Flood Inundation Maps for Swatara Creek, Dauphin County, PA

Provided in Partnership between the United States Army Corps of Engineers
and the
Susquehanna River Basin Commission

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Cover Photo: Monroe Valley Road, September 19, 2004, Swatara Creek at Harper Tavern – crest at 17.36' (courtesy of SRBC)

1 INTRODUCTION

1.1 BACKGROUND

Swatara Creek, located in Dauphin, Lebanon, and Schuylkill Counties, Pennsylvania, has a long history of flooding. Recorded flooding dates back to the early 1920s. More recently, Tropical Storm Agnes in June 1972 caused massive flooding throughout the region. Major flooding occurred in the winter of 1996 when a huge snow pack was quickly melted by heavy rain and warm temperatures, as well as in September 2004.

On September 4th through September 8th, 2011, the remnants of Tropical Storm Lee produced heavy rainfall in the Susquehanna River Basin, and is the flood of record for National Weather Service (NWS) forecast points on Swatara Creek. Rainfall totals exceeded 10-12 inches over a 48-hour period in some locations. Because portions of the Susquehanna River Basin were already saturated by Hurricane Irene rainfall a month earlier, the additional heavy rain associated with the remnants of Tropical Storm Lee produced widespread flash flooding and river flooding. Because of the extensive damages as a result of the flooding, the President declared a Federal Disaster (DR-4030-PA) in Pennsylvania, which affected over 30 counties in central and eastern parts of the state, including Dauphin, Lebanon, and Schuylkill Counties.

This project involves creating data for a non-structural flood hazard mitigation tool to inform the general public, local officials, and emergency managers of risk associated with the relative flood hazard. The tool is a set of three stage inundation map libraries for Swatara Creek based on three NWS flood forecast points. The flood forecast gages are located at Middletown, Hershey, and Harper Tavern. The stage inundation map libraries have been created for display on the NWS Advanced Hydrologic Prediction Service (AHPS) map viewer site. The project provides a graphical extension to river forecasts issued by NWS for Swatara Creek.

1.2 STUDY AREA

The study area includes 53 miles along the mainstem of Swatara Creek. The upstream limit of the inundation mapping is approximately 2.3 miles above the Schuylkill/Lebanon County line and the downstream limit is the confluence with the Susquehanna River at Middletown, PA. The inundation mapping spans all or parts of three counties (Dauphin, Lebanon, and Schuylkill Counties) and includes 18 municipalities. The inundation mapping is directly related to three U.S. Geological Survey (USGS) streamflow gages which are also NWS forecast points: USGS 01573000 Swatara Creek at Harper Tavern, USGS 01573560 Swatara Creek at Hershey, and USGS 01573600 Swatara Creek at Middletown (Figure 1.1).

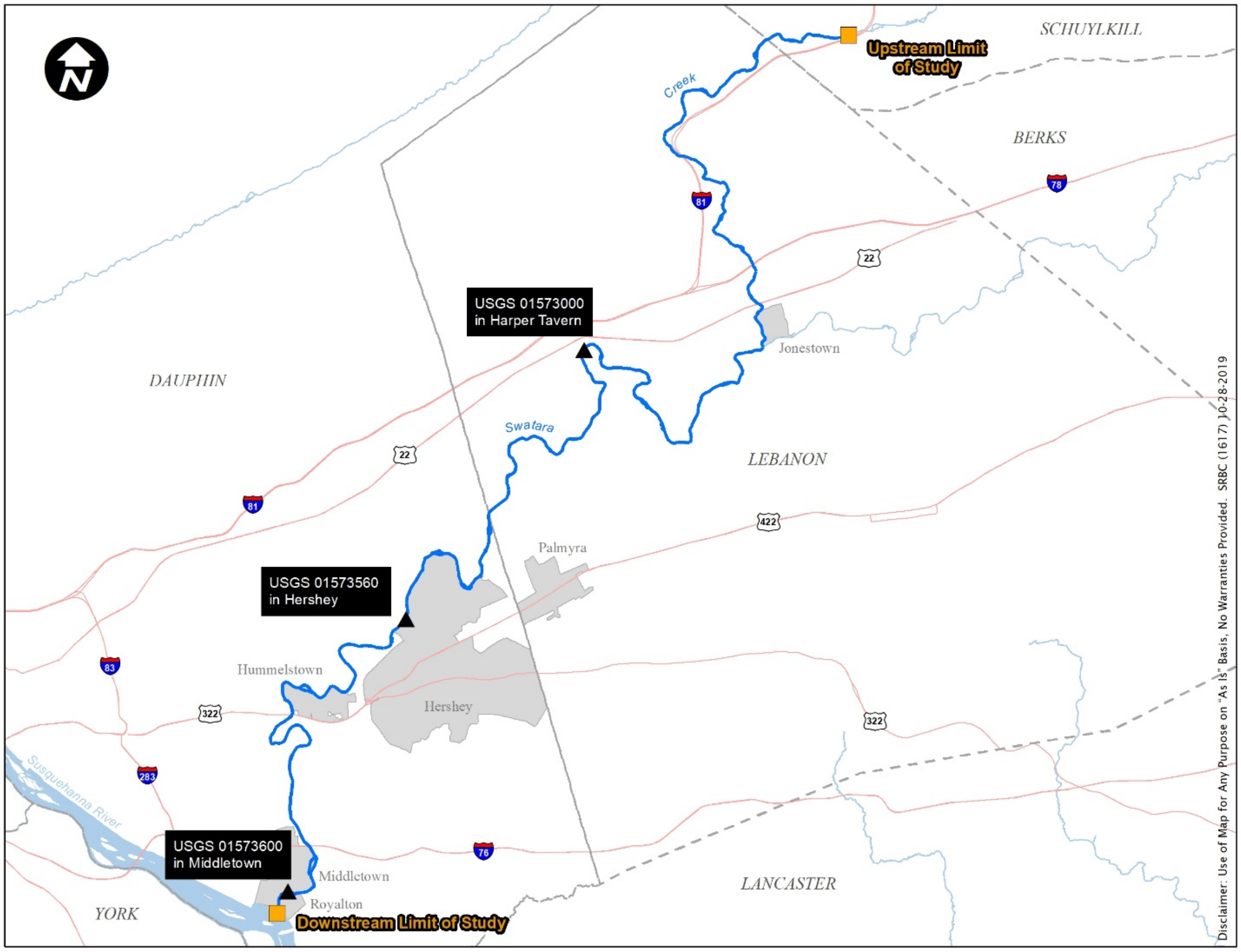

Figure 1.1. Study Area

1.3 LEVERAGED DATA

In response to the September 2011 flooding as a result of the remnants of Tropical Storm Lee, the Federal Emergency Management Agency (FEMA) funded U.S. Army Corps of Engineers (USACE)-Baltimore District under Interagency Agreement No. HSFE03-16-X-0200, to complete an updated hydrologic and hydraulic analysis for Swatara Creek to account for changes in the watershed and floodplain. The hydrologic changes included revised frequency flow estimates and the hydraulic changes included bridge replacement/relocation, floodplain development, and the collection of high water marks during the September 2011 flood. A hydraulic model was developed using the USACE HEC-RAS (version 5.0.3) program. This modeling, which will eventually be used by FEMA for identifying the Special Flood Hazard Area (SFHA) on their Digital Flood Insurance Rate Maps (DFIRMs), is outlined in the October 2017 report titled "*Swatara Creek Flood Study, Dauphin County, Lebanon County, and Schuylkill County, Pennsylvania.*" This report, in its entirety, is located in Appendix A.

2 INUNDATION MAPPING

The computation of water surface elevations to produce the inundation maps in this project were completed utilizing the FEMA HEC-RAS model discussed in Section 1.3. Because the FEMA HEC-RAS model was focused on computing water surface elevations for frequency flood events (i.e., 1 percent annual chance flood storm), modification to the flow file was completed to meet the objectives of the flood inundation mapping project. Modification to the flow file, as described below, was the only alteration made to the FEMA HEC-RAS model. There were no changes made to the geometry or hydraulic variables in the HEC-RAS model.

2.1 MODIFICATION TO HEC-RAS FLOW FILE

In order to create Flood Inundation Map (FIM) library layers that were separated in elevation by approximately 1-foot or less, the HEC-RAS flow file had to be augmented from its original eight (8) flow events to the final 37 flow events ranging from action stage to above the 0.2 percent annual chance event. To accomplish this, a rating curve for the Swatara Creek at Hershey was established for flows to 125% of the 500-year flood. The rating curve was correlated with the two upstream gages and the HEC-RAS model was used to extend rating curves for each of the gages. As the downstream gage at Middletown is stage only, discharge values for this gage were obtained directly from the calibrated HEC-RAS model. The corresponding stages and water surface elevations (WSELs) for all three of the gages in the study area is located in Appendix B; note that all FIM library layers may not be ultimately displayed on the NWS AHPS website.

When adding the additional flow events to the HEC-RAS model, it was noted that there are crossing profiles in some areas. These crossing profiles are minimal; only +/- 0.5 foot. Adjustments were made in the mapping to account for these differences.

2.2 INUNDATION MAPPING DEVELOPMENT

FIM library layers were created for the entire study area. The layers were created in a Geographic Information System (GIS) environment by combining the water-surface elevation profiles and digital elevation model (DEM) data for the study area. The following DEMs were used:

1. For Dauphin County, a 0.7-meter resolution DEM was provided by Dauphin County Information Technology for use in this project. This DEM was generated from QL2 LiDAR data flown in March 2016 by Quantum Spatial, Inc., for USGS under Contract G16PC00016.

2. For Lebanon and Schuylkill Counties, LiDAR was flown by Woolpert in 2008 in support of PAMAP. The LiDAR was downloaded from the Pennsylvania Spatial Data Access (PASDA) website (http://www.pasda.psu.edu) in 10,000' x 10,000' Bare Earth LAS and DEM (1-meter resolution) .tif format.

The 0.7-meter Dauphin County DEM (dated 2016) and the 1.0-meter PAMAP DEM (dated 2008) were merged into one 0.7-meter resolution DEM and then clipped to an appropriate buffer around Swatara Creek to create the project DEM which was used for the hydraulic modeling and inundation mapping.

Estimated flood-inundation boundaries for each simulated profile were developed with HEC–GeoRAS software. HEC–GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS by using a graphical user interface.

The HEC-RAS output file contained 37 modeled water-surface profiles within the study area, which contains three (3) NWS forecast points as well as the Swatara Creek at Inwood where no forecast is available but more than 20 years of record is available. The HEC-RAS GIS Export File contains GIS coordinate-based information that describes the modeling cross-section locations and the resulting water surface elevations at each modeling cross-section. The export file is first read into the GIS. The next step is to create water surface Triangular Integrated Networks (TINs) for each of the modeled incremental flood profiles. The TIN created is based on the water surface elevation at each cross-section. The water surface TIN is created without considering the bare earth DEM. The next step is to delineate a floodplain for each water surface TIN. A floodplain polygon is created based on the corresponding water surface TIN. Each floodplain polygon results from intersecting the water surface TIN with the bare earth DEM. The water surface TIN is converted to a grid and compared to the bare earth DEM. A depth grid is then created with values where the water surface grid is higher than the bare earth DEM. The depth grid is clipped by the bounding polygon to remove any areas outside the hydraulic model. The depth grid is then converted into a floodplain polygon feature class. This process resulted in the study area floodplain polygons and study area depth grids.

Prior to finalizing the data, the depth grids and floodplain polygons were reviewed and edited. The review and editing process consisted of general smoothing and clean-up plus two major steps: 1) removing any disconnected waterbodies, and 2) bridge clips. Step 1 involved checking all hydraulically disconnected wet areas. If there was evidence that a wet, disconnected pond was hydraulically connected (i.e., an underground pipe connected the flood source to the disconnected pond), no action was taken. Low areas or depressions that did not have some obvious connection to flood sources were removed from the inundation map representation. Step 2 involved making the depth grids and floodplain polygons as accurate as possible by clipping bridges if they were still usable during a flood event. A clipped bridge means it is not shown as flooded and will remain usable. A bridge was clipped (and shown as being usable) as long as the lowest portion of the bridge was not impacted by water. Once the lowest portion of the bridge was impacted, all subsequent and higher elevation flood profiles were not clipped. For the non-mainstem bridges, if the road-surface elevation of the bridge was not flooded, the bridge was clipped and shown to be usable for that flood profile. Once the lowest road-surface elevation associated with a bridge was impacted by water, all subsequent and higher elevation flood profiles would not be clipped.

2.3 FINAL MAPPING AREAS

The final step in the FIM library development was to separate the study area into three (3) reaches as they will be displayed on NWS AHPS. This was done in consultation with the NWS and the cooperating partners. To ensure seamless coverage throughout the study area, the extent of each of the individual reaches is coincident with the adjacent reach. In the development of the final mapping areas, consideration was given to hydraulic and geographic changes, political boundaries, and distance from the nearest forecast point. The final mapping areas are shown in Figure 2.1.

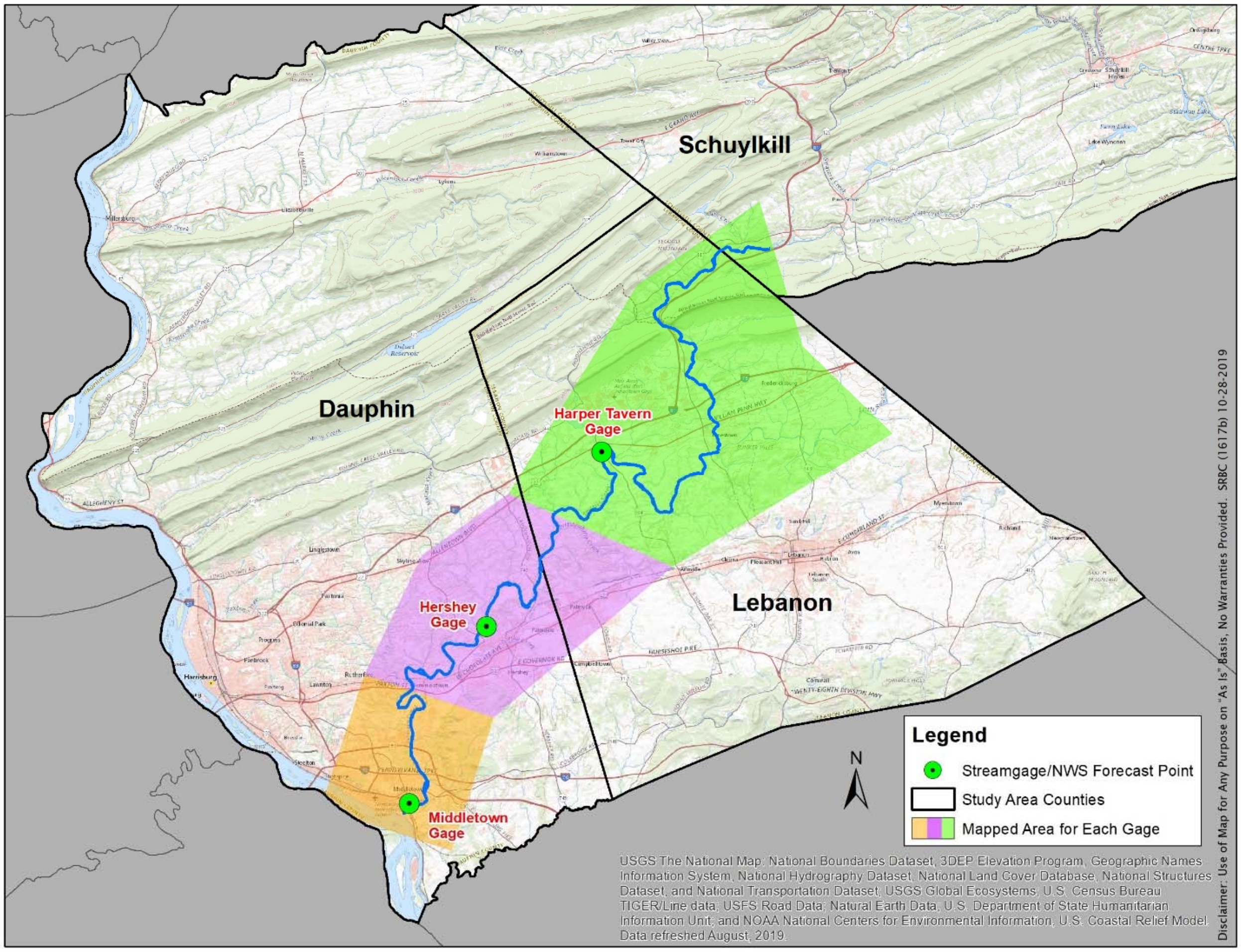

Figure 2.1. Gage Mapping Areas

3 INUNDATION MAPPING LIMITATIONS

3.1 UNCERTAINTY

Flood-inundation maps provide expected boundaries of inundated areas with a distinct line related to stage at a reference stream gage within the study reach. However, there exists some uncertainty with the distinct line and the boundaries depicted should be considered a reasonable approximation of expected flooding. The flood boundaries displayed are estimated based on water stages/flows at selected USGS streamgages. Water-surface elevations along the stream reaches are estimated by steady-state hydraulic modeling, assuming unobstructed flow, and using discharges and hydrologic conditions anticipated at the USGS streamgages. The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of the date of the published map. Unique meteorological factors (timing and distribution of precipitation) may cause actual discharges along the modeled reach to vary from assumed during a flood and lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated backwater from major tributaries along the mainstem or from localized debris or ice jams. Inundated areas shown should not be used for navigation, regulatory, permitting, or other legal purposes. These maps are provided as a quick reference, emergency planning tool. The SRBC and USACE assume no legal liability or responsibility for any direct, indirect, incidental, consequential, special, or exemplary damages or lost profit resulting from the use or misuse of this information.

The user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by a precipitation or snowmelt event, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the flow and stage (water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations). For more information on AHPS forecasts, please see:
http://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.

