: PA20221101170642190000
Clicked Point (Latitude, Longitude): 40.98529, -76.47510
Time: 2022-11-01 13:07:03 -0400



Collapse All

Basin Characteristics

Parameter Code	Parameter Description	Value	Unit
BSLOPD	Mean basin slope measured in degrees	7.4556	degrees
BSLOPDRAW	Unadjusted basin slope, in degrees	7.6747	degrees
BSLPDRPA20	Unadjusted basin slope, in degrees, from PA v1	8.0597	degrees
CARBON	Percentage of area of carbonate rock	6.61	percent
CENTROXA83	X coordinate of the centroid, in NAD_1983_Albers, meters	125127.9655	meters
CENTROYA83	Basin centroid horizontal (y) location in NAD 1983 Albers	220914.8729	meters
DRN	Drainage quality index from STATSGO	3.1	dimensionless
DRNAREA	Area that drains to a point on a stream	4.61	square miles
ELEV	Mean Basin Elevation	739	feet
ELEVMAX	Maximum basin elevation	1234	feet
FOREST	Percentage of area covered by forest	36.9236	percent
GLACIATED	Percentage of basin area that was historically covered by glaciers	0	percent
IMPNLCD01	Percentage of impervious area determined from NLCD 2001 impervious dataset	3.3317	percent
LC01DEV	Percentage of land-use from NLCD 2001 classes 21-24	12.9981	percent
LC11DEV	Percentage of developed (urban) land from NLCD 2011 classes 21-24	13.8486	percent
LC11IMP	Average percentage of impervious area determined from NLCD 2011 impervious dataset	3.5326	percent
LONG_OUT	Longitude of Basin Outlet	-76.475081	degrees

Parameter Code	Parameter Description	Value	Unit
MAXTEMP	Mean annual maximum air temperature over basin area from PRISM 1971-2000 800-m grid	60	degrees F
OUTLETXA83	X coordinate of the outlet, in NAD_1983_Albers,meters	128301.8771	meters
OUTLETYA83	Y coordinate of the outlet, in NAD_1983_Albers, meters	221542.8818	meters
PRECIP	Mean Annual Precipitation	41	inches
ROCKDEP	Depth to rock	3.4	feet
STORAGE	Percentage of area of storage (lakes ponds reservoirs wetlands)	1.92	percent
STRDEN	Stream Density -- total length of streams divided by drainage area	1.91	miles per square mile
STRMTOT	total length of all mapped streams (1:24,000-scale) in the basin	8.78	miles
URBAN	Percentage of basin with urban development	4.3006	percent

Peak-Flow Statistics

Peak-Flow Statistics Parameters [Peak Flow Region 3 SIR 2019 5094]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	1.42	1280
CARBON	Percent Carbonate	6.61	percent	0	100

Peak-Flow Statistics Flow Report [Peak Flow Region 3 SIR 2019 5094]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	ASEp
50-percent AEP flood	194	ft^3/s	41.7
20-percent AEP flood	362	ft^3/s	39.6
10-percent AEP flood	510	ft^3/s	38.3
4-percent AEP flood	737	ft^3/s	38.5
2-percent AEP flood	935	ft^3/s	38.9
1-percent AEP flood	1160	ft^3/s	40.1
0.5-percent AEP flood	1410	ft^3/s	41.3
0.2-percent AEP flood	1800	ft^3/s	43.7

Peak-Flow Statistics Citations

Roland, M.A., and Stuckey, M.H.,2019, Development of regression equations for the estimation of flood flows at ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2019–5094, 36 p. (https://doi.org/10.3133/sir20195094)

Low-Flow Statistics

Low-Flow Statistics Parameters [Low Flow Region 2]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	4.93	1280

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
PRECIP	Mean Annual Precipitation	41	inches	35	50.4
STRDEN	Stream Density	1.91	miles per square mile	0.51	3.1
ROCKDEP	Depth to Rock	3.4	feet	3.32	5.65
CARBON	Percent Carbonate	6.61	percent	0	99

Low-Flow Statistics Disclaimers [Low Flow Region 2]

One or more of the parameters is outside the suggested range. Estimates were extrapolated with unknown errors.

Low-Flow Statistics Flow Report [Low Flow Region 2]

Statistic	Value	Unit
7 Day 2 Year Low Flow	0.265	ft^3/s
30 Day 2 Year Low Flow	0.409	ft^3/s
7 Day 10 Year Low Flow	0.082	ft^3/s
30 Day 10 Year Low Flow	0.134	ft^3/s
90 Day 10 Year Low Flow	0.26	ft^3/s

Low-Flow Statistics Citations

Stuckey, M.H.,2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84 p. (http://pubs.usgs.gov/sir/2006/5130/)

Annual Flow Statistics

Annual Flow Statistics Parameters [Statewide Mean and Base Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	2.26	1720
ELEV	Mean Basin Elevation	739	feet	130	2700
PRECIP	Mean Annual Precipitation	41	inches	33.1	50.4
FOREST	Percent Forest	36.9236	percent	5.1	100
URBAN	Percent Urban	4.3006	percent	0	89

Annual Flow Statistics Flow Report [Statewide Mean and Base Flow]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	ASEp
Mean Annual Flow	5.75	ft^3/s	12	12

Annual Flow Statistics Citations

Stuckey, M.H.,2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84 p. (http://pubs.usgs.gov/sir/2006/5130/)

General Flow Statistics

General Flow Statistics Parameters [Statewide Mean and Base Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	2.26	1720
PRECIP	Mean Annual Precipitation	41	inches	33.1	50.4
CARBON	Percent Carbonate	6.61	percent	0	99
FOREST	Percent Forest	36.9236	percent	5.1	100
URBAN	Percent Urban	4.3006	percent	0	89

General Flow Statistics Flow Report [Statewide Mean and Base Flow]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	ASEp
Harmonic Mean Streamflow	1.22	ft^3/s	38	38

General Flow Statistics Citations

Stuckey, M.H.,2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84 p. (http://pubs.usgs.gov/sir/2006/5130/)

Base Flow Statistics

Base Flow Statistics Parameters [Statewide Mean and Base Flow]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	2.26	1720
PRECIP	Mean Annual Precipitation	41	inches	33.1	50.4
CARBON	Percent Carbonate	6.61	percent	0	99
FOREST	Percent Forest	36.9236	percent	5.1	100
URBAN	Percent Urban	4.3006	percent	0	89

Base Flow Statistics Flow Report [Statewide Mean and Base Flow]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE	ASEp
Base Flow 10 Year Recurrence Interval	1.98	ft^3/s	21	21
Base Flow 25 Year Recurrence Interval	1.71	ft^3/s	21	21
Base Flow 50 Year Recurrence Interval	1.57	ft^3/s	23	23

Base Flow Statistics Citations

Stuckey, M.H.,2006, Low-flow, base-flow, and mean-flow regression equations for Pennsylvania streams: U.S. Geological Survey Scientific Investigations Report 2006-5130, 84 p. (http://pubs.usgs.gov/sir/2006/5130/)

Bankfull Statistics

Bankfull Statistics Parameters [Statewide Bankfull Noncarbonate 2018 5066]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	2.62	207
CARBON	Percent Carbonate	6.61	percent		

Bankfull Statistics Parameters [Appalachian Highlands D Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	0.07722	940.1535

Bankfull Statistics Parameters [Valley and Ridge P Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	0.100386	395.999604

Bankfull Statistics Parameters [USA Bieger 2015]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	4.61	square miles	0.07722	59927.7393

Bankfull Statistics Flow Report [Statewide Bankfull Noncarbonate 2018 5066]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE
Bankfull Area	41.6	ft^2	64
Bankfull Streamflow	173	ft^3/s	74
Bankfull Width	28.8	ft	59
Bankfull Depth	1.49	ft	56

Bankfull Statistics Flow Report [Appalachian Highlands D Bieger 2015]

Statistic	Value	Unit
Bieger_D_channel_width	28.6	ft
Bieger_D_channel_depth	1.74	ft
Bieger_D_channel_cross_sectional_area	50.6	ft^2

Bankfull Statistics Flow Report [Valley and Ridge P Bieger 2015]

Statistic	Value	Unit
Bieger_P_channel_width	25.9	ft
Bieger_P_channel_depth	1.55	ft
Bieger_P_channel_cross_sectional_area	41.7	ft^2

Bankfull Statistics Flow Report [USA Bieger 2015]

Statistic	Value	Unit
Bieger_USA_channel_width	21.2	ft
Bieger_USA_channel_depth	1.67	ft
Bieger_USA_channel_cross_sectional_area	39	ft^2

Bankfull Statistics Flow Report [Area-Averaged]

PIl: Prediction Interval-Lower, PIu: Prediction Interval-Upper, ASEp: Average Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE
Bankfull Area	41.6	ft^2	64
Bankfull Streamflow	173	ft^3/s	74

Statistic	Value	Unit	SE
Bankfull Width	28.8	ft	59
Bankfull Depth	1.49	ft	56
Bieger_D_channel_width	28.6	ft	
Bieger_D_channel_depth	1.74	ft	
Bieger_D_channel_cross_sectional_area	50.6	ft^2	
Bieger_P_channel_width	25.9	ft	
Bieger_P_channel_depth	1.55	ft	
Bieger_P_channel_cross_sectional_area	41.7	ft^2	
Bieger_USA_channel_width	21.2	ft	
Bieger_USA_channel_depth	1.67	ft	
Bieger_USA_channel_cross_sectional_area	39	ft^2	

Bankfull Statistics Citations

Clune, J.W., Chaplin, J.J., and White, K.E.,2018, Comparison of regression relations of bankfull discharge and channel geometry for the glaciated and nonglaciated settings of Pennsylvania and southern New York: U.S. Geological Survey Scientific Investigations Report 2018–5066, 20 p. (https://doi.org/10.3133/sir20185066)
Bieger, Katrin; Rathjens, Hendrik; Allen, Peter M.; and Arnold, Jeffrey G.,2015, Development and Evaluation of Bankfull Hydraulic Geometry Relationships for the Physiographic Regions of the United States, Publications from USDA-ARS / UNL Faculty, 17p. (https://digitalcommons.unl.edu/usdaarsfacpub/1515?utm_source=digitalcommons.unl.edu%2Fusdaarsfacpub%2F1515&utm_medium=PDF&utm_campaign=PDFCoverPages)

Application Version: 4.11.1
StreamStats Services Version: 1.2.22
NSS Services Version: 2.2.1

Appendix B

USGS HIGH WATER MARK DATA

HWM ID: 13408

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.46314
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	
Peak Summaries	
Elevation (ft)	

HWM Information

HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Mud
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Good: +/- 0.10 ft
Bank	
Location Description	HWM transferred from small garage with grey vinyl siding at 435 West First St. Transferred to telephone pole 63 ft bankward across street and 65 ft upstream.
Latitude	41.001331
Longitude	-76.463143
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	2.6
Flag/Found Date	10/25/2011
Surveyed Date	5/31/2012
Surveyed Elevation	485.8
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	
Tranquil/Stillwater HWM	Yes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DL3

HWM ID: 13409

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.46314
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	
Peak Summaries	

Elevation (ft)

HWM Information	
HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Debris
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Fair: +/- 0.20 ft
Bank	
Location Description	HWM is debris in shrubs just downstream of house number 139. Mark was transferred to telephone pole ID 35479/N30746 49 ft upstream on same road side
Latitude	41.003316
Longitude	-76.464023
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	1/3/1900
Flag/Found Date	10/25/2011
Surveyed Date	41060
Surveyed Elevation	486.4
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	
Tranquil/Stillwater HWM	Yes

HWM ID: 13410

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.46314
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	
Peak Summaries	

Elevation (ft)

HWM Information	
HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Seed line
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Fair: +/- 0.20 ft
Bank	
Location Description	HWM was seed line on door jamb of garage. Mark transferred to tree 90 ft streamward.
Latitude	41.00222
Longitude	-76.464225
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	1/5/1900
Flag/Found Date	10/25/2011
Surveyed Date	Invalid date
Surveyed Elevation	486.4
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	
Tranquil/Stillwater HWM	Yes


HWM ID: 13411

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.46314
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	

HWM Information

HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Mud
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Fair: +/- 0.20 ft
Bank	
Location Description	Located at house address 49 Drinker St. Transferred HWM to telephone pole from door 75 ft downstream on same side of road. Pole Id 35520/N30772
Latitude	41.003972
Longitude	-76.462821
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	4.7
Flag/Found Date	10/25/2011
Surveyed Date	5/31/2012
Surveyed Elevation	488.4
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	
Tranquil/Stillwater HWM	Yes


2
ATTCH. 35520
N30772

HWM ID: 13412

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.4631
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	
Peak Summaries	

Elevation (ft)

HWM Information	
HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Mud
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Fair: +/- 0.20 ft
Bank	
Location Description	HWM found on siding of house number 87 on Drinker St. Transferred to telephone pole ID N30759/35510 downstream and across road from house
Latitude	41.00362
Longitude	-76.4631
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	1/5/1900
Flag/Found Date	########
Surveyed Date	41060
Surveyed Elevation	487.9
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	
Tranquil/Stillwater HWM	Yes

HWM ID: 13413

Site Information

Site Number	PACOL16098
Site Description	NW OF BLOOMSBURG; T-360 COUNTY BR#67
Latitude	41.00278
Longitude	-76.46314
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Address	
City	
State	PA
ZIP Code	
County	Columbia County
Waterbody	Fishing Creek
Drainage Area (sq mi)	---
Station ID for USGS gage	
Station ID for NOAA gage	
Other Station ID	
Peak Summaries	
Elevation (ft)	

HWM Information

HWM Label	no_label
Provisional or Approved	Provisional
Event	September 2011 flood - Tropical Storm Lee
HWM Type	Mud
Marker	Nail and HWM tag
HWM Environment	Riverine
HWM Quality	Good: +/- 0.10 ft
Bank	
Location Description	HWM is transferred from house #441 on West First St to telephone pole directly across street, distance from house to telephone pole =36 ft.
Latitude	41.001229
Longitude	-76.463455
Horizontal Datum	NAD83
Horizontal Collection Method	Map (digital or paper)
Height above ground	3.9
Flag/Found Date	10/25/2011
Surveyed Date	Invalid date
Surveyed Elevation	485.8
Vertical Datum	NAVD88
Vertical Collection Method	RT-GNSS
Uncertainty	
Notes	


U.S. GEOLOGICAL SURVEY
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Appendix C

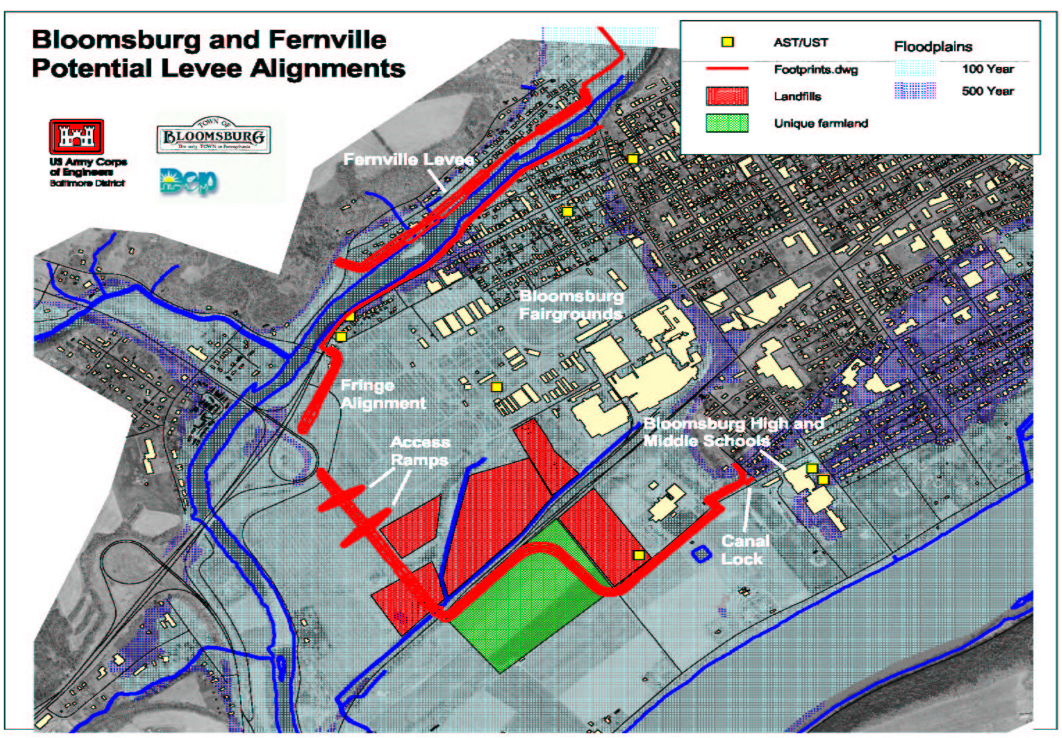
2012 USACE H&H REPORT

Bloomsburg, PA Flood Risk Management Study (FRMS)
Update of Hydrology and Hydraulics for Inclusion of Tropical Storm Lee Event
June 2012

Introduction:

The Bloomsburg flood risk management project is in the pre-construction engineering and design (PED) phase of design. The feasibility study evaluated an array of alternative plans based on reducing the flood damages in Bloomsburg along Fishing Creek and the Susquehanna River. To help in intermediate PED design decisions, the hydrology and hydraulics (H&H) portion of a risk and uncertainty (R&U) analysis was performed in October 2010 for the line of protection along Fishing Creek and the Susquehanna River. Since the completion of the risk and uncertainty analysis, Tropical Storm Lee (TSLee) occurred in September 2011, producing record breaking peak flows. The hydrology was updated to include the period of record up to this event to determine its effect on peak flow frequency on the Susquehanna River and Fishing Creek at Bloomsburg. The revised peak discharges were used to update the water surface profiles along the Susquehanna River and Fishing Creek in the project area. This report documents the process of the update, the results and how Tropical Storm Lee affected the H&H for the Bloomsburg FRMS. See Figure 1 for a map presenting the Bloomsburg line of protection (LOP).

FIGURE 1
Bloomsburg Flood Risk Management Project Line of Protection



Hydrology:

The subsequent years of record since the completion of the R&UA were added to the period of record for the applicable gage locations. Gage data were not directly available at Bloomsburg. The nearest gages on the Susquehanna River are at Danville, PA, approximately 10.3 miles downstream of the project area with a drainage area of 11220 square miles (sq mi) and at Wilkes-Barre, PA, approximately 39.5 miles upstream of the project area with a drainage area of 9960 sq mi. The period of record for the Danville gage was increased to 1900-2011 (112 years). The historic period of record for the Wilkes-Barre gage was increased to 1865-2011 (147 years). These gages were used to develop a peak flow frequency curve for the Susquehanna River at the Bloomsburg project area (drainage area = 10560 sq mi). Fishing Creek has a gage located 5.5 miles north of Bloomsburg with a drainage area of 274 sq mi. The period of record for the gage was increased by two years to 1936, 1939-2011 (75 years). A discontinued gage also existed on Fishing Creek from 1914-1931 (18 years). It was located near the Railroad Street Bridge in Bloomsburg with a drainage area of 355 sq mi. Both sets of gage data were used to analyze the peak flow frequency on Fishing Creek at the Bloomsburg project area (drainage area = 385 sq mi).

Fishing Creek Peak Flow Frequency Analysis:

The peak flow values for the entire period of record from both of the U.S. Geological Survey (USGS) gages on Fishing Creek were transposed to the project location downstream (385 sq mi) by using a drainage area relationship as presented in equation (Eq.) 1.

$$Q_{U/S}/Q_{D/S} = (DA_{U/S}/DA_{D/S}) \qquad \text{(Eq. 1)}$$

The peak flow data is presented in Table 1.

TABLE 1

Fishing Creek at Bloomsburg, PA

at USGS gages # 01539000 (DA=274 mi^2) and # 01540000 (DA=355 mi^2)

and at Bloomsburg FRMS Project Site (DA=385 mi^2)

Years of Record 1914-1931, 1936, 1939-2011

Date	Peak Discharge at USGS gage DA = 355 mi^2 (cfs)	Peak Discharge at Project Site DA = 385 mi^2 (cfs)	Date	Peak Discharge at USGS gage DA = 274 mi^2 (cfs)	Peak Discharge at Project Site DA = 385 mi^2 (cfs)
3/28/1914	10600	11500	3/10/1964	13600	19100
2/25/1915	14000	15200	2/8/1965	2860	4020
7/26/1916	19700	21400	2/14/1966	4760	6690
3/28/1917	6920	7500	3/15/1967	3900	5480
10/30/1917	16700	18100	11/3/1967	3730	5240
7/21/1919	4770	5170	6/16/1969	15300	21500
3/13/1920	11800	12800	4/3/1970	9100	12800
12/14/1920	10000	10800	2/27/1971	3650	5130
6/6/1922	13000	14100	6/22/1972	30900	43400
7/29/1923	13200	14300	12/6/1972	5520	7760
9/30/1924	23000	24900	12/21/1973	5250	7380
2/12/1925	15000	16300	9/26/1975	29400	41300
11/13/1925	6380	6920	10/18/1975	9700	13600
11/16/1926	21500	23300	10/9/1976	19700	27700
7/6/1928	16900	18300	3/27/1978	8120	11400
5/3/1929	17100	18500	3/5/1979	12300	17300
11/18/1929	5630	6110	3/21/1980	5550	7800
3/29/1931	3720	4030	2/2/1981	8430	11800
	Peak Discharge	Peak Discharge	6/6/1982	3980	5590
	at USGS gage	at Project Site	4/16/1983	9920	13900
Date	DA = 274 mi^2	DA = 385 mi^2	12/13/1983	13000	18300
	(cfs)	(cfs)	11/29/1984	4040	5680
3/18/1936	17600	24700	3/15/1986	17200	24200
12/10/1938	4420	6210	9/13/1987	5720	8040
3/31/1940	18100	25400	2/2/1988	4030	5660
4/6/1941	3340	4690	5/7/1989	7680	10800
5/23/1942	13400	18800	10/20/1989	5220	7330
12/30/1942	14300	20100	12/4/1990	7960	11200
11/9/1943	12000	16900	3/27/1992	5070	7120
9/19/1945	4790	6730	4/11/1993	14300	20100
5/28/1946	14200	20000	11/28/1993	7660	10800
7/22/1947	4150	5830	11/28/1994	8270	11600
4/15/1948	6120	8600	1/19/1996	21300	29900
12/30/1948	11700	16400	12/2/1996	12700	17800
1/7/1950	5560	7810	1/9/1998	13600	19100
12/4/1950	14000	19700	1/24/1999	13000	18300
3/11/1952	16200	22800	2/28/2000	4860	6830
11/22/1952	8660	12200	12/17/2000	10200	14300
4/17/1954	6140	8630	5/14/2002	13200	18500
8/19/1955	8070	11300	10/12/2002	8600	12100
10/16/1955	7540	10600	9/18/2004	15200	21400
4/6/1957	9610	13500	4/3/2005	16300	22900
12/21/1957	8430	11800	6/28/2006	41200	57900
1/22/1959	8130	11400	11/16/2006	10400	14600
4/4/1960	12200	17100	3/5/2008	14800	20800
2/26/1961	13200	18500	12/12/2008	4330	6080
4/8/1962	5540	7780	1/25/2010	17500	24600
3/27/1963	4050	5690	9/8/2011	56000	78700

A peak flow frequency curve was developed for Fishing Creek at the FRMS project site using the program HEC-SSP (Hydraulic Engineering Center – Statistical Software Package) version 1.1. Since Fishing Creek is unaffected by regulation, the Log-Pearson Type III distribution was used. The regional skew coefficient was determined from a map developed for the North Atlantic Division for a study of the affects of Tropical Storm Agnes in the Susquehanna and Potomac River Basins in June 1972. The study report is titled "Hydrologic Study, Tropical Storm Agnes, North Atlantic Division, December 1975".

The regional skew for Fishing Creek at the Bloomsburg FRMS project site is 0.45, with the mean square error of the map equal to 0.2. These values along with the natural flows were input into HEC-SSP to determine a peak flow frequency curve. The resulting statistics are presented in Table 2. The peak flow frequency curve is presented in Figure 2. Table 3 presents a comparison of the peak flow frequency with and without the additional two years of record which includes Tropical Storm Lee. The addition of these 2 events to the period of record caused a 17.8% increase in the 100 year discharge.

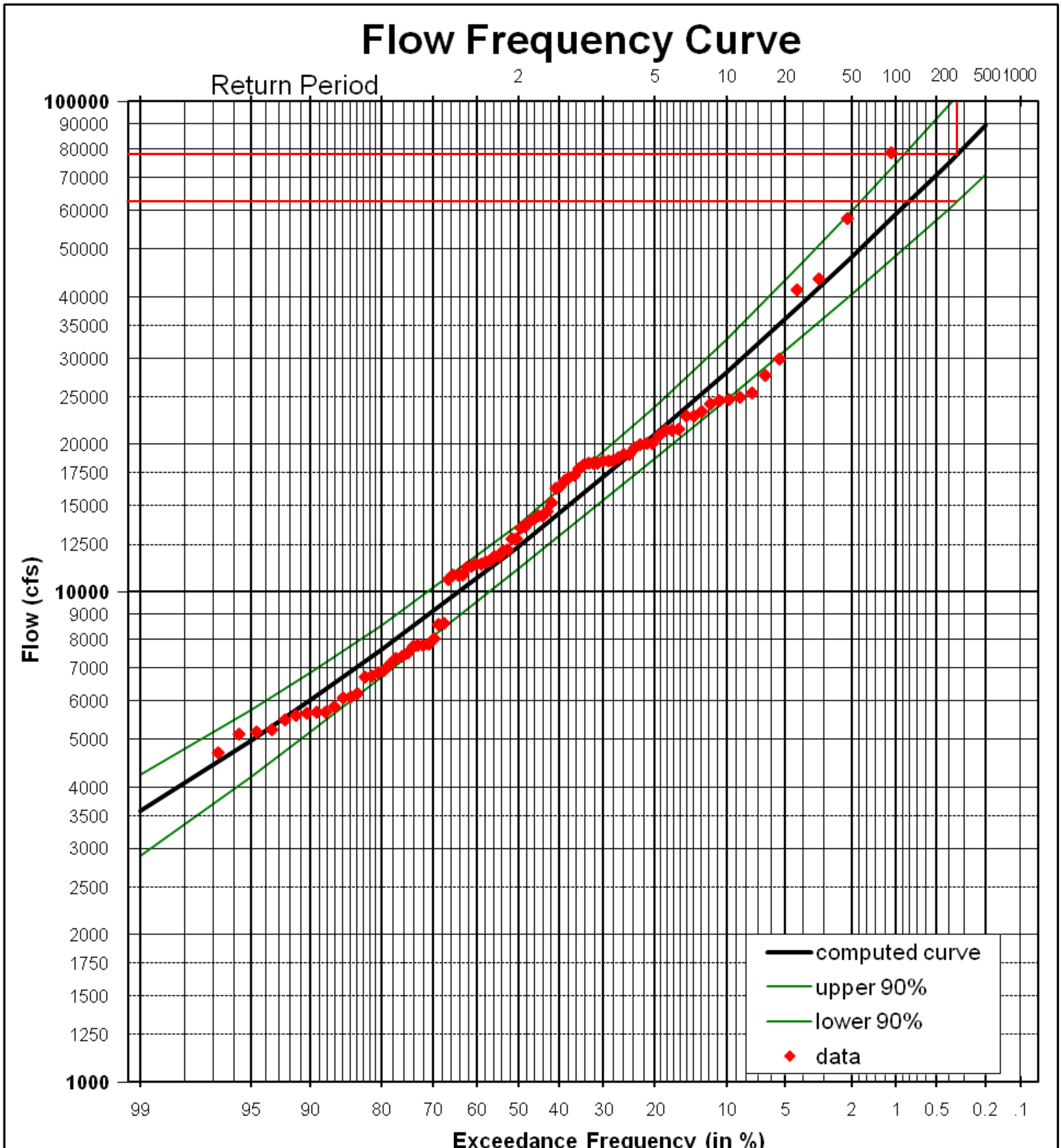
TABLE 2

HEC-SSP Results

Fishing Creek at Bloomsburg, PA FRMS Project Site DA = 385 sq mi				
Computed Curve	Expected Probability	Percent Chance Exceedance	Confidence Limits	
			0.05	0.95
Flow, cfs			Flow, cfs	
89578	---	0.2	119989	70928
75305	---	0.4	98657	60646
58902	---	1	74828	48558
48225	---	2	59791	40491
38822	---	4	46928	33215
28064	---	10	32761	24620
20956	---	20	23830	18707
12379	---	50	13733	11148
7622	---	80	8545	6693
6011	---	90	6834	5168
4981	---	95	5740	4201
3569	---	99	4229	2899

Log Transform: Flow, cfs		Number of Events	
Mean	4.105	Historic events	0
Standard Dev	0.262	High Outliers	0
Station Skew	0.239	Low Outliers	0
Regional Skew	0.450	Zero or Missing	0
Weighted Skew	0.291	Systemic Events	92
Adopted Skew	0.291	Historic Period	98

FIGURE 2



Frequency Statistics

Log Transform of Flow, cfs		Number of Events		Fishing Creek at Bloomsburg
Mean	4.105	Historic Events	0	Drainage Area = 385 sq mi
Standard Dev	0.262	High Outliers	0	
Station Skew	0.239	Low Outliers	0	Period of Record
Regional Skew	0.450	Zero or Missing	0	1914-1931, 1936, 1939-2011
Weighted Skew	0.291	Systematic Events	92	
Adopted Skew	0.291	Historic Period	98	May 2012

TABLE 3

Fishing Creek at Bloomsburg, PA FRMS Project Site DA = 385 sq mi			
Flood Event	Percent Chance Exceedance	Q from Oct 2010 R&U - No TSLee	Q with TSLee (cfs)
500 yr	0.2	71300	89600
250 yr	0.4	61600	75300
100 yr	1	50000	58900
50 yr	2	42000	48200
25 yr	4	34800	38800
10 yr	10	26100	28100
5 yr	20	20000	21000
2 yr	50	12200	12400

Susquehanna River Peak Flow Frequency Analysis:

The stream gage at Wilkes-Barre, PA is located on the Susquehanna River upstream of Bloomsburg and the gage at Danville, PA is located downstream of Bloomsburg. These gages were used to develop a peak flow frequency curve on the Susquehanna River at the Bloomsburg project area. Additional years of record since the October 2010 R&U analysis were added to the gage data. However, the gage at Wilkes-Barre malfunctioned and a peak for the TSLee event was not recorded. The discharge for TSLee at Wilkes-Barre was estimated by the Corps of Engineers (COE) using the rating curve at the gage derived from the Wyoming Valley LFP HEC-2 model. The USGS published a provisional discharge that is still being evaluated as of the date of this analysis. The peak flow frequency analysis for the Susquehanna River at Wilkes-Barre and Bloomsburg was performed with both the USGS provisional discharge and the COE estimated discharge. Both sets of results will be presented. When the TSLee discharge is finalized, this analysis may need to be recomputed. The gage data for these gages is presented in Tables 4 and 5.