APPENDIX A

Swatara Creek Flood Study
Dauphin County, Lebanon County, and Schuylkill County, Pennsylvania

FEMA Region III
Swatara Creek Flood Study

Dauphin County, Lebanon County, and Schuylkill County
Pennsylvania

INTER-AGENCY AGREEMENT: HSFE03-16-X-0200
MIP Case Number 15-03-0142S

October 2017

Prepared by: U.S Army Corps of Engineers

Swatara Creek Flood Study

Document History

Document Location

Location
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload

Revision History

Version Number	Version Date	Summary of Changes	Team/Author
1.0	October 2017	Initial Condition	USACE-Baltimore District

Client Distribution

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1. Project Summary

1.1. Introduction

The U.S. Army Corps of Engineers - Baltimore District (USACE) has completed Flood Study activities in accordance with Inter-Agency Agreement No. HSFE03-16-X-0200 for Swatara Creek in Dauphin, Lebanon, and Schuylkill Counties in south-central Pennsylvania (hereafter known as “the Project”).

The limit of study for the hydrologic analysis in this project is the Swatara Creek watershed (Figure 1.1). The Swatara Creek watershed has a drainage area of approximately 572.0 square miles at its confluence with the Susquehanna River in Middletown, Pennsylvania. The watershed spans several municipalities across the counties of Dauphin, Lebanon, Schuylkill, and Berks. The hydraulic limit of study for this project is Swatara Creek from its confluence with the Susquehanna River upstream to approximately 7,000 feet upstream of Swopes Valley Road in Pine Grove Township in Schuylkill County, a distance of approximately 52.9 miles. The upstream limit of the hydraulic modeling ties into a HEC-RAS model completed by GG3 Joint Venture for Federal Emergency Management Agency (FEMA) in February 2013 under Task Order HASFE03-12-J-0008 of Contract No. HASFE03-08-D0007 (Reference 1).

This study supersedes the detailed flood study (Zone AE) for Swatara Creek in the 8/2/12 FEMA Flood Insurance Study (FIS) for Dauphin County, Pennsylvania (Reference 2), the detailed flood study (Zone AE) and approximate flood study (Zone A) in the 6/5/2012 FEMA FIS for Lebanon County, Pennsylvania (Reference 3), and the approximate flood study (Zone A) in the 11/19/04 FEMA FIS for Schuylkill County, Pennsylvania (Reference 4). The project location and a detailed map of the Project area is shown in Figure 1.1.

A description of the Project activities from the Inter-Agency Agreement Statement of Work is shown below.

1.2. Project Scope of Work

1.2.1. Perform Field Survey

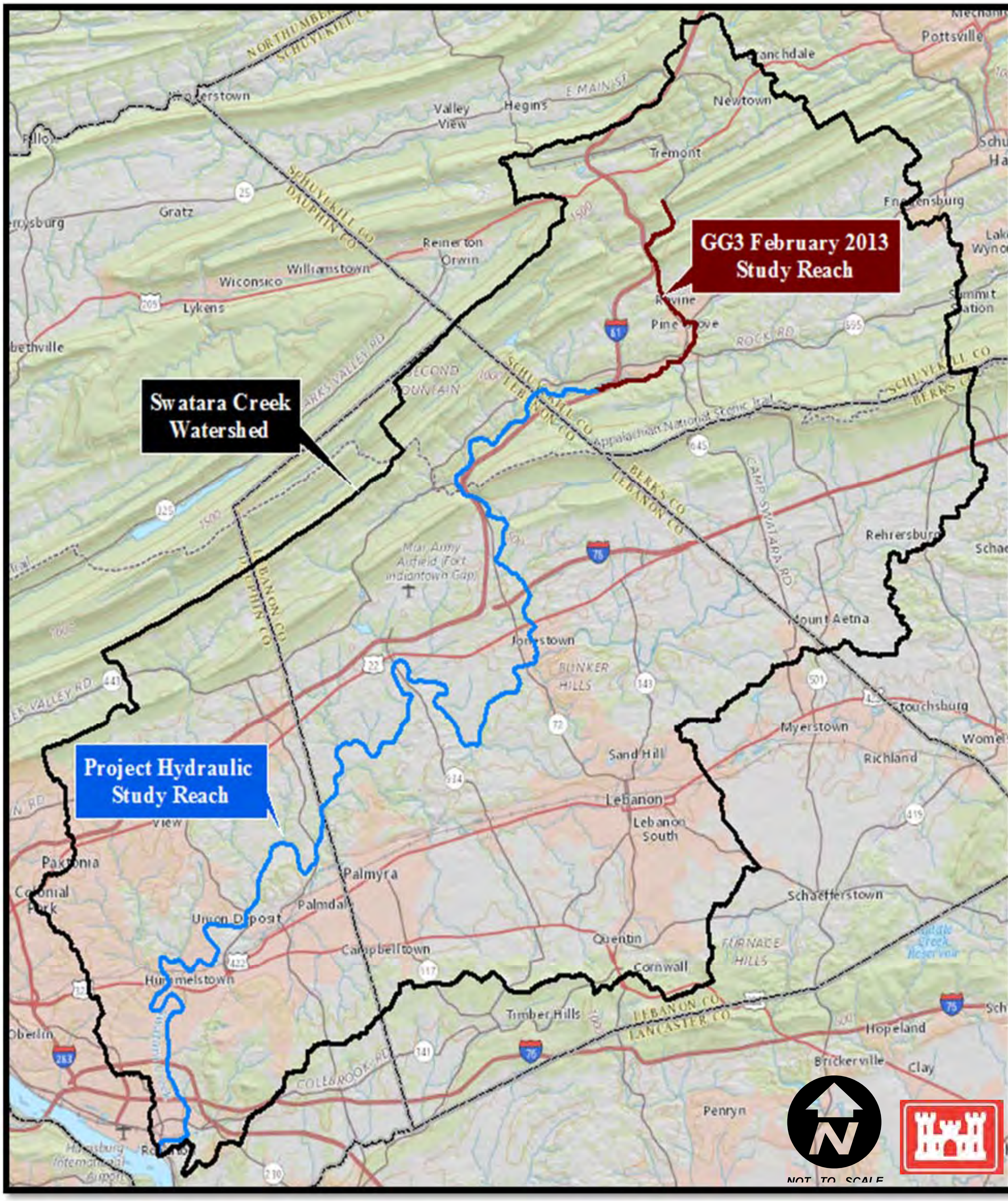
Scope: To supplement any field reconnaissance conducted during the Project Discovery phase of this project, USACE shall conduct field reconnaissance of the specific study area to determine conditions along the floodplain(s), types and numbers of hydraulic and/or flood-control structures, apparent maintenance or lack thereof of existing hydraulic structures, and other parameters needed for the hydrologic and hydraulic analyses.

USACE shall conduct field surveys, obtaining the physical dimensions of hydraulic and flood-control structures in the areas of model updates, and cross sections in.

Standards: All Field Survey work shall be performed in accordance with the standards specified in FEMA’s *Guidelines and Standards Policy Memo.*

Assumptions: Upstream and downstream cross sections will be surveyed at all structures, along with the structure dimensions, per FEMA flood study engineering standards and guidance. Channel cross section survey will occur approximately every mile between structures, supplemented with modeled cross-sections derived from high-resolution topographic data every 500 to 1000 feet or better.

Figure 1.1: Project Area



Deliverables: USACE shall make the following products available to FEMA by uploading the digital data to the MIP, in accordance with the outlined schedule:

- TSDN report, specific to this Data Development task, to be uploaded to the MIP as part of the data development task upload, and at any subsequent change in the data, including;
  - A report summarizing the findings of the field reconnaissance;
  - Documentation of the horizontal and vertical datum, projection, and units;
  - A summary that describes and provides the results of all automated or manual QA/QC review steps taken during the preparation of the FIRM as outlined in the approved QA/QC Plan.
  - Support documentation and Certification of Work;
  - Where paper documentation is required by State Law for Professional certifications, USACE may submit the paper in addition to a scanned version of the paper for the digital record. Please coordinate with the Regional and/or State representative to verify state reporting requirements; and
- Maps and drawings that provide the detailed survey results;
- Survey notebook containing cross section and structure data;
- Digital versions of draft text for inclusion in the FIS report, in editable format (.doc or .docx) (prepared in accordance with the latest FIS Report Technical Reference);
- Digital survey data consistent with the Data Capture Standard (per the current DCS Technical Reference and FIRM Database Technical Reference, Table 2) i.e. L_Survey_Pt;
- Metadata file complying with the latest NFIP Metadata Profiles Specifications

1.2.2. Develop Topographic Data

Scope: Existing topographic/elevation data (previously flown and/or processed) will be used to produce flood studies and related products. This data is available in the form of LiDAR elevation data prepared by the United States Geological Survey (USGS) for Dauphin County (dated 2015) and the PAMAP Program for Lebanon and Schuylkill Counties (dated 2008)

USACE shall obtain the above-mentioned topographic data for the floodplain areas to be studied including overbank areas. These data will be used for hydrologic analysis, hydraulic analysis, floodplain boundary delineation and/or testing of floodplain boundary standard compliance. USACE shall gather availability, currency, and accuracy information for existing topographic data covering the affected communities in this SOW. USACE shall use topographic data for work in this SOW only if it is better quality than that of the original study or effective studies. The Mapping Partner will ensure that the FEMA Geospatial Data Coordination Policy and Implementation Guide is followed and the data obtained or to be produced are documented properly as per those policies and guidelines.

Requirements for leveraging existing Topographic Data: USACE shall use topographic data as listed above. The source of the topographic data must be listed as well. USACE shall coordinate with other team members conducting field surveys as part of this SOW. Accuracy for the topographic data shall be evaluated based on the current FEMA requirements for flood hazard study level of detail.

USACE also shall update the topographic maps and/or DEMs for the subject flooding sources using the data collected under this Topographic Data Development process and via field surveys. In addition, USACE shall address all concerns or questions regarding the topographic data development that are raised during the independent QC review, or during the National Quality Validation Process (formerly defined in Procedure Memorandum 42).

Standards: All Topographic Data Development work shall be performed in accordance with the standards specified in FEMA's *Guidelines and Standards Policy Memo.*

Deliverables: USACE shall make the following products available to FEMA by uploading the digital data to the MIP in accordance with the schedule.

- Mass points (LiDAR LAS files);
- Identification of data voids and methods used to supplement data voids (populate S_Topo_Confidence feature class in the FIRM Database);
- TIN data;
- Gridded digital elevation model data;
- Digital contour data (2 foot contours);
- Hillshade DEMs
- National Geodetic Survey data sheets for Network Control Points used to control remote-sensing and ground surveys;
- Other supporting files consistent with the DCS (per the current DCS Technical Reference and FIRM Database Technical Reference, Table 2);
- Metadata file complying with the latest NFIP Metadata Profiles Specifications;
- TSDN report, specific to this Data Development task, to be uploaded to the MIP as part of the data development task upload, and at any subsequent change in the data, including;
    - A narrative describing the scope of work, direction from FEMA, issues, information for next mapping partner, summary of methodology and results; confirmation of horizontal and vertical datum, projections, and units of all data used, etc.;
    - Identification of data voids and methods used to supplement data voids (also populated in S_Topo_Confidence in the FIRM Database per Table 2 of the FIRM Database Technical Reference)
    - A summary that describes and provides the results of all automated or manual QA/QC review steps taken during the preparation of the FIRM as outlined in the approved QA/QC Plan;
    - Support documentation and Certification of Work;
    - Where paper documentation is required by State Law for Professional certifications, USACE may submit the paper in addition to a scanned version of the paper for the digital record. Please coordinate with the Regional and/or State representative to verify state reporting requirements; and
- Updates to the National Digital Elevation Program (NDEP) project tracking at http://www.ndep.gov/.

1.2.3. Develop Hydrologic Data

Scope: USACE shall perform hydrologic analyses for Swatara Creek. USACE shall calculate peak flood discharges for the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance events using a gage analysis. These flood discharges will be the basis for subsequent Hydraulic Analyses performed under this SOW. In addition, USACE shall address all concerns or questions regarding the hydrologic analyses that are raised during the independent QA/QC review performed.

USACE shall document automated data processing and modeling algorithms, and provide the data to FEMA to ensure these are consistent with FEMA standards. Digital datasets (such as elevation, basin, or land use data) are to be documented and provided to FEMA in the latest FIRM Database schema where applicable for approval before performing the hydrologic analyses to ensure the datasets meet minimum requirements. If non-commercial (i.e., custom-developed) software is used for the analysis, then USACE shall provide full user documentation, technical algorithm documentation, and the software to FEMA for review before performing the hydrologic analyses.

Standards: All Hydrologic Analyses work shall be performed in accordance with the standards specified in FEMA's *Guidelines and Standards Policy Memo.*

Deliverables: USACE shall make the following products available to FEMA by uploading the digital data to the MIP in accordance with the schedule.

- Digital copies of all hydrologic modeling (input and output) files for the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance events;
    - Metadata file;
    - Digital Summary of Discharges Tables presenting discharge data for the flooding sources for which hydrologic analyses were performed, plus L_Summary_Discharges table;
    - Digital versions of draft text for inclusion in the FIS report, in editable format (.doc or .docx) (prepared in accordance with the latest FIS Report Technical Reference);
    - Digital versions of all backup data used in the analysis including work maps;
    - Format Hydrology Database or Data Delivery consistent with the DCS and FEMA standards for all return periods (per the latest DCS Technical Reference and FIRM Database Technical Reference, Table 2);
    - Deliverables shall include all input and output data, and final products in the format of the latest FIRM database structure;
    - TSDN, specific to this Data Development task, to be uploaded to the MIP as part of the data development task upload, and at any subsequent change in the data, including;
        - Summary report that describes and provides the results of all automated or manual QA/QC review steps taken during the preparation of the FIRM as outlined in the approved QA/QC Plan;

- Where paper documentation is required by State Law for Professional certifications, USACE may submit the paper in addition to a scanned version of the paper for the digital record. Please coordinate with the Regional and/or State representative to verify state reporting requirements;
- Summary of the hydrologic analysis for each study area; and
- QA/QC checklist(s)

1.2.4. Develop Hydraulic Data

Scope: USACE shall perform hydraulic analyses for Swatara Creek. The modeling will include the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance events based on peak discharges computed under Hydrologic Analyses. The hydraulic methods used for this analysis will include enhanced level hydraulic modeling. The enhanced level will include field surveys, use of the best available elevation data, floodways, and the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance events.

USACE shall use the cross-section and field data collected during Field Survey and the topographic data collected during the Topographic Data Collection, when appropriate, to perform the hydraulic analyses. Cross-section data from the original HEC-2 models, if appropriate and available, shall be obtained for the wet section portion of the cross-sections. The hydraulic analyses will be used to establish flood elevations and regulatory floodways for the subject flooding sources.

USACE shall use the FEMA CHECK-2 or CHECK-RAS checking program to verify the reasonableness of the hydraulic analyses. To facilitate the independent QA/QC review, USACE shall provide explanations for unresolved messages from the CHECK-2 or CHECK-RAS program, as appropriate. In addition, USACE shall address all concerns or questions regarding the hydraulic analyses that are raised during the independent QA/QC review.

USACE shall document automated data processing and modeling algorithms for GIS-based modeling and provide the data to FEMA for review to ensure these are consistent with the standards outlined above. Digital datasets are to be documented and provided to FEMA for approval before performing the hydraulic analyses to ensure the datasets meet minimum requirements. If non-commercial (i.e., custom-developed) software is used for the analyses, then USACE shall provide full user documentation, technical algorithm documentation, and software to FEMA for review before performing the hydraulic analyses.

Any flooding sources associated with a levee that are mapped as providing protection on effective FIRMs, but will not meet certification requirements for the new FIRMs, will require revised hydraulic analysis. This revised analysis should be done in accordance with FEMA standards and guidance as appropriate.

Standards: All Hydraulic Data work shall be performed in accordance with the standards specified in FEMA's *Guidelines and Standards Policy Memo.*

Deliverables: USACE shall make the following products available to FEMA by uploading the digital data to the MIP review in accordance with the schedule.

- Digital profiles of the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual chance events, representing existing conditions using the FEMA RASPLOT program or similar software;
- Metadata file in the latest metadata specification;

- Digital Floodway Data Tables for each flooding source that is compatible with the latest FIRM database, exportable via RASPLOT 3.0;
- Digital hydraulic modeling (input and output) files;
- Digital tables with range of Manning's "n" values per the latest FIRM Database Technical Reference (L_ManningsN);
- Explanations for unresolved messages from the CHECK-2 or CHECK-RAS program, as appropriate;
- Digital versions of all backup data used in the analyses;
- Digital versions of draft text for inclusion in the FIS report, in editable format (.doc or .docx) (prepared in accordance with the latest FIS Report Technical Reference);
- Deliverables will include all input and output data, GIS data layers, and final products in the format of the latest FIRM database structure;
- Format Hydraulic Database or Data Delivery consistent with the DCS and FEMA standards (per the current DCS Technical Reference and FIRM Database Technical Reference, Table 2);
- Depth grids for all studied streams for all frequencies as required;
- TSDN, specific to this Data Development task, to be uploaded to the MIP as part of the data development task upload, and at any subsequent change in the data, including;
    - A summary that describes the methodologies used, input and outputs, and provides the results of all automated or manual QA/QC review steps taken during the preparation of the FIRM as outlined in the approved QA/QC Plan;
    - Where paper documentation is required by State Law for Professional certifications, you shall submit the paper in addition to a scanned version of the paper for the digital record. Please coordinate with the Regional and/or State representative to verify reporting requirements for your state; and
    - Appropriate leverage information, including who paid for the data and the amount of data used by the Flood Risk Project.

1.2.5. Perform Floodplain Mapping

<u>Scope for Enhanced Riverine Study</u>: USACE shall delineate the 1% and 0.2% annual chance floodplain boundaries and the regulatory floodway boundaries (if required) and any other applicable elements for the flooding sources for which hydrologic, enhanced hydraulic, and/or coastal analyses were performed. USACE shall incorporate all new or revised hydrologic, hydraulic, and/or coastal modeling and shall use the topographic data acquired under Develop Topographic Data to delineate the floodplain and regulatory floodway boundaries on a digital work map.

USACE shall incorporate the results of all effective Letters of Map Change (LOMCs) for all affected communities on the FIRM and provide to the appropriate PTS the required submittals for incorporation into the National Flood Hazard Layer (NFHL). Also, USACE shall address all concerns or questions regarding Floodplain Mapping that are raised during the independent QA/QC review.

USACE shall capture flood hazard engineering and/or mapping data quality issues encountered during this activity in the CNMS data model for the area of interest. These issues will be entered as "Requests" or "Needs" in the CNMS data model based on the nature of the deficiency encountered. Detailed information on performing this task can be found in the relevant standards specified in accordance with the standards specified in FEMA's *Guidelines and Standards Policy Memo.*

Standards: All floodplain mapping work shall be performed in accordance with the standards specified in accordance with the standards specified in FEMA's *Guidelines and Standards Policy Memo.* USACE will perform self-certification audits for the Floodplain Boundary Standards for all flood hazard areas.

Deliverables: Upon completion of floodplain mapping for all flooding sources in this project, USACE shall make the following products available to FEMA by uploading the digital data to the MIP in accordance with the schedule:

- A metadata file complying with the latest NFIP Metadata Profiles Specifications, must accompany the compliant digital data;
- Draft FIRM database prepared in accordance with FEMA standards (per the current latest DCS Technical Reference and latest FIRM Database Technical Reference, Table 2);
- Digital versions of input and output for any computer programs that were used consistent with the DCS (per the current latest DCS Technical Reference and latest FIRM Database Technical Reference, Table 2);
- Digital versions of draft FIS report, Floodway Data Tables and updated profiles including all profiles and tables converted appropriate datum, as well as any other necessary items for the finalization of the preliminary FIS; in editable format (.doc or .docx) (prepared in accordance with the latest FIS Report Technical Reference), as well as the corresponding components in the latest FIRM Database format.
- All input data, output data, intermediate data processing products, and GIS data layers shall be submitted consistent with the DCS where applicable (per the current latest DCS Technical Reference and latest FIRM Database Technical Reference, Table 2); and
- TSDN, specific to this Data Development task, to be uploaded to the MIP as part of the data development task upload, and at any subsequent change in the data, including;
    - A summary that describes and provides the results of all automated or manual QA/QC review steps taken during the preparation of the FIRM as outlined in the approved QA/QC Plan;
    - Any backup or supplemental information including supporting calculations and assumptions used in the mapping required for the independent QA/QC review of Hydrologic, Coastal and /or Hydraulic Analyses and Floodplain Mapping consistent with the DCS (per the current latest DCS Technical Reference and latest FIRM Database Technical Reference, Table 2);
    - An explanation for the use of existing topography for the studied reaches, if appropriate;
    - Written summary of the analysis methodologies;
    - Support documentation and Certification of Work; and

- Where paper documentation is required by State Law for Professional certifications, USACE may submit the paper in addition to a scanned version of the paper for the digital record. Please coordinate with the Regional and/or State representative to verify state reporting requirements.

1.2.6. Other Tasks

Under the SOW, USACE was also scoped to perform non-technical tasks such as Project Management, Project Risk Identification and Mitigation, and Perform Community Engagement and Project Outreach.

2. Study Methodology and Results

2.1. Field Survey

2.1.1. Data Acquisition

The field survey data for the study was collected by USACE and the Susquehanna River Basin Commission (SRBC) in March 2017. USACE was responsible for the field survey of hydraulic structures (bridges, culverts, weirs) and man-made channel features such as retaining walls. The SRBC acquired the "wet sections" or bathymetric data for the Swatara Creek at select locations.

2.1.2. Surveyed Stream Reaches

The surveyed stream reaches in this project include Swatara Creek from its confluence with the Susquehanna River in Middletown, Pennsylvania, upstream to the tie-in point with the existing GG3 HEC-RAS model (Reference 1). The upstream limit of survey is located approximately 7,000 feet upstream of Swopes Valley Road in Pine Grove Township, Schuylkill County, Pennsylvania. The extent of survey is shown in Figure 2.1. The surveyed stream reaches in this project are shown in Table 2.1.

Table 2.1: Surveyed Stream Reaches

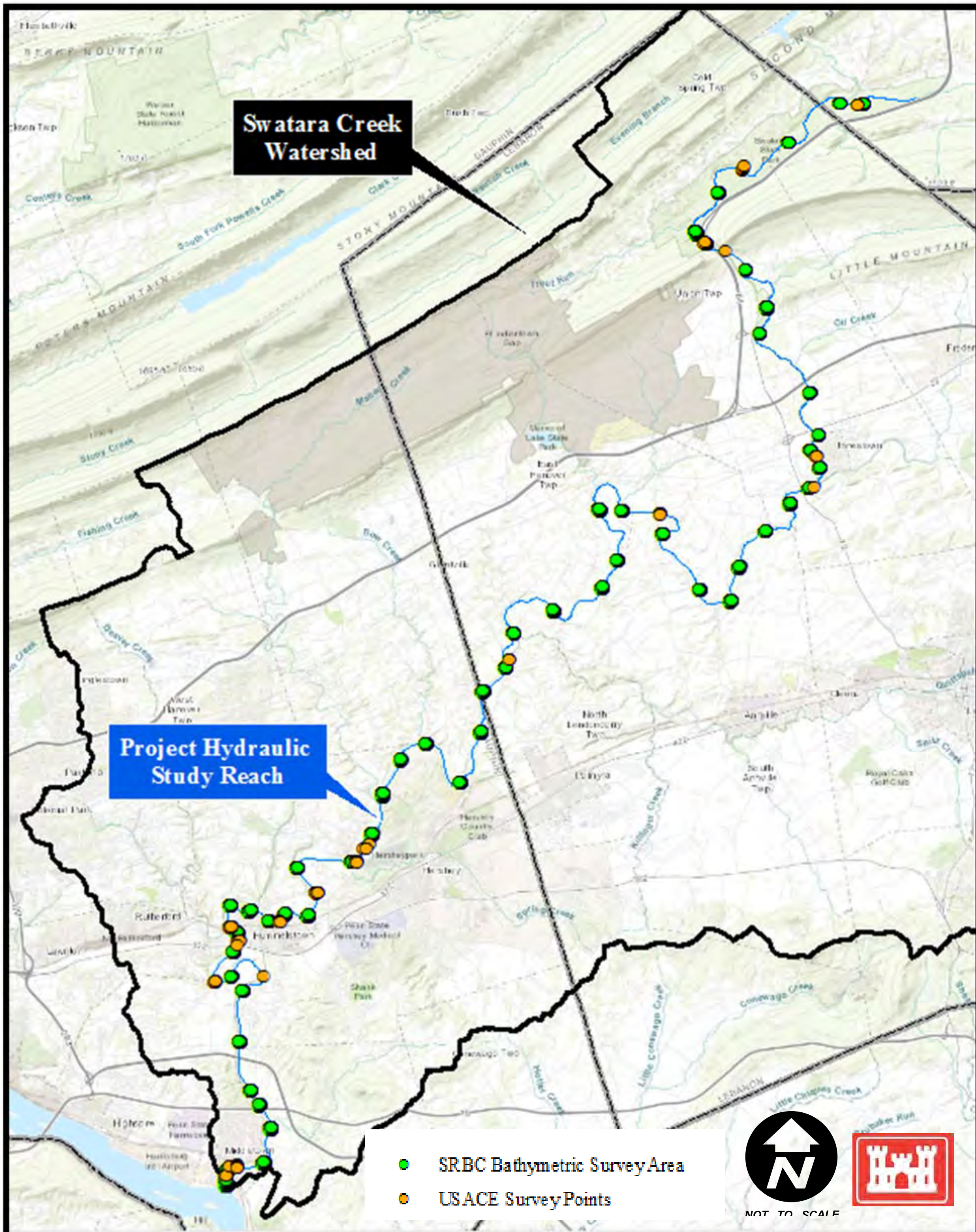
Stream Name	From Reach	To Reach
Swatara Creek	At confluence with the Susquehanna River	Approximately 7,000 feet upstream of Swopes Valley Road in Pine Grove Township, Schuylkill County

2.1.3. Survey Methodology

For the survey of hydraulic structures and man-made channel features, the field data was collected by USACE using a Real Time Kinematic (RTK) survey unit. Watershed level control was established by Virtual Reference Station (VRS) networks using RTK solutions using Continuously Operating Reference Station (CORS) network stations. Real time occupations were for 5 epochs for an observed control point. In areas with multiple watershed level control points, these control points were checked across the control network for vertical consistency and independently checked against National Geodetic Survey (NGS), state or local monumentation if available and recoverable.

The Swatara Creek bathymetric data was collected by SRBC using the Sontek's HydroSurveyor system as well as a Trimble R8 GPS receiver. The HydroSurveyor system is comprised of two components which include the HydroSurveyor Acoustic Doppler Profiler (ADP®) platform and data collection software (also called "HydroSurveyor"). The ADP platform is Sontek's "M9" affixed to a small floating trimaran. Bathymetric transects at 53 locations within the study reach were developed by obtaining a water surface elevation (NAVD88) using the Trimble R8 unit at the transect location. Fixing the water surface elevation obtained from the R8 unit as the reference plane within the HydroSurveyor software, the ADP was pulled around the transect location, using a SBRC owned power boat, in a sinuous pattern such that representative coverage of the bathymetric surface was obtained. The ADP collects depth information using four angled and one vertical acoustic beam. The HydroSurveyor software uses a proprietary process to interpolate

Figure 2.1: Extent of Swatara Creek Survey



bathymetric surface elevations at a user selected grid cell size. The Swatara Creek bathymetric data was processed using a 10’ grid cell size to minimize processing time and manage file sizes while maintaining an accurate representation of the channel bottom. The interpolated bathymetry was exported from HydroSurveyor as a “.csv” file containing XYZ coordinates/elevation and then imported into ESRI ArcGIS for incorporation into project modeling efforts.

2.1.4. Data Post-Processing

The survey data is in conformance with the North American Datum of 1983 (NAD 83). All elevation values were in feet and referenced to the North American Vertical Datum of 1988 (NAVD 88). These data were projected to the NAD83 Pennsylvania State Plane Zone South coordinate system. Structure and cross section data was compiled into the FEMA FIRM Database L_Survey_Pt table format. The coordinate systems used for the products from the field survey is listed in Table 2.2.

Table 2.2: Field Survey Project Coordinate Systems

Coordinate System	Datum	Horizontal Units	Vertical Datum	Vertical Units
PA State Plane South	WGS1984, GRS80 Spheroid	Feet	NAVD88	Feet

2.1.5. Survey Quality Assurance Review

Field survey data undergoes a multilevel review process for accuracy and completeness prior to submitting the final deliverables. The data is reviewed for accuracy of rod and instrument heights and survey codes as well as completeness at the site prior to leaving each hydraulic feature. A second level of review occurs during the daily download and processing procedure. Raw data and photos are reviewed for completeness and accuracy and necessary corrections noted in the field are made. A third level of review occurs as the data is processed as a group on the watershed level. Points are reviewed for accuracy against available NGS control and/or available contour data and are displayed on an aerial background to check for positional accuracy. A final level of review occurs during preparation of deliverables. Points are reviewed for accuracy of survey codes and general position and elevation. Photos and sketches are reviewed for accuracy, completeness, and consistency.

Thorough quality control of all survey data (SRBC and USACE data) was completed by the U.S. Army Corps of Engineers - Baltimore District in accordance with the U.S. Army Corps of Engineers - Baltimore District Quality Management Plan. The QA/QC certification is in Appendix C.

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2.1.6. Exceptions

Survey data development tasks vary from study to study. As a result, some submittal exceptions may apply. Exceptions applicable to Field Survey Data development task are listed below with an explanation of why the featured item was not included as a deliverable.

- All survey data compiled as part of this task is included in this TSDN or the MIP.

2.1.7. Conclusions

The field survey data was collected and delivered in accordance with the procedures described in FEMA’s Data Capture standards and guidance dated May 2014.

2.1.8. Required Field Survey Deliverables

The required deliverables, shown in Table 2.3, were submitted to the FEMA MIP at:
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload\Survey
J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload\Survey
J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload\Survey

Table 2.3: Field Survey Deliverables

Required Deliverable	Provided	Location	Format
General Field Survey Narrative	Yes	This TSDN, also MIP	PDF
P.E. or PLS Certification	Yes	Appendix A of This TSDN, also MIP	PDF
Field Survey Metadata	Yes	MIP	XML
Photos	Yes	MIP	JPG
Sketches	Yes	MIP	PDF
Survey Data	Yes	MIP (L_Survey_Pt)	DBF
Supplemental Data	Yes	MIP	DBF/SHP
Spatial Files	Yes	MIP (S_Submittal_Info, and USACE survey location points)	SHP/pGDB/fGDB
FIS Report Files	Yes	L_Source_Cit	XLS/CSV/DBF/MDB
QA/QC	Yes	Appendix C of this TSDN, also MIP	PDF

2.2. Develop Topographic Data

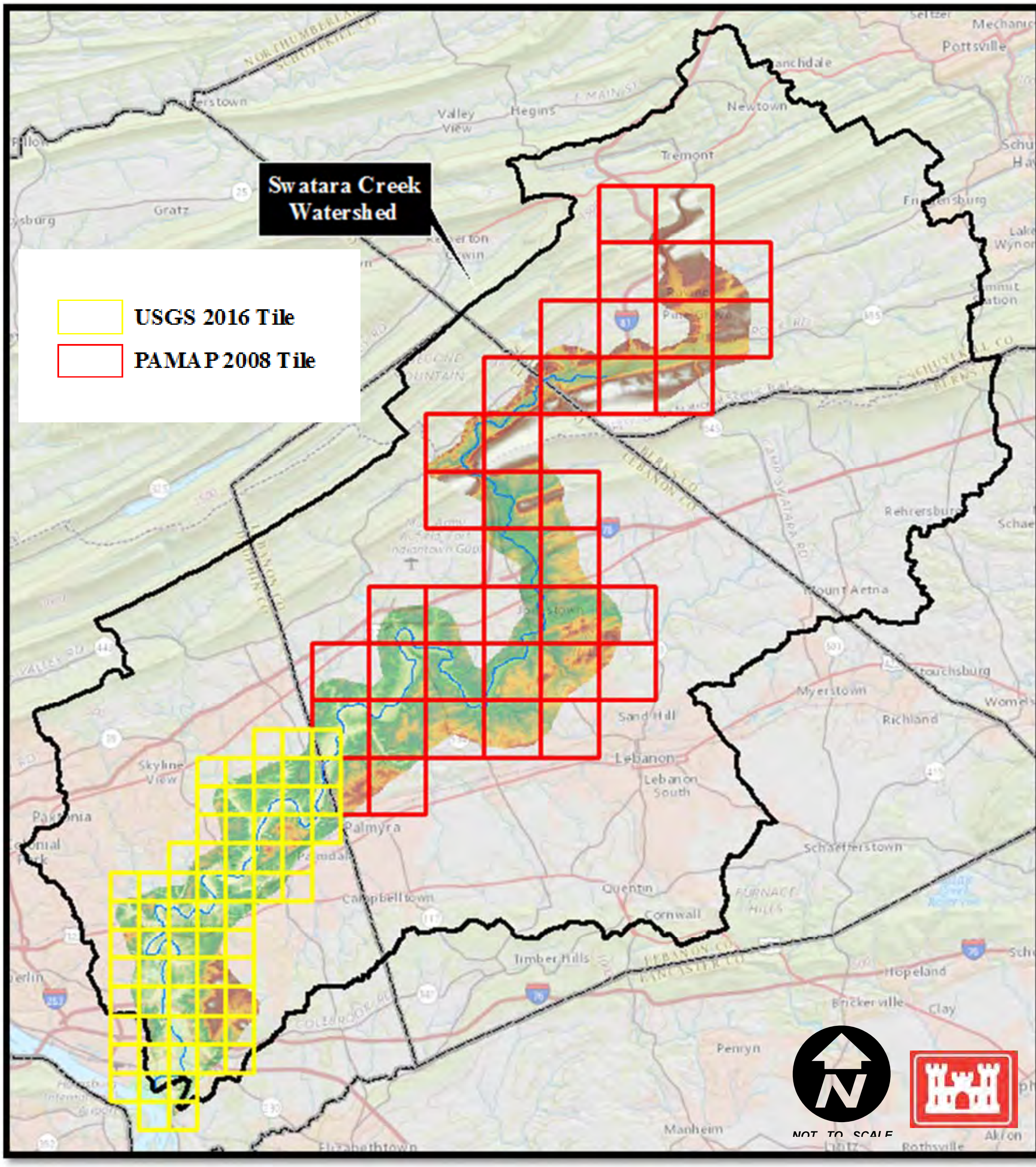
2.2.1. Data Source Acquisition

A project digital elevation model (DEM) (or “project DEM”) was created for the project area from two different sources. For Dauphin County, a 0.7-meter resolution DEM was provided by Dauphin County Information Technology for use in this project. This DEM was generated from QL2 LiDAR data flown in March 2016 by Quantum Spatial, Inc. for the United States Geological Survey (USGS) under Contract G16PC00016. The methodology for the acquisition and processing of this data is outlined in the December 5, 2016 report prepared by Quantum Spatial, Inc. (Reference 5).

For Lebanon and Schuylkill Counties, LiDAR was flown by Woolpert from 2006 to 2008 in support of PAMAP. The LiDAR was downloaded from the Pennsylvania Spatial Data Access (PASDA) website (http://www.pasda.psu.edu) (Reference 6) in 10,000’ x 10,000’ Bare Earth LAS and DEM (1-meter resolution) .tif format in North American Datum of 1983 (NAD83) State Plane Pennsylvania South Federal Information Processing Standards (FIPS) 3702 Feet projection. Vertical units were in North American Vertical Datum of 1988 (NAVD88) with elevations in feet. This data was downloaded for the Project in February 2017 by USACE.

The 0.7-meter Dauphin County DEM (dated 2016) and the 1.0-meter PAMAP DEM (dated 2008) was merged into one 0.7-meter resolution DEM and then clipped to an appropriate buffer around Swatara Creek to create the project DEM which was used for the hydraulic modeling. A map showing the location of the project DEM and the respective tiles used to create the project DEM is shown in Figure 2.2.