TABLE 4

Susquehanna River at Wilkes-Barre, PA

USGS gage # 01536500

Drainage Area = 9960 sq mi

Historic Years of Record 1865-2011

Date	Observed Peak Q (cfs)	Regulated by	Date	Observed Peak Q (cfs)	Regulated by
3/18/1865	232000	N/A	4/1/1951	128000	Plus East Sidney
1/24/1891	164000	N/A	3/13/1952	124000	Plus East Sidney
4/4/1892	112000	N/A	12/12/1952	98000	Plus East Sidney
5/5/1893	115000	N/A	5/5/1954	78900	Plus East Sidney
5/21/1894	97100	N/A	3/3/1955	85900	Plus East Sidney
4/10/1895	113000	N/A	3/9/1956	186000	Plus East Sidney
4/1/1896	135000	N/A	4/7/1957	107000	Plus East Sidney
10/15/1896	88600	N/A	4/8/1958	170000	Plus East Sidney
4/26/1898	78900	N/A	1/23/1959	113000	Plus East Sidney
3/6/1899	82100	N/A	4/2/1960	184000	Plus East Sidney
3/2/1900	94500	N/A	2/27/1961	163000	Plus Stillwater
11/28/1900	115000	N/A	4/2/1962	128000	Plus Stillwater
3/2/1902	213000	N/A	3/28/1963	131000	Plus Stillwater
3/25/1903	119000	N/A	3/10/1964	188000	Plus Stillwater
3/9/1904	204000	N/A	2/14/1965	44600	Plus Stillwater
3/26/1905	129000	N/A	2/15/1966	93500	Plus Stillwater
4/1/1906	81300	N/A	3/29/1967	84800	Plus Stillwater
3/16/1907	65500	N/A	3/24/1968	101000	Plus Stillwater
2/17/1908	130000	N/A	4/7/1969	80500	Plus Stillwater
5/2/1909	125000	N/A	4/4/1970	115000	Plus Stillwater
3/3/1910	157000	N/A	3/17/1971	110000	Plus Aylesworth
3/29/1911	94500	N/A	6/24/1972	345000	Plus Aylesworth
4/3/1912	127000	N/A	4/6/1973	91800	Plus Aylesworth
3/28/1913	184000	N/A	12/28/1973	93400	Plus Aylesworth
3/29/1914	182000	N/A	9/27/1975	228000	Plus Aylesworth
2/26/1915	127000	N/A	2/19/1976	118000	Plus Aylesworth
4/2/1916	160000	N/A	9/26/1977	121000	Plus Aylesworth
3/28/1917	75700	N/A	1/27/1978	116000	Plus Aylesworth
3/15/1918	124000	N/A	3/7/1979	192000	Plus Tioga-Hammond
5/24/1919	66900	N/A	3/23/1980	104000	Plus Tioga-Hammond
3/13/1920	155000	N/A	2/22/1981	104000	Plus Cowanesque

TABLE 4 - CONTINUED
Susquehanna River at Wilkes-Barre, PA
USGS gage # 01536500
Drainage Area = 9960 sq mi
Historic Years of Record 1865-2011

Date	Observed Peak Q (cfs)	Regulated by	Date	Observed Peak Q (cfs)	Regulated by
3/10/1921	86600	N/A	10/29/1981	86400	Plus Cowanesque
11/29/1921	117000	N/A	4/16/1983	138000	Plus Cowanesque
3/5/1923	91800	N/A	12/14/1983	192000	Plus Cowanesque
4/8/1924	129000	N/A	3/14/1985	55800	Plus Cowanesque
2/13/1925	145000	N/A	3/16/1986	172000	Plus Cowanesque
3/26/1926	90100	N/A	4/5/1987	98500	Plus Cowanesque
11/17/1926	121000	N/A	5/21/1988	82200	Plus Cowanesque
10/20/1927	141000	N/A	5/12/1989	117000	Plus Cowanesque
4/22/1929	159000	N/A	2/18/1990	74900	Plus Cowanesque
3/9/1930	67600	N/A	10/25/1990	134000	Plus Cowanesque
3/30/1931	74700	N/A	3/28/1992	92000	Plus Cowanesque
4/2/1932	107000	N/A	4/2/1993	185000	Plus Cowanesque
8/25/1933	99800	N/A	3/26/1994	148000	Plus Cowanesque
3/6/1934	85500	N/A	1/22/1995	72100	Plus Cowanesque
7/10/1935	151000	N/A	1/20/1996	221000	Plus Cowanesque
3/20/1936	232000	N/A	11/10/1996	128000	Plus Cowanesque
1/23/1937	77300	N/A	1/9/1998	138000	Plus Cowanesque
9/24/1938	64900	N/A	1/25/1999	112000	Plus Cowanesque
2/22/1939	137000	N/A	2/29/2000	129000	Plus Cowanesque
4/1/1940	212000	Arkport	4/11/2001	96800	Plus Cowanesque
4/7/1941	138000	Arkport	3/28/2002	78900	Plus Cowanesque
3/11/1942	111000	Arkport	3/22/2003	122000	Plus Cowanesque
1/1/1943	191000	Plus Whitney Pt.	9/19/2004	227000	Plus Cowanesque
5/9/1944	90000	Plus Whitney Pt.	4/4/2005	189000	Plus Cowanesque
3/5/1945	119000	Plus Whitney Pt.	6/28/2006	218000	Plus Cowanesque
5/29/1946	210000	Plus Whitney Pt.	3/16/2007	123000	Plus Cowanesque
4/7/1947	151000	Plus Whitney Pt.	3/5/2008	115000	Plus Cowanesque
3/23/1948	193000	Plus Whitney Pt.	3/10/2009	84900	Plus Cowanesque
12/31/1948	82700	Plus Whitney Pt.	1/27/2010	122000	Plus Cowanesque
3/30/1950	172000	Plus Almond	9/9/2011	295000	USGS Provisional
			9/9/2011	336000	COE Estimated

TABLE 5
Susquehanna River at Danville, PA
USGS gage # 01540500
Drainage Area = 11220 sq mi
Years of Record 1900-2011

Date	Observed Peak Q (cfs)	Regulated by	Date	Observed Peak Q (cfs)	Regulated by
3/2/1900	105000	N/A	3/9/1956	175000	Plus East Sidney
11/28/1900	135000	N/A	4/8/1957	114000	Plus East Sidney
3/3/1902	243000	N/A	4/8/1958	169000	Plus East Sidney
3/25/1903	132000	N/A	1/24/1959	112000	Plus East Sidney
3/27/1904	148000	N/A	4/2/1960	198000	Plus East Sidney
3/26/1905	136000	N/A	2/28/1961	167000	Plus Stillwater
4/1/1906	99500	N/A	4/2/1962	136000	Plus Stillwater
3/17/1907	73400	N/A	3/29/1963	130000	Plus Stillwater
2/17/1908	122000	N/A	3/11/1964	261000	Plus Stillwater
5/2/1909	134000	N/A	2/14/1965	44900	Plus Stillwater
3/3/1910	165000	N/A	2/15/1966	98900	Plus Stillwater
3/29/1911	97300	N/A	3/30/1967	87500	Plus Stillwater
4/3/1912	129000	N/A	3/24/1968	104000	Plus Stillwater
3/28/1913	192000	N/A	4/7/1969	81700	Plus Stillwater
3/29/1914	186000	N/A	4/4/1970	122000	Plus Stillwater
2/26/1915	141000	N/A	3/17/1971	111000	Plus Aylesworth
4/2/1916	175000	N/A	6/25/1972	363000	Plus Aylesworth
3/29/1917	92900	N/A	12/8/1972	99600	Plus Aylesworth
3/16/1918	139000	N/A	12/29/1973	103000	Plus Aylesworth
5/24/1919	80800	N/A	9/28/1975	257000	Plus Aylesworth
3/14/1920	170000	N/A	2/19/1976	120000	Plus Aylesworth
3/10/1921	101000	N/A	9/27/1977	122000	Plus Aylesworth
11/30/1921	133000	N/A	3/23/1978	116000	Plus Aylesworth
3/5/1923	105000	N/A	3/7/1979	188000	Plus Tioga-Hammond
4/8/1924	142000	N/A	3/23/1980	104000	Plus Tioga-Hammond
2/13/1925	162000	N/A	2/22/1981	105000	Plus Cowanesque
3/27/1926	101000	N/A	10/30/1981	83300	Plus Cowanesque
11/17/1926	142000	N/A	4/17/1983	149000	Plus Cowanesque
10/21/1927	156000	N/A	4/7/1984	194000	Plus Cowanesque
4/23/1929	163000	N/A	3/14/1985	55300	Plus Cowanesque
3/9/1930	78700	N/A	3/16/1986	173000	Plus Cowanesque
3/30/1931	88500	N/A	4/6/1987	104000	Plus Cowanesque
4/2/1932	119000	N/A	5/21/1988	83500	Plus Cowanesque
8/25/1933	119000	N/A	5/15/1989	116000	Plus Cowanesque
3/6/1934	98600	N/A	2/18/1990	70900	Plus Cowanesque
7/11/1935	153000	N/A	10/25/1990	124000	Plus Cowanesque
3/20/1936	250000	N/A	3/29/1992	89200	Plus Cowanesque
1/23/1937	93400	N/A	4/3/1993	187000	Plus Cowanesque
10/24/1937	79400	N/A	3/26/1994	139000	Plus Cowanesque

2/22/1939	139000	N/A	1/22/1995	73700	Plus Cowanesque

TABLE 5 - CONTINUED
Susquehanna River at Danville, PA
USGS gage # 01540500
Drainage Area = 11220 sq mi
Years of Record 1900-2011

Date	Observed Peak Q (cfs)	Regulated by	Date	Observed Peak Q (cfs)	Regulated by
4/2/1940	222000	Arkport	1/21/1996	209000	Plus Cowanesque
4/7/1941	142000	Arkport	12/3/1996	130000	Plus Cowanesque
3/11/1942	116000	Arkport	1/10/1998	143000	Plus Cowanesque
1/1/1943	204000	Plus Whitney Pt.	1/25/1999	116000	Plus Cowanesque
5/9/1944	97600	Plus Whitney Pt.	2/29/2000	132000	Plus Cowanesque
3/5/1945	121000	Plus Whitney Pt.	4/11/2001	97800	Plus Cowanesque
5/29/1946	234000	Plus Whitney Pt.	5/15/2002	84700	Plus Cowanesque
4/7/1947	150000	Plus Whitney Pt.	3/22/2003	130000	Plus Cowanesque
3/24/1948	184000	Plus Whitney Pt.	9/19/2004	220000	Plus Cowanesque
1/1/1949	89600	Plus Whitney Pt.	4/4/2005	202000	Plus Cowanesque
3/30/1950	168000	Plus Almond	6/28/2006	260000	Plus Cowanesque
12/5/1950	131000	Plus East Sidney	3/17/2007	123000	Plus Cowanesque
3/13/1952	127000	Plus East Sidney	3/6/2008	124000	Plus Cowanesque
12/13/1952	103000	Plus East Sidney	3/11/2009	84600	Plus Cowanesque
5/5/1954	82100	Plus East Sidney	1/27/2010	130000	Plus Cowanesque
3/3/1955	85900	Plus East Sidney	9/9/2011	311000	Plus Cowanesque

There are eight major Corps of Engineers dam projects that are regulated for flood risk management in the Susquehanna River Basin upstream of Danville, Wilkes-Barre, and Bloomsburg. They are, in order of the year they became operational: Arkport (1940), Whitney Point (1942), Almond (1949), East Sidney (1950), Stillwater (1960), Aylesworth (1970), Tioga-Hammond (1978), and Cowanesque (1980). The period of record for the gages on the Susquehanna River at Danville and Wilkes-Barre therefore are not homogeneous, since the flood risk management projects have been in operation for different lengths of time, beginning in the 1940s. A total of 10.6% of the drainage area at the Danville gage and 11.9% of the drainage area at the Wilkes-Barre gage is influenced by the dams. The observed discharges since 1940 were adjusted to natural (unregulated) conditions using the following methodology.

The Baltimore District (NAB) has kept records of reservoir inflow, outflow and routed net flow hydrographs for high flow events since 1993. These records were used to produce natural flows for each corresponding regulated flow for 22 events. A document search produced an additional historic event that had calculated natural flows with corresponding regulated flows. The combination of the NAB data and historic data was used to develop natural (unregulated) vs. existing (regulated) conditions peak flow relationship curves for the Susquehanna River at Danville and Wilkes-Barre gages. A series of curves were developed for the gages for conditions of regulation by each of the eight dam projects as they came online and were used to adjust the observed peak flows at the gages to natural flows. The curves are presented as Figures 3 thru 18.