Figure 2.2: Topographic Data Sources



2.2.2. Data Processing

Hydrology DEMs

A gage analysis was used for the hydrologic data development in this project. In order to transfer the results of the gage analysis to ungaged location, the drainage area to the desired flow point is required. Pennsylvania StreamStats was used to compute the drainage areas to the respective ungaged flow points. StreamStats uses a 30-meter DEM as described in the bibliography of the U.S. Geological Survey document *Regression Equations for Estimating Flood Flows at Selected Recurrence Intervals for Ungaged Streams in Pennsylvania, Scientific Investigations Report (SIR) 2008-5102* (Reference 7).

Hydraulic DEMs

The project DEM, as described above, was used for the hydraulic analysis associated with this project. Figure 2.2 shows the location of the tiles used for the project DEM. with a list of the tiles provided in Table 2.4.

Table 2.4: PAMAP DEM Tiles for Project

PAMAP Tile	PAMAP Tile	USGS Tile	USGS Tile
37002280PAS	44002320PAS	33502250PAS	36002260PAS
37002290PAS	44002330PAS	33502255PAS	36002265PAS
38002280PAS	44002340PAS	33502260PAS	36002270PAS
38002290PAS	45002320PAS	33502265PAS	36002275PAS
38002300PAS	**USGS Tile**	34002245PAS	36002280PAS
38002310PAS	31002250PAS	34002250PAS	36502260PAS
38002320PAS	31002255PAS	34002255PAS	36502265PAS
39002280PAS	31502245PAS	34002260PAS	36502270PAS
39002290PAS	31502250PAS	34002265PAS	36502275PAS
39002300PAS	31502255PAS	34502245PAS	36502280PAS
39002310PAS	32002245PAS	34502250PAS	37002260PAS
39002320PAS	32002250PAS	34502255PAS	37002265PAS
39002330PAS	32002255PAS	34502260PAS	37002270PAS
40002290PAS	32002260PAS	34502265PAS	37002275PAS
40002300PAS	32002265PAS	35002245PAS	37002280PAS
40002310PAS	32502245PAS	35002250PAS	37502270PAS
40002320PAS	32502250PAS	35002255PAS	37502275PAS
40002330PAS	32502255PAS	35002260PAS	37502280PAS
41002310PAS	32502260PAS	35002265PAS	
41002320PAS	32502265PAS	35002270PAS	
42002300PAS	33002245PAS	35002275PAS	
42002310PAS	33002250PAS	35502255PAS	
42002320PAS	33002255PAS	35502260PAS	
43002300PAS	33002260PAS	35502265PAS	
43002310PAS	33002265PAS	35502270PAS	
44002310PAS	33502245PAS	35502275PAS	

2.2.3. Output Coordinate System and Units

The terrain data is referenced in the North American Datum of 1983 (NAD 83). All elevation values are in feet and referenced to the North American Vertical Datum of 1988 (NAVD 88). These data were projected to the NAD83 Pennsylvania State Plane Zone South coordinate system. The coordinate systems of the topographic data is listed in Table 2.5.

Table 2.5: Topographic Data Project Coordinate Systems

County	Coordinate System	Datum	Horizontal Units	Vertical Datum	Vertical Units
Dauphin, Lebanon, and Schuylkill	PA State Plane South Zone	NAD83	Feet	NAVD88	Feet

2.2.4. Quality Assurance Review

Topographic data evaluation was not necessary for the source topographic data as all elevation data used has previously been accepted and determined to be of adequate quality for engineering and floodplain mapping workflow steps.

2.2.5. LiDAR/DEMs

Results of the accuracy testing for the Dauphin County LiDAR data is located in the December 5, 2016 report prepared by Quantum Spatial, Inc. (Reference 5). Results from the accuracy testing according to the LiDAR project level metadata for the PAMAP data is as follows:

- National Standard for Spatial Data Accuracy (NSSDA)/FEMA: (1) Compared to criteria Root Mean Square Error (RMSE) less than or equal to 0.61 feet (ft) in Open Terrain, tested 0.34 ft; (2) Compared to criteria $Accuracy_z$ less than or equal to 1.19 ft at 95 percent confidence level, tested 0.67 ft.

- National Digital Elevation Program (NDEP)/American Society of Photogrammetry and Remote Sensing (ASPRS): (1) Compared to criteria Fundamental Vertical Accuracy (FVA) less than or equal to 1.19 ft at 95 percent confidence level, tested 0.67 ft; (2) Compared to criteria Consolidated Vertical Accuracy (CVA) less than or equal to 2.38 ft at 95 percent confidence level, tested 0.90 ft.

2.2.6. Required Topographic Data Deliverables

The required deliverables, shown in Table 2.6, were submitted to the FEMA MIP at:
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload\Terrain\2173208
J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload\Terrain\2173208
J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload\Terrain\2173208

Table 2.6: Topographic Data Deliverables

Required Deliverable	Provided	Location	Format
General Project Narrative	Yes	This TSDN, also MIP	PDF
P.E. or PLS Certification	No	n/a	n/a
Topographic Metadata	Yes	MIP	XML
Source Topographic Data	Yes	MIP (in Source folder, by subtype per Data Capture Technical Reference)	LAS, ESRI DEM, TIFF, SHP/MDB/GDB
Final Topographic Data	Yes	MIP (in Final folder, by subtype per Data Capture Technical Reference)	ESRI DEM, TIN, TIFF, SHP/MDB/GDB
Supplemental Data	No	MIP (per Data Capture Technical Reference)	N/A
Spatial Files	Yes	MIP (S_Submittal_Info, S_Topo_Confidence, LiDAR tile index)	SHP/pGDB/fGDB
FIS Report Files	Yes	L_Source_Cit	XLS/CSV/DBF/MDB
QA/QC	No	n/a	n/a

2.2.7. Exceptions

Topographic Data development tasks vary from study to study. As a result, some submittal exceptions may apply. Exceptions applicable to the Topographic Data development task are listed below with an explanation of why the featured item was not included as a deliverable.

- All topographic data compiled as part of this task is included in this TSDN or the MIP.

2.2.8. Conclusion

The topographic data for this project was collected and delivered in accordance with the procedures described in FEMA's Data Capture standards and guidance dated November 2014.

2.2.9. FIS Report Tables

See Appendix E for the following FIS tables required as part of Topographic Data Development, all of which are derived from data in the FIRM Database:

- FIS Report Table 23, Summary of Topographic Elevation Data used in Mapping
- FIS Report Table 33, Bibliography and References

2.3. Develop Hydrologic Data

2.3.1. Methodology Overview

FEMA's Guidelines and Specifications state that hydrologic analyses, to determine the discharge characteristics along stream reaches under study, can be developed based on statewide regression equations, statistical analysis of stream gage data, or hydrologic (rainfall-runoff) models developed for the watershed. The Swatara Creek watershed contains five United States Geological Survey (USGS) gages. Four of these gages measure stream flow and stage (01572025- Swatara Creek near Pine Grove, PA; 01572190- Swatara Creek near Inwood, PA; 01573000- Swatara Creek at Harper Tavern, PA; and 01573560- Swatara Creek near Hershey, PA), and one measures just stage (01573600-Swatara Creek at Middletown, PA). Due to the abundance of historical flow data at these gages, a statistical analysis was chosen as the methodology for computing peak flows for the Swatara Creek watershed. The location of the four stream flow gages used in the statistical analysis for Swatara Creek is shown in Figure 2.3.

2.3.2. Methods

The typical steps in completing a statistical analysis for a watershed in Pennsylvania includes:

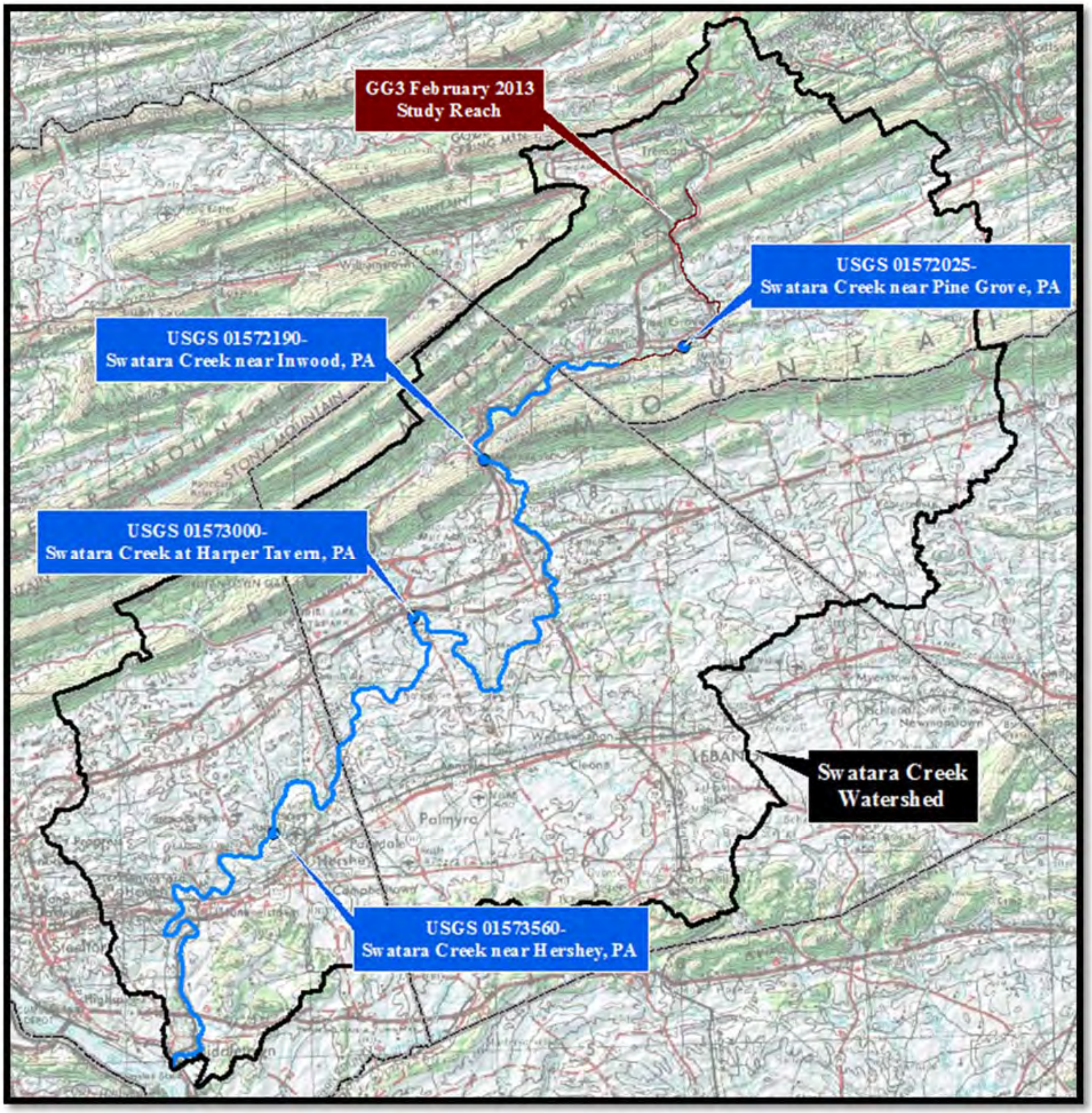
(1) Developing updated flood-frequency curves using, historically, *Bulletin 17B, Guidelines for Determining Flood Flow Frequency* (Reference 8), through the USGS PeakFQWin program. Recently, however, a new approach for statistical analysis, called Expected Moments Algorithm (EMA), has gained in use and is recommended for use by the USGS in the draft *Guidelines for Determining Flood Flow Frequency, Bulletin 17C* (Reference 9). The EMA methodology is also available in the USGS PeakFQWin program.

(2) Often, recorded results of a statistical analysis at gaging stations, especially those with a short period of record, may not be representative of peak flows from long periods of record. Because of this, peak flow estimates using PeakFQ (Bulletin 17B or 17C) are combined with peak flow estimates from regression equations at the station, to compute the weighted estimate of peak flow for that station. For the Swatara Creek watershed, the regression equations that would be used for weighting is found in SIR 2008-5102 (Reference 7).

(3) Transferring the peak flows from the gages to ungaged site using methods outlined in USGS *Water-Resources Investigations Report 00-4189, Techniques for Estimating Magnitude and Frequency of Peak Flows for Pennsylvania Streams (WRIR 00-4189*) (Reference 10).

Initial computations using this process showed a significant difference between the statistical analysis results at the gages and the results from the regression equations. The regression equations were producing much lower values than the statistical analysis, which could skew the weighting of the peak flow results at the gages considerably. USACE coordinated with the USGS on this issue and the USGS indicated that the regression equations in this watershed are suspect since the watershed has experienced significant flooding since the regression equations were developed. At USGS 01573000- Swatara Creek at Harper Tavern, PA, which has nearly 100 years of record, the statistical analysis computed 1-percent annual chance flood peak flow of 50,980 cubic feet per second (cfs). The results from the regression equations indicate a value of 36,400 cfs. The regression equations were not developed taking into consideration the flooding from Tropical Storm Lee in 2011. USGS indicated that the regression equations would be updated in the Fall 2018 timeframe, but

Figure 2.3: USGS Gages used in Hydrologic Analysis



recommended proceeding with the analysis using EMA and not weighting the values at the gages using regression equations for this watershed and situation in particular.

Therefore, the methodology used for this hydrologic analysis includes computing the peak flows at the four gaged sites using PeakFQ EMA to water year 2016 and transferring to ungaged sites directly, without weighting, using the methods outlined in WRIR 00-4189.

2.3.3. Models and Computer Tools Used

For the statistical analysis at the USGS gages, PeakFQ Version 7.1, dated March 2014, was used. PeakFQ implements both the Bulletin 17B and EMA procedures for flood-frequency analysis of streamflow records, providing estimates of flood magnitudes and their corresponding variance for a range of 15 annual exceedance probabilities, including 0.6667, 0.50, 0.4292 0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002 (recurrence intervals 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years, respectively.) The output also includes estimates of the parameters of the log-Pearson Type III frequency distribution, including the logarithmic mean, standard deviation, skew, and mean square error of the skew. The output graph includes the fitted frequency curve, systematic peaks, low outliers, censored peaks, interval peaks, historic peaks, thresholds, and confidence limits (Reference11).

To determine the drainage areas at ungaged sites, the USGS StreamStats program was used. StreamStats is a web application that incorporates GIS to provide users with access to an assortment of analytical tools that are useful for a variety of water-resources planning and management purposes, and for engineering and design purposes. StreamStats provides tools that allow users to select sites on ungaged streams and obtain the drainage-basin boundary, compute selected basin characteristics, and estimate selected streamflow statistics using regression equations, among other tools (Reference 12).

2.3.4. Regression Analysis

As noted in Section 2.3.2, initial computations showed a significant difference between the statistical analysis results at the gages and the results from the regression equations. The regression equations were producing much lower values than the statistical analysis, which could skew the weighting of the peak flow results at the gages considerably. Therefore, regression analysis was not used in this project.

2.3.5. Parameter Estimation

Discharge node locations along Swatara Creek were selected based on engineering judgment. The discharge nodes were generally placed at the USGS gages, and at stream confluences to capture contributing drainage area and flow changes. Discharge nodes were also placed at major roads and at corporate boundaries. A total of 35 flow points were identified for the hydrologic analysis, and are shown in Figure 2.4. The only input parameter required was drainage area, which was determined using the USGS StreamStats program.

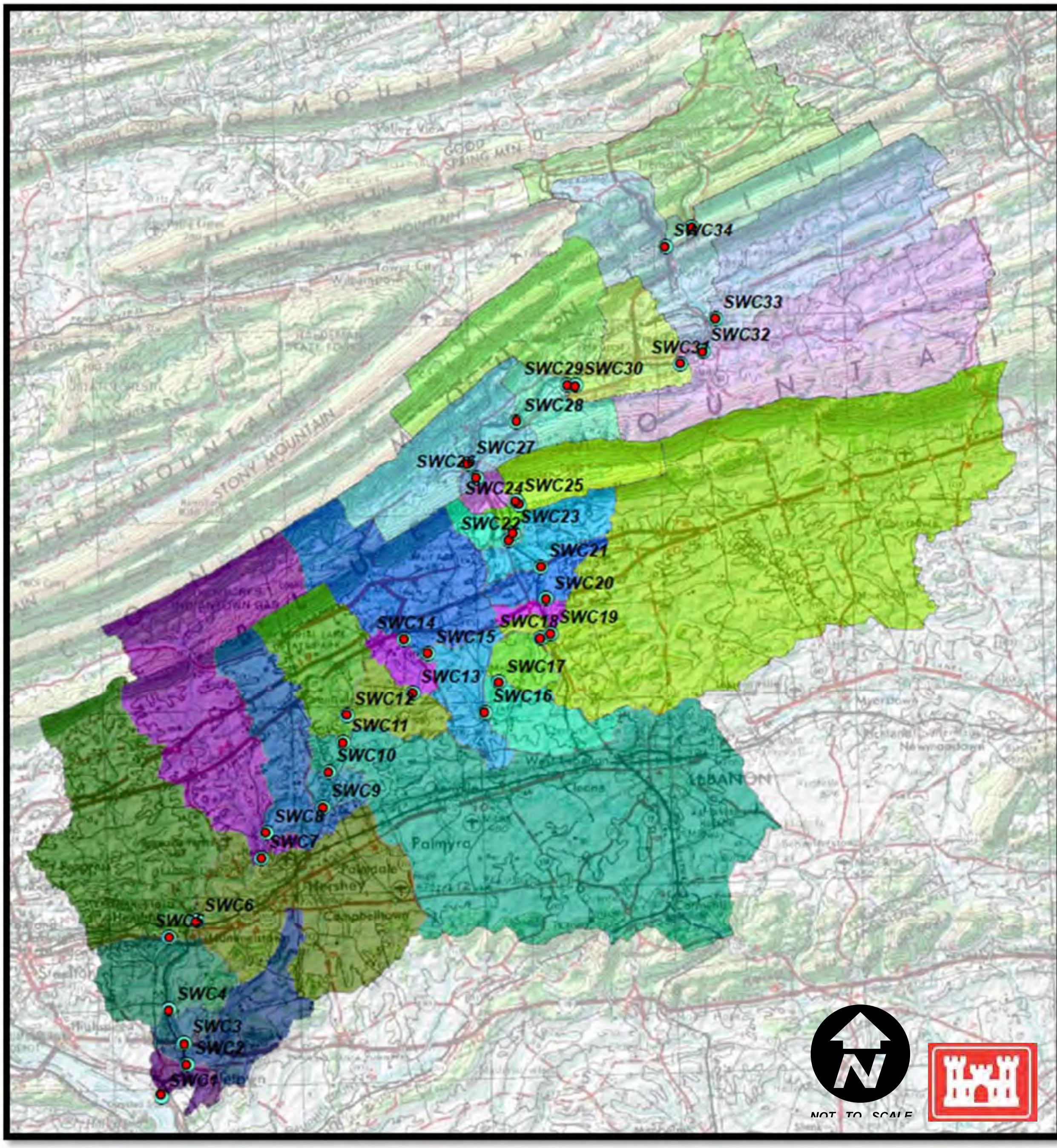
Drainage Basin Area Delineation

The drainage area delineation to each of the hydrology nodes associated with this study was completed using the StreamStats program. Figure 2.4 shows the Swatara Creek watersheds, as delineated using the 30-meter DEM in USGS StreamStats (Reference 13).

Regression Parameters

As noted in Section 2.3.2, initial computations showed a significant difference between the statistical analysis results at the gages and the results from the regression equations. The regression equations were producing much lower values than the statistical analysis, which could skew the weighting of the peak flow results at the gages considerably. Therefore, regression analysis was not used in this project.

Figure 2.4: Flow Points and Drainage Boundaries



2.3.6. Gage Analysis

The use of gage data in developing hydrology within a watershed is based on USGS gaging stations selected based upon three criteria: (1) the gaging station is located on the study stream; (2) the gaging stations has a minimum of 10 years of continuous record; and (3) for transferring flows of ungaged sites, the contributing drainage area for the discharge point falls between 0.5 to 1.5 times the drainage area at the gaging station.

There are four USGS gaging stations that were utilized in this gage analysis. The location of these gages is shown in Figure 2.3, with data on each gaging station shown in Table 2.7.

Table 2.7: USGS Stream Flow Gages used in Hydrologic Analysis

Flow Point	USGS Gage	Drainage Area (sq. mi.)	Years of Record Used (to Water Year 2016)	Record Flow*
SWC31	01572025- Swatara Creek near Pine Grove, PA	116.0	28	23100
SWC26	01572190- Swatara Creek near Inwood, PA	167.0	28	29500
SWC14	01573000-Swatara Creek at Harper Tavern, PA	336.0	98	74800
SWC7	01573560- Swatara Creek near Hershey, PA	483.0	42	96900

**Record flow at all gages from September 2011 storm event (Lee)*

PeakFQ Version 7.1, dated March 2014, utilizing EMA, was used to estimate the frequency curves for the four gages listed in Table 2.7. The results of the analysis is shown in Table 2.8, with full PeakFQ outputs located in Appendix F.

Table 2.8: PeakFQ Frequency Flow Estimates at USGS Gages

Flow Point	USGS Gage	Peak Flow (cfs)							
		2yr	5yr	10yr	25yr	50yr	100yr	200yr	500yr
SWC31	01572025	3620	6311	8873	13280	17620	23070	30000	41670
SWC26	01572190	4875	8543	11990	17850	23550	30650	40000	54440
SWC14	01573000	9248	15250	20850	30320	39530	50980	65230	89450
SWC7	01573560	10200	17330	24130	35890	47530	62240	80000	112900

2.3.7. Discharge Weighting and Discharge Transfer

As noted in Section 2.3.2, initial computations showed a significant difference between the statistical analysis results at the gages and the results from the regression equations. The regression equations were producing much lower values than the statistical analysis, which could skew the weighting of the peak flow results at the gages considerably. Therefore, regression analysis and discharge weighting was not used in this project.

To transfer to the results of the flood frequency estimates from the gaged locations to the ungaged sites, USGS gage transfer equations were utilized. For flow points between two gages, Equation 4 from WRIR 00-4189 was used:

$$Q_{T(C)} = Q_{T(AC)} \times \frac{DA_B - DA_C}{DA_B - DA_A} + Q_{T(BC)} \times \frac{DA_C - DA_A}{DA_B - DA_A} \quad (4)$$

where $Q_{T(C)}$ is the final weighted discharge at ungaged site C, in cubic feet per second;
$Q_{T(AC)}$ is the weighted and moved discharge from upstream streamflow-gaging station (gage A), in cubic feet per second;
$Q_{T(BC)}$ is the weighted and moved discharge from downstream streamflow-gaging station (gage B), in cubic feet per second;
DA_A is the drainage area of the upstream streamflow gage A;
DA_B is the drainage area of the downstream streamflow gage B; and
DA_C is the drainage area of ungaged site C.

For the flow points upstream of the USGS 01572025- Swatara Creek near Pine Grove, PA and downstream of USGS 01573560- Swatara Creek near Hershey, PA, the translation equation below was used:

$$Q_u = (A_u/A_g)^b Q_g$$

Where: Q_u is the discharge at ungaged flow point, in cfs;
A_u is the drainage area of the ungaged flow point;
A_g is the drainage area of the gaged flow point;
Q_g is the discharge at the gaged flow point, in cfs; and
b is a drainage area basin characteristic coefficient

Values for b are frequency based and were taken from the Region 3 estimates from SIR 2008-5102*:*

Region 3	
Q2	.82143
Q5	.79492
Q10	.78127
Q50	.75816
Q100	.75043
Q500	.73500

The same methodology was used for the September 2011 (Lee) storm event and Agnes in June 1972, as these storms were also included in the hydraulic modeling for calibration purposes. The 1-percent plus flow was also completed using this methodology. The 1-percent plus is defined as the flood discharge that includes the average predictive error for the methods being used. To compute the 1-percent plus discharge at the gages, the confidence limits in the Peak FQ program was lowered to .84 (84-percent) to compute the 1-percent plus discharge. The values at the gaged sites were transferred to the ungaged flow points using the same methodology described above.

The results of the transfer of peak flows from the gaged flow points to the ungaged flow points is shown in Table 2.9, with computations located in Appendix F.

Table 2.9: Peak Flow Estimates for All Flow Points using Transfer Methods

Flow Point	Drainage Area (mi2)	Peak Flow (cfs)										
		2yr	5yr	10yr	25yr	50yr	100yr	200yr	500yr	100yr Plus	Agnes 1972	LEE 2011
SWC35	25.9	1056	1916	2750	4186	5654	7489	9892	13843	10137	10011	9200
SWC34	33.5	1305	2351	3362	5103	6871	9084	11966	16725	12296	12111	11165
SWC33	48.7	1775	3166	4504	6807	9125	12028	15783	22018	16282	15974	11920
SWC32	74.6	2519	4443	6285	9453	12608	16564	21640	30124	22423	21901	16490
SWC31*	116.0	3620	6311	8873	13280	17620	23070	30000	41670	31230	30362	23100
SWC30	125.0	3841	6705	9423	14086	18666	24408	31765	33039	43924	32088	23840
SWC29	145.0	4334	7580	10645	15879	20992	27380	35686	48931	37058	35814	26739
SWC28	151.0	4481	7843	11012	16416	21690	28272	36863	50434	38264	36904	27492
SWC27	166.0	4850	8499	11929	17760	23434	30501	39804	54190	41279	39584	29375
SWC26*	167.0	4875	8543	11990	17850	23550	30650	40000	54440	41480	39760	29500
SWC25	169.0	4927	8622	12095	17998	23739	30891	40299	54854	41899	40112	30036
SWC24	178.0	5160	8980	12567	18662	24590	31973	41642	56719	43786	41682	32449
SWC23	179.0	5186	9019	12619	18735	24685	32094	41791	56926	43996	41855	32717
SWC22	180.0	5211	9059	12672	18809	24779	32214	41941	57133	44205	42028	32985
SWC21	187.0	5393	9337	13039	19326	25441	33056	42986	58583	45673	43231	34861
SWC20	191.0	5496	9495	13248	19621	25819	33537	43583	59412	46511	43914	35933
SWC19	192.0	5522	9535	13301	19695	25914	33657	43732	59619	46721	44084	36201
SWC18	298.0	8265	13742	18858	27516	35937	46409	59557	81578	68943	61032	64614
SWC17	301.0	8342	13861	19015	27737	36221	46770	60005	82199	69572	61486	65418
SWC16	308.0	8523	14139	19382	28254	36882	47612	61050	83650	71040	62541	67295
SWC15	315.0	8705	14417	19749	28770	37544	48454	62095	85100	72507	63589	69171
SWC14*	336.0	9248	15250	20850	30320	39530	50980	65230	89450	76910	66700	74800
SWC13	339.0	9267	15292	20917	30434	39693	51210	65531	89929	76942	67140	75251
SWC12	344.0	9300	15363	21029	30623	39965	51593	66034	90726	76995	67872	76003
SWC11	355.0	9371	15519	21274	31040	40564	52435	67139	92481	77112	69471	77656
SWC10	435.0	9889	16651	23059	34071	44918	58563	75177	105243	77961	80745	89684
SWC9	438.0	9909	16693	23126	34185	45081	58793	75479	105721	77992	81157	90135
SWC8	450.0	9986	16863	23394	34640	45734	59712	76684	107636	78120	82797	91939
SWC7*	483.0	10200	17330	24130	35890	47530	62240	80000	112900	78470	87248	96900
SWC6	514.0	10735	18208	25332	37651	49825	65214	83769	118182	82220	91358	101531
SWC5	546.0	11281	19104	26556	39443	52160	68238	87597	123546	86032	95534	106238
SWC4	557.0	11467	19409	26973	40054	52955	69267	88900	125371	87330	96954	107840
SWC3	559.0	11501	19465	27048	40164	53099	69454	89136	125702	87565	97212	108131
SWC2	569.0	11670	19741	27426	40717	53817	70384	90313	127350	88738	98496	109579
SWC1	572.0	11720	19824	27539	40882	54032	70662	90666	127844	89089	98880	110012

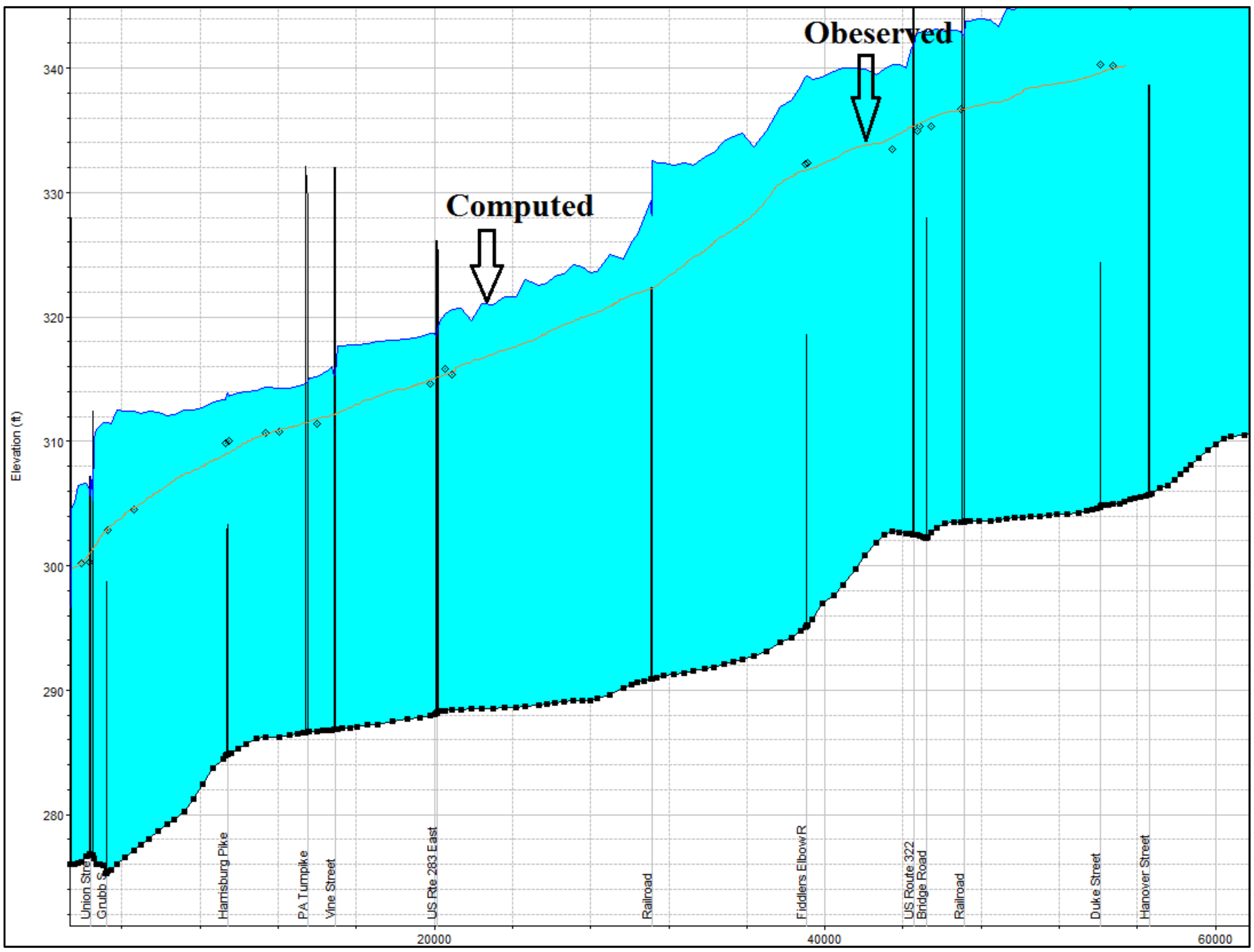
*USGS gage locations

These flows were input into the hydraulic modeling to begin the calibration process of the hydraulic modeling to the rating curves at the USGS gages and high water marks for the September 2011 (Lee) storm event. The calibration process resulted in excellent matches to gage rating curves and high water marks for areas at and upstream of USGS 01573560- Swatara Creek near Hershey, PA (Flow Point SWC7). For areas downstream of this location, the peak flows for the September 2011 (Lee) storm event were causing considerable higher water surface elevations (4+ feet) than the observed high water marks, even when adjusting hydraulic factors outside of the normal range (i.e. reducing Manning's n values to less than .010, eliminating ineffective flow areas, etc.). It became apparent that losses in flow likely occurred downstream of USGS 01573560- Swatara Creek near Hershey, PA, which primarily would impact flood elevations in the Borough of Middletown and surrounding areas. Section 2.3.8 outlines the research conducted and evidence of these flow losses.

2.3.8. Flow Losses

For areas downstream of USGS 01573560- Swatara Creek near Hershey, PA (Flow Point SWC7), the peak flows for the September 2011 (Lee) storm event were causing considerable higher water surface elevations (4+ feet) than the observed high water marks, even when adjusting hydraulic factors outside of the normal range (i.e. reducing Manning's n values to less than .010, eliminating ineffective flow areas, etc.). This is outlined in Figure 2.5.

Figure 2.5: Initial Computed vs. Observed Profile-September 2011 (Lee) Storm Event



Research was conducted to determine if flow losses were possible in this reach of the Swatara Creek. Typical causes of flow losses during a flood event in a watershed include man-made or natural storage of floodwaters or man-made or natural diversions into other watersheds. It was determined that the likely loss in flow in this reach is due to significant karst topography in this reach, and for the September 2011 (Lee) storm event, losses into surface features, in particular, quarries. The supporting data for this determination includes:

1. The inability to calibrate the hydraulic model to the September 2011 (Lee) storm event, only in this reach, even after adjusting hydraulic factors outside the normal range.

2. There is a significant number of karst features in this reach (Figure 2.6). The Epler Formation runs through this area, which is limestone bedrock, and contains the Indian Echo Caverns. A meeting was held with staff from Indian Echo Caverns in June 2017 to discuss the history and nature of flooding at the Indian Echo Caverns. Significant flooding, which reached the outside entrance of the caverns, has occurred during Agnes in 1972, 1975, 2000, and September 2011 (Lee).

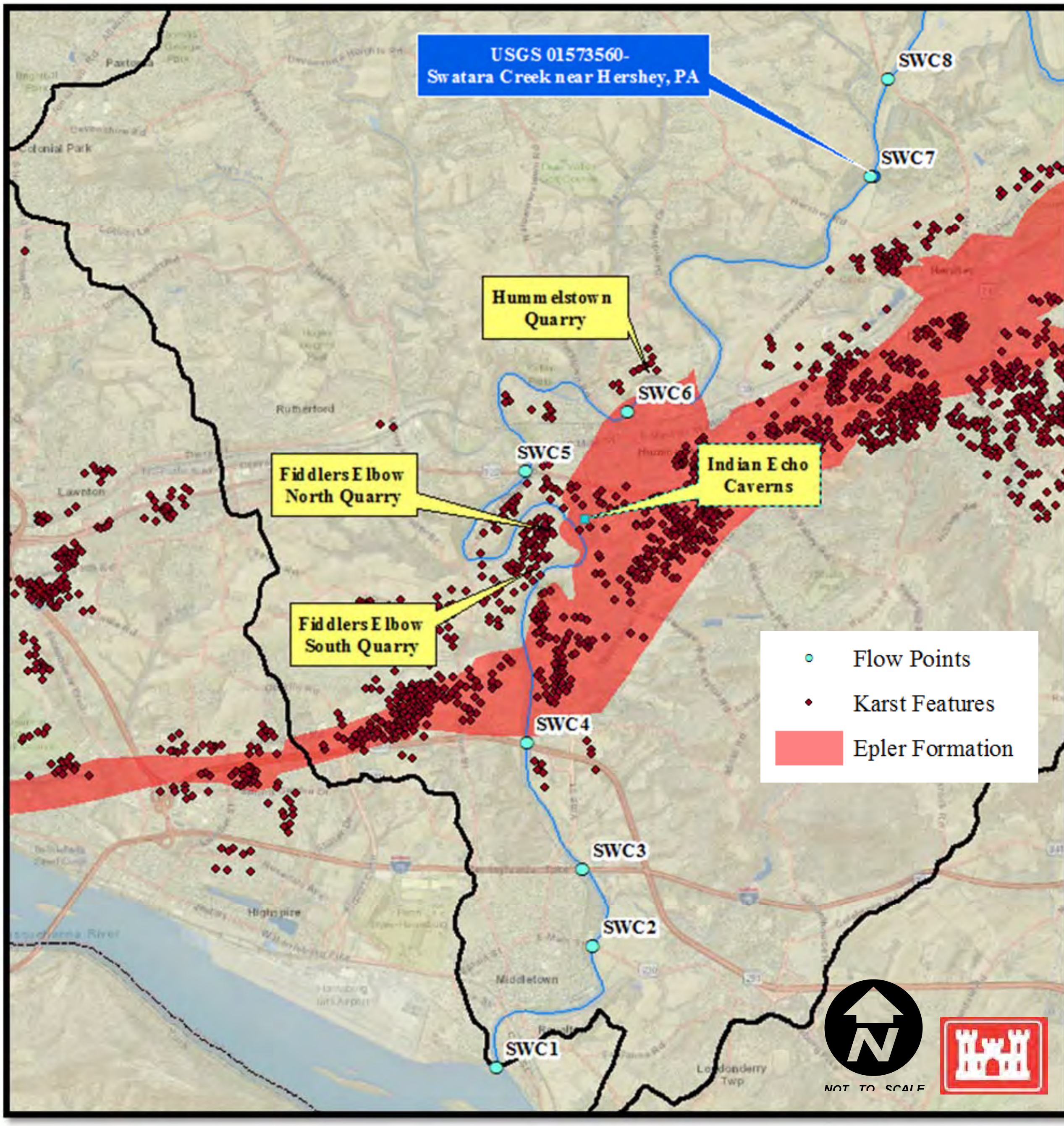
   In the caverns, generally flooding occurs from the inside out, until the water level on the inside reaches the water level on the outside of the caverns. Water will begin to fill up the caverns well before a significant rise in the Swatara Creek occurs through unmapped entry points from the stream into the limestone caverns. The cavern is up to 35 ft. deep in some areas, and although a general map and location of the caverns is known, other nearby unmapped caverns may exist in the Epler Formation.