FIGURE 3

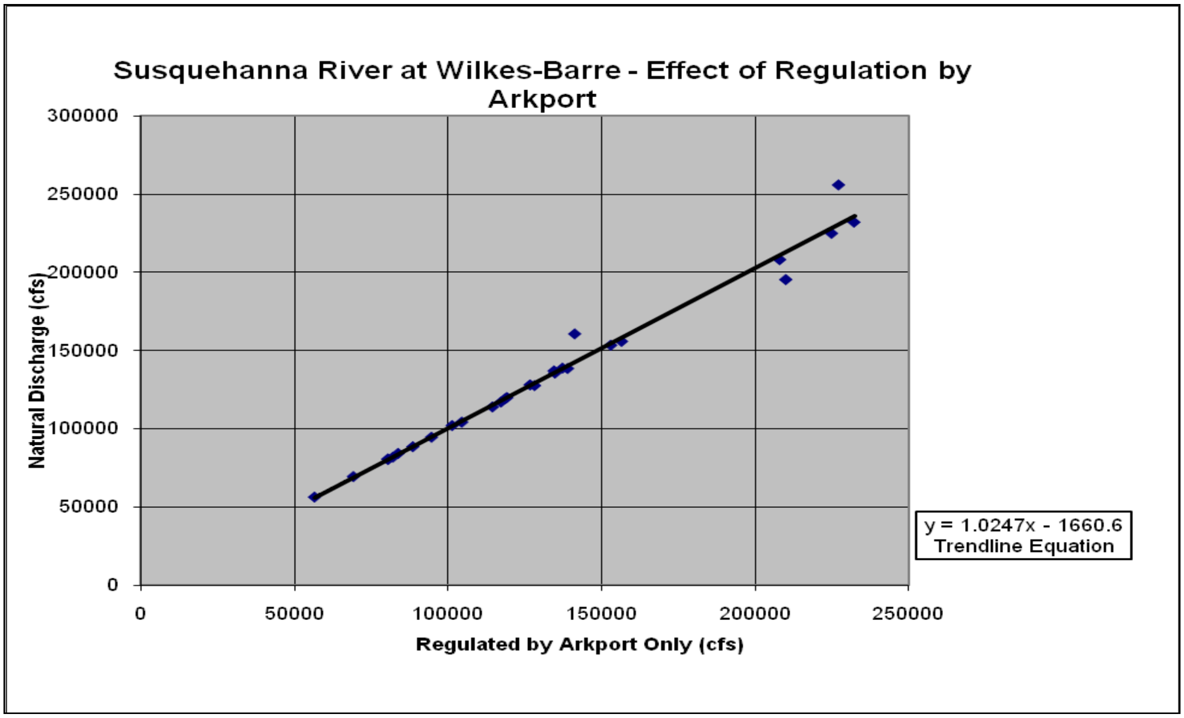


FIGURE 4

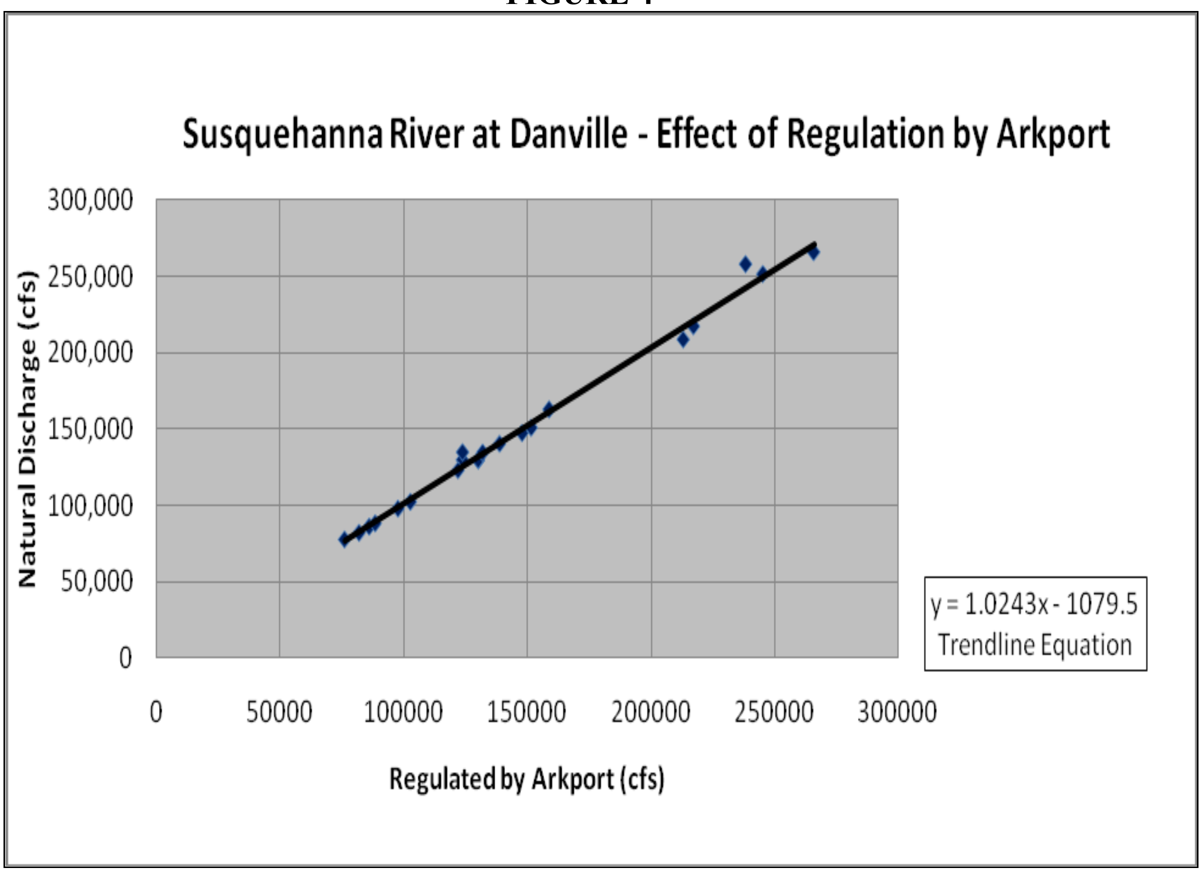


FIGURE 5

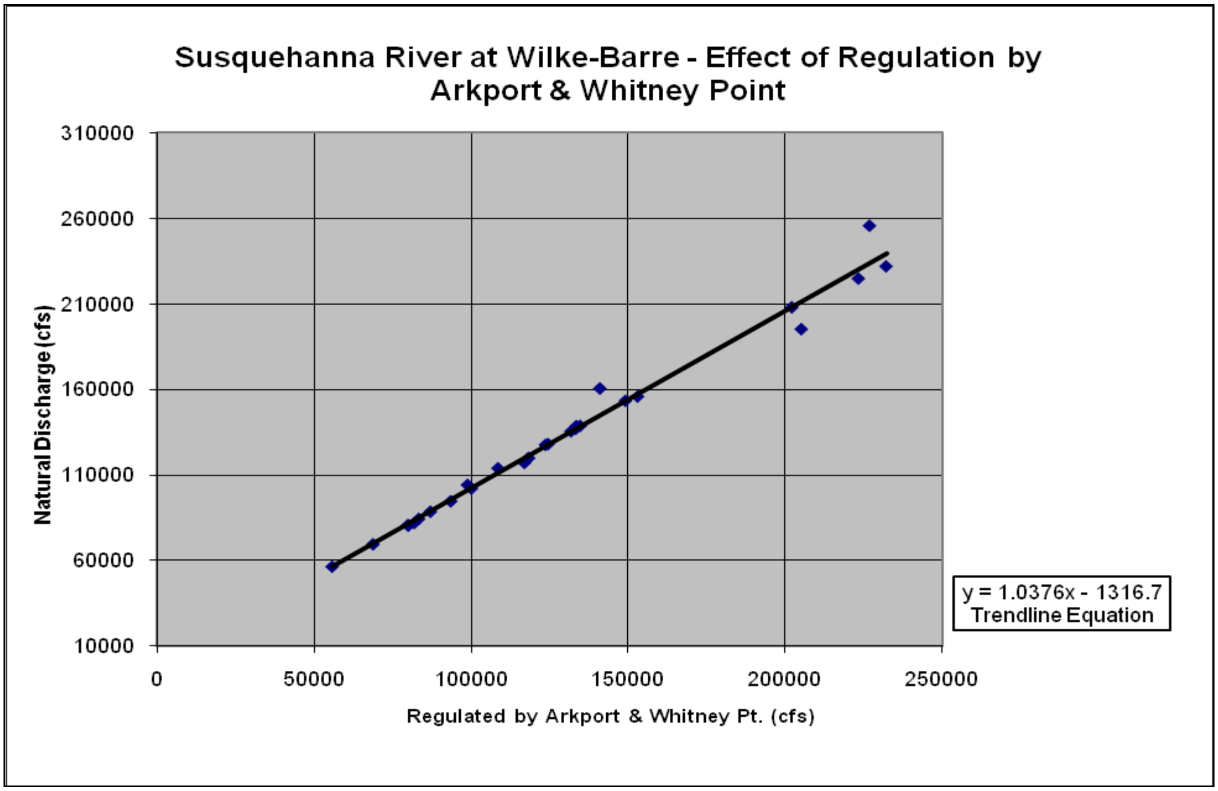


FIGURE 6

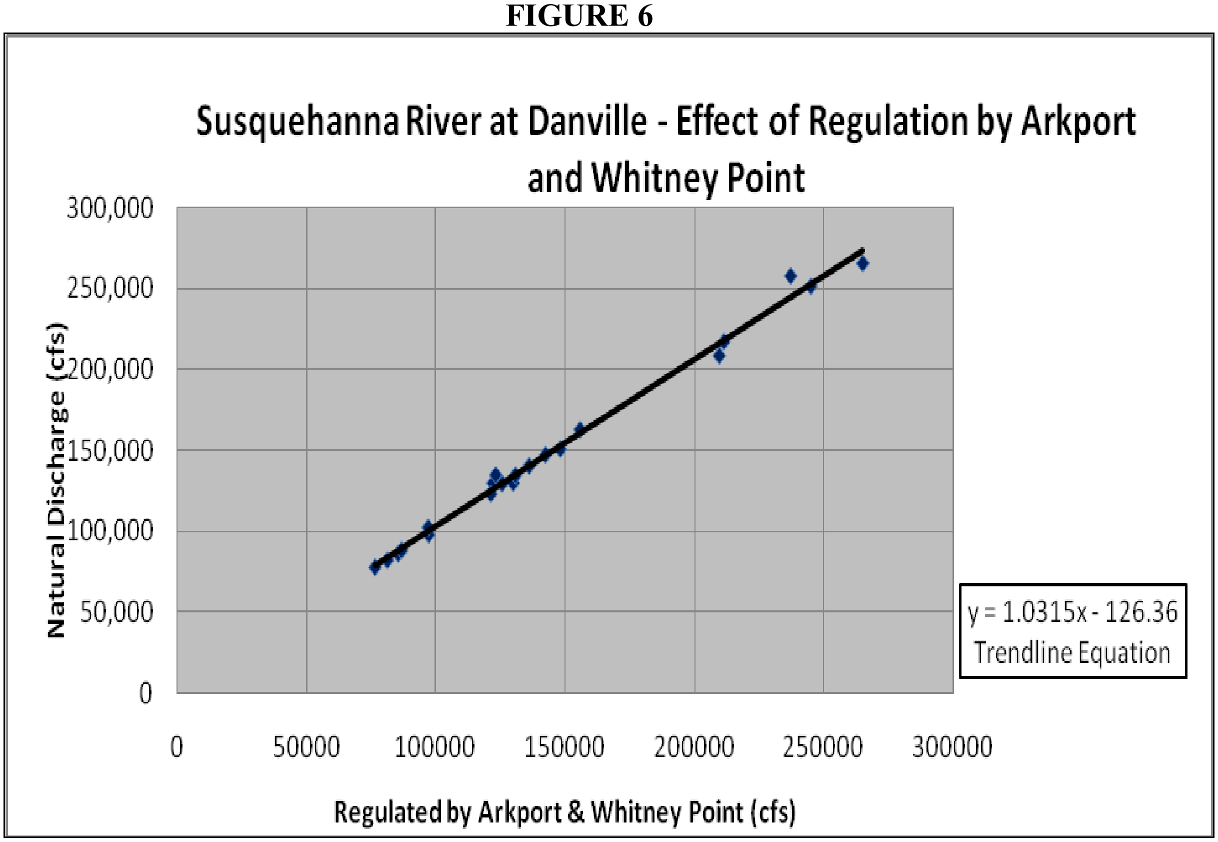


FIGURE 7

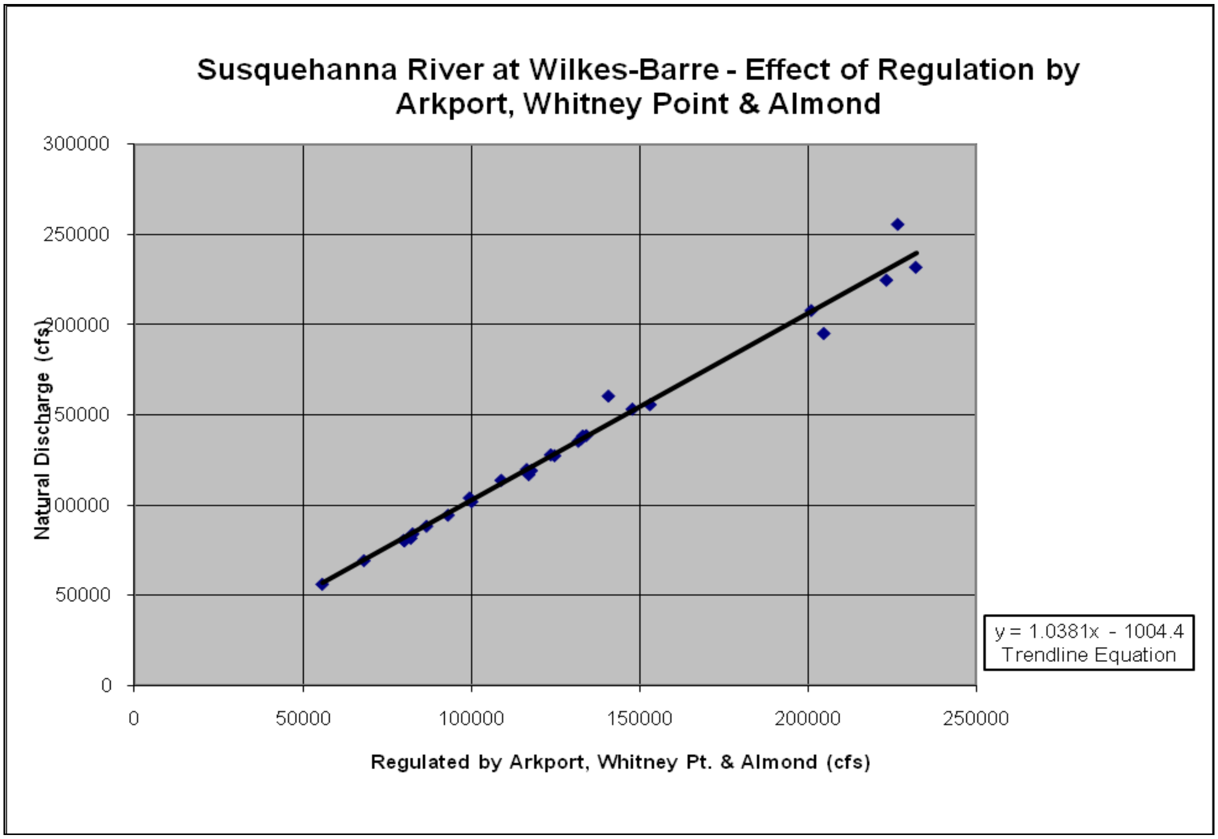


FIGURE 8

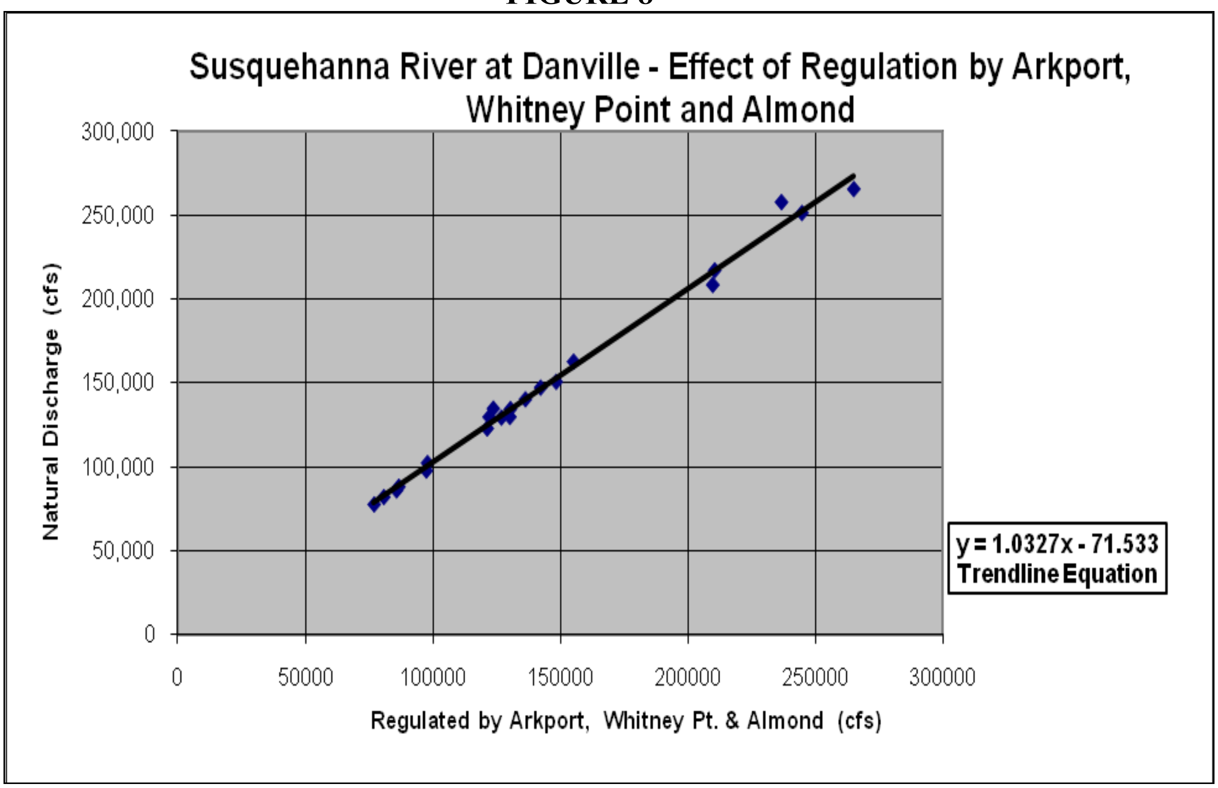


FIGURE 9

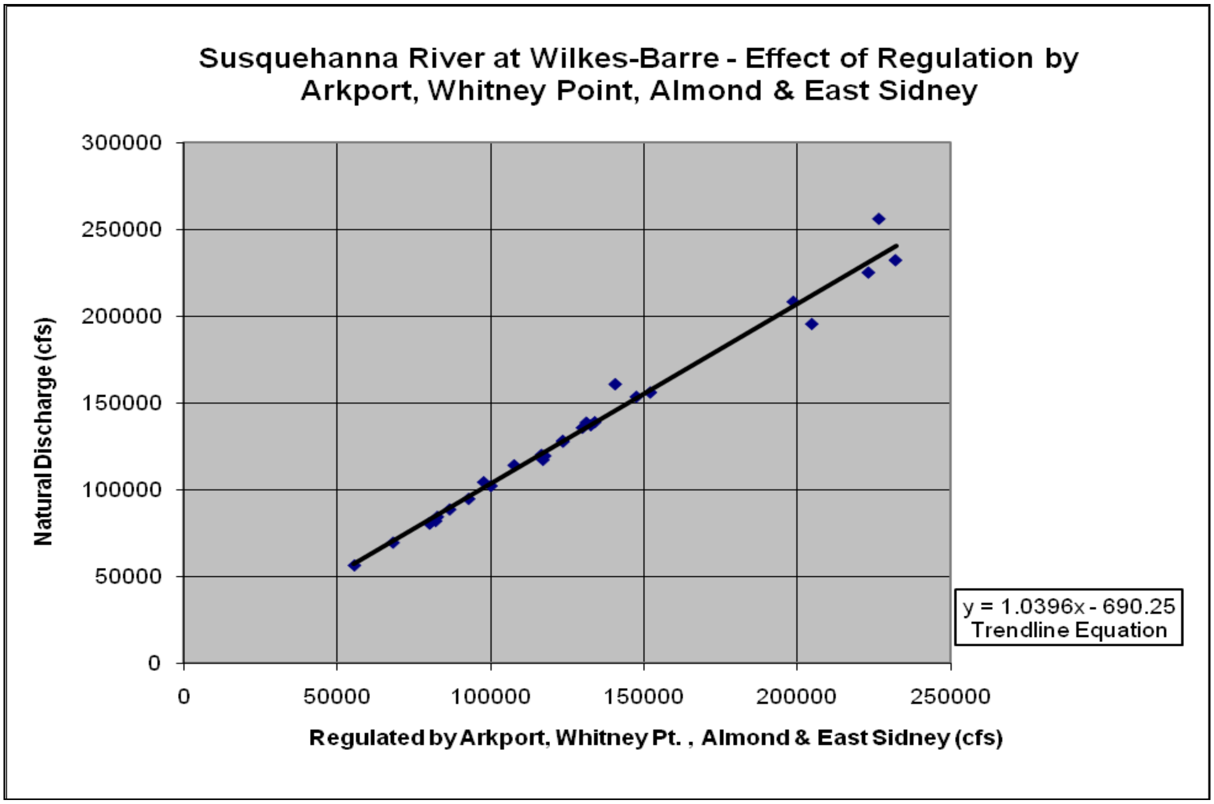


FIGURE 10

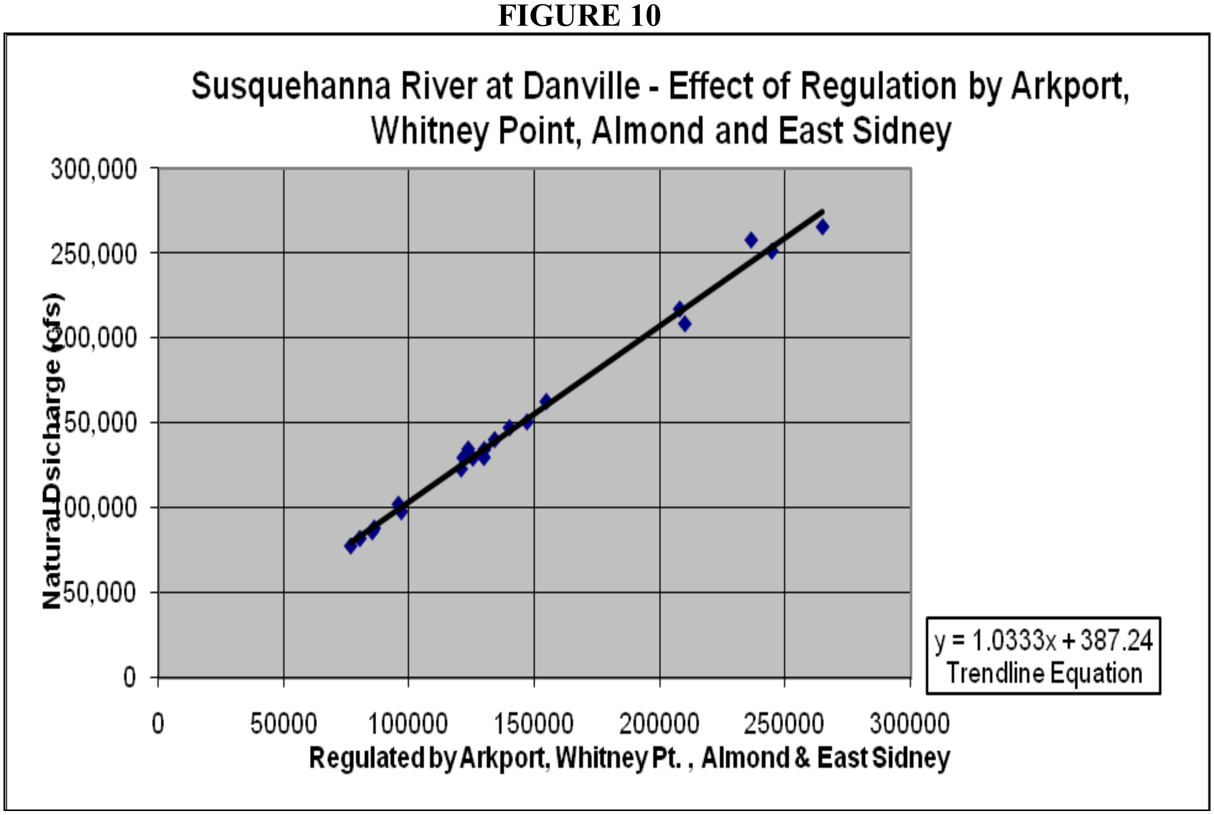


FIGURE 11

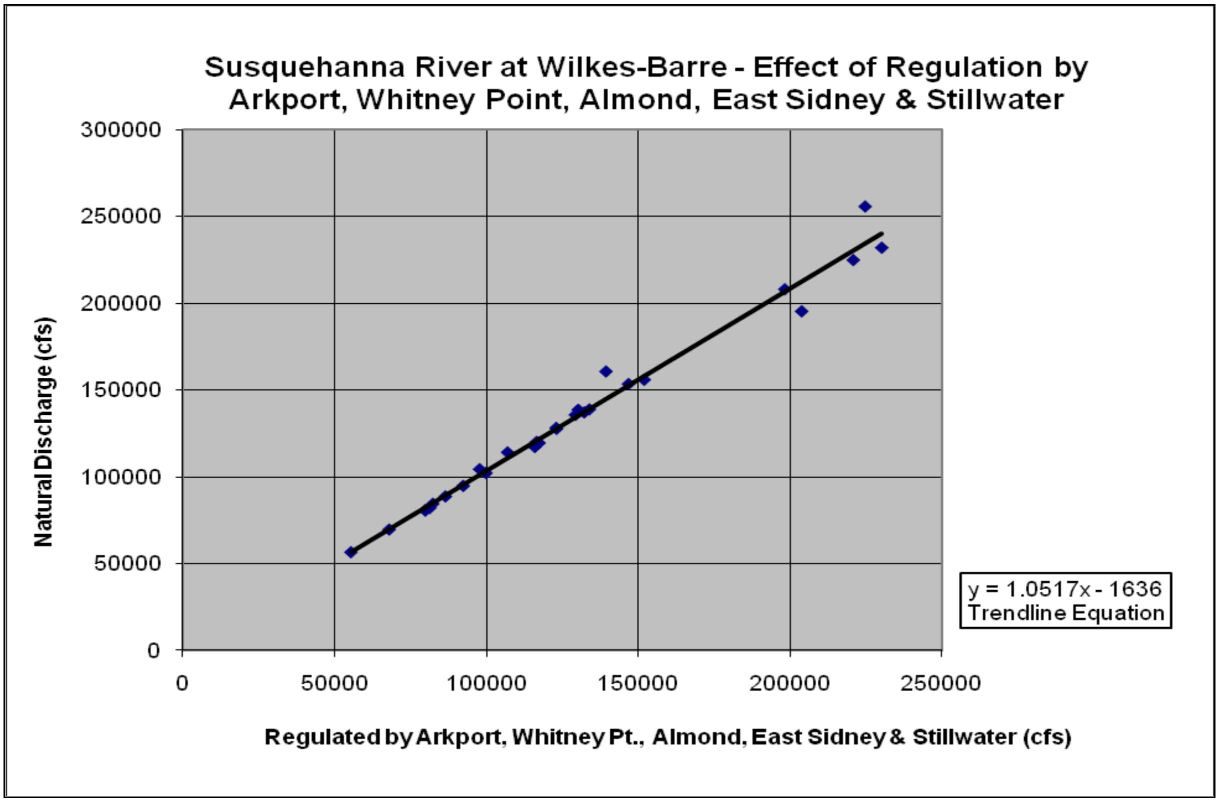


FIGURE 12

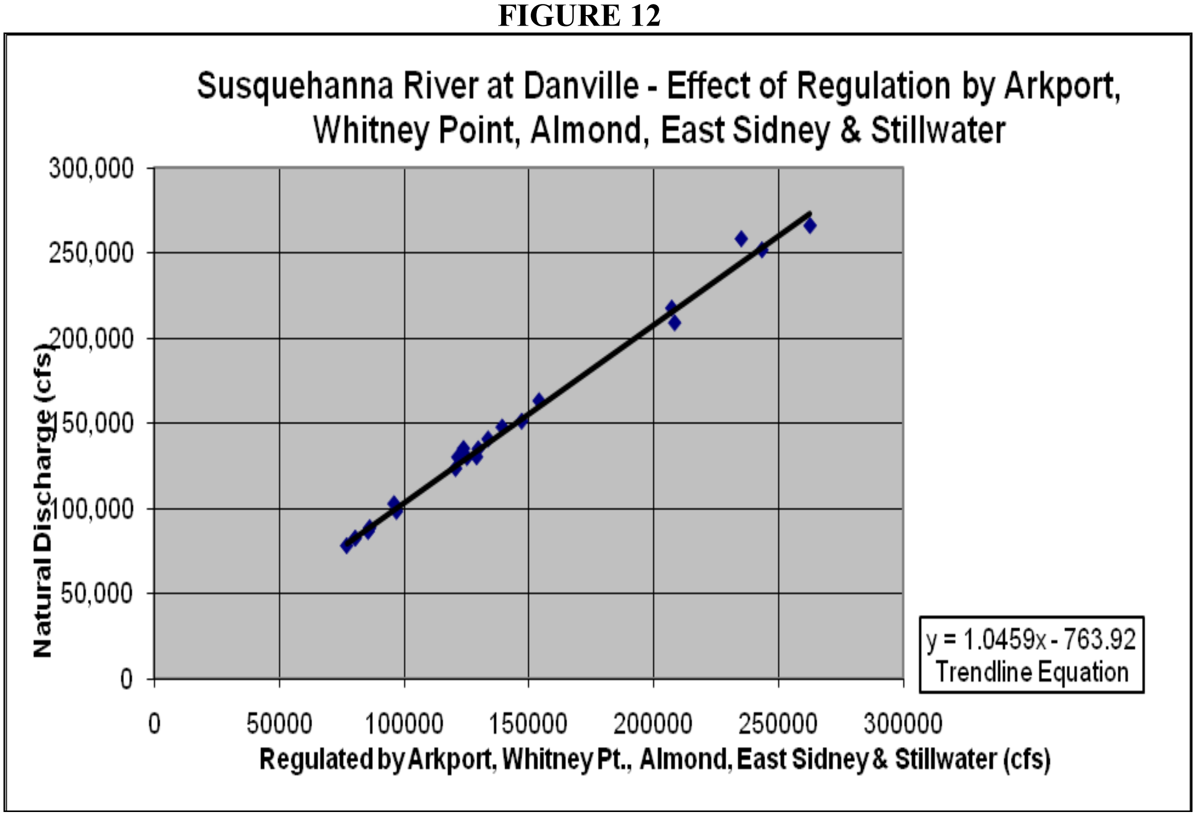


FIGURE 13

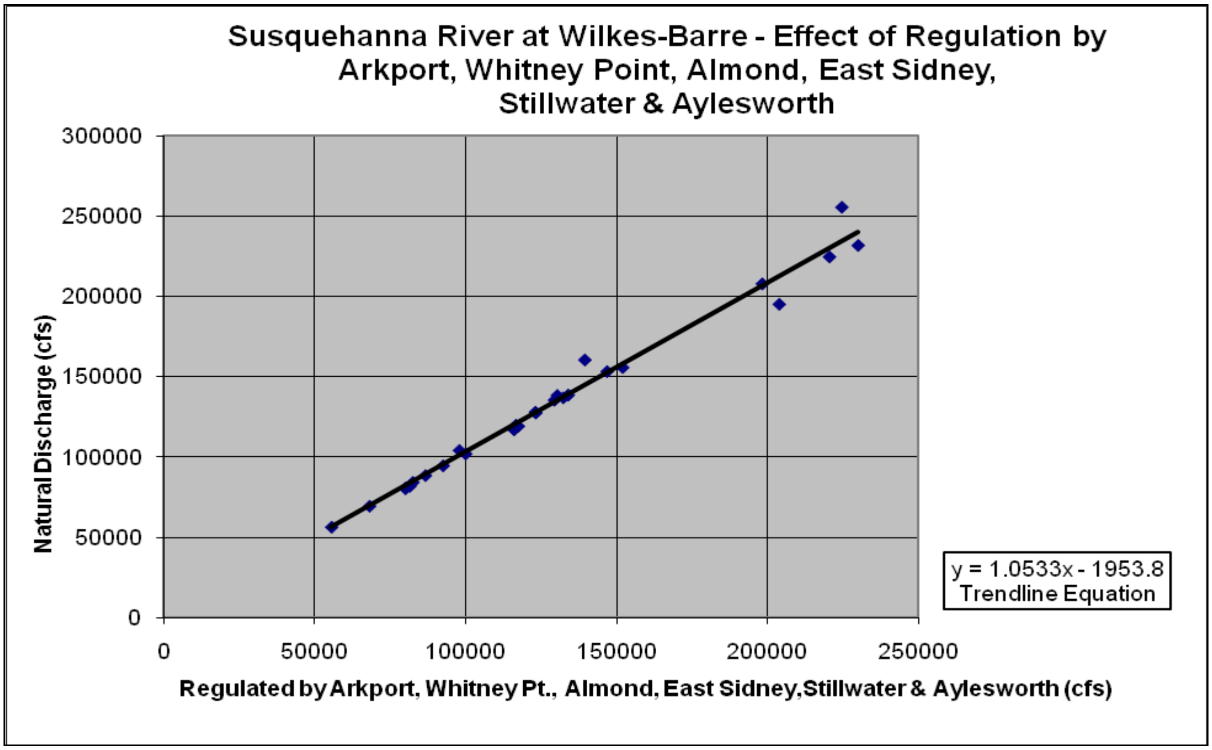


FIGURE 14

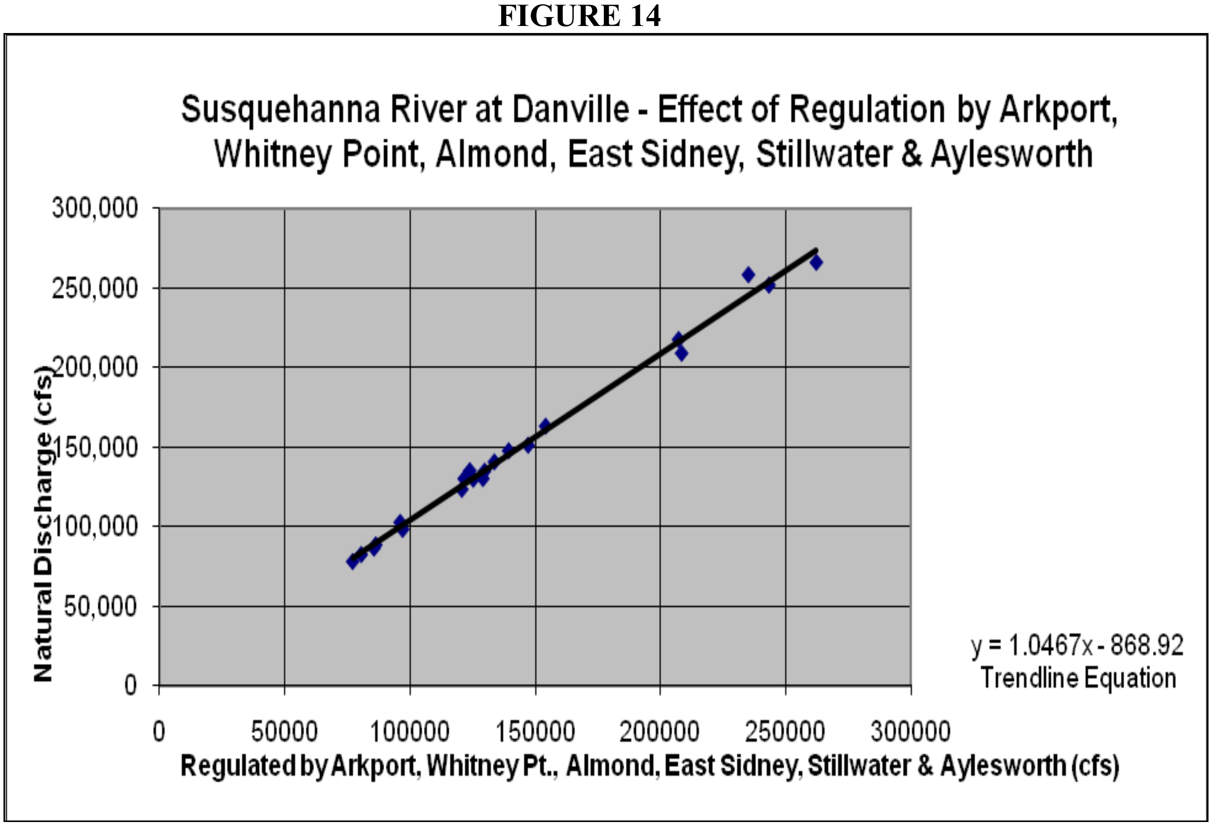


FIGURE 15

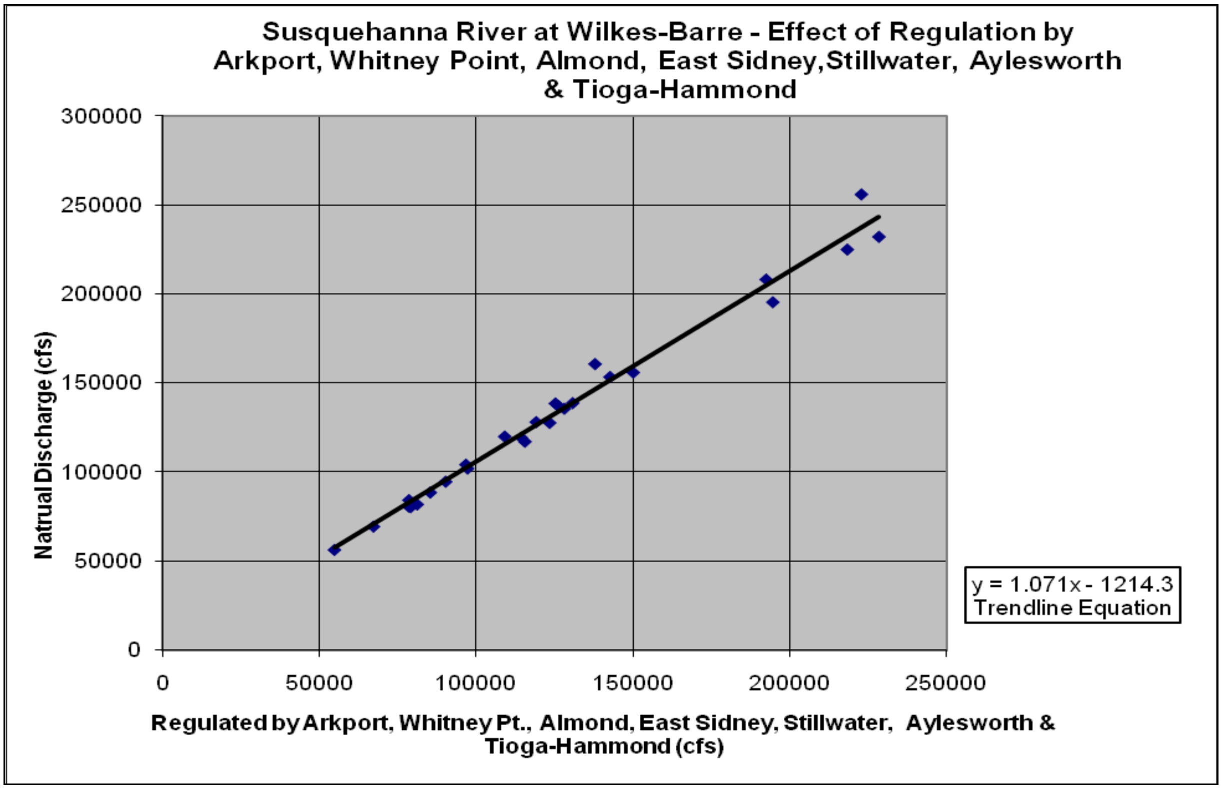

Susquehanna River at Wilkes-Barre - Effect of Regulation by Arkport, Whitney Point, Almond, East Sidney,Stillwater, Aylesworth & Tioga-Hammond
300000
250000
200000
150000
100000
50000
0
Natrual Discharge (cfs)
0
50000
100000
150000
200000
250000
y = 1.071x - 1214.3
Trendline Equation
Regulated by Arkport, Whitney Pt., Almond, East Sidney, Stillwater, Aylesworth & Tioga-Hammond (cfs)

FIGURE 16

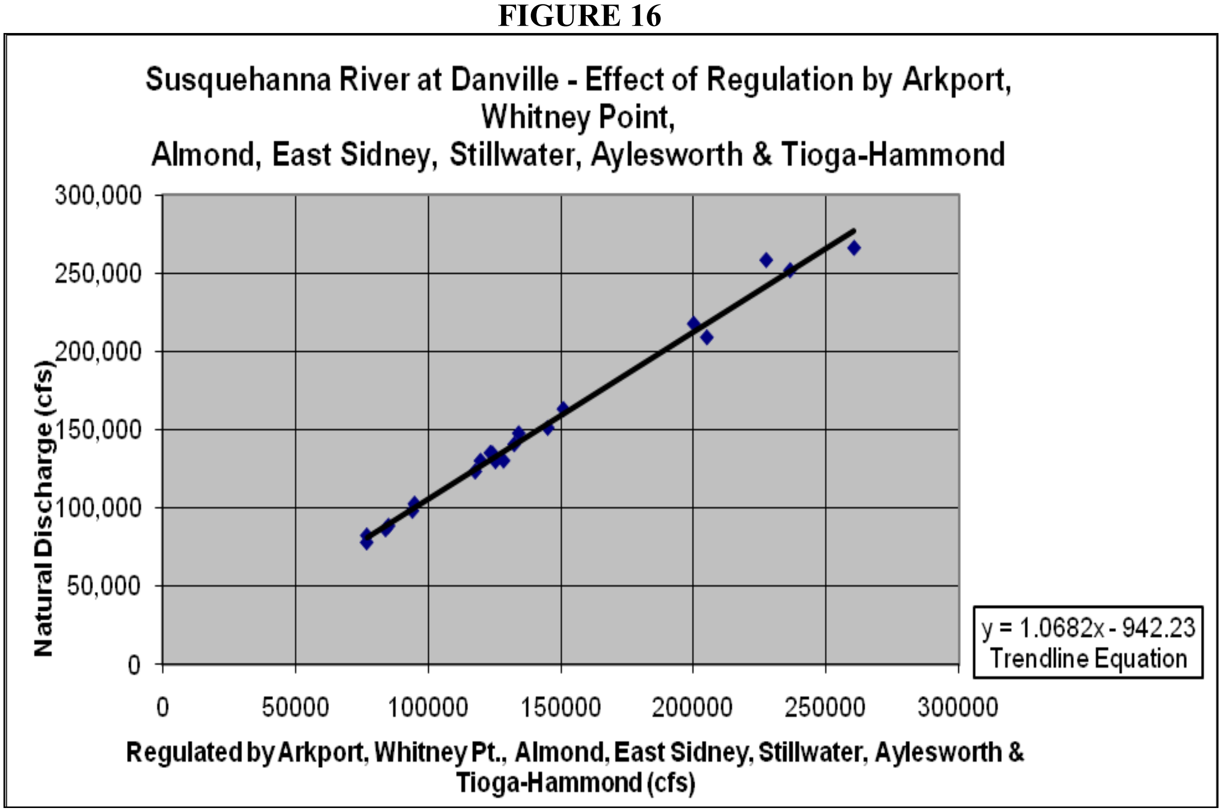

Susquehanna River at Danville - Effect of Regulation by Arkport, Whitney Point,
Almond, East Sidney, Stillwater, Aylesworth & Tioga-Hammond
300,000
250,000
200,000
150,000
100,000
50,000
0
Natural Discharge (cfs)
0
50000
100000
150000
200000
250000
300000
y = 1.0682x - 942.23
Trendline Equation
Regulated by Arkport, Whitney Pt., Almond, East Sidney, Stillwater, Aylesworth & Tioga-Hammond (cfs)

FIGURE 17

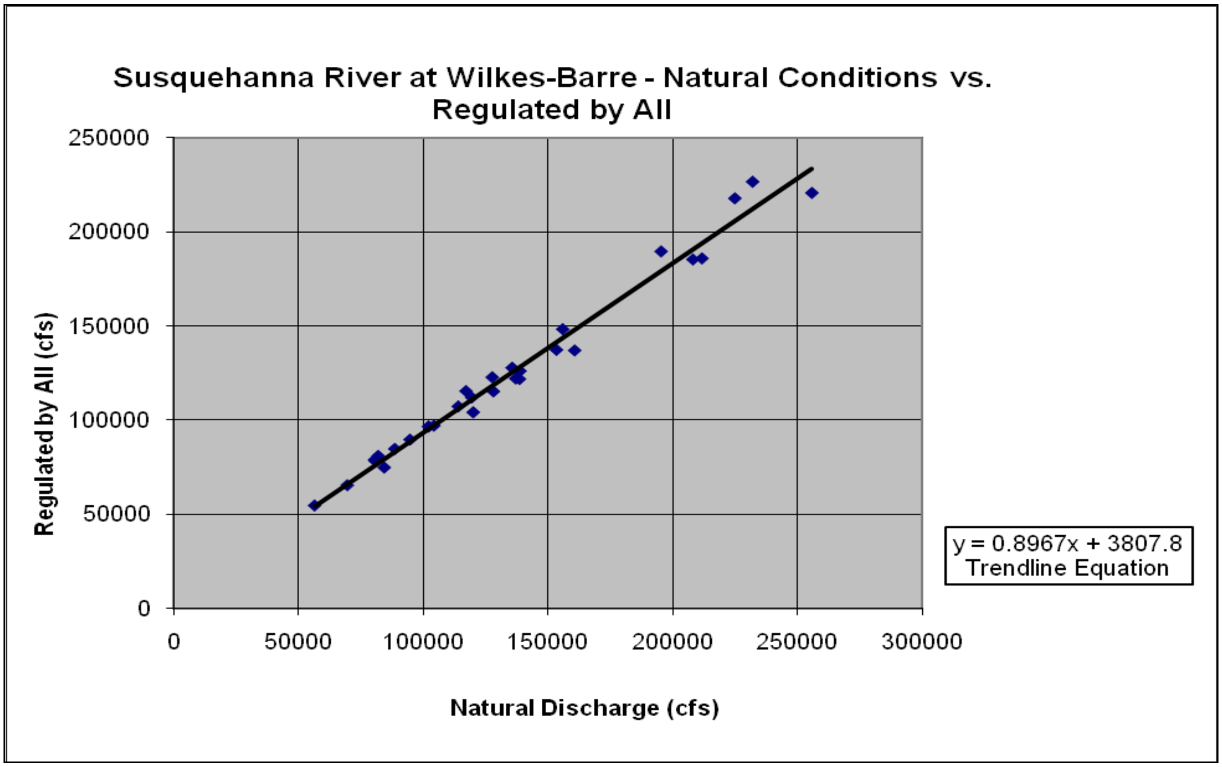
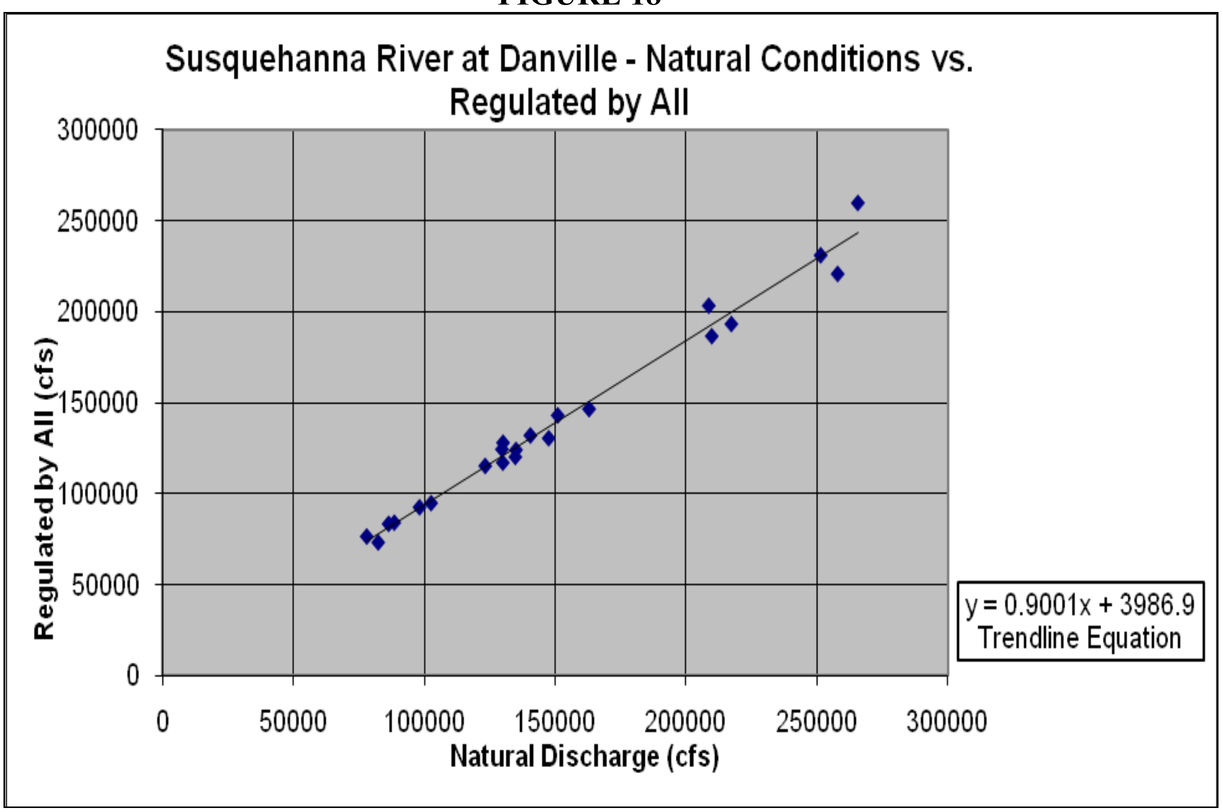


FIGURE 18



The relationship curves were used to adjust the portion of the period of record where the observed discharges were affected by regulation to produce a homogeneous natural (unregulated) conditions period of record for the Susquehanna River at the Wilkes-Barre and Danville gages. The resulting discharge records are presented in Tables 6 and 7.

TABLE 6
Susquehanna River at Wilkes-Barre, PA
USGS gage # 01536500
Drainage Area = 9960 sq mi
Historic Years of Record 1865-2011

Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)	Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)
3/18/1865	232000	232000	4/1/1951	128000	132400
1/24/1891	164000	164000	3/13/1952	124000	128200
4/4/1892	112000	112000	12/12/1952	98000	101200
5/5/1893	115000	115000	5/5/1954	78900	81300
5/21/1894	97100	97100	3/3/1955	85900	88600
4/10/1895	113000	113000	3/9/1956	186000	192700
4/1/1896	135000	135000	4/7/1957	107000	110500
10/15/1896	88600	88600	4/8/1958	170000	176000
4/26/1898	78900	78900	1/23/1959	113000	116800
3/6/1899	82100	82100	4/2/1960	184000	190600
3/2/1900	94500	94500	2/27/1961	163000	169800
11/28/1900	115000	115000	4/2/1962	128000	133000
3/2/1902	213000	213000	3/28/1963	131000	136100
3/25/1903	119000	119000	3/10/1964	188000	196100
3/9/1904	204000	204000	2/14/1965	44600	45300
3/26/1905	129000	129000	2/15/1966	93500	96700
4/1/1906	81300	81300	3/29/1967	84800	87500
3/16/1907	65500	65500	3/24/1968	101000	104600
2/17/1908	130000	130000	4/7/1969	80500	83000
5/2/1909	125000	125000	4/4/1970	115000	119300
3/3/1910	157000	157000	3/17/1971	110000	113900
3/29/1911	94500	94500	6/24/1972	345000	361400
4/3/1912	127000	127000	4/6/1973	91800	94700
3/28/1913	184000	184000	12/28/1973	93400	96400
3/29/1914	182000	182000	9/27/1975	228000	238200
2/26/1915	127000	127000	2/19/1976	118000	122300
4/2/1916	160000	160000	9/26/1977	121000	125500
3/28/1917	75700	75700	1/27/1978	116000	120200
3/15/1918	124000	124000	3/7/1979	192000	204400
5/24/1919	66900	66900	3/23/1980	104000	110200
3/13/1920	155000	155000	2/22/1981	104000	111700
3/10/1921	86600	86600	10/29/1981	86400	92100
11/29/1921	117000	117000	4/16/1983	138000	149700
3/5/1923	91800	91800	12/14/1983	192000	209900
4/8/1924	129000	129000	3/14/1985	55800	58000

TABLE 6 - CONTINUED
Susquehanna River at Wilkes-Barre, PA
USGS gage # 01536500
Drainage Area = 9960 sq mi
Historic Years of Record 1865-2011

Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)	Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)
2/13/1925	145000	145000	3/16/1986	172000	187600
3/26/1926	90100	90100	4/5/1987	98500	105600
11/17/1926	121000	121000	5/21/1988	82200	87400
10/20/1927	141000	141000	5/12/1989	117000	126200
4/22/1929	159000	159000	2/18/1990	74900	79300
3/9/1930	67600	67600	10/25/1990	134000	145200
3/30/1931	74700	74700	3/28/1992	92000	98400
4/2/1932	107000	107000	4/2/1993	185000	202100
8/25/1933	99800	99800	3/26/1994	148000	160800
3/6/1934	85500	85500	1/22/1995	72100	76200
7/10/1935	151000	151000	1/20/1996	221000	242200
3/20/1936	232000	232000	11/10/1996	128000	138500
1/23/1937	77300	77300	1/9/1998	138000	149700
9/24/1938	64900	64900	1/25/1999	112000	120700
2/22/1939	137000	137000	2/29/2000	129000	139600
4/1/1940	212000	215600	4/11/2001	96800	103700
4/7/1941	138000	139700	3/28/2002	78900	83700
3/11/1942	111000	112100	3/22/2003	122000	131800
1/1/1943	191000	196900	9/19/2004	227000	248900
5/9/1944	90000	92100	4/4/2005	189000	206500
3/5/1945	119000	122200	6/28/2006	218000	238900
5/29/1946	210000	216600	3/16/2007	123000	132900
4/7/1947	151000	155400	3/5/2008	115000	124000
3/23/1948	193000	198900	3/10/2009	84900	90400
12/31/1948	82700	84500	1/27/2010	122000	131800
3/30/1950	172000	177500	9/9/2011	USGS 295000	USGS 324700
			9/9/2011	COE 336000	COE 370500

TABLE 7

Susquehanna River at Danville, PA

USGS gage # 01540500

Drainage Area = 11220 sq mi

Years of Record 1900-2011

Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)	Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)
3/2/1900	105000	105000	3/9/1956	175000	181200
11/28/1900	135000	135000	4/8/1957	114000	118200
3/3/1902	243000	243000	4/8/1958	169000	175000
3/25/1903	132000	132000	1/24/1959	112000	116100
3/27/1904	148000	148000	4/2/1960	198000	205000
3/26/1905	136000	136000	2/28/1961	167000	173900
4/1/1906	99500	99500	4/2/1962	136000	141500
3/17/1907	73400	73400	3/29/1963	130000	135200
2/17/1908	122000	122000	3/11/1964	261000	272200
5/2/1909	134000	134000	2/14/1965	44900	46200
3/3/1910	165000	165000	2/15/1966	98900	102700
3/29/1911	97300	97300	3/30/1967	87500	90800
4/3/1912	129000	129000	3/24/1968	104000	108000
3/28/1913	192000	192000	4/7/1969	81700	84700
3/29/1914	186000	186000	4/4/1970	122000	126800
2/26/1915	141000	141000	3/17/1971	111000	115300
4/2/1916	175000	175000	6/25/1972	363000	379100
3/29/1917	92900	92900	12/8/1972	99600	103400
3/16/1918	139000	139000	12/29/1973	103000	106900
5/24/1919	80800	80800	9/28/1975	257000	268100
3/14/1920	170000	170000	2/19/1976	120000	124700
3/10/1921	101000	101000	9/27/1977	122000	126800
11/30/1921	133000	133000	3/23/1978	116000	120500
3/5/1923	105000	105000	3/7/1979	188000	199900
4/8/1924	142000	142000	3/23/1980	104000	110200
2/13/1925	162000	162000	2/22/1981	105000	112200
3/27/1926	101000	101000	10/30/1981	83300	88100
11/17/1926	142000	142000	4/17/1983	149000	161100
10/21/1927	156000	156000	4/7/1984	194000	211100
4/23/1929	163000	163000	3/14/1985	55300	57000
3/9/1930	78700	78700	3/16/1986	173000	187800
3/30/1931	88500	88500	4/6/1987	104000	111100
4/2/1932	119000	119000	5/21/1988	83500	88300
8/25/1933	119000	119000	5/15/1989	116000	124400
3/6/1934	98600	98600	2/18/1990	70900	74300
7/11/1935	153000	153000	10/25/1990	124000	133300
3/20/1936	250000	250000	3/29/1992	89200	94700
1/23/1937	93400	93400	4/3/1993	187000	203300
10/24/1937	79400	79400	3/26/1994	139000	150000

TABLE 7 - CONTINUED
Susquehanna River at Danville, PA
USGS gage # 01540500
Drainage Area = 11220 sq mi
Years of Record 1900-2011

Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)	Date	Observed Peak Q (cfs)	Natural Peak Q (cfs)
2/22/1939	139000	139000	1/22/1995	73700	77500
4/2/1940	222000	226300	1/21/1996	209000	227800
4/7/1941	142000	144400	12/3/1996	130000	140000
3/11/1942	116000	117700	1/10/1998	143000	154400
1/1/1943	204000	210300	1/25/1999	116000	124400
5/9/1944	97600	100500	2/29/2000	132000	142200
3/5/1945	121000	124700	4/11/2001	97800	104200
5/29/1946	234000	241200	5/15/2002	84700	89700
4/7/1947	150000	154600	3/22/2003	130000	140000
3/24/1948	184000	189700	9/19/2004	220000	240000
1/1/1949	89600	92300	4/4/2005	202000	220000
3/30/1950	168000	173400	6/28/2006	260000	284400
12/5/1950	131000	135700	3/17/2007	123000	132200
3/13/1952	127000	131600	3/6/2008	124000	133300
12/13/1952	103000	106800	3/11/2009	84600	89600
5/5/1954	82100	85200	1/27/2010	130000	140000
3/3/1955	85900	89100	9/9/2011	311000	341100

The program HEC-SSP (Hydraulic Engineering Center – Statistical Software Package) version 1.1 was used to develop natural conditions peak flow frequency curves using the Log-Pearson Type III distribution. A regional study of skew coefficients was not available for the large drainage areas at Wilkes-Barre and Danville on the Susquehanna River, therefore, skew coefficients were determined using the a map developed for Bulletin 17B.

The regional skew for Wilkes-Barre is 0.30 and for Danville is 0.31, with the mean square error of the map equal to 0.302. The Wilkes-Barre gage record was extended to a historic period of record using the peak flow on March 1865. The USGS records states that the maximum know stage prior to 1899 occurred on 18 March 1865. Therefore, the historic period of record was specified in the HEC-SSP program as beginning in 1865 with a high threshold equal to the maximum peak discharge. The skew values along with the natural flows for the gages were input into HEC-SSP to determine peak flow frequency curves at the gages; the resulting statistics are presented in Tables 8 - 10.

TABLE 8

Susquehanna River at Wilkes-Barre, PA - Natural Conditions Using USGS Provisional Tropical Storm Lee Discharge				
Computed Curve	Expected Probability	Percent Chance Exceedance	Confidence Limits	
			0.05	0.95
Flow, cfs			Flow, cfs	
400672	---	0.2	465733	353997
362098	---	0.4	416287	322713
313600	---	1	355048	282847
278769	---	2	311795	253856
245191	---	4	270767	225481
202069	---	10	219248	188298
169517	---	20	181487	159449
122993	---	50	130021	116309
91000	---	80	96780	84953
78337	---	90	83975	72307
69489	---	95	75071	63469
56016	---	99	61494	50104

Log Transform: Flow, cfs		Number of Events	
Mean	5.096	Historic events	0
Standard Dev	0.161	High Outliers	0
Station Skew	0.213	Low Outliers	0
Regional Skew	0.300	Zero or Missing	0
Weighted Skew	0.224	Systemic Events	121
Adopted Skew	0.224	Historic Period	147

TABLE 9

Susquehanna River at Wilkes-Barre, PA - Natural Conditions Using COE Estimated Tropical Storm Lee Discharge				
Computed Curve	Expected Probability	Percent Chance Exceedance	Confidence Limits	
			0.05	0.95
Flow, cfs			Flow, cfs	
413656	---	0.2	482541	364425
372120	---	0.4	429107	330839
320307	---	1	363488	288386
283443	---	2	317603	257733
248194	---	4	274453	227993
203382	---	10	220847	189395
169930	---	20	182016	159765
122756	---	50	129826	116027
90818	---	80	96638	84732
78304	---	90	83976	72243
69606	---	95	75218	63561
56441	---	99	61943	50504

Log Transform: Flow, cfs		Number of Events	
Mean	5.096	Historic events	0
Standard Dev	0.162	High Outliers	0
Station Skew	0.266	Low Outliers	0
Regional Skew	0.300	Zero Events	0
Weighted Skew	0.271	Missing Events	0
Adopted Skew	0.271	Systemic Events	121
		Historic Period	147

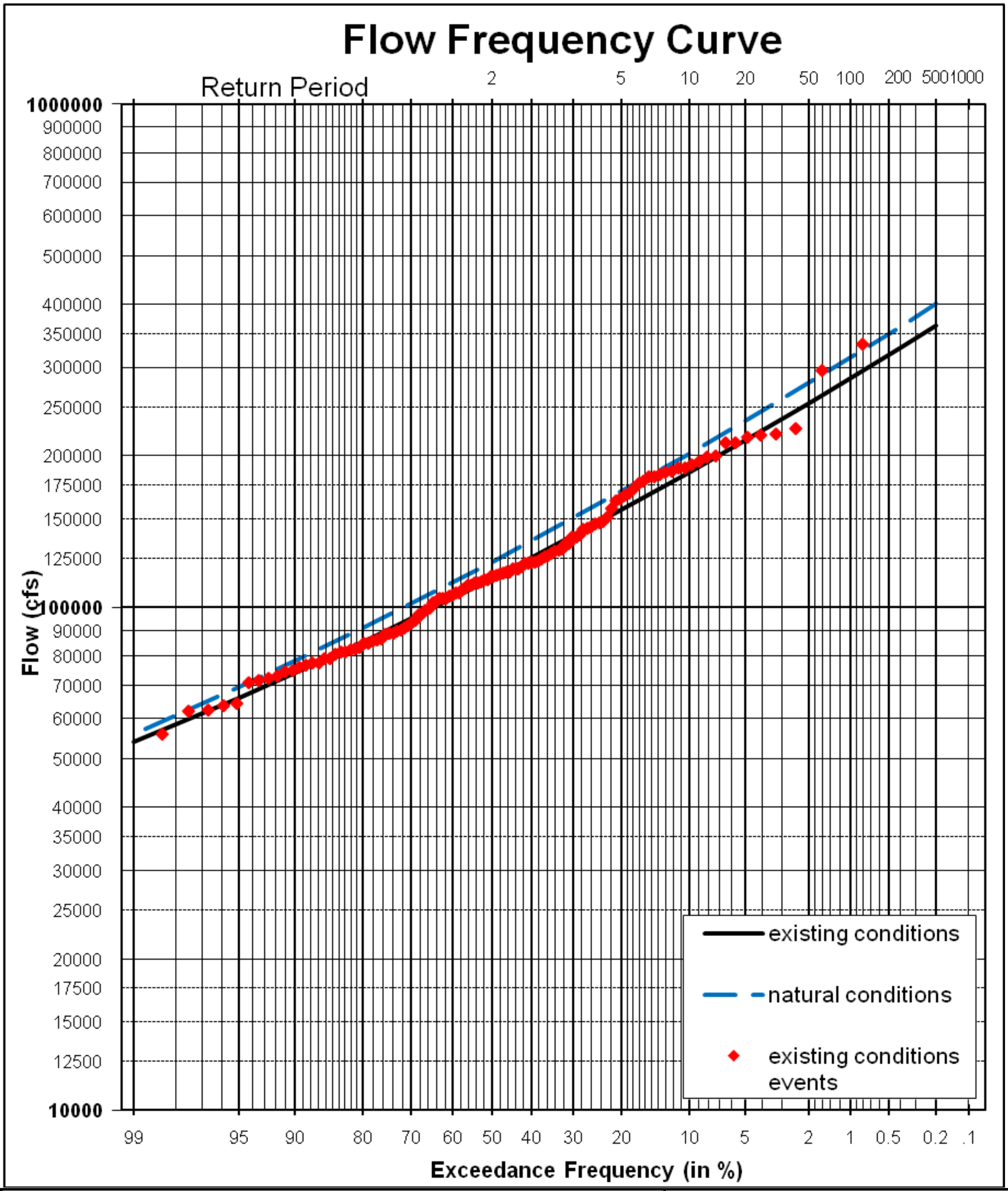
TABLE 10
HEC-SSP Results – Natural Conditions

Susquehanna River at Danville, PA - Natural Conditions Danville - FLOW-PEAK				
Computed Curve	Expected Probability	Percent Chance Exceedance	Confidence Limits	
			0.05	0.95
Flow, cfs			Flow, cfs	
422076	---	0.2	493082	371753
381480	---	0.4	440556	339040
330488	---	1	375608	297404
293919	---	2	329833	267101
258702	---	4	286488	237488
213531	---	10	232173	198700
179469	---	20	192454	168608
130834	---	50	138477	123568
97405	---	80	103719	90778
84169	---	90	90342	77540
74916	---	95	81040	68284
60817	---	99	66849	54273

Log Transform: Flow, cfs		Number of Events	
Mean	5.123	Historic events	0
Standard Dev	0.158	High Outliers	0
Station Skew	0.232	Low Outliers	0
Regional Skew	0.310	Zero Events	0
Weighted Skew	0.245	Missing Events	0
Adopted Skew	0.245	Systematic Events	112

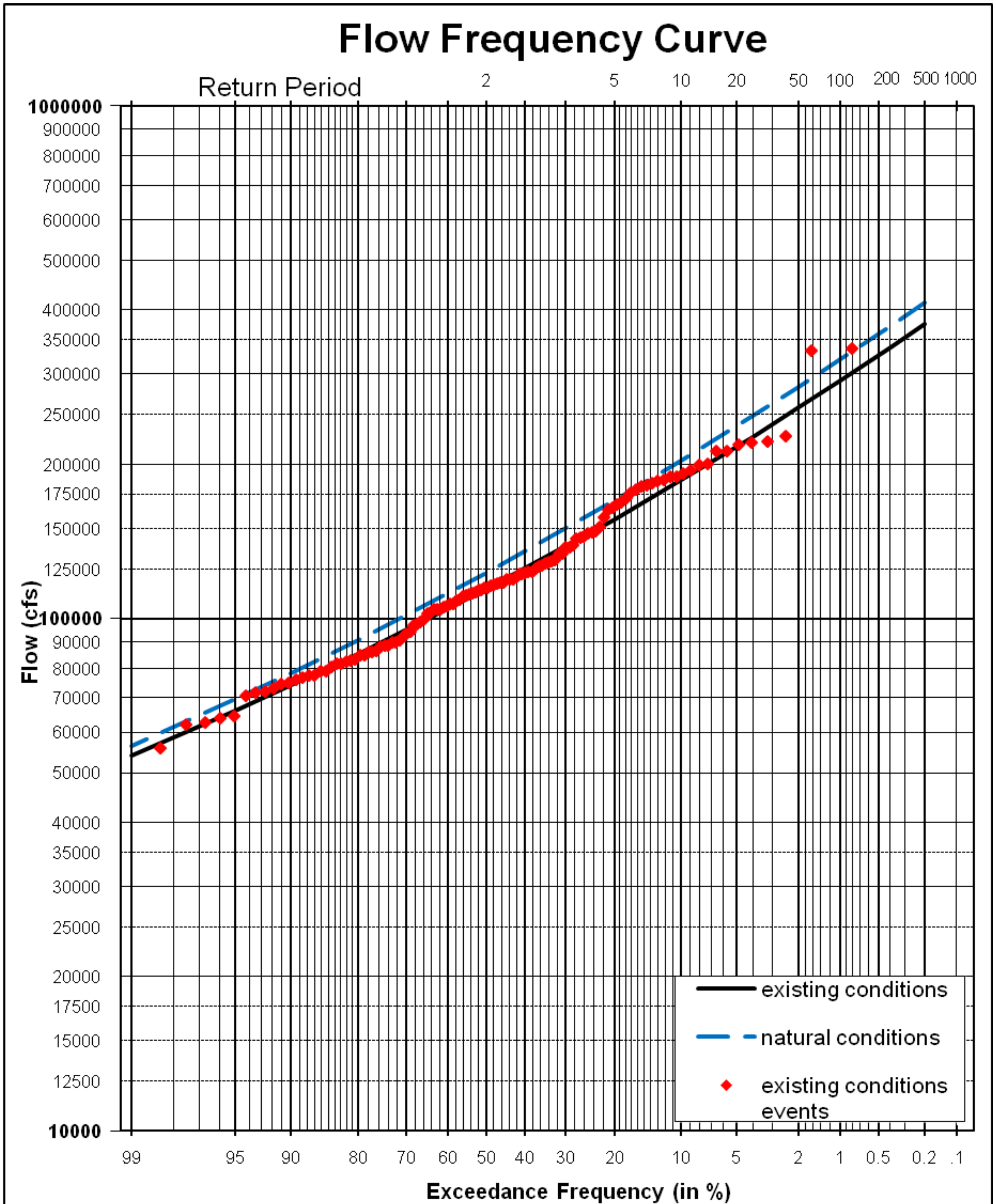
The computed discharges determined from the HEC-SSP program were then adjusted to existing conditions using the natural vs. regulated by all (8 dams) relationship curves for Wilkes-Barre and Danville gages. The resulting frequency curves are presented below in Figures 19 - 21. A table of existing conditions discharge vs. frequency is presented in Table 11.