3. There were three quarries present in this reach at the time of the September 2011 (Lee) storm event, the Hummelstown Quarry, Fiddlers Elbow North Quarry, and Fiddlers Elbow South Quarry (Figure 2.6). Based upon discussions with staff at Pennsy Supply, Inc., the current owners and operators of these quarries, the Hummelstown Quarry had little overflow from Swatara Creek and the Fiddlers Elbow South Quarry had minimal storage capacity during the flood; however, the Fiddlers Elbow North Quarry had significant overflow from Swatara Creek into the quarry, causing significant damages to buildings and equipment. The floodwaters were stored in this deep quarry and had to be pumped out after the flood event.

Quantifying the amount of flow losses in this area would be difficult using physical data since the location and size of underground features is unknown. Therefore, an approach was developed to model the quarries and losses due to underground caverns as lateral structures in the hydraulic model. The losses to the quarries would be from a weir at the lowest point of entry into the quarry, which could be determined through topographic mapping. The losses to the caverns, however, was determined through an iterative process using observed high water marks from the September 2011 (Lee) storm event, Agnes in 1972, and low flow stage measurements at USGS 01573600-Swatara Creek at Middletown, PA, which is downstream of the loss reach. This approach also gave high confidence in the theory that losses do occur, in that the quarries were present in September 2011 when Lee occurred, but were not present in 1972 during Agnes. Thus, by calibrating the models to both events with and without the quarries, there is a greater confidence in the losses associated with the geologic features. This process is explained in detail in Section 2.4.3 of this report.

Through the iterative calibration process that accounted for these losses, the hydraulic model calibrated well in the initially problematic reach. Therefore, the peak flows listed in Table 2.9 were adjusted to account for these losses. The peak flow values listed in Table 2.9 can be considered the "potential conditions" peak flows, in that future natural or man-made changes occur in the watershed that prevent these flood losses, these flows could be reached. The changes could include alterations to the quarries or natural conditions that prevent losses in the caverns (i.e. cave-ins, caverns full of water prior to the storm, etc.…) For example, since the time of the September 2011 (Lee) storm event, Pennsy Supply, Inc. raised

Figure 2.6: Potential Flood Loss Locations in Lower Swatara Creek Watershed



the elevation of the ground where floodwater entered the quarry, causing the damage. Thus, the losses associated with this feature during the September 2011 (Lee) storm event is higher than the losses in the existing-conditions analysis.

The existing-conditions flow values are shown in Table 2.10. Also shown is the revised estimates for the historical flood events accounting for the flow losses.

Table 2.10: Existing-Conditions and Historical Storm Peak Flows with Flood Losses

Flow Point	Drainage Area (mi2)	Peak Flow (cfs)							
		10yr	25yr	50yr	100yr	500yr	100yr Plus	Agnes 1972[A]	LEE 2011[B]
SWC35	25.9	2750	4186	5654	7489	13843	10137	10011	9200
SWC34	33.5	3362	5103	6871	9084	16725	12296	12111	11165
SWC33	48.7	4504	6807	9125	12028	22018	16282	15974	11920
SWC32	74.6	6285	9453	12608	16564	30124	22423	21901	16490
SWC31*	116.0	8873	13280	17620	23070	41670	31230	30362	23100
SWC30	125.0	9423	14086	18666	24408	33039	43924	32088	23840
SWC29	145.0	10645	15879	20992	27380	48931	37058	35814	26739
SWC28	151.0	11012	16416	21690	28272	50434	38264	36904	27492
SWC27	166.0	11929	17760	23434	30501	54190	41279	39584	29375
SWC26*	167.0	11990	17850	23550	30650	54440	41480	39760	29500
SWC25	169.0	12095	17998	23739	30891	54854	41899	40112	30036
SWC24	178.0	12567	18662	24590	31973	56719	43786	41682	32449
SWC23	179.0	12619	18735	24685	32094	56926	43996	41855	32717
SWC22	180.0	12672	18809	24779	32214	57133	44205	42028	32985
SWC21	187.0	13039	19326	25441	33056	58583	45673	43231	34861
SWC20	191.0	13248	19621	25819	33537	59412	46511	43914	35933
SWC19	192.0	13301	19695	25914	33657	59619	46721	44084	36201
SWC18	298.0	18858	27516	35937	46409	81578	68943	61032	64614
SWC17	301.0	19015	27737	36221	46770	82199	69572	61486	65418
SWC16	308.0	19382	28254	36882	47612	83650	71040	62541	67295
SWC15	315.0	19749	28770	37544	48454	85100	72507	63589	69171
SWC14*	336.0	20850	30320	39530	50980	89450	76910	66700	74800
SWC13	339.0	20917	30434	39693	51210	89929	76942	67140	75251
SWC12	344.0	21029	30623	39965	51593	90726	76995	67872	76003
SWC11	355.0	21274	31040	40564	52435	92481	77112	69471	77656
SWC10	435.0	23059	34071	44918	58563	105243	77961	80745	89684
SWC9	438.0	23126	34185	45081	58793	105721	77992	81157	90135
SWC8	450.0	23394	34640	45734	59712	107636	78120	82797	91939
SWC7*	483.0	24130	35890	47530	62240	112900	78470	87248	96900
SWC6	514.0	25332	37651	49825	65214	118182	82220	91358	101531
SWC5	546.0	26556	39443	52160	68238	118714	85977	95534	104819
SWC4	557.0	25448	35321	44662	57053	96540	68312	76379	74299
SWC3	559.0	25523	35431	44806	57240	96871	68547	76997	74590
SWC2	569.0	25901	35984	45524	58170	98519	69720	78281	76038
SWC1	572.0	26014	36149	45739	58448	99013	70071	78665	76471

**USGS gage locations*
A- Flood losses do not include Hummelstown or Fiddlers Elbow North Quarries (not in existence)
B-Flood losses include Fiddlers Elbow North Quarry with topography at time of September 2011 (Lee) Flood

2.3.9. Quality Assurance Review

Hydrologic analysis data undergoes a multilevel review process for accuracy and completeness prior to submitting the final deliverables.

The hydrologic data was reviewed internally by members of the project team that were not involved in the computation of the flow values. A quality control review certification is included in Appendix C of this document.

2.3.10. Summary of Discharges

A summary of the results of the existing-conditions hydrologic analysis is located in Appendix E, FIS Table 5, Summary of Discharges.

2.3.11. Discharge Comparison- Project vs. Effective FIS

A comparison between the project peak flows, computed in this project using the gage analysis and methodology accounting for flood loss, and the effective FEMA peak flows in the respective FISs for the counties in this project area, is shown in Table 2.11. The revised peak flows compare well with the effective values due to most of the effective hydrology in this watershed is based upon a gage analysis or equations derived from gage data, and with the USGS 01573000-Swatara Creek at Harpers Tavern, PA having nearly 100 years of record, the values should not vary significantly due to this long period of record.

Table 2.11: Discharge Comparison-Project vs. Effective FIS

Flow Point	Location	Drainage Area (sq. mi)	Peak Discharge (cfs)			
			10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Project						
SWC31	At USGS 01572025-Swatara Creek near Pine Grove, PA	116.0	8873	17620	23070	41670
SWC28	At upstream corporate limit of Swatara Township	151.0	11012	21690	28272	50434
SWC14	At USGS 01573000-Swatara Creek at Harpers Tavern, PA	336.0	20850	39530	50980	89450
SWC10	At confluence with Quittapahilla Creek	435.0	23059	44918	58563	105243
SWC1	At confluence with Susquehanna River	572.0	26014	45739	58448	99013
Effective FIS for Dauphin and Lebanon Counties						
SWC31*	At USGS 01572025-Swatara Creek near Pine Grove, PA	116.0	9630	17740	22640	38620
SWC28	At upstream corporate limit of Swatara Township	150.4	10550	20832	27482	50337
SWC14	At USGS 01573000-Swatara Creek at Harpers Tavern, PA	337.0	19482	37247	48350	86443
SWC10	At confluence with Quittapahilla Creek	436.1	23697	44842	57909	102737
SWC1	At confluence with Susquehanna River	570.0	22000	41000	52000	86000

**Effective values for this location taken from preliminary FIS data for Schuylkill County, PA*

2.3.12. Exceptions

The hydrologic analysis for this project was delivered in accordance with the procedures described in FEMA's Data Capture standards and guidance dated November 2014, with no exceptions.

2.3.13. Conclusions

The hydrologic analysis for this project was completed using PeakFQ Version 7.1, dated March 2014, utilizing EMA, to estimate the flow frequency at four USGS stream flow gages in the Swatara Creek watershed. These gaged estimates were transferred to ungaged flow points using standard USGS equations. Due to issues with calibration, it was determined that flood losses occurred in lower reaches of the project area, which resulted in an approach to account for these losses utilizing the hydraulic model and observed data, all discussed in Section 2.4.

2.3.14. Required Hydrologic Data Deliverables

The required deliverables for the hydrologic analysis, shown in Table 2.12, were submitted to the FEMA MIP at:
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload\Hydrology\2173209
J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload\Hydrology\2173209
J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload\Hydrology\2173209

Table 2.12: Hydrologic Data Deliverables

Required Deliverable	Provided	Location	Format
General Project Narrative / Hydrology Report	Yes	This TSDN, also MIP	PDF
P.E. or PLS Certification	Yes	Appendix A of This TSDN, also MIP	PDF
Hydrology Metadata	Yes	MIP	XML
Correspondence	Yes	Appendix B of this TSDN, also MIP	PDF
Simulations	Yes	MIP	Input and Output Files - Native Format
Supplemental Data	Yes	MIP	Native Format
Spatial Files	Yes	MIP (S_Gage if applicable, S_Hydro_Reach, S_Nodes, S_Subbasins, S_Submittal_Info)	SHP/pGDB/fGDB
FIS Report Files	Yes	This TSDN, also MIP, L_Source_Cit, L_Summary_Discharges, L_Summary_Elevations (if applicable)	DBF/MDB/GDB
QA/QC	Yes	Appendix C of this TSDN, also MIP	PDF

2.3.15. FIS Report Tables

See Appendix E for the following FIS tables required as part of Perform Hydrologic Analyses, all of which are derived from data in the FIRM Database:

- FIS Report Table 4, Basin Characteristics
- FIS Report Table 5, Summary of Discharges
- FIS Report Table 7: Summary of Hydrologic and Hydraulic Analyses
- FIS Report Table 33, Bibliography and References

2.4. Develop Hydraulic Data

2.4.1. Detailed Study Hydraulic Methods

The USACE HEC-GeoRAS program was used to develop basic input attributes to export to the USACE HEC-RAS (version 5.0.3) program, which calculated water surface elevations for the 10-, 25-, 50-, 100-, 100Plus-, and 500-year floods for Swatara Creek.

2.4.2. Models and Computer Tools Used

The hydraulic analysis in this study was completed using the USACE HEC-RAS (version 5.0.3) program, which calculated water surface elevations for the 10-, 25-, 50-, 100-, 100Plus-, and 500-year floods. The USACE HEC-GeoRAS program was used to develop basic input attributes to export to the USACE HEC-RAS Program.

Over bank station/elevation data was derived from the 1-meter resolution project DEM discussed in Section 2.2. The HEC-GeoRAS pre-processing utility was used to develop the over bank data from the DEM. Channel station/elevation data was taken from or interpolated from the SRBC survey completed in March 2017 (discussed in Section 2.2). River stationing was computed by the HEC-GeoRAS program. The stations represent feet upstream of the confluence with the Susquehanna River.

Stationing for river crossings was computed by the HEC-GeoRAS program. Elevation and geometric data for the crossings were taken from a bridge survey completed by USACE in November 2015. The crossings included in the model and the source of data are listed in Table 2.13.

Table 2.13: Crossings in the HEC-RAS Model

Survey ID	RAS Station	Crossing	Data Source
SC47/SC47A	272464	Swopes Valley Road	USACE field survey on 3/1/17
SC100	253365	Sand Siding Trail	USACE field survey on 3/9/17 and as-built plans provided by PADCNR dated 3/31/11
SC46	240207	Appalachian Trail	USACE field survey on 3/1/17
SC45	238581	U.S. Route 81 South	PENNDOT bridge plans S-7297 dated 1966
SC44	238407	U.S. Route 81 North	PENNDOT bridge plans S-24858 dated 2003 and S-7297 dated 1966
SC43	237456	Abandoned Railroad	USACE field survey on 3/1/17
SC42	230374	Monroe Valley Road	PENNDOT bridge plans S-24775 dated 2003
SC41/SC41A	223953	Lickdale Road	PENNDOT bridge plans S-21318 dated 1995
SC40/SC39	214810	U.S. Route 78 West	PENNDOT bridge plans S-7567A dated 1966

Table 2.13: Crossings in the HEC-RAS Model (Continued)

Survey ID	RAS Station	Crossing	Data Source
SC37/SC38	214699	U.S. Route 78 East	PENNDOT bridge plans S-7567A dated 1966
SC36/SC36A/SC36B	208109	U.S. Route 22	PENNDOT bridge plans S-30310 dated 2010 and USACE field survey on 4/19/17
SC34	204167	Jonestown Road	from USACE field survey on 3/2/17
SC33	199808	Abandoned Railroad	USACE field survey on 3/2/17
SC32	198493	Ebeneazer Road (PA Route 72)	Data from PENNDOT bridge plans S-531 dated 1929
SC31	184820	Heilmandale Road	PENNDOT bridge plans S-17805 dated 1989
SC30	178069	Ono Road	PENNDOT bridge plans S-5519 dated 1965
SC29	161153	Yordy Bridge Road	USACE field survey on 3/2/17
SC28	151335	Bellgrove Road	from PENNDOT bridge plans S-15092 dated 1983
SC27	139168	Blacks Bridge Road	PENNDOT bridge plans S-28875 dated 2010
SC26/SC26A/SC25	117359	Gravel Hill Road	PENNDOT bridge plans S-5515 dated 1965 and USACE field survey on 2/9/17 and 3/30/17.
SC24	104488	Laudermilch Road	PENNDOT bridge plans S-10791 dated 1974
SC23	85066	Sand Beach Road	PENNDOT bridge plans S-4415 dated 1960
SC21/SC22	77742	Hershey Road (PA Route 39)	PENNDOT bridge plans S-5568A dated 1967 and USACE field survey on 2/9/17
SC20	76806	Weir	USACE field survey on 3/2/17
SC19	75022	Hanover Street	USACE field survey on 2/9/17
SC18	63942	Private Drive (Pennsy Supply Road)	USACE field survey on 3/2/17
SC17	56745	Hanover Street	USACE field survey on 2/9/17
SC15	54271	Duke Street	PENNDOT bridge plans S-22A04 dated September 2015
SC14	47238	Norfolk Southern Railroad	USACE field survey on 3/2/17
SC13	45347	Bridge Road/ West Main Street	USACE field survey on 2/9/17
SC12	44674	U.S. Route 322	PENNDOT bridge plans S-19051 dated April 1992 and USACE field survey on 2/9/17

Table 2.13: Crossings in the HEC-RAS Model (Continued)

Survey ID	RAS Station	Crossing	Data Source
SC11	39204	Fiddlers Elbow Road.	USACE field survey on 2/9/17
SC10	31279	Middletown-Hummelstown Railroad	USACE field survey on 3/2/17
SC9	20340	U.S. Route 283 West	PENNDOT bridge plans S-9094 dated December 1968
SC8	20253	U.S. Route 283 East	PENNDOT bridge plans S-9094 dated December 1968
SC7	15046	Vine Street	PENNDOT plans
SC6	13581	Pennsylvania Turnpike	Turnpike Commission bridge plans T-251.08S002-3-02
SC5	9570	Harrisburg Pike (PA Route 230)/Main Street	PENNDOT plans S-33123 dated August 2015 and USACE field survey on 3/30/17
SC4	3376	Grubb Street	USACE field survey on 3/1/17
SC3	2689	Amtrak Railroad	USACE field survey on 3/1/17
SC2	2521	Union Street	PENNDOT plans T085-127-L210 dated June 2007
SC1	1528	Old Canal Street	USACE field survey on 3/1/17

Roughness values were assigned using engineering judgment supported by data sources such as aerial photography, field photographs, and effective FEMA FIS data. Values for Swatara Creek ranged from .028-.045 in the channel and .013-.20 in the over bank areas. These values were adjusted during the calibration process using the “Flow Roughness Factors” option in HEC-RAS, where n values were reduced or increased as flood elevations increased. Ineffective flow areas were set appropriately at crossings and in other areas, and obstructions in the cross-section geometry represent buildings that would cause obstructions to flood flow.