FIGURE 19



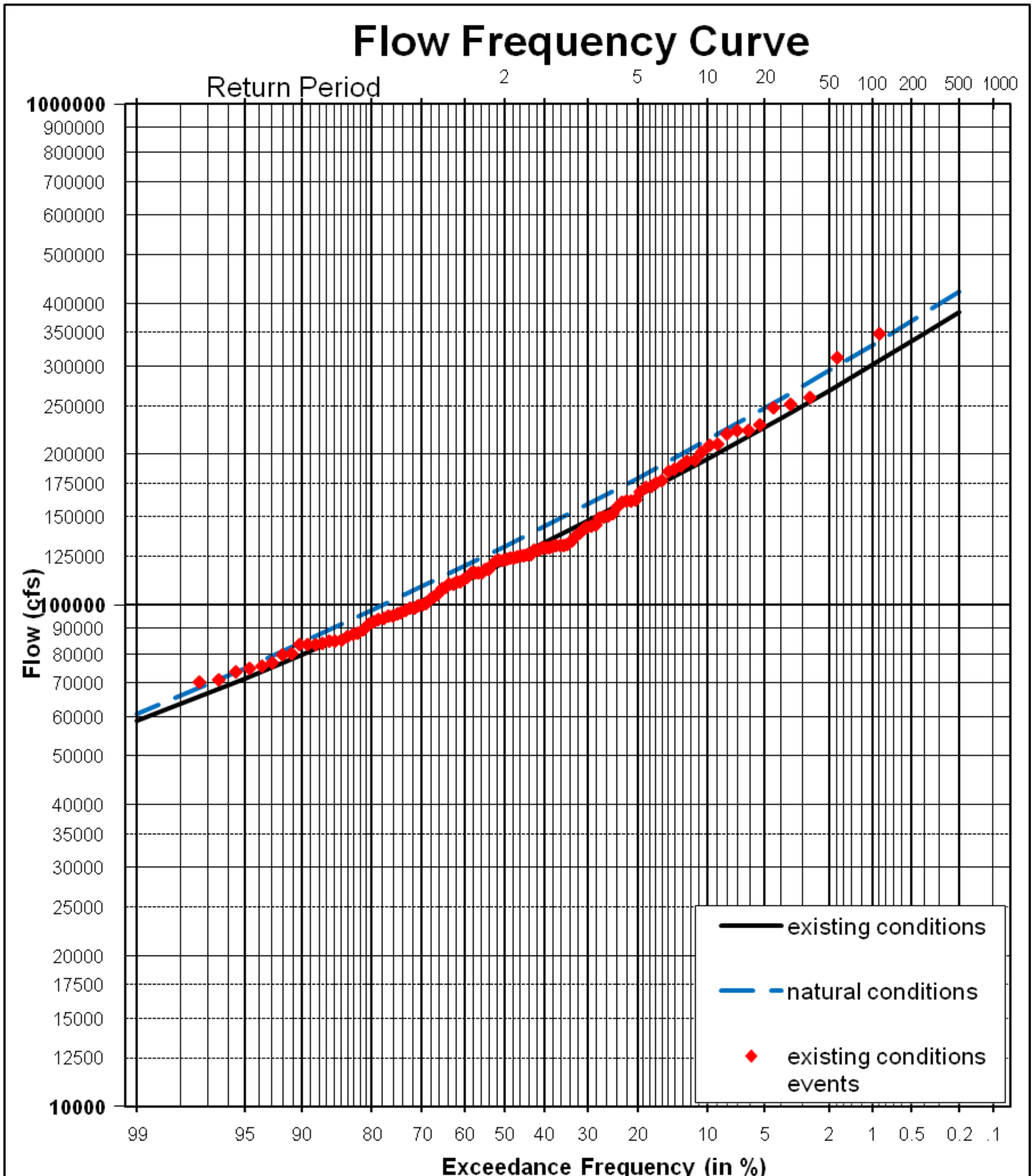
Frequency Statistics For Natural Conditions		Number of Events		Susquehanna River at Wilkes-Barre, PA USGS Gage 01536500
Mean	5.096	Historic Events	0	Drainage Area = 9660 sq mi
Standard Dev	0.161	High Outliers	0	Period of Record 1891-2011
Station Skew	0.213	Low Outliers	0	Historic Period of Record 1865-2011
Regional Skew	0.300	Zero or Missing	0	Includes USGS Provisional Tropical
Weighted Skew	0.224	Systematic Events	121	Storm Lee Discharge
Adopted Skew	0.224	Historic Period	147	May 2012

FIGURE 20



Frequency Statistics For Natural Conditions		Number of Events		Susquehanna River at Wilkes-Barre, PA USGS Gage 01536500
Mean	5.096	Historic Events	0	Drainage Area = 9660 sq mi
Standard Dev	0.162	High Outliers	0	Period of Record 1891-2011
Station Skew	0.266	Low Outliers	0	Historic Period of Record 1865-2011
Regional Skew	0.300	Zero or Missing	0	Includes COE Estimated Tropical
Weighted Skew	0.271	Systematic Events	121	Storm Lee Discharge
Adopted Skew	0.271	Historic Period	147	May 2012

FIGURE 21



Frequency Statistics				
For Natural Conditions		Number of Events		Susquehanna River at Danville, PA
Mean	5.123	Historic Events	0	
Standard Dev	0.158	High Outliers	0	USGS Gage 01540500
Station Skew	0.232	Low Outliers	0	Drainage Area = 11220 sq mi
Regional Skew	0.310	Zero or Missing	0	Period of Record 1900-2011
Weighted Skew	0.245	Systematic Events	112	
Adopted Skew	0.245			May 2012

TABLE 11

Existing Conditions Peak Flow Frequency				
Percent Chance Exceedance	Event	Susquehanna River at Wilkes-Barre DA=9960 sq mi		Susquehanna River at Danville DA=11200 sq mi
		Q with USGS TSLee (cfs)	Q with COE TSLee (cfs)	Q with TSLee (cfs)
0.2	500 yr	363000	375000	384000
0.4	250 yr	329000	337000	347000
1.0	100 yr	285000	291000	301000
2.0	50 yr	254000	258000	269000
4.0	25 yr	224000	226000	237000
10.0	10 yr	185000	186000	196000
20.0	5 yr	156000	156000	166000
50.0	2 yr	114000	114000	122000

The existing (regulated) conditions discharge values for the Bloomsburg project area were determined by linearly interpolating between the Wilkes-Barre and Danville gage locations based on drainage area, using equation 2 below. The drainage area for the Susquehanna River at the Bloomsburg project area is calculated just upstream of the confluence of Fishing Creek.

$$Q_B = \frac{(Q_D - Q_{WB})}{(A_D - A_{WB})} \cdot (A_B - A_{WB}) + Q_{WB} \qquad \text{(Eq. 2)}$$

Where:

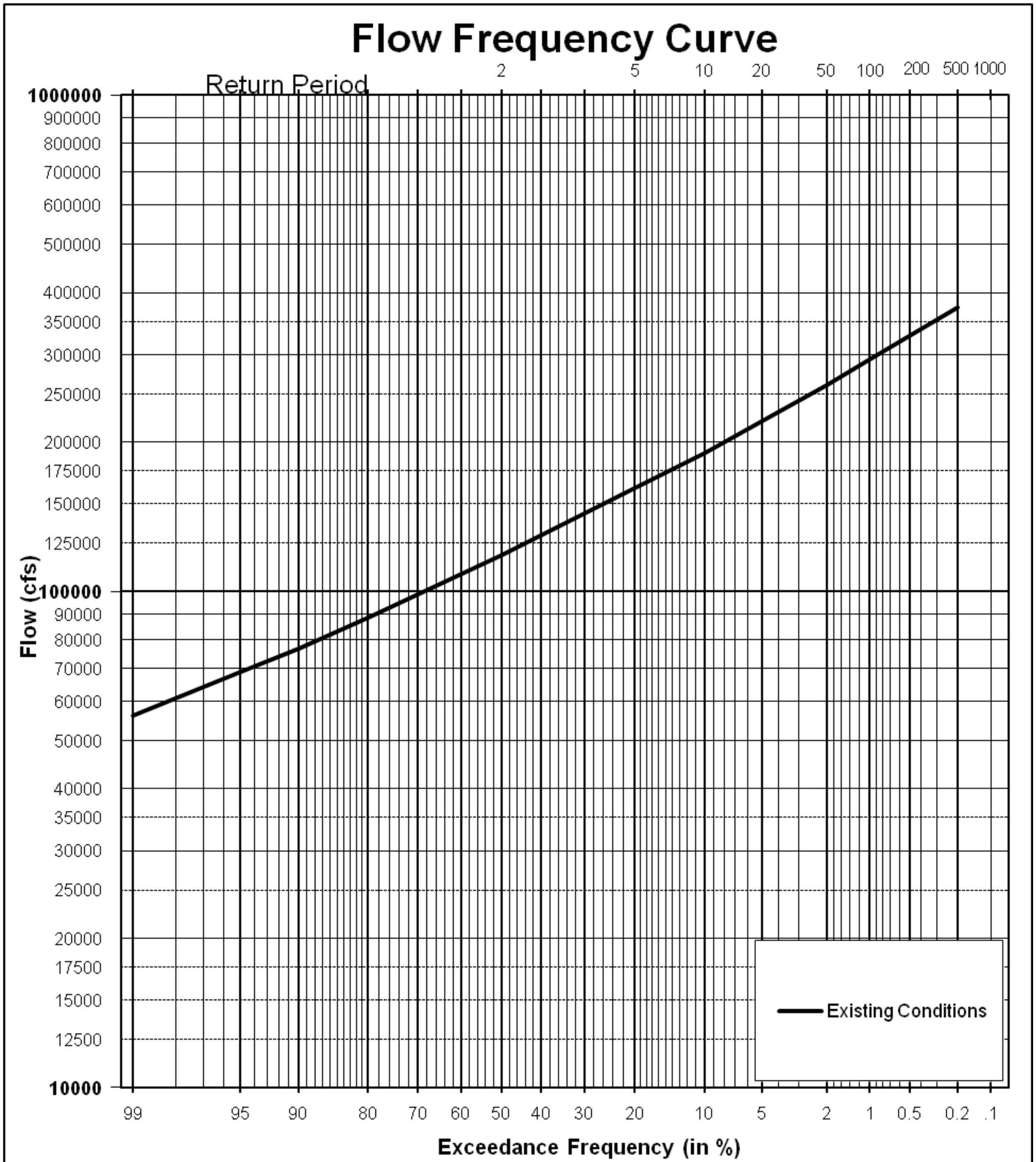
Q_B = Flow at Bloomsburg [cfs]
Q_D = Flow at Danville [cfs]
Q_{WB} = Flow at Wilkes-Barre [cfs]
A_B = Drainage Area at Bloomsburg [sq. mi.] (10560 sq mi)
A_D = Drainage Area at Danville [sq. mi.] (11220 sq mi)
A_{WB} = Drainage Area at Wilkes-Barre [sq. mi.] (9960 sq mi)

Equation 2 linearly interpolates the flow value at the Bloomsburg location based on the flow values at the upstream and downstream gage stations. The resulting table of existing conditions discharge frequency values for Bloomsburg is presented in Table 12, and the peak flow frequency curves in Figure 22 and 23. Table 12 also presents a comparison of the peak flow frequency with and without the additional 2-3 years of record which includes Tropical Storm Lee. The addition of these events to the period of record caused a 5% increase in the 100 year discharge when using the COE TSLee discharge and a 3.9% increase when using the USGS provisional TSLee discharge.

TABLE 12

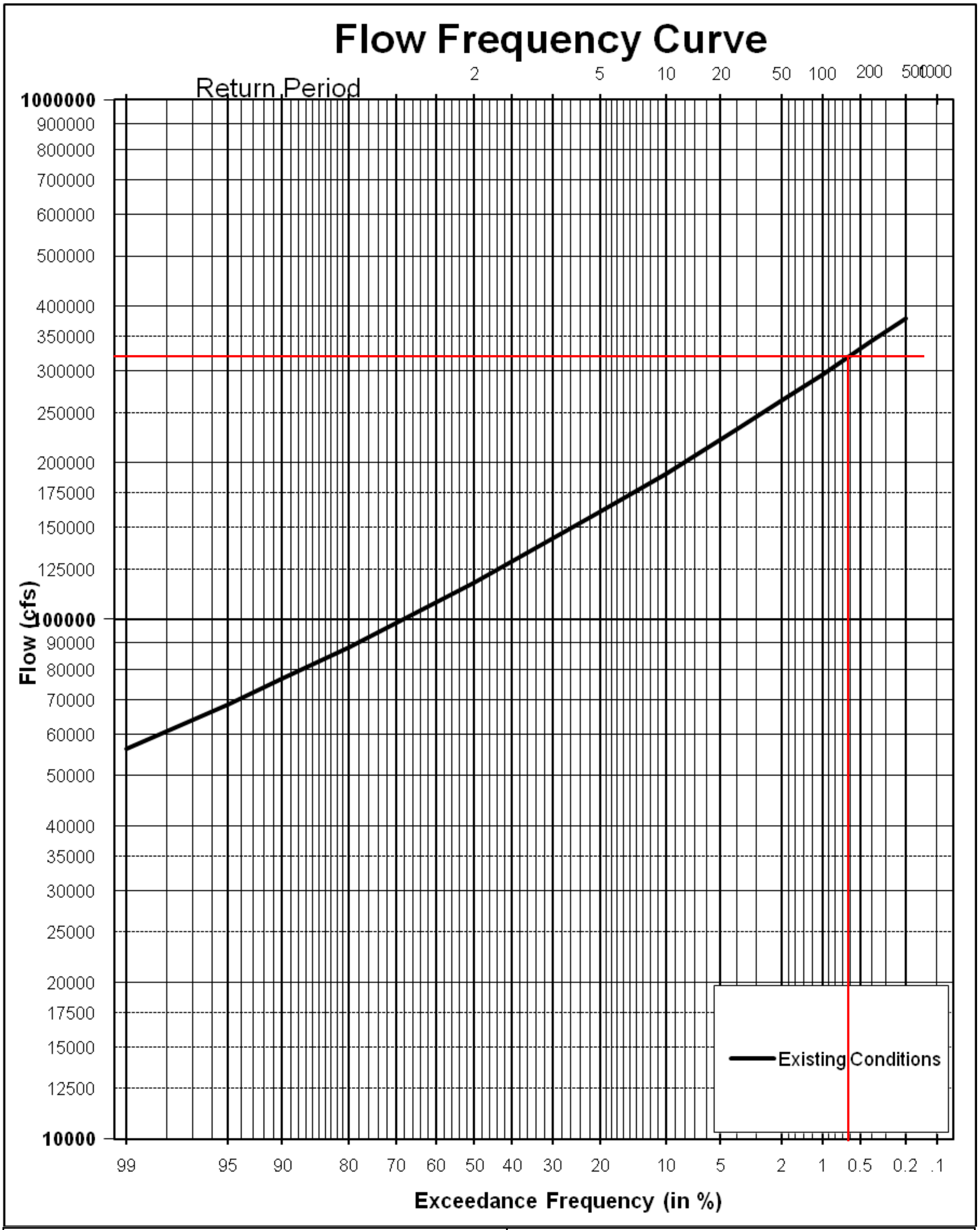
Susquehanna River at Bloomsburg u/s Fishing Creek DA=10560 sq mi Existing Conditions Peak Flow Frequency				
Percent Chance Exceedance	Event	Q from Oct 2010 R&U - No TSLee	Q with USGS TSLee (cfs)	Q with COE TSLee (cfs)
0.2	500 yr	354000	373000	379000
0.4	250 yr	322000	338000	342000
1.0	100 yr	282000	293000	296000
2.0	50 yr	253000	261000	263000
4.0	25 yr	224000	230000	231000
10.0	10 yr	187000	190000	191000
20.0	5 yr	159000	161000	161000
50.0	2 yr	117000	118000	118000

FIGURE 22



Curve calculated by using peak flow data from gages at Wilkes-Barre (historic period of record 1865-2011) and Danville (period of record 1900-2011) and adjusting for drainage area.	Susquehanna River at Bloomsburg, PA Upstream of Fishing Creek Basin Area = 10560 sq mi Existing Conditions Includes USGS Provisional Tropical Storm Lee Discharge May 2012

FIGURE 23



Curve calculated by using peak flow data from gages at Wilkes-Barre (historic period of record 1865-2011) and Danville (period of record 1900-2011) and adjusting for drainage area.	Susquehanna River at Bloomsburg, PA Upstream of Fishing Creek Basin Area = 10560 sq mi Existing Conditions Includes COE Estimated Tropical Storm Lee Discharge May 2012

The existing conditions discharge values for the stream reaches in the Bloomsburg project area are shown in Table 13. The values using the COE estimated TS Lee discharge were used for the economic update.

TABLE 13

Existing Conditions Discharges for Use in HEC-RAS Model

COE TSLee Values Used for Economic Update

			With USGS TS Lee Q		With COE TS Lee Q	
Flood Event	Percent Chance Exceedance	Fishing Creek (cfs)	Susquehanna u/s Fishing Creek (cfs)	Susquehanna d/s Fishing Creek (cfs)	Susquehanna u/s Fishing Creek (cfs)	Susquehanna d/s Fishing Creek (cfs)
500	0.2	89600	373000	462600	379000	468600
250	0.4	75300	338000	413300	342000	417300
100	1	58900	293000	351900	296000	354900
50	2	48200	261000	309200	263000	311200
25	4	38800	230000	268800	231000	269800
10	10	28100	190000	218100	191000	219100
5	20	21000	161000	182000	161000	182000
2	50	12400	118000	130400	118000	130400

Hydraulics:

The Army Corps of Engineers Baltimore District developed a best estimate, low risk estimate and high risk estimate hydraulic model for the Bloomsburg FRMS using the program HEC-RAS for the purpose of hydraulic modeling for the feasibility study and for use in the October 2010 R&U analysis. The HEC-RAS model was updated with the new hydrology that includes the COE estimate for TSLee. The resulting best estimate with and without project conditions water surface elevations from the HEC-RAS model for the cross sections chosen to represent the damage reaches in the economic analysis are presented in Tables 14 - 17. The increase in the water surface elevations caused by including the TSLee event in the hydrology can be seen by comparing the tables. For example, the 100 yr without project conditions WSEL increased from 482.1 ft NAVD88 to 486.1 ft NAVD88 at the downstream portion of Fishing Creek (FC Reach 1), and increased from 478.2 ft NAVD88 to 482.0 ft NAVD88 on the Susquehanna River upstream of the confluence of Fishing Creek (SR Reach 5).

TABLE 14

Without Project Water Surface Elevation (ft NAVD88) from Best Estimate Model
Includes effects of Tropical Storm Lee

		Percent Chance Exceedance							
Damage Reach	Cross Section	50 (2-yr)	20 (5-yr)	10 (10-yr)	4 (25-yr)	2 (50-yr)	1 (100-yr)	0.4 (250-yr)	0.2 (500-yr)
FC Reach 1	3861	470.1	472.9	475.0	479.3	483.0	486.1	489.0	491.6
FC Reach 2	6468	471.5	474.8	476.5	479.5	483.1	486.2	489.1	491.7
FC Reach 3	10246	473.9	477.3	478.6	215.9	483.3	486.4	489.3	491.8
FC Reach 4	12804	476.3	480.1	482.2	484.9	486.7	488.9	490.5	492.9
SR Reach 5	12230.8	469.9	472.4	474.2	477.0	479.5	482.0	485.7	488.9
SR Reach 6	13434	470.2	472.7	474.5	477.3	479.6	482.1	485.8	489.0

TABLE 15

With Project Water Surface Elevation (ft NAVD88) from Best Estimate Model Includes effects of Tropical Storm Lee									
		Percent Chance Exceedance							
Damage Reach	Cross Section	50 (2-yr)	20 (5-yr)	10 (10-yr)	4 (25-yr)	2 (50-yr)	1 (100-yr)	0.4 (250-yr)	0.2 (500-yr)
FC Reach 1	3861	470.1	472.9	475.1	479.3	483.1	486.2	489.1	491.6
FC Reach 2	6468	471.6	474.8	477.5	480.8	483.9	486.9	489.8	492.4
FC Reach 3	10246	473.9	478.1	481.4	485.5	488.1	490.7	493.5	495.7
FC Reach 4	12804	476.4	480.5	483.6	487.8	490.6	493.5	496.7	499.0
SR Reach 5	12230.8	469.9	472.4	474.1	477.0	479.4	482.0	485.7	488.9
SR Reach 6	13434	470.2	472.7	474.5	477.3	479.6	482.1	485.7	488.9

TABLE 16

Without Project Water Surface Elevation (ft NAVD88) from Best Estimate Model From Oct 2010 R&UA (without Tropical Storm Lee)									
		Percent Chance Exceedance							
Damage Reach	Cross Section	50 (2-yr)	20 (5-yr)	10 (10-yr)	4 (25-yr)	2 (50-yr)	1 (100-yr)	0.4 (250-yr)	0.2 (500-yr)
FC Reach 1	3861	469.7	472.0	473.8	476.2	478.8	482.1	486.2	487.9
FC Reach 2	6468	471.2	474.1	475.7	477.2	479.1	482.3	486.3	488.0
FC Reach 3	10246	473.6	477.4	477.8	478.3	479.8	482.6	486.4	488.2
FC Reach 4	12804	476.2	480.0	481.5	483.7	485.2	486.7	489.2	490.1
SR Reach 5	12230.8	469.4	471.5	472.9	474.7	476.4	478.2	480.6	482.5
SR Reach 6	13434	469.7	471.9	473.3	475.1	476.7	478.5	480.8	482.6

TABLE 17

With Project Water Surface Elevation (ft NAVD88) from Best Estimate Model From Oct 2010 R&UA (without Tropical Storm Lee)									
		Percent Chance Exceedance							
Damage Reach	Cross Section	50 (2-yr)	20 (5-yr)	10 (10-yr)	4 (25-yr)	2 (50-yr)	1 (100-yr)	0.4 (250-yr)	0.2 (500-yr)
FC Reach 1	3861	469.6	471.6	473.1	475.2	477.1	480.5	485.3	487.8
FC Reach 2	6468	471.2	474.0	475.9	478.9	480.4	482.2	486.3	488.6
FC Reach 3	10246	473.7	477.4	480.0	483.7	486.0	487.8	490.8	492.6
FC Reach 4	12804	476.2	479.9	482.5	486.1	488.5	490.6	493.8	495.9
SR Reach 5	12230.8	469.4	471.5	472.9	474.7	476.4	478.2	480.6	482.4
SR Reach 6	13434	469.7	471.9	473.4	475.1	476.7	478.5	480.8	482.6

The standard deviation in the stage-discharge function is needed for R&U analysis and for economic calculations. The difference in the water surface elevation between the high and low risk estimate from the HEC-RAS model is used to calculate the standard deviation about the mean (best) estimate as follows:

Standard Deviation = 95% band/4 = (high estimate stage-low estimate stage)/4

The low and high risk HEC-RAS models were developed as follows.

A sensitivity analysis was performed to determine the appropriate adjustments to hydraulic factors for the high risk and low risk scenarios. The uncertainty in the following hydraulic factors was considered in the sensitivity analysis: starting water surface elevations, roughness coefficients, ineffective flow designations, and bridge debris. None of these variables are potentially more important than the Manning's "n" values. Therefore, the high and low risk discharge estimates have been calculated primarily by increasing or decreasing the Manning's "n" values. The expected risk Manning's "n" values were determined during the field reconnaissance, using observations and following the guidance in EM 1110-2-1416 and Chow (1959). The HEC-RAS model was then calibrated using highwater marks that were determined by contacting 42 citizens that owned properties in the flood prone areas of Bloomsburg. Of those 42 properties, 12 highwater marks were found to be useable for three flood events: June 1972, September 1975, and January 1996. The Manning's "n" values used in the HEC-RAS model were adjusted within reasonable limits to produce without project conditions water surface profiles for the three events that matched closely (+ or – 0.5 ft.) with the highwater marks. Table 3.1 in the HEC-RAS Hydraulic Reference Manual was used to adjust the Manning's "n" values for the high and low risk models. Manning's "n" values for the low risk model were decreased using the minimum values in the table and the Manning's "n" values for the high risk model were increased using the maximum values. To simulate the effects of accumulated debris, the expected risk model assumed floating debris at bridges to be 4 ft. wide and 2 ft. high based on observations reported by townspeople. For the high risk model, floating pier debris was increased to 6 ft wide by 3 ft high, and for the low risk model it was decreased to 3 ft wide by 1 ft high.

Other hydraulic variables were not modified. Ineffective flow areas were kept in place for both the high and low estimate on both the right and left banks. It was felt that due to the existing land use and existing obstructions no variation should be made to the high and low condition without clear justification. Modeling coefficients and flow calculation methods remained the same for both high and low conditions as there is little to no justification for significant changes to these model inputs based on available information.

A summary of model deviations made to the best estimate hydraulic model are included in Table 18 below for both the high and low boundary condition.

TABLE 18

Model Deviations for High and Low Estimates

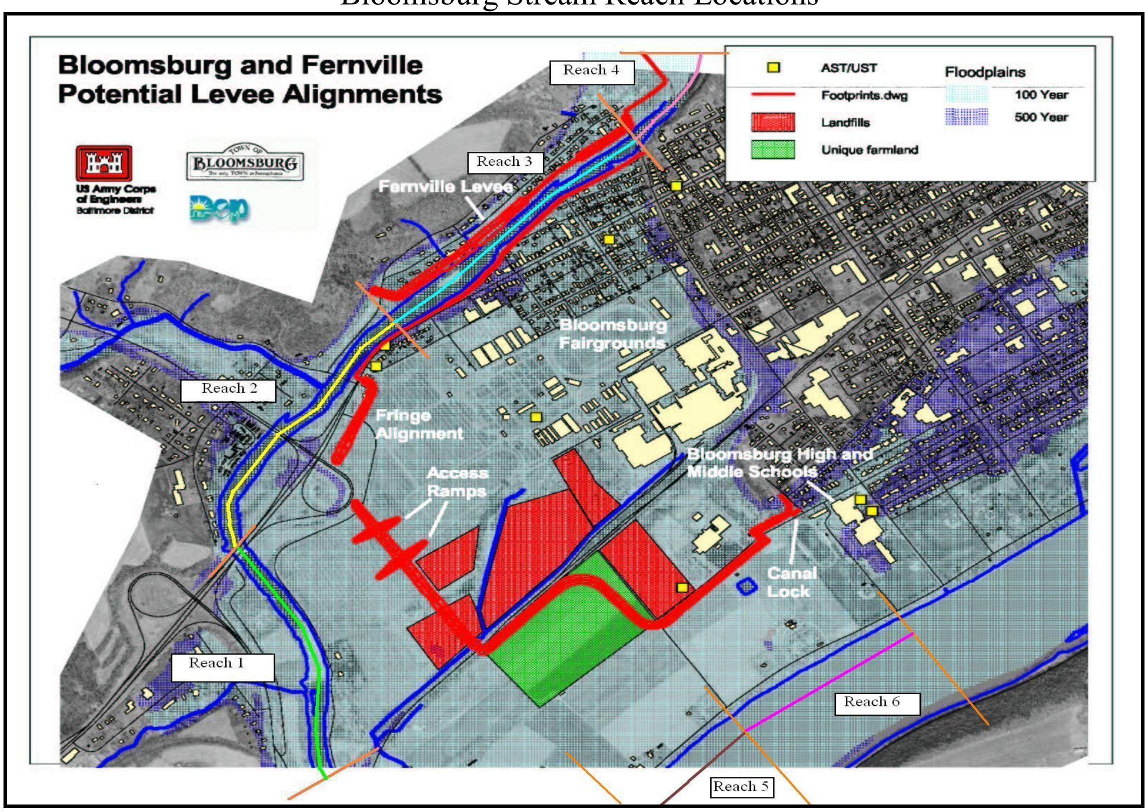
Hydraulic Variable Modified:	High Risk Estimate:	Low Risk Estimate:
Manning's "n" Value:	Increased by using maximum value in Table 3.1 from HEC-RAS Hydraulic Reference Manual	Decreased by using minimum value in Table 3.1 from HEC-RAS Hydraulic Reference Manual
Bridge Pier Geometry:	Floating pier debris increased to 6' wide by 3' high	Floating pier debris decreases to 3' wide by 1' high

Flood Damage Analysis Program (HEC-FDA):

The HEC-FDA program is used to analyze risk and uncertainty on the Bloomsburg FRMS LOP and to evaluate economic benefits. For analysis purposes, the Fishing Creek portion of the LOP was divided into four stream reaches and the Susquehanna River portion was divided into two reaches. The four Fishing Creek segments include a Bloomsburg LOP reach downstream of the Rt. 11 interchange, a Bloomsburg LOP reach upstream of the Rt. 11 interchange, a reach with both the Fernville LOP on the right bank and the Bloomsburg LOP on the left bank, and the upstream reach of the Bloomsburg LOP. The two Susquehanna River segments include an upstream and downstream section. See Figure 24 for a map of the stream reach locations.

FIGURE 24

Bloomsburg Stream Reach Locations



The upstream and downstream HEC-RAS model station boundaries for each reach segment are provided in Table 19. Also included in Table 19 is the index station used as reference point when determining the confidence interval associated with each damage reach segment. For each reach segment the index station was selected at the approximate midpoint of the levee segment.

TABLE 19
Reach Segment Station Boundaries

Reach Segment	Downstream Station	Upstream Station	Index Station
Reach 1: Fishing Creek - Bloomsburg LOP d/s of Rt 11	2436	5359	3861
Reach 2: Fishing Creek - Bloomsburg LOP u/s of Rt 11	5473	8847	6468
Reach 3: Fishing Creek - Fernville and Bloomsburg LOPs	9439	11886	10246
Reach 4: Fishing Creek - Upstream Bloomsburg LOP	12366	14129.8	12804
Reach 5: Susquehanna River - Downstream portion of LOP	11634.2	12827.4	12230.8
Reach 6: Susquehanna River - Upstream portion of LOP	12827.4	14020.6	13424

The peak flow frequency analysis for Fishing Creek incorporated a total of 92 years of record at Fishing Creek in Bloomsburg; 18 years were from the discontinued gage and 74 years from the present gage. To determine the equivalent record length for use in the HEC-FDA calculations, the gage record length was reduced to account for the error associated with transposing the Fishing Creek gage data to the Bloomsburg project site location as per table 4-5 in EM1110-2-1619. The discontinued gage was within the 20% drainage area requirements shown in table 4-5, so that part of the record was reduced by 10%. The present gage drainage area is greater than the 20% requirement (29%), so that part of the record was reduced by 20%. This yields an equivalent record length of 75 years. The analytical techniques (Log-Pearson Type III) incorporated in the HEC-FDA model were used to evaluate the variance associated with the frequency discharge data used.

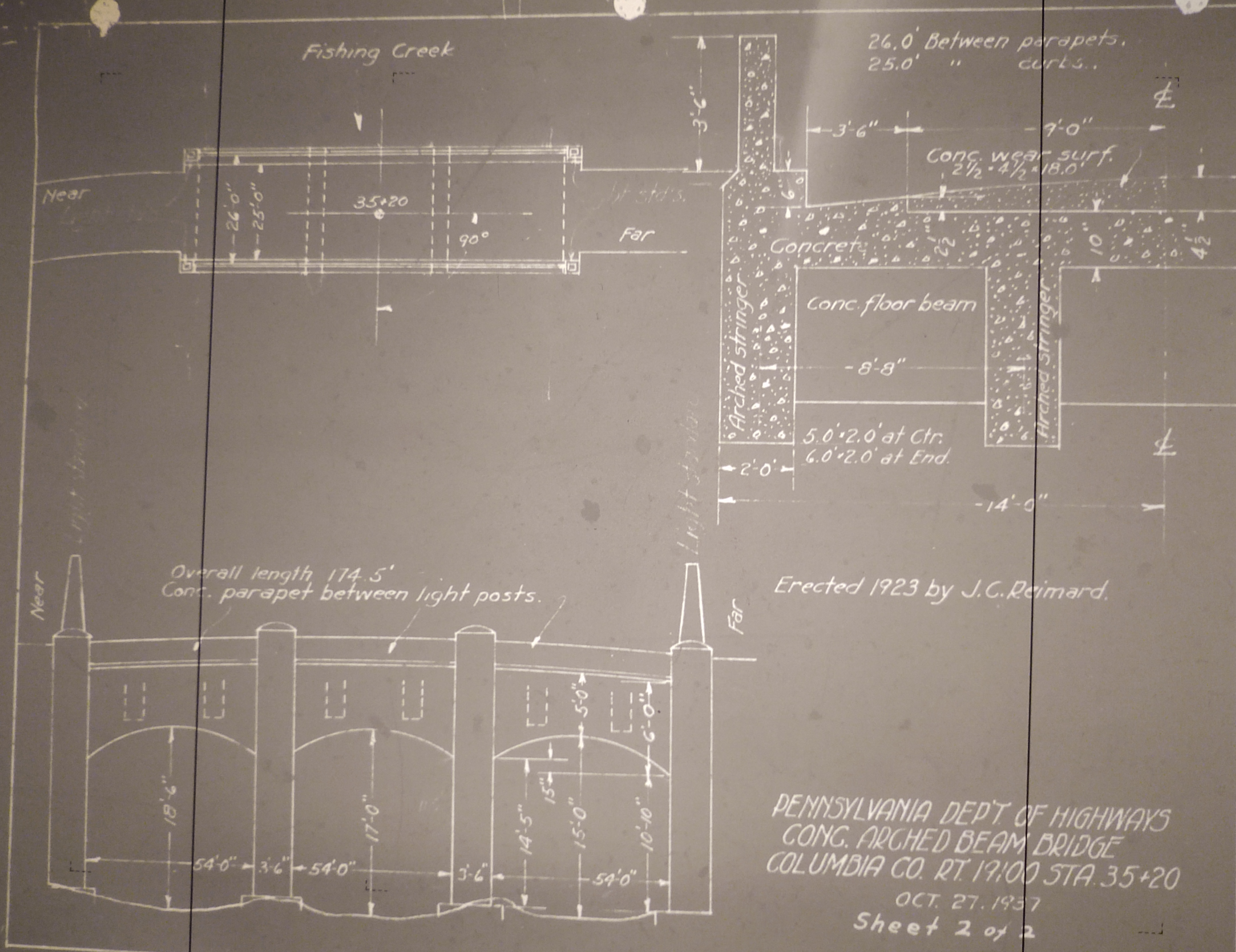
The peak flow frequency analysis for the Susquehanna River incorporated a period of record of 112 years at the Danville gage and 121 years at the Wilkes-Barre gage. The equivalent record length for use in the HEC-FDA calculations was reduced to account for the calculations performed to account for the reduction in discharge due to regulation and for transposing the Danville and Wilkes-Barre regulated discharges to the Bloomsburg project site. Both gages are within the 20% drainage area requirement in table 4-5 of EM1110-2-1619. The average record length of 116.5 years was reduced by 10% to produce an equivalent record length of 105 years. The discharges at the project site are affected by regulation, so graphical techniques incorporated in the HEC-FDA model were used to evaluate the variance associated with the frequency discharge data used.

The HEC-FDA model was built using the water surface profiles for the without project conditions and with-project best estimate conditions profiles. The exceedance probability functions and stage-discharge functions for Bloomsburg on the Susquehanna River and Fishing Creek were derived from the water surface profiles. The standard deviation in the stage-discharge function was determined from the with-project high risk conditions and with-project low risk conditions water surface. The exceedance probability functions input included the Log Pearson Type III statistics for Fishing Creek and the equivalent years of record for both the Susquehanna River and Fishing Creek.

The HEC-FDA model using the data that included the COE estimate for Tropical Storm Lee was provided to the economist for their use in determining updated benefits.

Appendix D

RED MILL ROAD BRIDGE – SUPPORTING DATA FOR CALIBRATION


Fishing Creek
26.0' Between parapets.
25.0' " curbs..
3'-6"
3'-6"
9'-0"
Conc. wear surf.
2½ - 4½ - 18.0'
Near
35+20
26'-0"
25'-0"
90°
Far
Concrete
Conc. floor beam
Arched stringer
Arched stringer
8'-8"
5.0'-2.0' at Ctr.
6.0'-2.0' at End.
2'-0"
14'-0"
Overall length 174.5'
Conc. parapet between light posts.
Erected 1923 by J.C. Reimard.
Near
Far
18'-6"
17'-0"
14'-5"
15"
15'-0"
5'-0"
6'-0"
10'-10"
54'-0"
3'-6"
54'-0"
3'-6"
54'-0"
PENNSYLVANIA DEPT. OF HIGHWAYS
CONC. ARCHED BEAM BRIDGE
COLUMBIA CO. RT. 19100 STA. 35+20
OCT. 27. 1937
Sheet 2 of 2

D-9012 CADD (02-90) REVISION (10-04) PLOTTED: 15-AUG-2011 13:29

OPERATOR:
FILE NAME: G:\ds4\Columbia\19-4003-005\19-4003-005con.GEN

PLAN PREPARATION
DESIGNER VANCE W. COHICK

FEDERAL PROJECT NO. X031-234-L11E

	DISTRICT	COUNTY	TOWNSHIP	BOROUGH	ROUTE	SECTION	TOTAL SHEETS
B00	3-0	COLUMBIA	MONTOUR	———	42	005	26
			HEMLOCK		4003	005	
			———	TOWN OF BLOOMSBURG	T-809	———	

WBS ELEMENT

T/P	SYS	SR or WO	SPUR	PHA	SECTION	ORG.	PRG.	P_C
P	0	0 4 0 0 3	0	7	0 0 5	0 3 1 0 3	6 2	1

S.R. 42 PREVIOUSLY KNOWN AS L.R. 1115
S.R. 4003 PREVIOUSLY KNOWN AS L.R. 19100

MPMS/ECMS No. 5550

COMMONWEALTH OF PENNSYLVANIA

DEPARTMENT OF TRANSPORTATION

DRAWINGS FOR CONSTRUCTION OF

STATE ROUTE 42 SECTION 005

IN COLUMBIA COUNTY

FROM STA. 1+15.00 TO STA. 24+75.00 LENGTH 2093.77 FT. 0.397 MI.

FROM SEG. 0440 OFFSET 0202 TO SEG. 0470 OFFSET 0119

FROM SEG. 0441 OFFSET 0202 TO SEG. 0451 OFFSET 1177

AND

STATE ROUTE 4003 SECTION 005

FROM STA. 34+35.00 TO STA. 36+91.62 LENGTH 256.62 FT. 0.049 MI.

FROM SEG. 0011 OFFSET 0256 TO SEG. 0011 OFFSET 0000

AND

TOWNSHIP ROAD NO. T-809

FROM STA. 29+50.00 TO STA. 34+35.00 LENGTH 485.00 FT. 0.092 MI.

TOTAL LENGTH 2585.39 FT. 0.538 MI.

ALSO INCLUDED:

TRAFFIC CONTROL PLAN	11 SHEETS
EROSION AND SEDIMENT POLLUTION CONTROL PLAN	4 SHEETS
TRAFFIC SIGNAL PLAN	6 SHEETS
SIGNING AND PAVEMENT MARKING PLAN	8 SHEETS
EXISTING STRUCTURE PLANS	NOT AVAILABLE

SCALE

HORIZONTAL 0 25 50 FEET

VERTICAL 0 5 10 FEET

DESIGN DESIGNATION

SR 42

		TRAFFIC DATA	
HIGHWAY CLASSIFICATION	-URBAN CORE COMMUNITY ARTERIAL	CURRENT A.D.T.	- 6157 (2011)
DESIGN SPEED	-40 MPH POSTED	DESIGN YEAR A.D.T.	- 9332 (2012)
PAVEMENT WIDTH	-72 FT (CURB TO CURB)	D.H.V.	-840 (9%)
SHOULDER WIDTH	-N/A	D	-50%
MEDIAN WIDTH, MAXIMUM	- 15 FT	T	-6%
MINIMUM	- 4 FT		

SR 4003

		TRAFFIC DATA	
HIGHWAY CLASSIFICATION	- RURAL LOCAL ROAD	CURRENT ADT	- 1177 (2011)
DESIGN SPEED	- 30 MPH POSTED	DESIGN YEAR ADT	- 0 (2031)
PAVEMENT WIDTH	- 18'-0"	DHV-	0
SHOULDER WIDTH	- N/A	D	-100%
		T	-6%

PREPARED BY:
DISTRICT 3-0
PLANS UNIT

ERIC E. HIGH, P.E.
ASST. DIST. EXEC.
DATE: 8/15/11

RECOMMENDED DATE: AUGUST 15, 2011
DISTRICT PLANS ENGINEER

RECOMMENDED DATE: August 15, 2011
Sandra Tosca
DISTRICT EXECUTIVE

RECOMMENDED DATE: 8/17/2011
Scott Christie
DEPUTY SECRETARY

APPROVED DATE: 8/17/2011
Barry J. Schoch
SECRETARY OF TRANSPORTATION
(ON BEHALF OF THE GOVERNOR AS WELL AS HIMSELF)

OUTSIDE EDGE OF RECONSTRUCTION

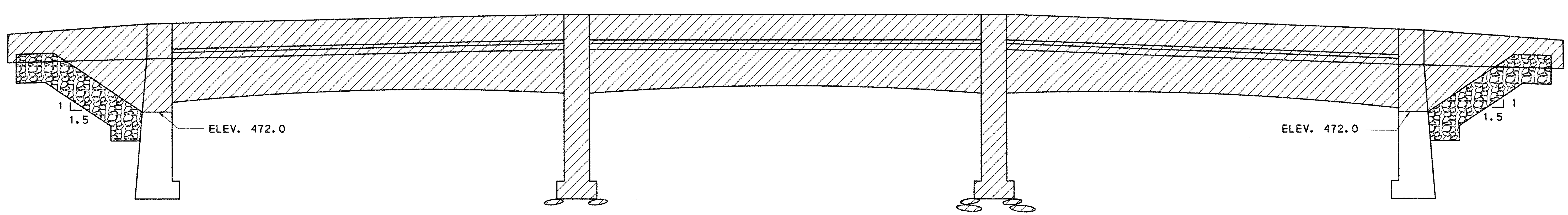
RTE.: OUTSIDE EDGE OF RECONSTRUCTION DISTANCE FROM SR 42 CONSTR ℄

STATION	OFFSET	SIDE	STATION	OFFSET	SIDE
5+38.50	30.38	LT	5+38.50	30.70	RT
5+50.00	30.51	LT	5+50.00	30.67	RT
5+75.00	30.76	LT	5+75.00	30.60	RT
6+00.00	30.94	LT	6+00.00	30.53	RT
6+25.00	30.94	LT	6+25.00	30.50	RT
6+50.00	30.96	LT	6+50.00	30.47	RT
6+75.00	31.50	LT	6+75.00	30.51	RT
7+00.00	32.17	LT	7+00.00	30.63	RT
7+25.00	32.74	LT	7+25.00	30.74	RT
7+50.00	33.35	LT	7+50.00	30.86	RT
7+75.00	33.84	LT	7+75.00	30.97	RT
8+00.00	34.15	LT	8+00.00	31.01	RT
8+25.00	34.14	LT	8+25.00	31.03	RT
8+50.00	34.15	LT	8+50.00	31.05	RT
8+75.00	34.15	LT	8+75.00	30.93	RT
9+00.00	34.15	LT	9+00.00	31.01	RT
9+25.00	34.11	LT	9+25.00	31.08	RT
9+50.00	34.04	LT	9+50.00	31.15	RT
9+75.00	34.03	LT	9+75.00	31.16	RT
10+00.00	34.02	LT	10+00.00	31.15	RT
10+25.00	34.02	LT	10+25.00	31.11	RT
10+50.00	34.01	LT	10+50.00	31.08	RT
10+75.00	34.01	LT	10+75.00	31.04	RT
11+00.00	34.00	LT	11+00.00	31.01	RT
11+25.00	34.00	LT	11+25.00	30.99	RT
11+50.00	34.00	LT	11+50.00	30.98	RT
11+75.00	34.00	LT	11+75.00	30.97	RT
12+00.00	33.99	LT	12+00.00	30.95	RT
12+25.00	33.98	LT	12+25.00	30.94	RT
12+50.00	33.97	LT	12+50.00	30.97	RT
12+75.00	33.97	LT	12+75.00	31.01	RT

OUTSIDE EDGE OF RECONSTRUCTION

RTE.: OUTSIDE EDGE OF RECONSTRUCTION DISTANCE FROM SR 42 CONSTR ℄

STATION	OFFSET	SIDE	STATION	OFFSET	SIDE
13+00.00	33.98	LT	13+00.00	31.03	RT
13+25.00	33.99	LT	13+25.00	31.00	RT
13+50.00	34.01	LT	13+50.00	30.97	RT
13+75.00	34.05	LT	13+75.00	30.94	RT
14+00.00	34.05	LT	14+00.00	30.92	RT
14+25.00	34.04	LT	14+25.00	30.90	RT
14+50.00	34.00	LT	14+50.00	30.91	RT
14+75.00	34.01	LT	14+75.00	30.91	RT
15+00.00	34.01	LT	15+00.00	30.82	RT
15+25.00	33.95	LT	15+25.00	31.09	RT
15+50.00	33.71	LT	15+50.00	30.43	RT
15+75.00	33.51	LT	15+75.00	29.63	RT
16+00.00	33.11	LT	16+00.00	28.84	RT
16+25.00	32.56	LT	16+25.00	28.11	RT
16+50.00	31.80	LT	16+50.00	27.43	RT
16+75.00	30.84	LT	16+75.00	26.81	RT
17+00.00	30.11	LT	17+00.00	26.25	RT
17+25.00	29.46	LT	17+25.00	25.75	RT
17+50.00	28.82	LT	17+50.00	25.30	RT
17+66.75	28.31	LT	18+75.00	20.69	RT
			19+00.00	20.24	RT
			19+25.00	19.81	RT
			19+50.00	19.37	RT
			19+75.00	19.05	RT
			20+00.00	18.85	RT
			20+25.00	18.63	RT
			20+50.00	18.24	RT
			20+75.00	17.89	RT
			21+00.00	17.56	RT
			21+25.00	17.39	RT
			21+50.00	17.30	RT
			21+75.00	17.17	RT
			22+00.00	16.94	RT
			22+25.00	16.78	RT
					RT



LIMITS OF REMOVAL

ITEM 1018-001 REMOVAL OF EXISTING BRIDGE

NOT TO SCALE

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL
T J CUNNINGHAM
ENGINEER
PE-054774-E

DISTRICT	COUNTY	ROUTE	SECTION	SHEET
3-0	COLUMBIA	42	005	25 OF 26
		4003	005	
		T-809	——	

HEMLOCK & MONTOUR TOWNSHIP, TOWN OF BLOOMSBURG

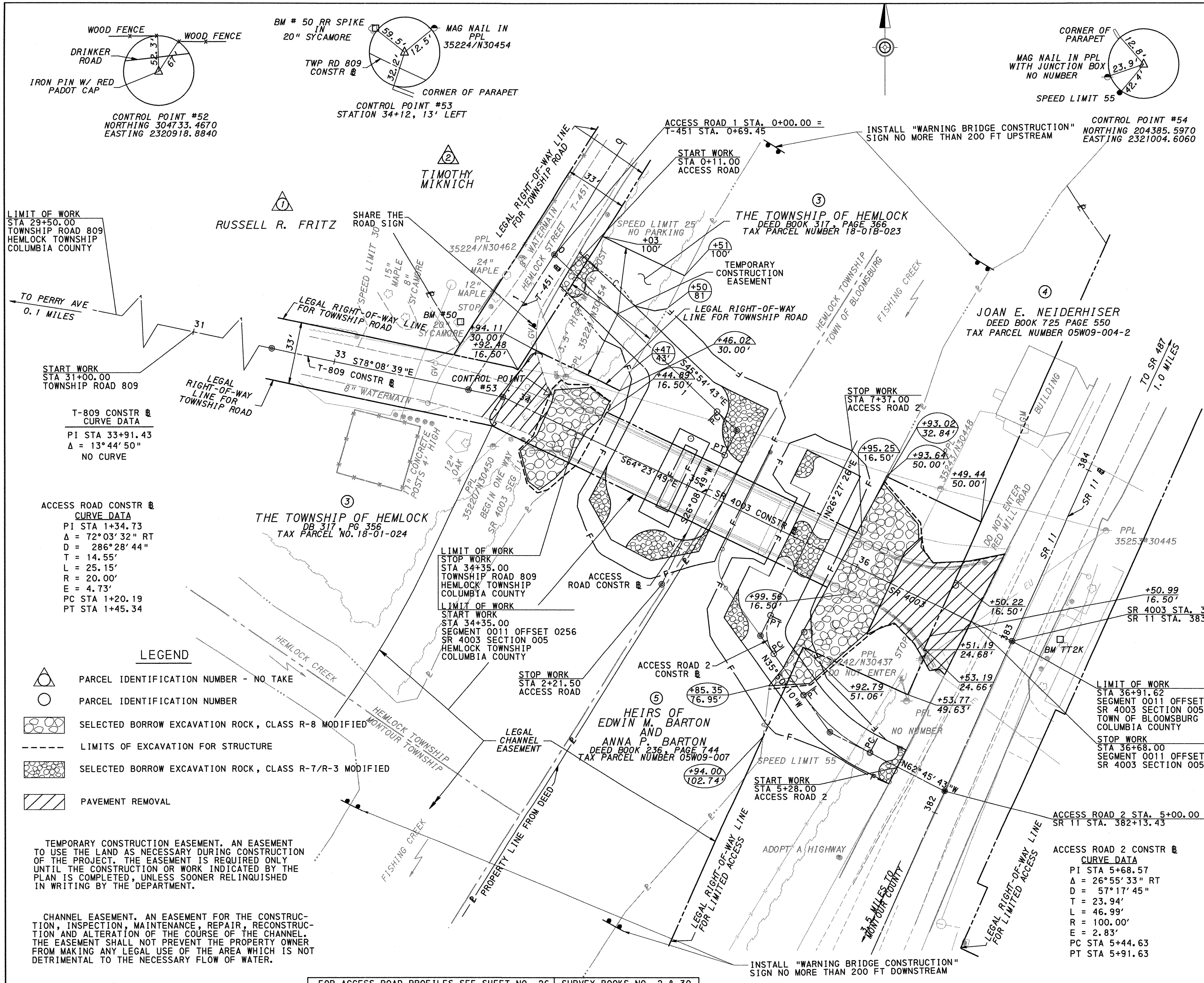
REVISION NUMBER	REVISIONS	DATE	BY

BM #50 ELEVATION 475.80
RAILROAD SPIKE IN 20" SYCAMORE TREE AT THE NORTHEAST CORNER OF RED MILL ROAD AND DRINKER ROAD

BM #51 ELEVATION 473.25
SQUARE CUT ON THE NORTHWEST WINGWALL OF BRIDGE ON PERRY AVE AT THE INTERSECTION WITH RED MILL RD

BM #52 ELEVATION 484.71
RAILROAD SPIKE IN 24" STUMP WEST SIDE OF SR 42 SOUTH OF PERRY AVE

BM TT 2 K USGS ELEVATION 478.03
BRASS DISK IN A 4" X 4" CONCRETE POST AT STATION 383+12, 23' RT OF SR 11 ℄



LEGEND

- △ PARCEL IDENTIFICATION NUMBER - NO TAKE
- ○ PARCEL IDENTIFICATION NUMBER
- SELECTED BORROW EXCAVATION ROCK, CLASS R-8 MODIFIED
- - - - - LIMITS OF EXCAVATION FOR STRUCTURE
- SELECTED BORROW EXCAVATION ROCK, CLASS R-7/R-3 MODIFIED
- PAVEMENT REMOVAL

TEMPORARY CONSTRUCTION EASEMENT. AN EASEMENT TO USE THE LAND AS NECESSARY DURING CONSTRUCTION OF THE PROJECT. THE EASEMENT IS REQUIRED ONLY UNTIL THE CONSTRUCTION OR WORK INDICATED BY THE PLAN IS COMPLETED, UNLESS SOONER RELINQUISHED IN WRITING BY THE DEPARTMENT.

CHANNEL EASEMENT. AN EASEMENT FOR THE CONSTRUCTION, INSPECTION, MAINTENANCE, REPAIR, RECONSTRUCTION AND ALTERATION OF THE COURSE OF THE CHANNEL. THE EASEMENT SHALL NOT PREVENT THE PROPERTY OWNER FROM MAKING ANY LEGAL USE OF THE AREA WHICH IS NOT DETRIMENTAL TO THE NECESSARY FLOW OF WATER.

ACCESS ROAD 2 CONSTR ℄ CURVE DATA
PI STA 5+68.57
Δ = 26°55'33" RT
D = 57°17'45"
T = 23.94'
L = 46.99'
R = 100.00'
E = 2.83'
PC STA 5+44.63
PT STA 5+91.63

ACCESS ROAD 2 CONSTR ℄ CURVE DATA
PI STA 6+30.60
Δ = 62°17'37" RT
D = 286°28'44"
T = 12.09'
L = 21.74'
R = 20.00'
E = 3.37'
PC STA 6+18.51
PT STA 6+40.25

COMMONWEALTH OF PENNSYLVANIA
REGISTERED PROFESSIONAL ENGINEER
T J CUNNINGHAM
PE-034774-E

FOR ACCESS ROAD PROFILES SEE SHEET NO. 26 | SURVEY BOOKS NO. 2 & 30

PLOTTED:20-JUL-2011 09:32
D-9012 CADD (02-90) REVISED (10-04)
OPERATOR:
FILE NAME: G:\ds4\Columbia\19-4003-005\19-4003-005.con

Appendix E

JOINT AGENCY MEETING MINUTES & PRESENTATION

BORTON LAWSON

Making Our Client's Vision a Reality

Lehigh Valley
Pittsburgh
Wilkes-Barre

Wilkes-Barre
613 Baltimore Drive
Suite 300
Wilkes-Barre, PA 18702

P: 570.821.1999
F: 570.821.1990

borton-lawson.com

MEETING MINUTES

RE: AGENCY REVIEW MEETING
Columbia County, PA - West End Flood Mitigation Study
Study Sponsor: Columbia County
Study Administrator: SEDA-Council of Governments
Study Consultant: Borton Lawson

DATE OF MEETING: October 24, 2022- 11:00 a.m.

DATE ISSUED: November 8, 2022

ATTENDEES:	**TITLE:**	**ORGANIZATION:**
Eric Stahley	Resiliency Officer	Columbia County
Geralee Zeigler	Flood Resiliency Program Analyst	SEDA-Council of Governments (SEDA-COG)
Teri Provost	Chief of Community Services Division	SEDA-Council of Governments (SEDA-COG)
Samantha Albert	Project Manager	Borton Lawson (BL)
Tom Lawson	Senior Engineer	Borton Lawson (BL)
Clint Sorber	Project Engineer	Borton Lawson (BL)
Chris McCue	Vice President	Borton Lawson (BL)
Curtis Barrick	Permit Chief North Central Office – Waterways and Wetlands	PADEP
Pete Geanacopoulos	Project Manager - Waterways Engineering and Wetlands	PADEP
Marion Gall	Project Manager-Biologist	USACE Baltimore District
Ben Kaiser	FEMA Compass Consultant	AECOM
Sarah Wolfe	Branch Chief for Floodplain Insurance	FEMA Region 3

Meeting Notes:

1. Samantha Albert of Borton Lawson (BL) opened the meeting by explaining the purpose of the meeting, and provided a high-level overview of the study including:

   a. Project background, study area, study purpose, BL's role, and the community's preferred flood mitigation alternative to construct a levee/floodwall system in the Town of Bloomsburg to reduce flood risk for approximately 350 structures.
   b. Completion of additional two-dimensional (2D) hydraulic modeling of Fishing Creek by BL to evaluate induced flooding with a proposed levee and mitigation alternatives to eliminate induced flooding. HEC-RAS 2D software was utilized for the modeling.
   c. The reason for completing additional 2D modeling was due to complexities of the project which include a levee system proposed to be located entirely within a regulated floodway, the extent of existing floodway that would be impacted by the proposed levee, the extent of the existing floodway that is located outside of Fishing Creek's banks in a developed area, and the requirement for a map revision of the floodplains/floodway.
   e. Columbia County/BL/SEDA-COG wanted to review the proposed project and mitigation alternatives with the agencies to obtain feedback on the 2D hydraulic modeling

approach, preliminary modeling results, and ultimately the requirements to allow successful agency permitting and map revision for the proposed project.

2. BL reviewed presentation slides prepared for the call (PDF of PowerPoint presentation attached to these meeting minutes) which included the following key points:

    a. Review of project limits - there are approximately 500 parcels and 350 structures that are included in the study area. A considerable extent of the floodway is located outside of Fishing Creek's banks.
    b. Project area has a history of flooding, including the 2011 Tropical Storm Lee event which is the record high flood event. Four (4) of the last five (5) flood events on Fishing Creek were concurrent with high water events of the Susquehanna River.
    c. Past flooding of Fishing Creek has resulted in very destructive velocities along State Route 11 in Bloomsburg; mitigation recommendations for this next phase of work (i.e., construction of proposed levee system in West End of Bloomsburg) addresses these areas.
    d. The final study phase version of the 2D hydraulic model of Fishing Creek includes the proposed levee/floodwall system with two primary proposed mitigation measures: (#1) benched floodplain on the Hemlock Township side of Fishing Creek and (#2) relief culverts under State Route 11 on the Bloomsburg side of the creek. The proposed solution mitigates most of the induced flooding from the proposed levee apart from a limited area of induced flooding of approximately 4-inches (relative to the BL modeled Existing Conditions BFE) impacting 2 structures.
    e. BL and Columbia County initially met with PADEP and FEMA, via separate meetings, on May 31, 2022, to review the proposed project and the approach to be taken using a full 2D model for further evaluation.
    f. Clint Sorber of BL explained the 2D hydraulic model calibration approach, existing conditions model development, and general comparison of BL's 2D model of existing conditions results versus the 1978 FEMA Effective Model of Fishing Creek. The updated 2D hydraulic model prepared by BL for existing conditions shows a BFE higher by 1 to 2 feet than the Effective model (developed in 1978)
    g. Tom Lawson of BL also explained the preliminary proposed alternatives that were evaluated are based on hydraulic modeling efforts to date, and additional modeling would be completed during the preliminary design phase of the project to refine the proposed levee alignment as well as the mitigation alternatives to potentially eliminate induced flooding entirely.

3. BL reviewed questions at the end of the presentation. The following was discussed:

    a. BL's 2D model of Fishing Creek for <u>existing conditions</u>, shows a BFE 1 to 2 feet higher than the FIRM for Fishing Creek. After discussion, Ben Kaiser (Compass FEMA) indicated if the review agency agreed with the 2D Modeling results, the resultant 2D BFE findings can be used as the basis for mitigation review and design.

    b. If the proposed project has zero (0 ft) increase in the floodplain, but not in the stream channel, is mitigation needed? Ben Kaiser indicated if induced flooding remains in the channel/floodplain areas, but induced flooding is mitigated around structures, those structures are not impacted. A certification of no impacts to structures will be required, or if there are impacts the project needs to identify which structures will be impacted and how mitigation will be achieved for these structures.

    c. If induced flooding on Fishing Creek is below the regulatory BFE in the area where BFE is determined by Susquehanna River backwater, is mitigation required? Ben Kaiser explained that BL will need to evaluate the increases in the floodway as well as floodplain, independent of backwater impacts. Ben explained it would not be considered an increase if the floodway elevation is not increasing; the focus/concern is impacted structures. ***Post Meeting Note: BL requested additional clarification on this question from Ben Kaiser/Compass FEMA.***

d. Is mitigation required if induced flooding is not eliminated but the lowest finished floor elevation of a structure is above the BFE? Sarah Wolfe of FEMA indicated that you need to consider if there is a basement in the structure; if the lowest finished floor elevation is above the new BFE, the existence of basements must be considered as they become the lowest floor. Additionally, you would need to ensure these structures are compliant as an elevated structure (e.g., flood vents in enclosed walls). Previously elevated, compliant structures may continue to meet all federal, state, and local requirements regardless of induced flooding. Whether such structures would be considered impacted is not a determination that FEMA would make. Coordination with PADEP and the local municipalities will be critical in this evaluation and determination. Curtis Barrick with PADEP indicated he would need to review with PADEP Harrisburg Central Office. He also mentioned if you are increasing flood elevations above existing BFE but are still compliant, you still may need a flood easement from the property owner.

e. The group discussed agency permitting strategy and special considerations related to agency approvals for the proposed project.

   FEMA CLOMR/LOMR – Ben Kaiser indicated one (1) CLOMR can be submitted for the entire project including the proposed levee and the proposed induced flooding mitigation alternatives. He acknowledged there could be some risk proceeding with design of the project without a LOMR in place for the updated Existing Conditions BFE; however, the likelihood would be that any differences identified would be minimal with agency review of the hydraulic model.

   PADEP CH 105 WOEP - Curtis Barrick explained PADEP would want the FEMA map revision addressed prior to the WOEP being issued. A Floodplain consistency letter from each community will be required as part of the permit application submission, which would consider and address impacts to structures and mitigation activities.

   USACE 404 Authorization/ Impacts to Waterways & Wetlands - Marion Gall inquired about impacts to wetlands with the proposed project. BL responded that impacts below the ordinary high-water mark would exist due to the requirement for armoring of the levee slope on the stream side of levee. BL identified an emergent wetland within the proposed footprint for the levee; however, BL will need to complete a wetland delineation during preliminary design to verify. If a wetland exists, BL believes impacts will be compensated by the presence of the benched floodplain. Marion advised that USACE has seen issues with developing wetlands as part of a constructed benched floodplain in streams due to potential for sediment deposition in these areas during high water events.