Normal depth was used as the downstream boundary condition. A normal depth slope of .0050 was used as the downstream boundary condition, and was determined to be the appropriate normal depth slope to match observed high water marks during the calibration process. Contraction and expansion coefficients at most bridges were set to 0.3 and 0.5, respectively. During the calibration process, however, these values were lowered to the standard 0.1 and 0.3 to better match observed high water marks.

Lateral structures in the HEC-RAS modeling play an important role to simulate flooding conditions in the downstream reach of Swatara Creek. As discussed in Section 2.3.8, an approach was developed to model the flow losses due to quarries and underground caverns. This was done using lateral structures in the HEC-RAS model. The losses to the quarries were modeled using a weir at the lowest point of entry into the quarry, and was determined through topographic mapping. The losses to the caverns were modeled as a gate with the size determined through an iterative process using observed high water marks from the September 2011 (Lee) storm event, Agnes in 1972, and low flow stage measurements at USGS 01573600-Swatara Creek at Middletown, PA. As shown in Figure 2.6, there are four significant features where flood losses could occur. These features were input into the HEC-RAS modeling for the respective geometry file in which the feature would create losses in the system. Three geometry files were created for the Swatara Creek HEC-RAS model to represent conditions present at different calibration points through the model development process. These geometries are listed below:

- Swatara Creek_Agnes 1972: This geometry (and plan) was used to calibrate the HEC-RAS model hydraulic factors to watershed conditions in 1972 during the Agnes event. The model was calibrated to high water marks and the USGS gages (discussed in Section 2.4.3). The geometry does not include lateral structures for Hummelstown Quarry and Fiddlers Elbow North Quarry because they did not exist. A lateral structure for Indian Echo Caverns and other karst features was included, which an iterative process was used to model this limestone area. Steady flows data includes Agnes 1972 flows computed by translation from the Harpers Tavern gage.

- Swatara Creek_Calibration: This geometry (and plan) was used to calibrate the HEC-RAS model hydraulic factors to watershed conditions during Lee in September 2011. The model was calibrated to high water marks from Lee in September 2011 (collected by USGS and Gannett Fleming, Inc.) and the rating curves for the USGS gages in Hershey, Harper Tavern, and Inwood. The geometry includes lateral structures for Hummelstown Quarry and Fiddlers Elbow North Quarry, using data from the 2008 PASDA DEM, and Indian Echo Caverns and other karst features, which an iterative process was used to model this limestone area.

- Swatara Creek_ExistingConditions: This geometry (and plan) is the existing-conditions plan for conditions present in 2017 (at the time of this project). This plan varies from the calibration plan in that the project DEM, using 2016 LIDAR data, was used for the lateral structure at Hummelstown North Quarry.

A list of the lateral structures included in the respective geometric files is shown in Table 2.14, with a description of each feature following the table.

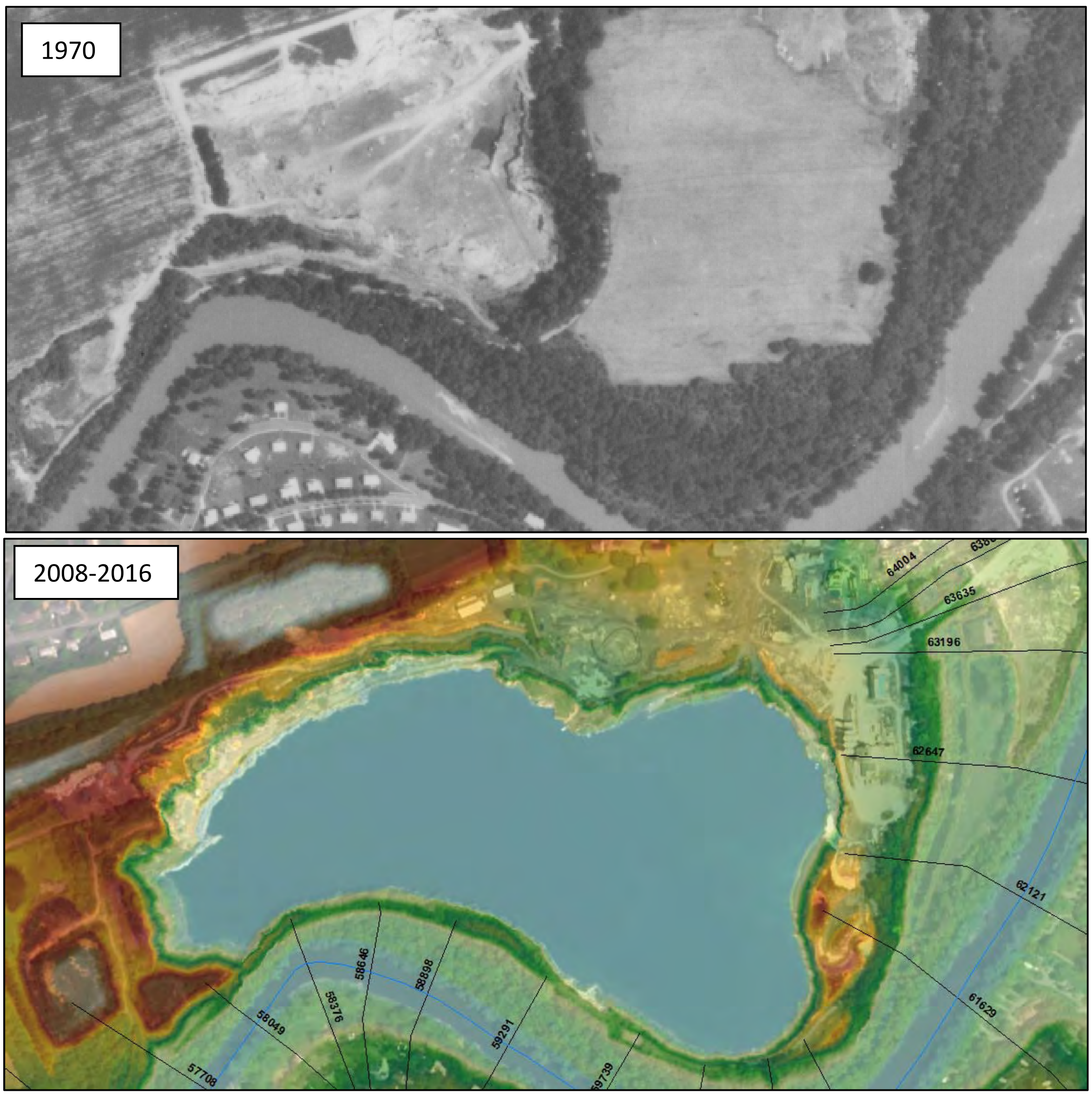
Table 2.14: Lateral Structures in the HEC-RAS Model

HEC-RAS Station	Location	Included in Geometry?		
		Agnes 1972	Calibration	Existing Conditions
60590	Hummelstown Quarry	No	Yes	Yes
38900	Fiddlers Elbow North Quarry	No	Yes	Yes
33200	Indian Echo Caverns and Karst Features	Yes	Yes	Yes
n/a	Fiddlers Elbow South Quarry	No	No	No

Hummelstown Quarry-Station 60590

Based upon aerial photography from 1970 and discussions with staff at Pennsy Supply, Inc., this quarry did not exist in June 1972 when Agnes flooding occurred (Figure 2.7). The quarry was in place during Lee in September 2011, and based upon the 2008 PASDA DEM, the bottom of the quarry (top of water) was at an approximate elevation of 192 feet (NAVD88). The approximate depth of the quarry at this time was 150 feet. For the calibration plan, the 2008 PASDA DEM was used to enter a lateral structure that is a 1229 feet long weir with a low elevation of 342.0 feet (NAVD88). The tailwater connection of this lateral structure was set to “out of the system”, as it is assumed the water would pond in this quarry without return to the Swatara Creek until pumping occurs.

Figure 2.7: Hummelstown Quarry



Fiddlers Elbow North Quarry-Station 38900

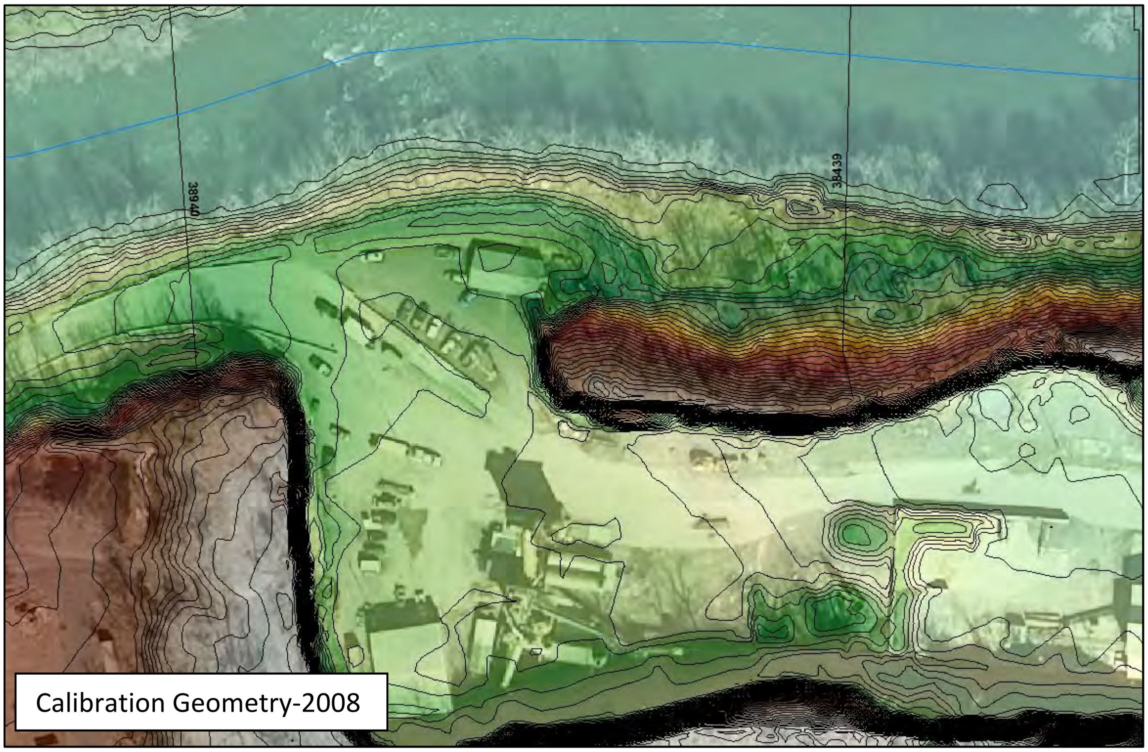
Based upon aerial photography from 1970 and discussions with staff at Pennsy Supply, Inc., and Indian Echo Caverns, this was just beginning to be developed June 1972 when Agnes flooding occurred (Figure 2.8). The quarry was in place during Lee in September 2011, and based upon the 2008 PASDA DEM, the bottom of the quarry (top of water) was at an approximate elevation of 246 feet (NAVD88). The approximate depth of the quarry at this time was 75.5 feet. For the calibration plan, the 2008 PASDA DEM was used to enter a lateral structure that is a 417 feet long weir with a low elevation of 321.5 feet (NAVD88). The tailwater connection of this lateral structure was set to “out of the system”, as it is assumed the water would pond in this quarry without return to the Swatara Creek until pumping occurs.

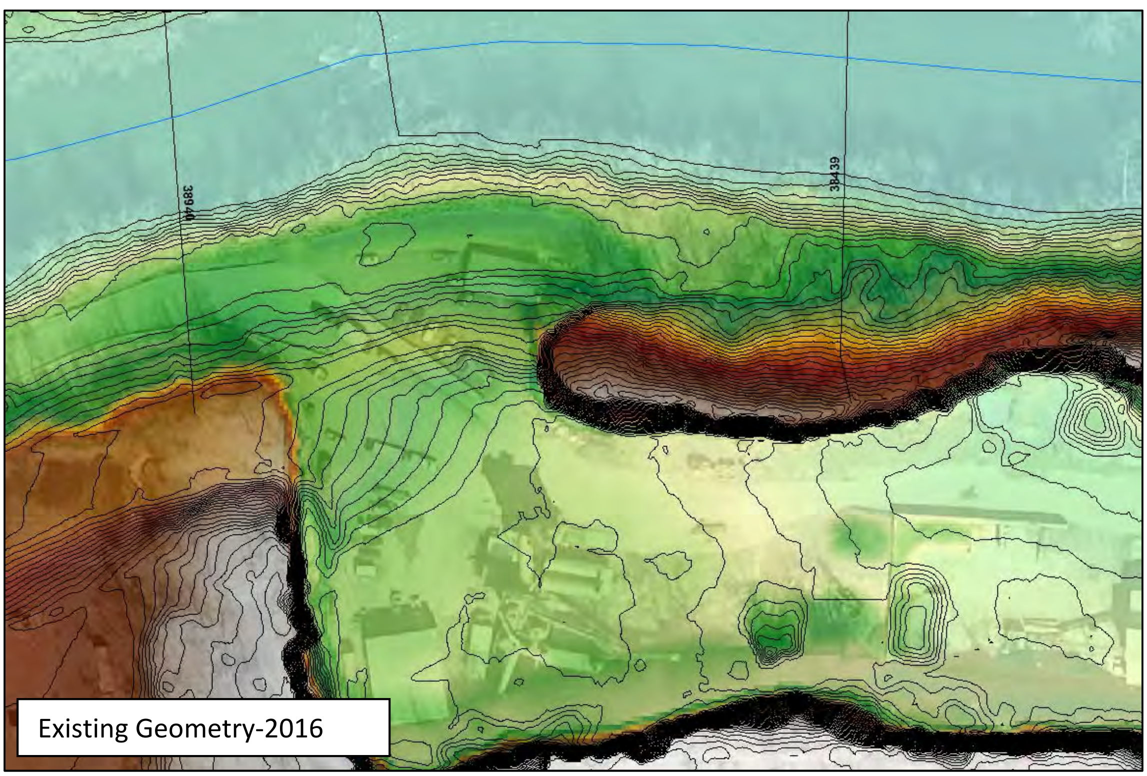
The entry point of floodwaters into this quarry is near the entrance on the western end near Fiddlers Elbow Road. During Lee in September 2011, this quarry sustained significant damages. Based upon discussions with Pennsy Supply, Inc. staff, flooding entered the quarry near the entrance, rushed down the hill eastward, destroying the existing buildings, and ponding in the quarry. The quarry later needed to be pumped out to remove the standing water.

Based upon high water marks at this location, flooding during Lee reach an elevation of approximately 332.3 feet (NAVD88), which would put the depth of flooding at the entry point well over 10 feet. Since the Lee event, Pennsy Supply, Inc. raised the elevation of the entrance to the quarry to protect their assets from future flooding (Figure 2.9). Thus, in the existing-conditions model, the 2016 project DEM was used to input the lateral structure. The existing-conditions lateral structure is a 308 ft. long weir with a low elevation of 335.0 feet (NAVD88). The depth of the quarry is roughly the same elevation as using the 2008 PASDA DEM, thus the same “out of system” approach was used for modeling this existing-conditions lateral structure.

Figure 2.8: Fiddlers Elbow North Quarry in 1970

Figure 2.9: Fiddlers Elbow North Quarry 2008-2016



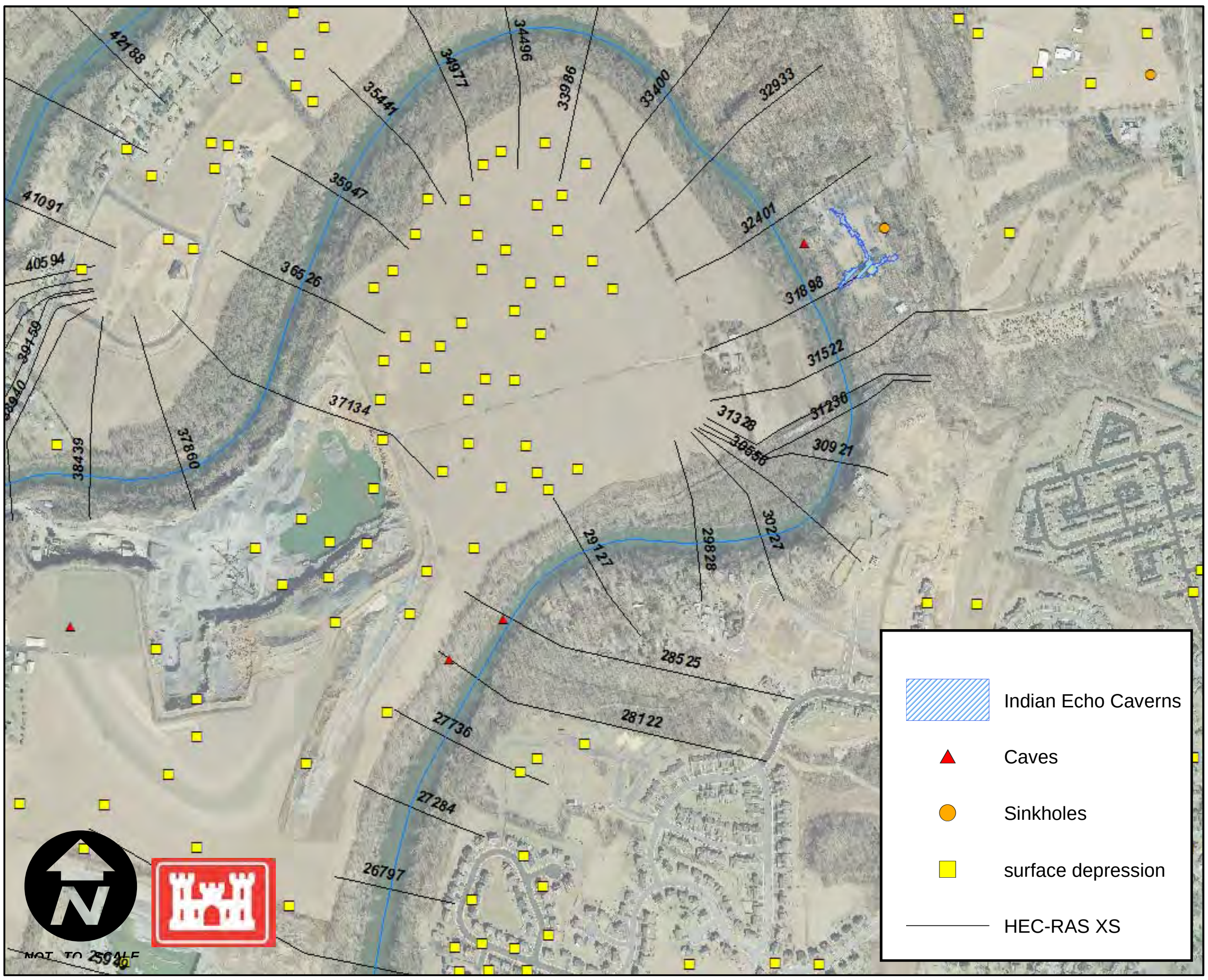


**2-ft contours shown*

Indian Echo Caverns and Karst Features-Station 33200

The lateral structure to account for the losses associated with Indian Echo Caverns and karst features is included in all geometries, as these below surface features were assumed to be present as-is since prior to Agnes in 1972. Indian Echo Caverns is one primary feature in the Epler Formation, which is carbonate rock that contains numerous caves, sinkholes, and surface depressions (Figure 2.10). The Indian Echo Caverns approach 50 ft. in depth in some locations.