Recorded by:

Borton Lawson

Samantha Albert

Samantha Albert, PE, PMP
Project Manager

BORTON LAWSON
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WEST END FLOOD MITIGATION STUDY
COLUMBIA COUNTY

AGENCY MEETING
PADEP, USACE, FEMA
OCTOBER 24, 2022

BORTON LAWSON

Introductions

Background

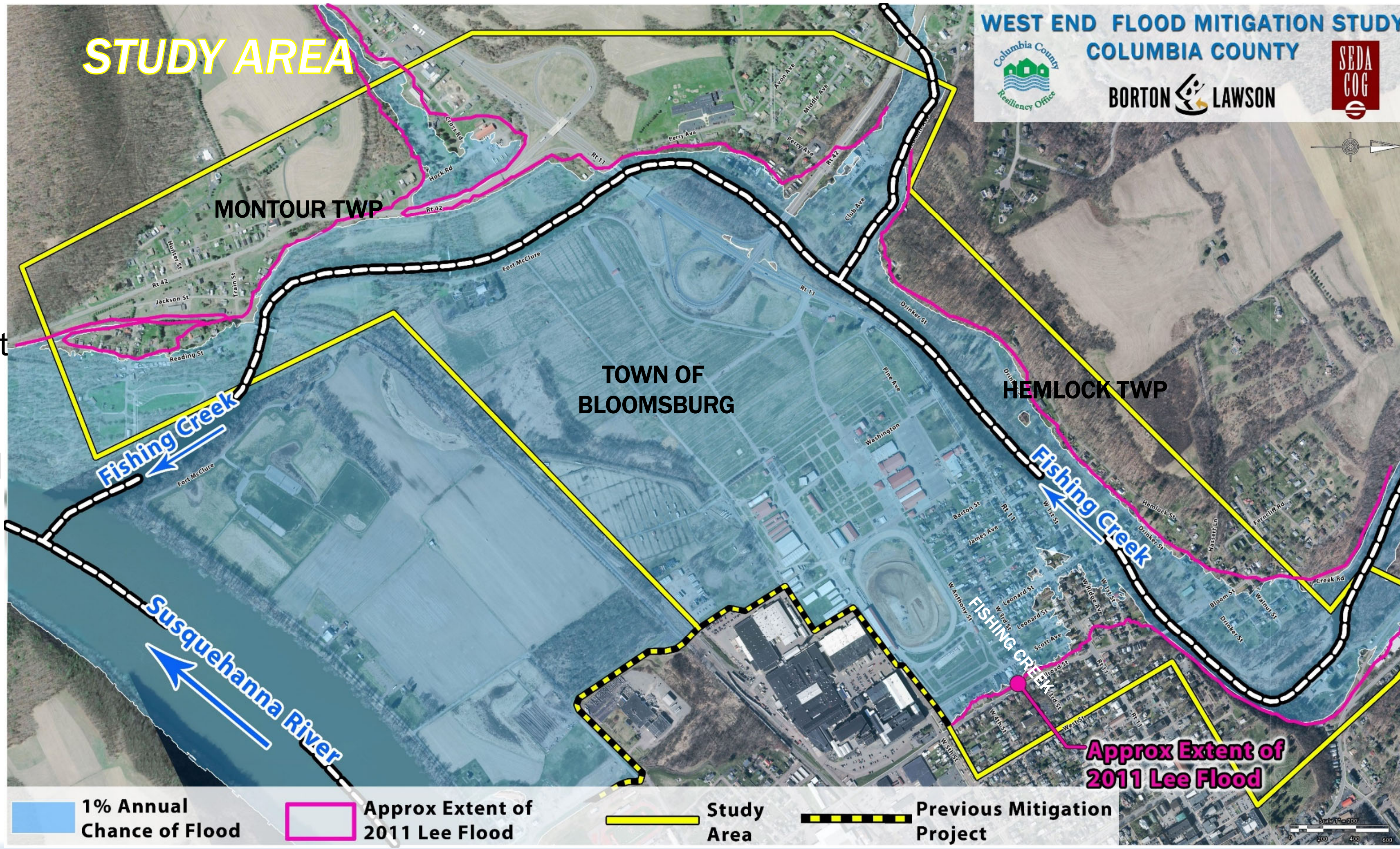
Columbia County sponsored flood mitigation study in April 2021 to identify best Structural and Non-Structural Flood Mitigation Alternatives for “West End of Bloomsburg”

West End Flood Study Area

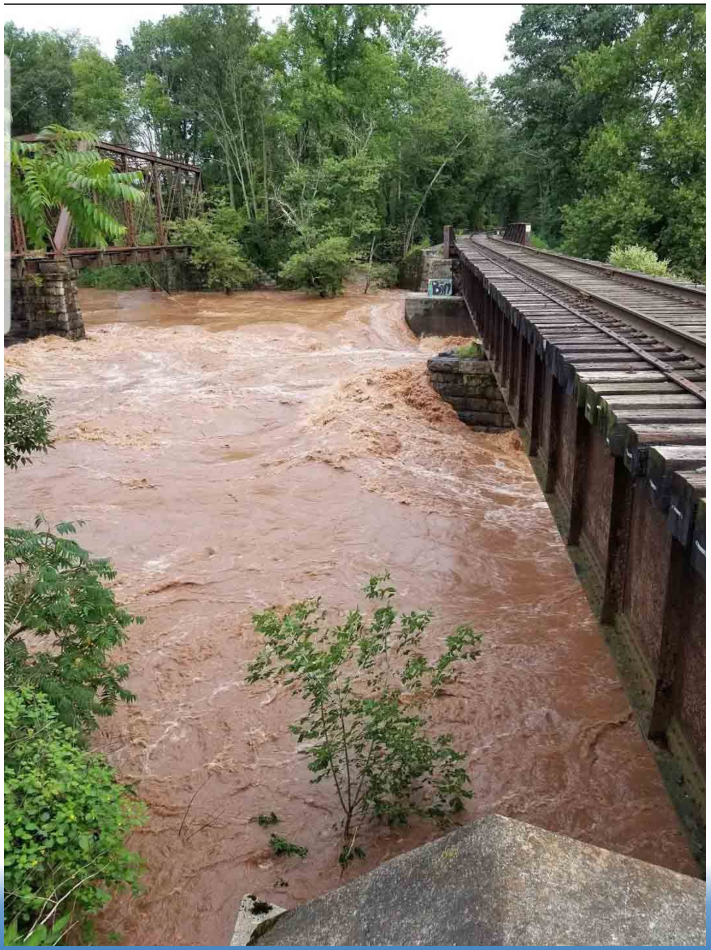
Floodplains of Fishing Creek in Town of Bloomsburg, Hemlock Twp & Montour Twp

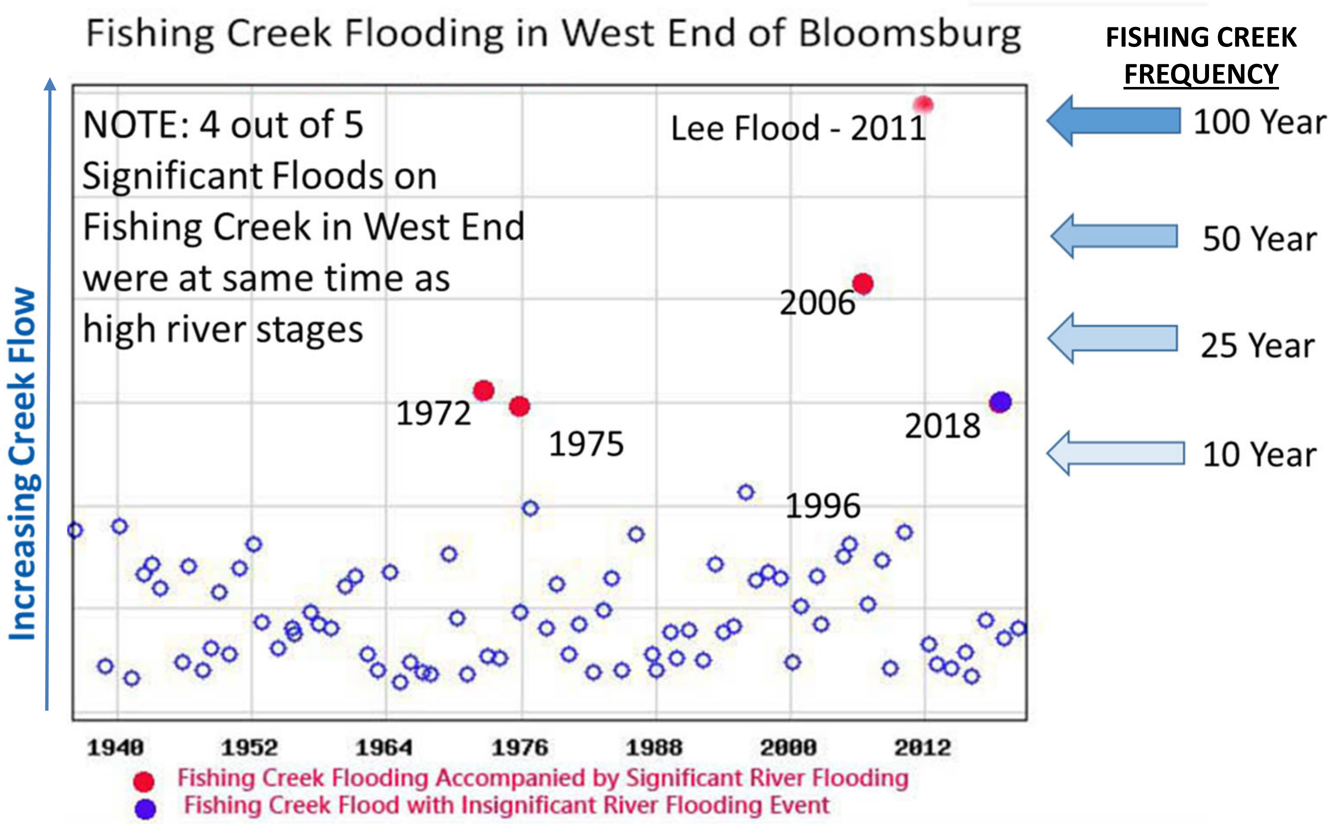
~500 parcels

~350 structures



History of Flooding



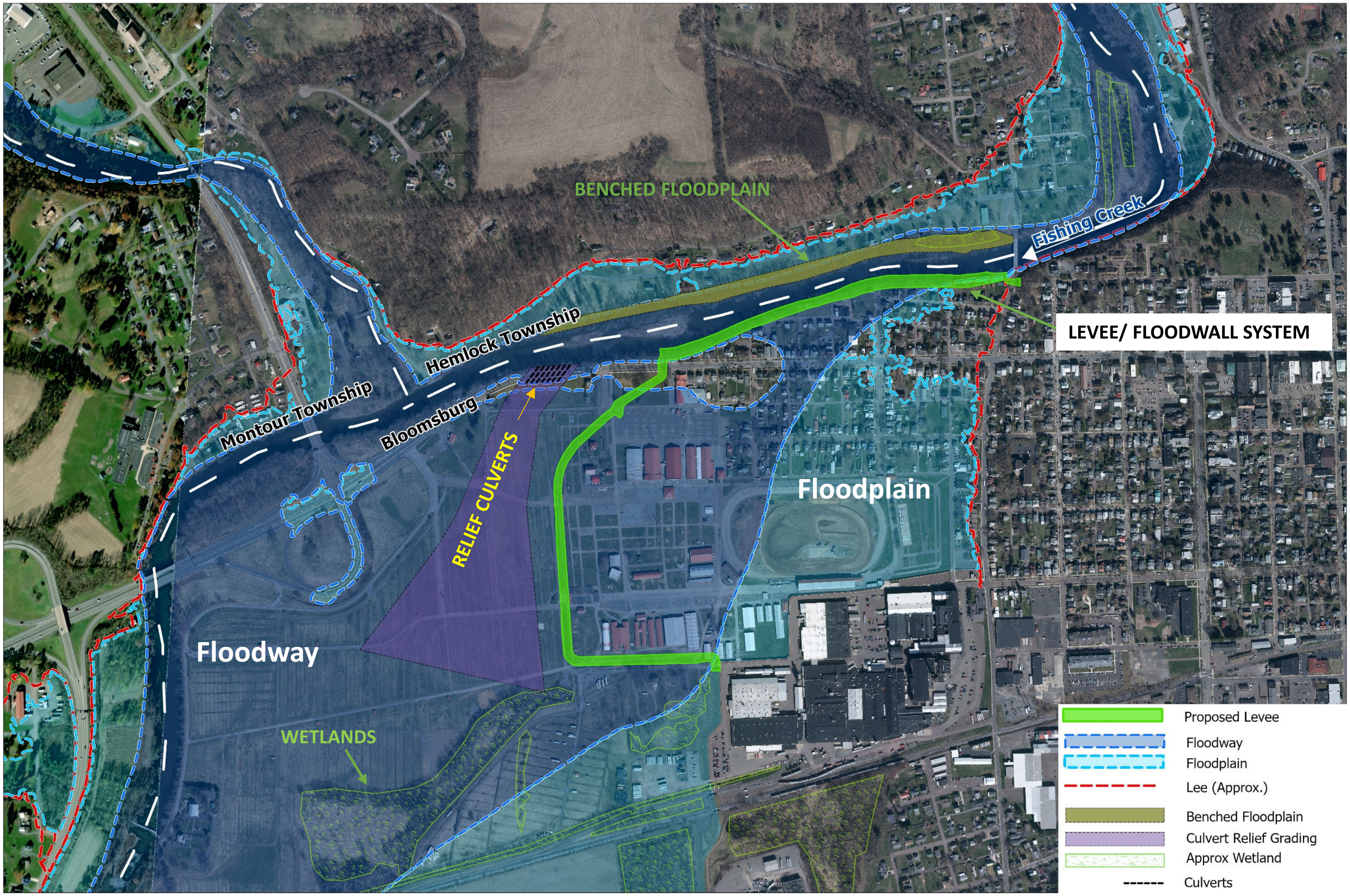


Study Outcomes

- Community Preference➔ construct a Levee/Floodwall System in Bloomsburg
- Due to complex and large extent of Floodway located outside of Fishing Creek's banks & proposed Levee/Floodwall System to be located entirely in regulated Floodway ➔ complete additional 2D Hydraulic Modeling of Fishing Creek with proposed Levee/Floodwall system to evaluate induced flooding, mitigation requirements, & agency permitting requirements

PROPOSED LEVEE SYSTEM & MITIGATION ALTERNATIVES

- Benched Floodplain
- Relief Culverts



FEMA & PADEP May 2022 Meetings

Separate meetings held on May 31, 2022

PADED Meeting

- Review of PA Title 25, Chapter 105, Subchapter F. Fills, Levees, Floodwalls and Streambank Retaining Devices, 105.271 General Design Criteria
- If there is an increase in flood heights, need to include flood easements or flood protection.
- Buyouts and/or elevating the homes could be used to satisfy these requirements.
- Any homeowners that hold out could prevent PADEP from granting approval.

FEMA Meeting

- Use of full 2D model (vs 1D/2D coupled model) is acceptable; follow FEMA 2D modeling guidance documents
- Duplicate Effective and Corrective Effective models not required with FEMA map revision using a 2D model
- Good practice to be within 0.5 Ft tie in to adjoining effective models
- Revised floodway delineation will be required for this project; Fishing Creek effective model is from Feb 1978 in HEC-2
- Increase in BFE requires mitigation

2D Model Set Up
HEC-RAS v. 6.2

- Generate Merged Terrain
  - PASDA Lidar
  - Aerial Topography from Thrasher
  - As-Built Surface from completed levee projects
  - Bathymetry of Fishing Creek
  - Channel Topography from FEMA XSs
  - Import/Extrude structures from county GIS data

Note: Lidar surfaces may carry error of 6”-12” in areas of tree cover. Accurate survey of top of stream bank along the modeled reach is necessary for refinement and verification of water surface elevations.

- Add model elements
  - Breaklines/Refinement Regions
  - Bridges/Culverts/Dams
  - Manning’s Roughness Values

- Develop Boundary Conditions
  - Select flows for Fishing Creek at Susquehanna River confluence using upstream gage data and agency reports
  - Determine coincident flow frequencies for Susquehanna River, Hemlock Creek, and Montour Run
  - Adjust Fishing Creek flow at upper boundary condition to account for coincident flows in tributaries downstream

- QA/QC

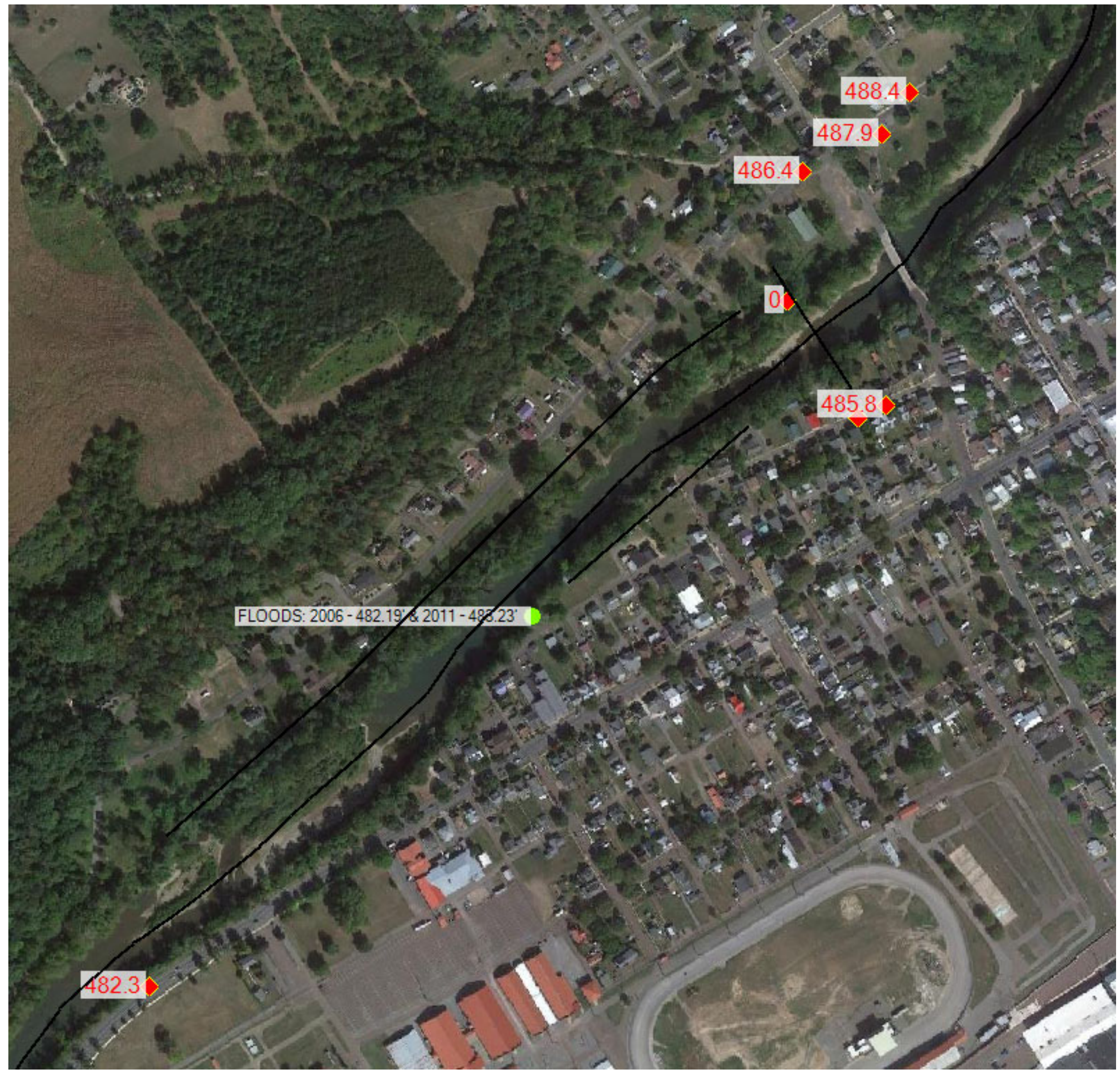
Calibration Modeling
Tropical Storm Lee – 2011 (Record Flood)

- Modify Terrain to reflect historical 2011 conditions.
  (i.e. add demolished homes, remove current levees)

- Add Red Mill Road Bridge to model – Bridge removed in 2014

- Target USGS High Water Marks established after Tropical Storm Lee – 2011 by adjusting the below parameters:
  - Manning's roughness coefficients
  - Fishing Creek vs. coincident tributary flows
  - Bridge modeling methods (Energy vs. Pressure)

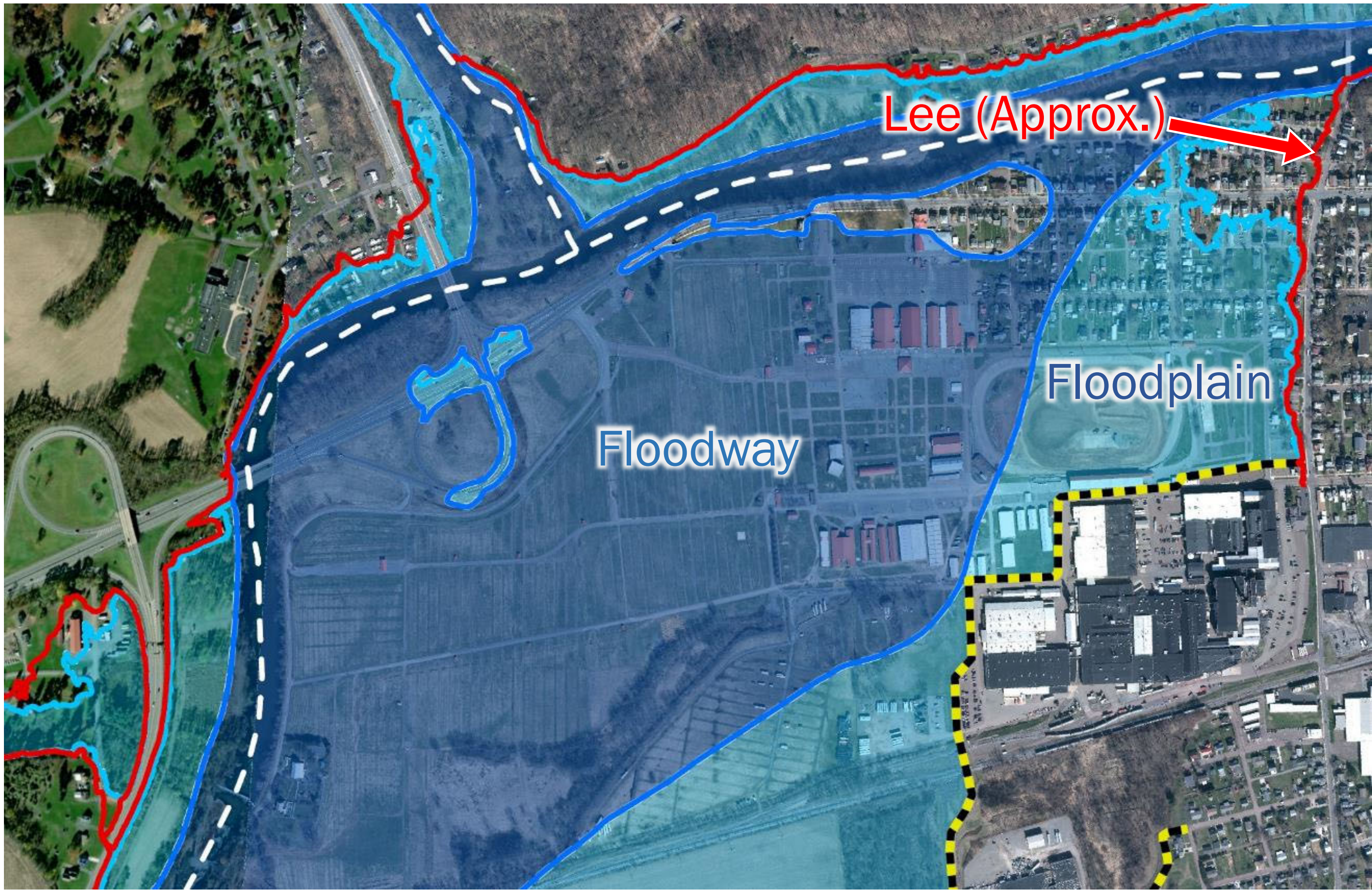
5 out of 7 calculated water surface elevations are within 0.5 feet of the recorded highwater marks.



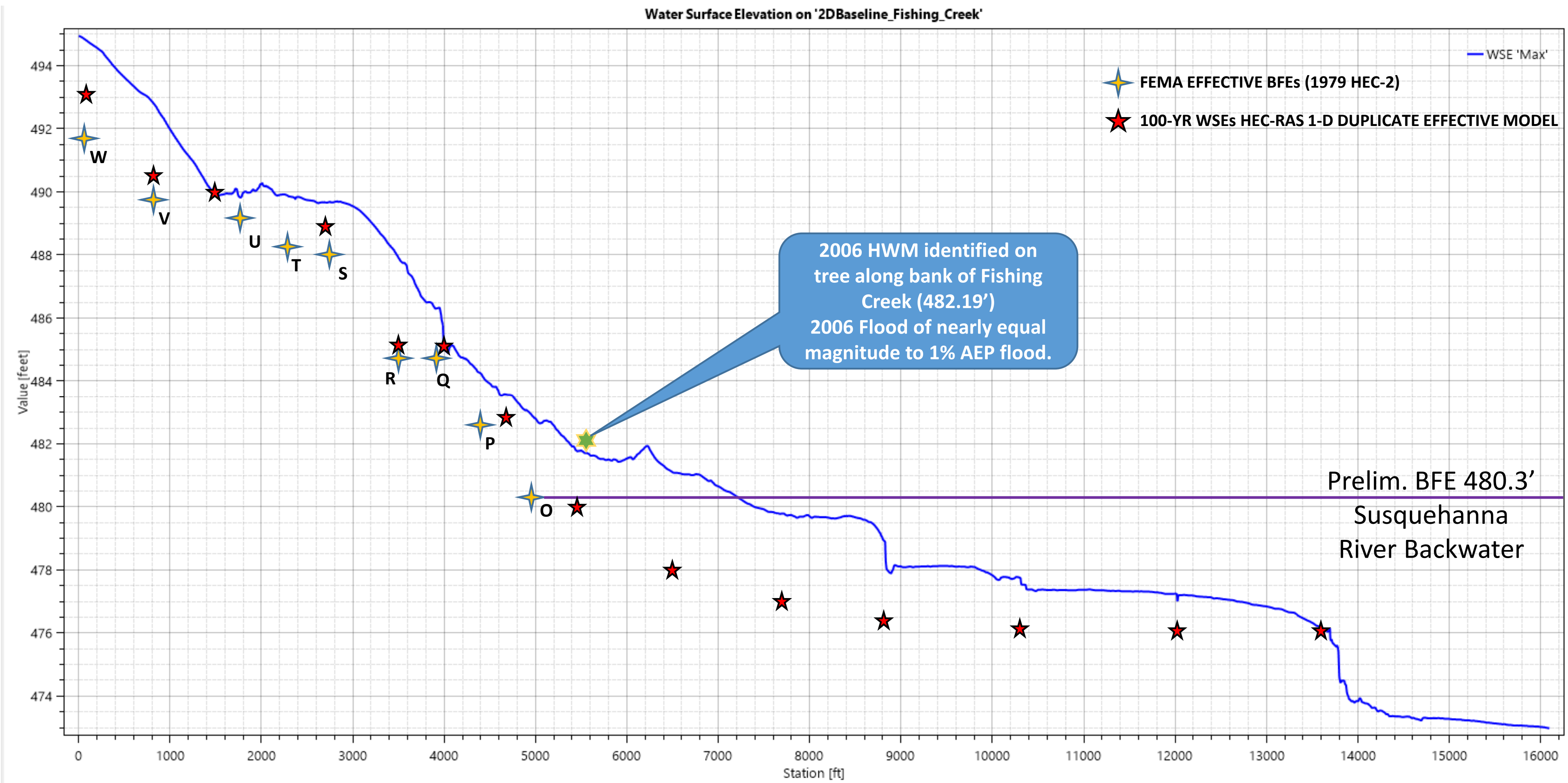
Existing Conditions Modeling
Base Flood <u>without</u> Levee System

<u>Existing Conditions</u>

- Copy model parameters from calibration model to existing conditions model.
- Adjust flows from 2011 record flood to base flood (1% Annual Exceedance Probability) magnitude.
- Modify terrain to reflect present day conditions including constructed levee systems and property acquisitions/demolitions since 2011.

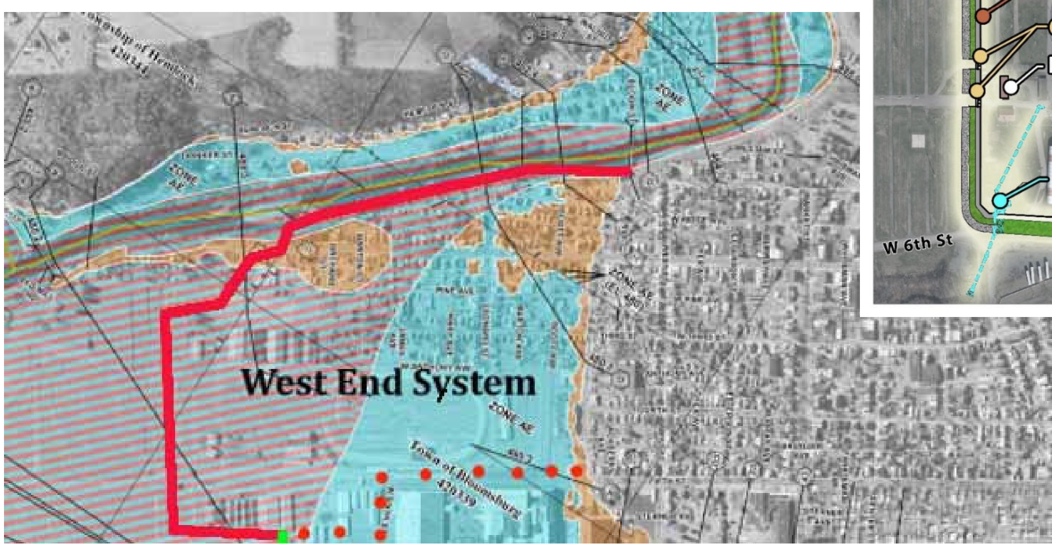


FEMA Effective (HEC-2) vs. BL Existing Conditions (HEC-RAS 2D) Profiles



Proposed Conditions Modeling
Base Flood with Levee System

- 6,200 LF Levee System
- Earthen, MSE, and Sheet Pile segments.
- Mitigates flooding risk from both Fishing Creek and Susquehanna River flooding.
- **Total of ~350** Residential and Commercial structures behind proposed levee system.

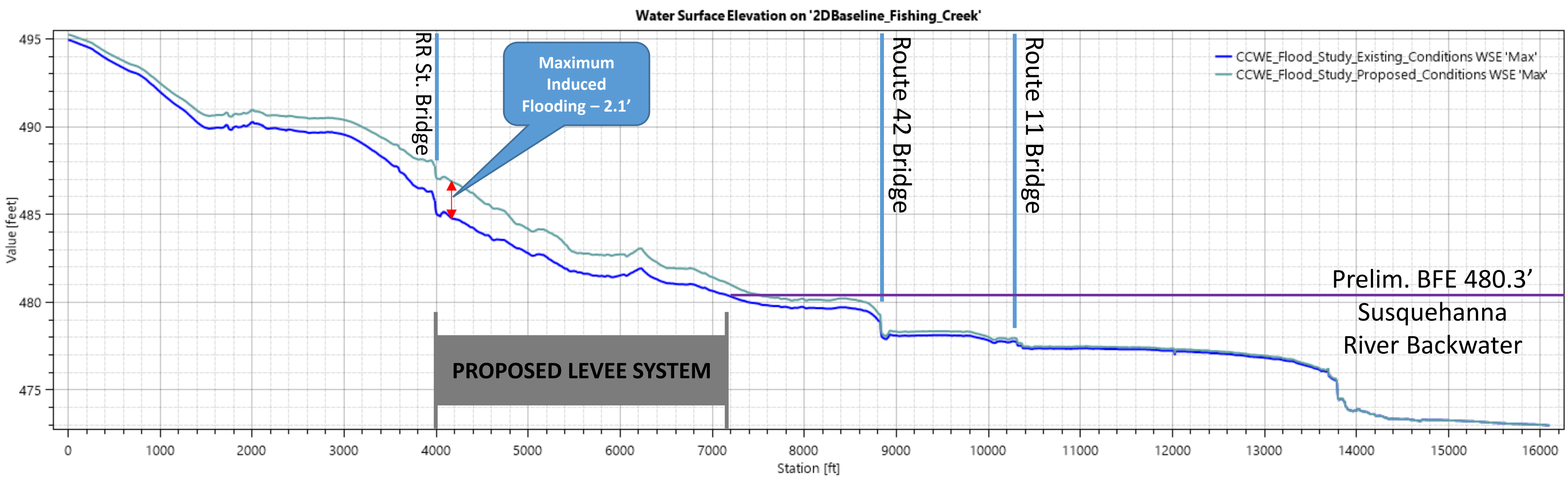


Induced Flooding

- Proposed Levee System entirely within regulated floodway.

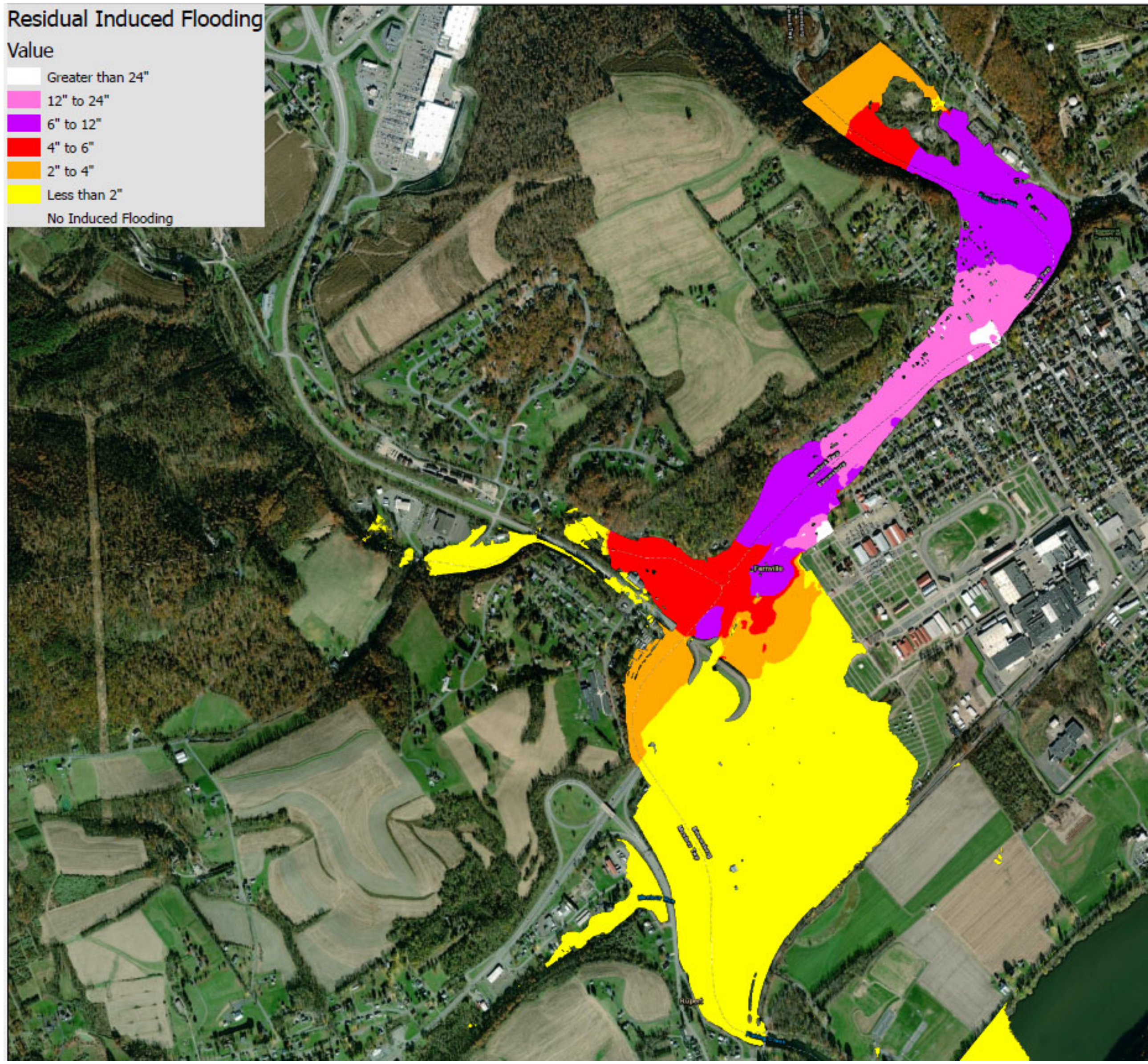
- No-Rise certification required OR demonstrate mitigation of impacts to structures.

- Flood easements or zoning restrictions where induced flooding does not impact structures.



Induced Flooding

With Proposed Levee Without Mitigation



MODELED MITIGATION ALTERNATIVES

- **Alternative 1 -** Multiple variations of benched floodplain extending upstream and downstream of Railroad Street and additional span on the Railroad Street Bridge.

- **Alternative 2 -** Variations of the proposed levee alignment to minimize floodway encroachment.

- **Alternative 3 -** Introduce Relief Culverts and Floodplain Reconnection immediately downstream of proposed levee.

- **Alternative 4 -** Combination of Alternatives 1, 2, & 3.

- **Alternative 5 -** Variations of additional spans and flood benches at Route 42 Bridge.

- **Alternative 6 -** Combination of Alternatives 1, 2, & 3 *(Similar to Alternative 4 except with alterations to relief culvert floodplain reconnection under SR 11 and elimination of Railroad Street Bridge lengthening.)*

PREFERRED ALTERNATIVE

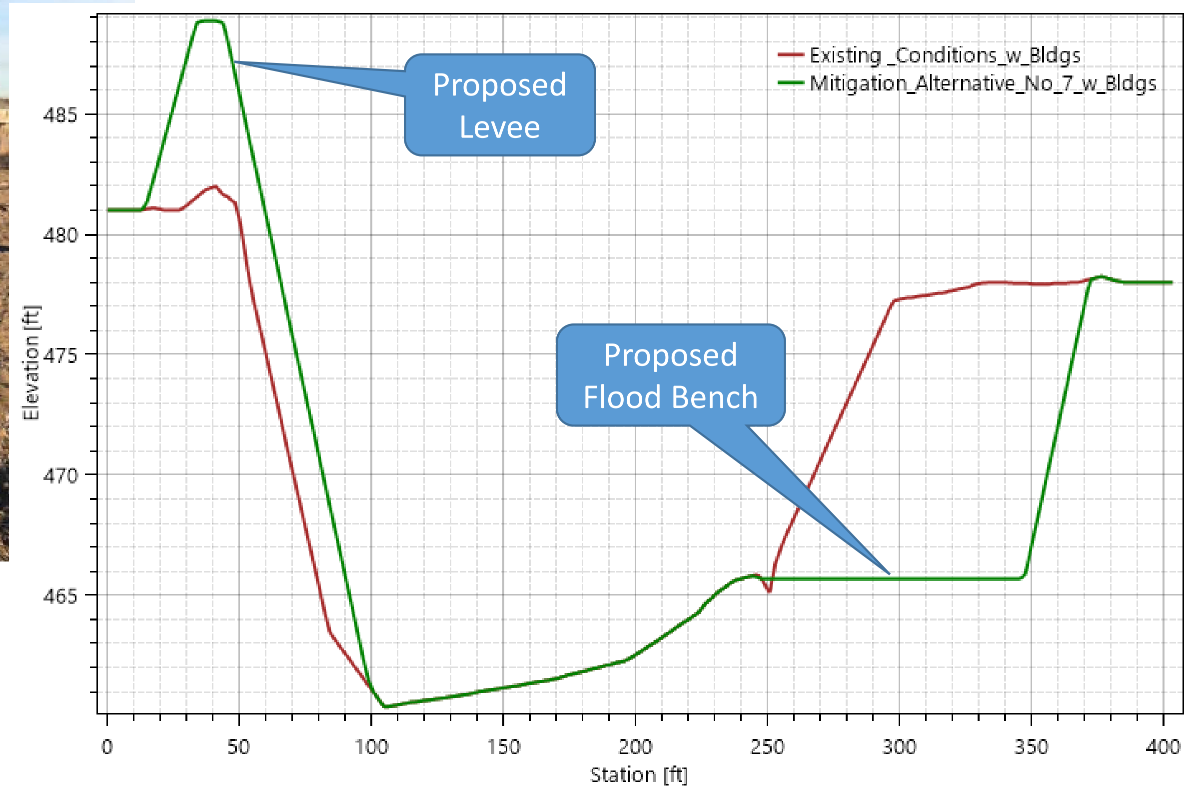
- **Alternative 7 – Similar to Alternative 6 except with additional modifications to the benched floodplain and proposed levee alignment.**

****Total of 16 alternatives modeled including revisions and combinations of those listed above.****

Alternative 7 - Mitigation Feature #1
Benched Floodplain

Typical Benched Floodplain

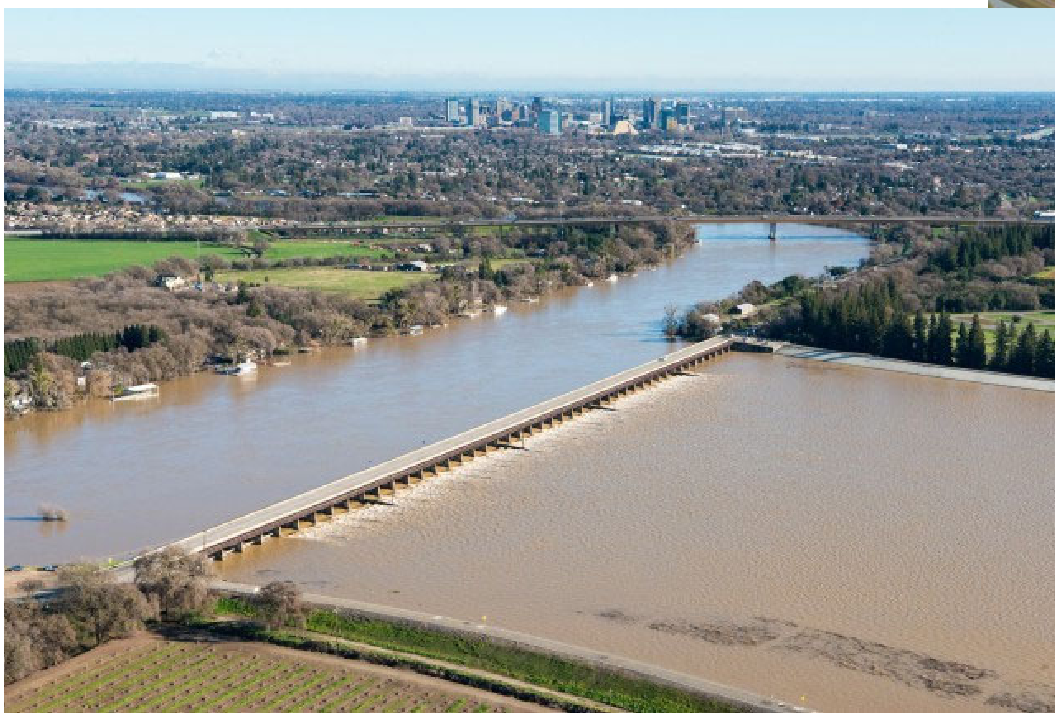
Existing vs. Proposed Cross Section



Alternative 7 - Mitigation Feature #2
Floodplain Connection/Relief Culverts

*Examples below of structures with similar type function.

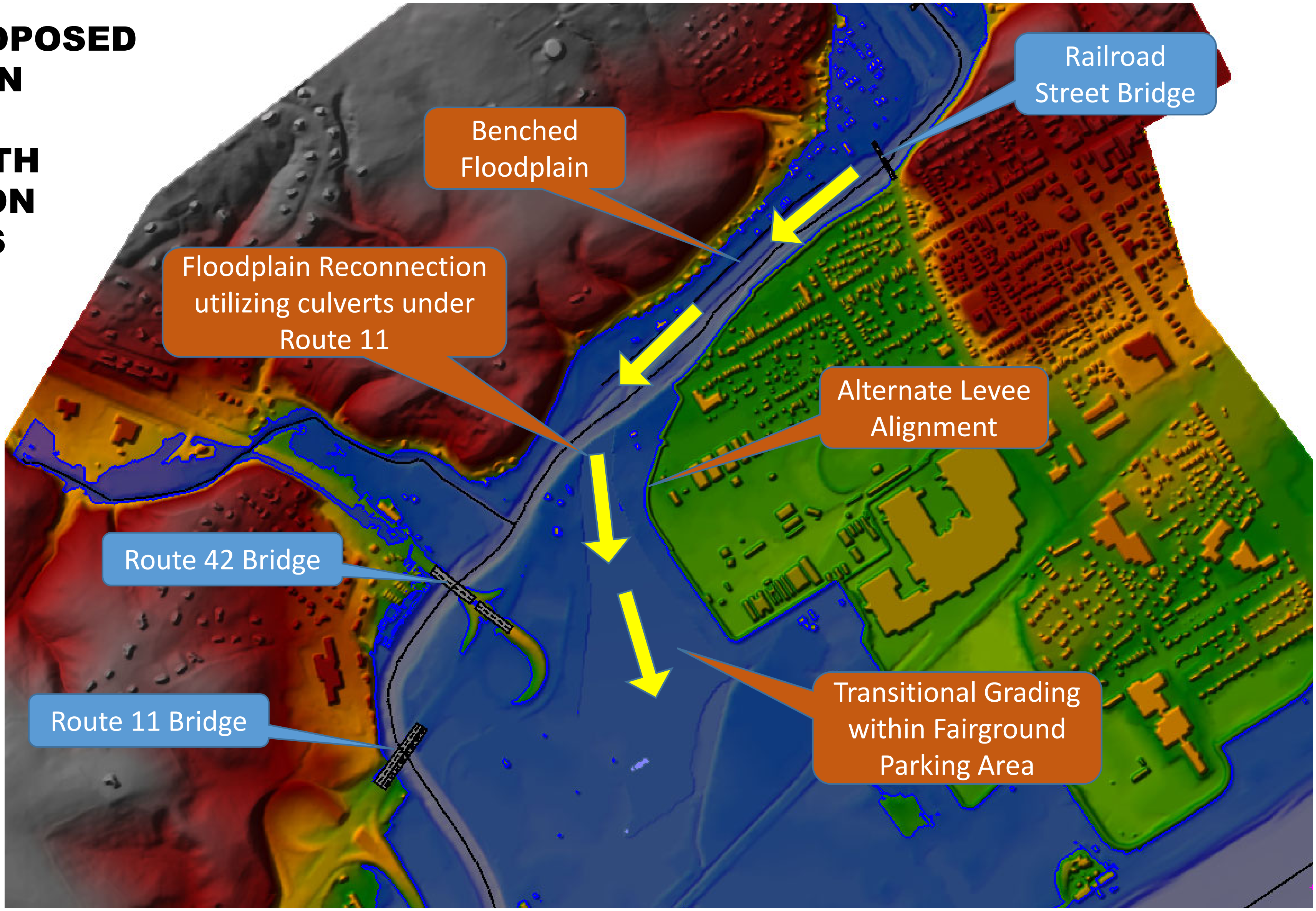
USACE – Mississippi Old River Control Structure
Louisiana

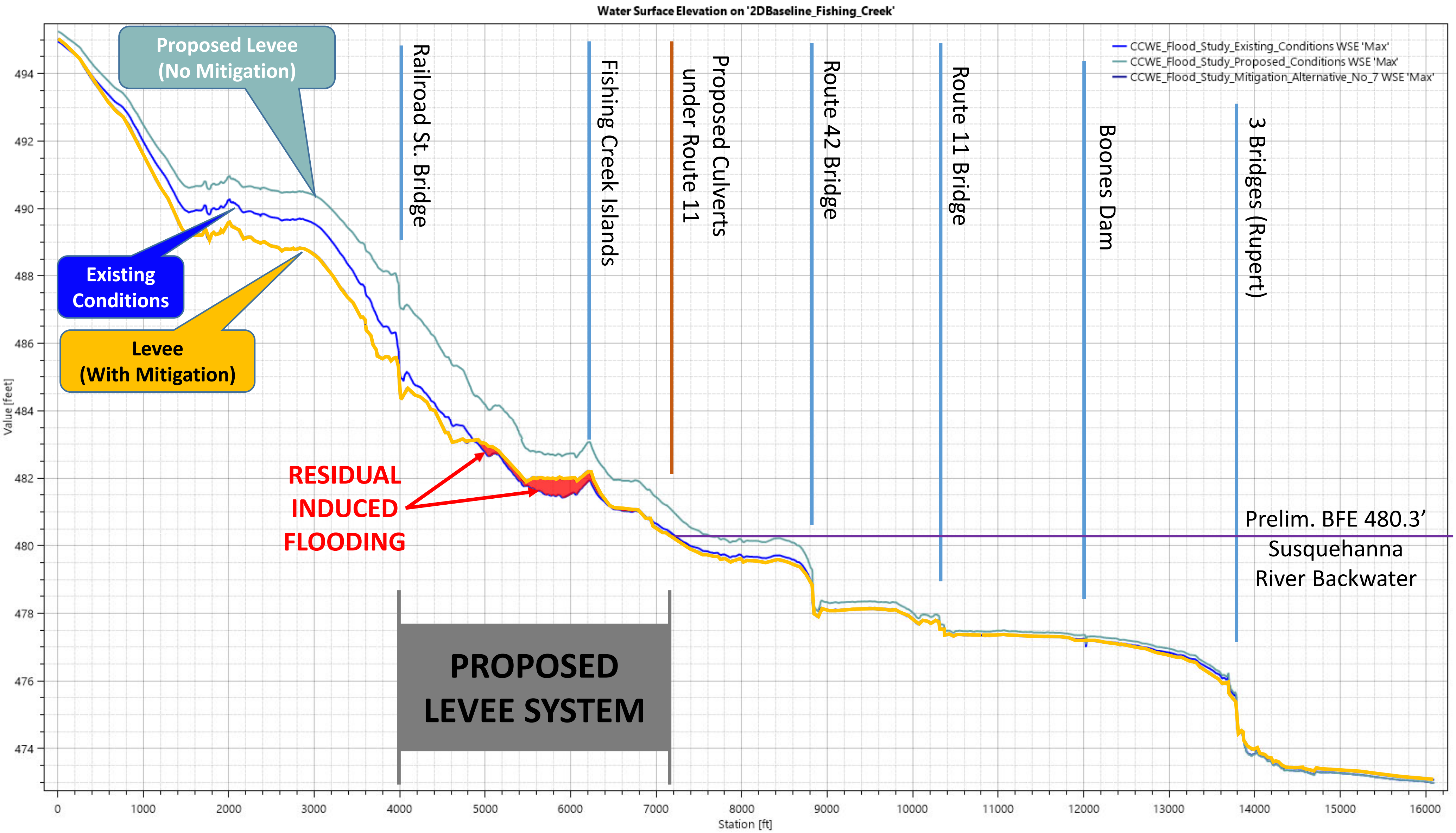


US Bureau of Reclamation – Yolo Bypass Habitat Restoration/Fish Passage Project
Sacramento, CA

FINAL PROPOSED CONDITION

LEVEE WITH MITIGATION FEATURES

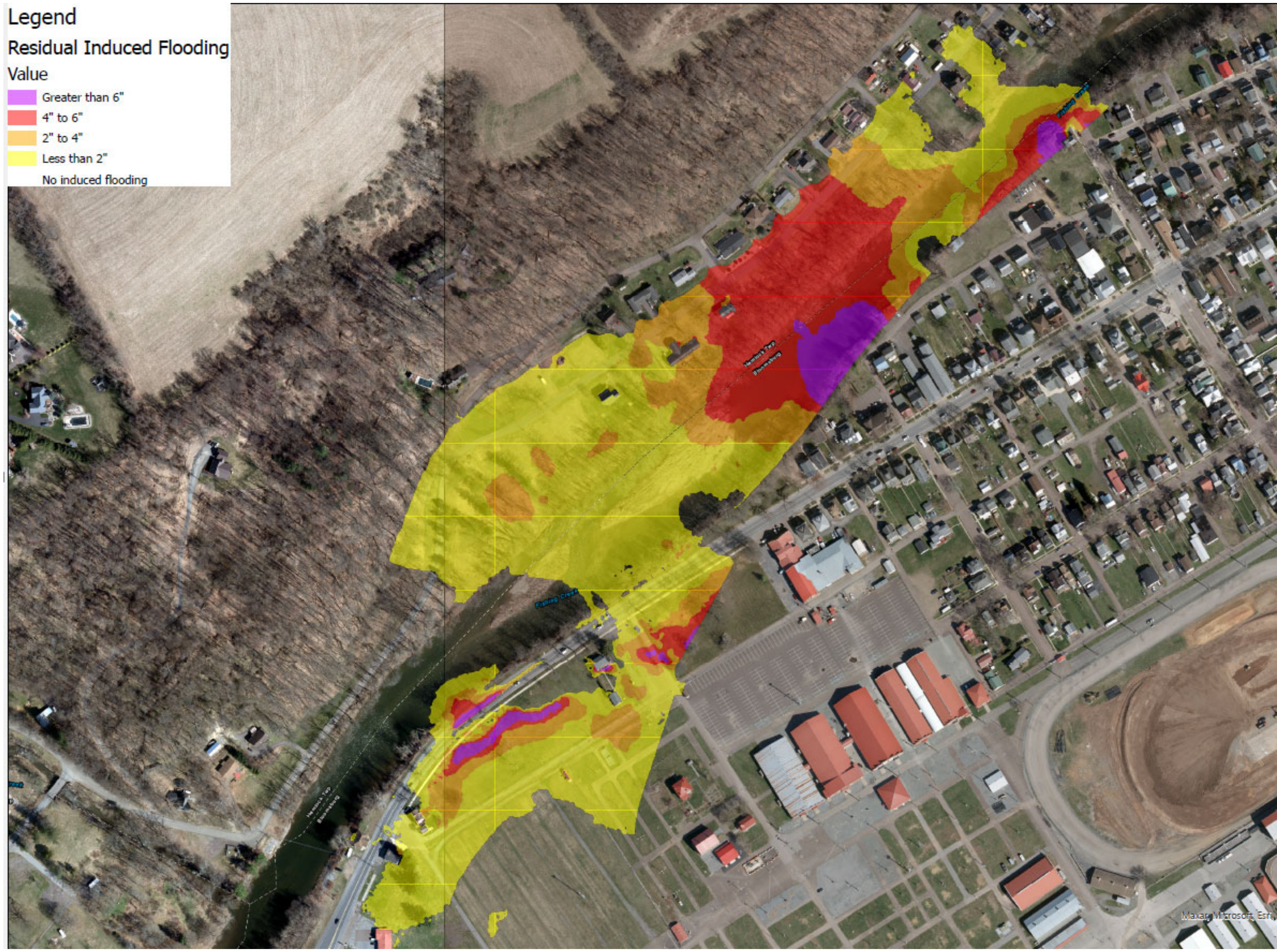



Water Surface Elevation on '2DBaseline_Fishing_Creek'
CCWE_Flood_Study_Existing_Conditions WSE 'Max'
CCWE_Flood_Study_Proposed_Conditions WSE 'Max'
CCWE_Flood_Study_Mitigation_Alternative_No_7 WSE 'Max'
Proposed Levee (No Mitigation)
Existing Conditions
Levee (With Mitigation)
Railroad St. Bridge
Fishing Creek Islands
Proposed Culverts under Route 11
Route 42 Bridge
Route 11 Bridge
Boones Dam
3 Bridges (Rupert)
RESIDUAL INDUCED FLOODING
Prelim. BFE 480.3'
Susquehanna River Backwater
PROPOSED LEVEE SYSTEM
Value [feet]
Station [ft]
494
492
490
488
486
484
482
480
478
476
474
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
14000
15000
16000

Residual Induced Flooding

Levee & Implementation of Mitigation Alternatives:

- **Benched Floodplain**
- **Relief Culverts**



STRUCTURES IMPACTED BY INDUCED FLOODING

Levee & Implementation of Mitigation Alternatives

- **Benched Floodplain**
- **Relief Culverts**

Proposed Levee

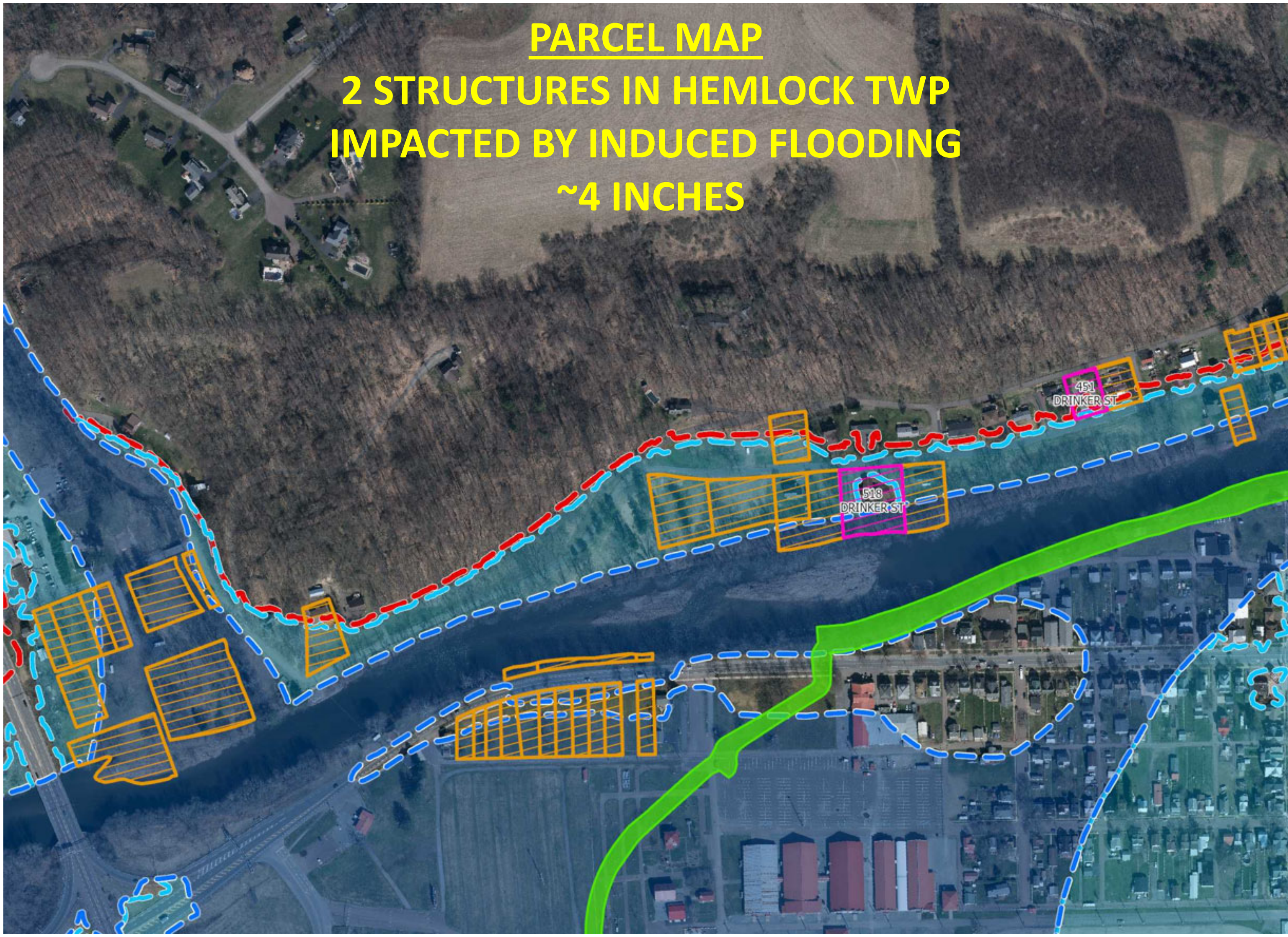
Buyout Parcels

Induced Flooding Parcels

Floodway

Floodplain

Lee (Approx.)



Meeting Summary

Summary/ Key Points & Questions

1. Borton Lawson developed an updated Existing Conditions 2D Hydraulic Model of Fishing Creek that has a **higher** BFE than Preliminary FIRM

2. Mitigation Requirements for Induced Flooding:
   a. Evaluated relative to the Borton Lawson updated 2D modeled BFE for Fishing Creek
   b. Condition where there is Zero (0 Ft) rise in floodplain, but not in channel, are structures in floodplain considered fully mitigated?
   c. If the induced flooding water surface on Fishing Creek is below the BFE on the preliminary FIRM in the areas where Susquehanna River backwater is higher than Fishing Creek flows, is mitigation required in these areas? The river backwater is shown on the FIRM, not the creek profile.
   d. Is mitigation required if induced flooding is not completely eliminated but lowest finished floor elevation of a structure is above the BFE by 1' or greater?

3. Clarification required on the PADEP CH 105 WOEP permit – 1 or 2 permits (Mitigation & Levee together, phased, or separate) and timing of permit(s) relative to FEMA CLOMR