Figure 2.10: Indian Echo Caverns and Karst Features



**Approximate location of Indian Echo Caverns from "Indian Echo Caverns Geology Map prepared by York Grotto National Speleogical Society" dated 1962 (provided by Indian Echo Caverns staff)*

Quantifying the amount of flow losses in this area would be difficult using physical data since the exact location and size (and amount of storage) of the underground features is unknown. Therefore, an approach was developed to model the losses due to underground caverns as lateral structures in the hydraulic model. The iterative process included modeling the losses using a lateral structure gate that was set at a size and elevation until the following criteria were met, which is based upon observed data in downstream locations:

1. Computed flood elevations for Lee in September 2011 match observed high water marks;

2. Computed flood elevations for Agnes in June 1972 match observed high water marks; and

3. Computed water surface elevations for more frequent, smaller flood events match observed water surface elevations at USGS 01573600-Swatara Creek at Middletown, PA, which is downstream of the loss reach.

The collection of high water mark data for Lee in September 2011 and Agnes in 1972 are discussed in Section 2.4.3. Since flow is not recorded at the Middletown gage, the calibration to more frequent, smaller flood events was accomplished by comparing flows from the Hershey gage and Middletown gage to determine storms that occurred that did not have any backwater influence from the Susquehanna River at the Middletown gage. This resulted in two storms being identified. The February 26, 2016 storm produced a peak flow of 10,300 cfs at the Hershey gage, which is approximately a 2-year storm. The flow from this storm produced a stage of 9.9 feet at the Middletown gage. The March 6, 2008 storm, which was approximately a 5-year storm, produced a peak flow of 17,400 at the Hershey gage and a stage of 14.8 feet at the Middletown gage. Results of the calibration to all events is located in Section 2.4.3.

This iterative process led to the use of a closed top overflow gate with a height of 10 feet, and width of 120 feet, and an invert elevation of 310.0 ft. (NAVD88) being used. This approach gives confidence in the theory that losses do occur as a result of the caverns and karst features, in that the quarries were present in September 2011 when Lee occurred, but were not present in 1972 during Agnes. Thus, by calibrating the models to both events with and without the quarries, there is a greater confidence in the losses associated with the geologic features (caverns and karst). In addition, by calibrating to the less frequent, smaller storm events, a higher level of confidence in the use of the invert elevation of 310.0 ft. is reached, as this is the time when losses would start in the model.

Fiddlers Elbow South Quarry

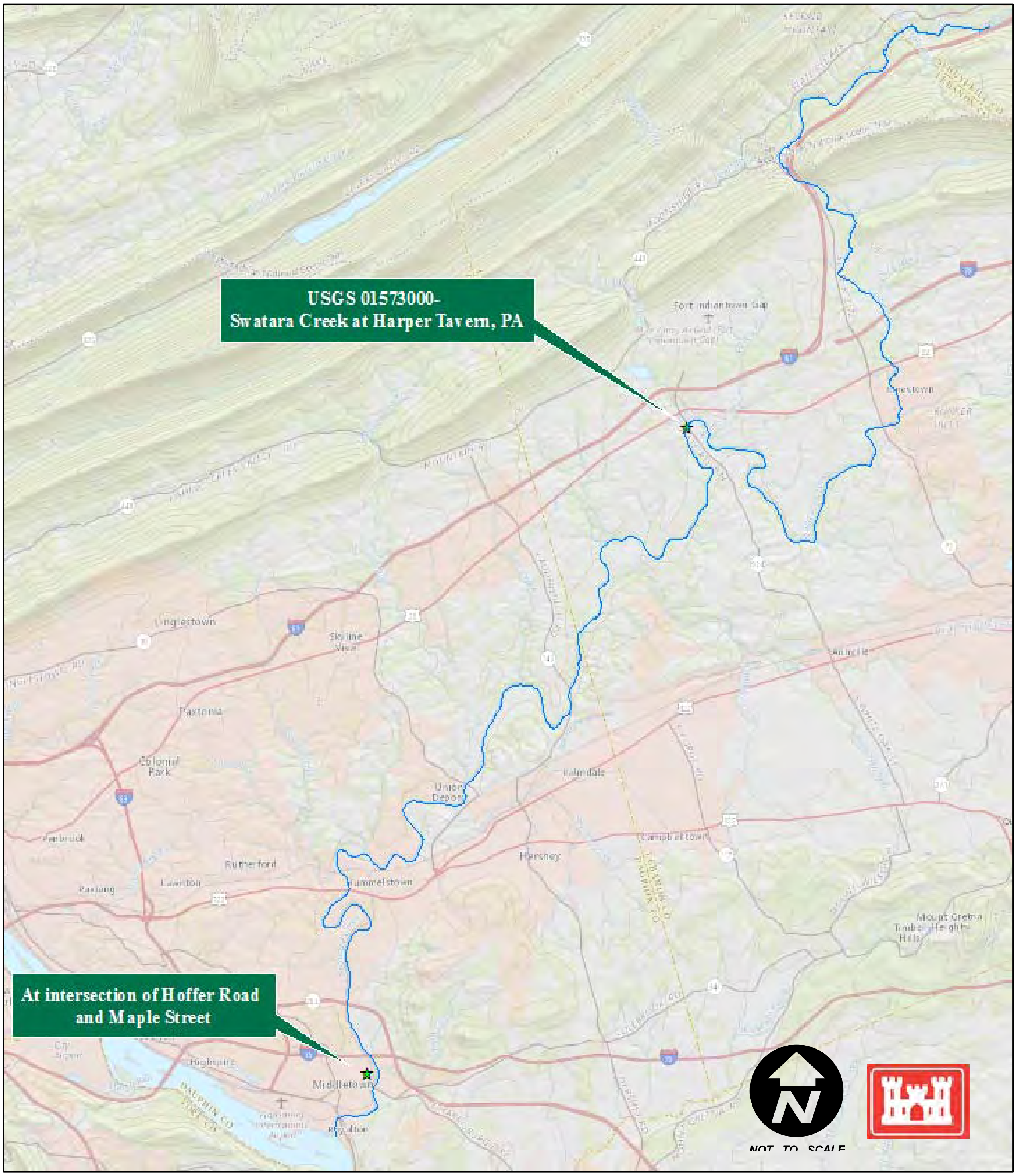
Based upon aerial photography from 1970 and discussions with staff at Pennsy Supply, Inc., and Indian Echo Caverns, this quarry was not present in 1972. In addition, based upon discussion with Pennsy Supply staff, this quarry had minimal storage capacity during the Lee in September 2011, and has since been shut down. Therefore, this quarry was not included as a lateral structure in any geometry file. The area is included in the geometry as a flood area, but is set as an ineffective flow area.

2.4.3. Calibration

Calibration of the HEC-RAS model was achieved primarily using the “Flow Roughness Factors” option in HEC-RAS, with additional minor tweaks to ineffective flow areas and contraction/expansion coefficients at bridges. The flow roughness factor option allows for the increase or decrease in roughness values for a reach as flow increases. Downstream of the Hershey gage, much of the calibration process relied heavily on the iterative process for accounting for flow losses to Indian Echo Caverns and karst features.

Several sources of data were used to calibrate the HEC-RAS model. For the Swatara Creek_Agnes 1972 plan, two points of calibration were used (Figure 2.11). These points include the measured stage/elevation at USGS 01573000- Swatara Creek at Harpers Tavern, PA, and a high water mark at the intersection of Hoffer Road and Maple Street in the Borough of Middletown.

Figure 2.11: High Water Marks for Swatara Creek_Agnes 1972 Plan



The high water mark at the intersection of Hoffer Road and Maple Street was taken from data in the November 1974 USACE report "*Tropical Storm Agnes, June 1972-Post Flood Report Volume II-Damage and Recovery*" (Reference 14). The elevation of this high water mark indicates that it was not a result of backwater from the Susquehanna River, as it is several feet higher than other high water marks in the primary backwater area in Middletown. Results of the calibration to this data is shown in Table 2.15.

Table 2.15: Calibration Results to Agnes in June 1972

HEC-RAS XS	Location	Flow (cfs)	Observed WSE (ft. NAVD88)	Computed WSE (ft. NAVD88)	Difference (ft.)
151086	At USGS 01573000	66700	379.7	379.5	-0.2
11501	At intersection of Hoffer Road and Maple Street	78282*	310.7	310.9	0.2

**Includes upstream flow loss from Indian Echo Caverns and Karst Features*

The Swatara Creek_Calibration plan was calibrated to high water marks from Lee in September 2011 and the rating curves for the USGS gages in Hershey, Harper Tavern, and Inwood (Figure 2.12). The high water marks from Lee in September 2011 were flagged by the USGS after the event and surveyed by Gannett Fleming, Inc. in April-June 2012. This work was completed for FEMA and is outlined in the July 2012 report "*High Water Mark Report-Susquehanna River Post Flood Investigations-Disaster Declaration DR-4030-PA*" (Reference 15).

Only high water marks that were noted as excellent, good, or fair were used in the calibration process. In addition, any high water marks downstream of Union Street were not used in the calibration process as these may have been influenced by backwater from the Susquehanna River.

At each USGS gage, the most recent rating curves were supplied by USGS. The models were then calibrated to all profiles included in the calibration plan. Table 2.16 shows the results of the calibration to the USGS rating curves in the Swatara Creek_Calibration plan, and Table 2.17 shows the results of the calibration to surveyed high water marks from Lee in September 2011.

In addition to the calibration to Lee in September 2011 and the USGS rating curves, the model was also calibrated to more frequent, smaller storm events at USGS 01573600-Swatara Creek at Middletown, PA (Figure 2.13) through the iterative process of setting the variables for the lateral structure for the Indian Echo Caverns and karst features at Station 33200. As discussed in Section 2.4.2, two storms were identified for calibration. These storms include the February 26, 2016 storm, which is approximately a 2-year storm, and the March 6, 2008 storm, which was approximately a 5-year storm. The results of the calibration to stages/elevations at USGS 01573600 is shown in Table 2.18.

During the calibration process, primary hydraulic variables were not changed between plans. The base roughness values, flow roughness factors, and all other hydraulic variables are identical in all geometric files and plans. Ineffective flow areas were slightly adjusted between plans based upon bridge overtopping. The results of the calibration process show the difference between observed and computed values generally less than +/- 0.5 ft. in most locations.

Figure 2.12: High Water Marks for Swatara Creek_Calibration Plan

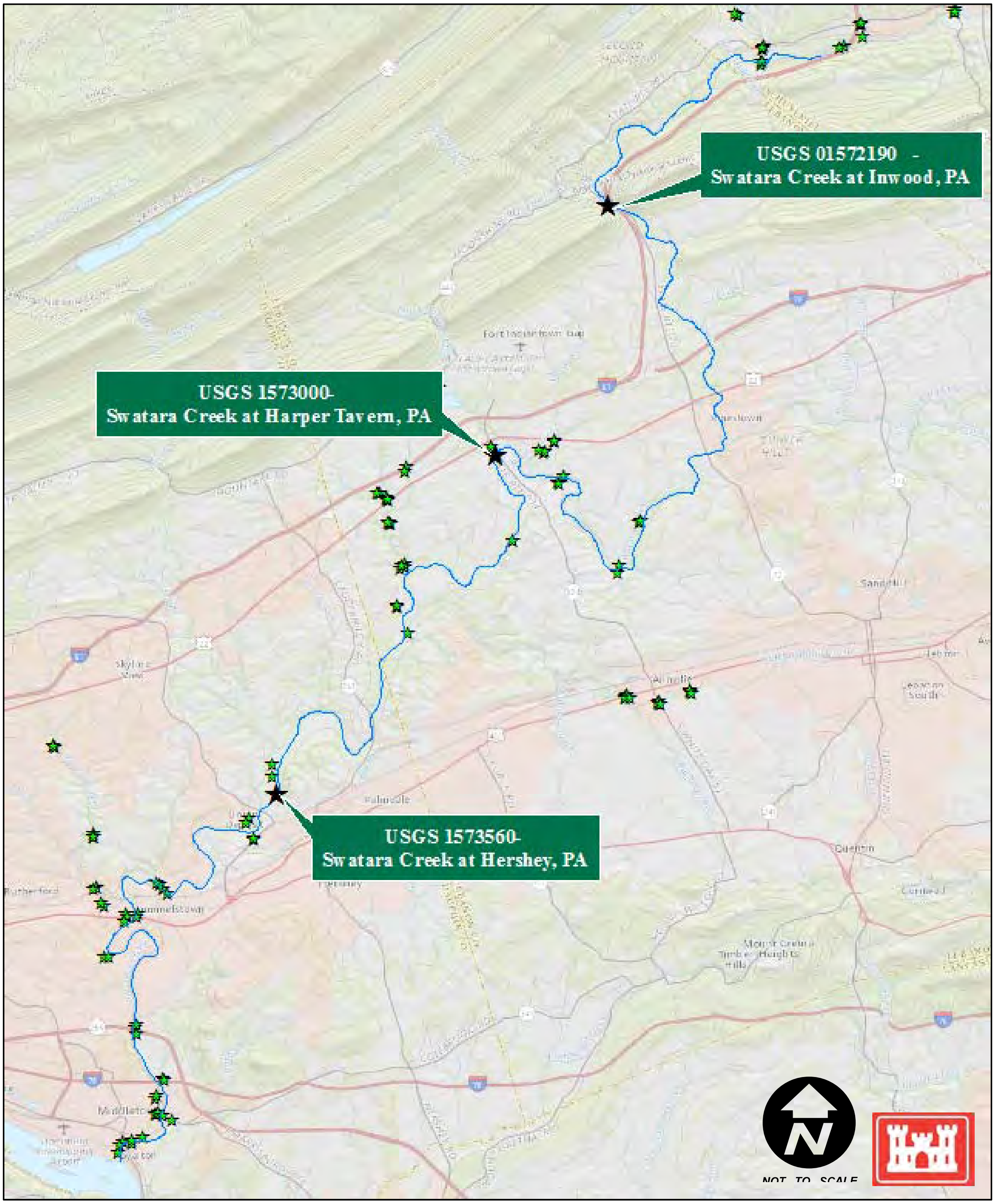


Table 2.16: Calibration Results to USGS Rating Curves in Swatara Creek_Calibration Plan

HEC-RAS XS	USGS Gage	Profile	Flow (cfs)	Observed WSE (ft. NAVD88)	Computed WSE (ft. NAVD88)	Difference (ft.)
239726	1572190- Inwood	2YR	4875	436.9	437.4	0.5
		5YR	8543	440.4	440.5	0.1
		10YR	11990	443.1	442.7	-0.4
		25YR	17850	446.3	445.8	-0.5
		50YR	23550	448.5	447.9	-0.6
		LEE	29500	449.9	449.8	-0.1
		100YR	30650	450.0	450.3	0.3
		200YR	40000	*	453.7	*
		100YRPLUS	41899	*	454.4	*
		500YR	54440	*	457.8	*
151086	1573000- Harper Tavern	2YR	9248	366.7	366.6	-0.1
		5YR	15250	370.5	370.3	-0.2
		10YR	20850	372.8	372.4	-0.4
		25YR	30320	375.3	375.2	-0.1
		50YR	39530	376.9	377.0	0.1
		100YR	50980	378.4	378.6	0.2
		200YR	65230	379.8	379.3	-0.5
		LEE	74800	380.5	380.7	0.2
		100YRPLUS	76910	380.6	380.4	-0.2
		500YR	89450	*	382.0	*
80429	1573560- Hershey	2YR	10200	333.0	333.3	0.3
		5YR	17330	336.3	336.2	-0.1
		10YR	24130	338.9	339.0	0.1
		25YR	35890	342.2	341.6	-0.6
		50YR	47530	344.8	344.8	0.0
		100YR	62240	347.4	347.8	0.4
		100YRPLUS	78470	350.0	349.4	-0.6
		200YR	80000	350.2	349.1	-1.1
		LEE	96900	352.5	351.7	-0.8
		500YR	112900	354.4	353.8	-0.6

**Rating does not extend to this flow value*

Table 2.17: Calibration Results to Lee in September 2011 in Swatara Creek_Calibration Plan

HEC-RAS XS	Location	Flow (cfs)	HWM ID	Observed WSE (ft. NAVD88)	Computed WSE (ft. NAVD88)	Difference (ft.)
272513	At Swopes Valley Road	23840	23600UR2	482.9	482.7	-0.2
239726	At USGS 01572190	29500	n/a	449.9	449.8	-0.1
184772	At Heilmandale Road	65418	19820DR3	401.9	401.1	-0.8
178019	At Ono Road	67295	19821DR3	397.3	397.2	-0.1
177842	At Ono Road	67295	19821DL3	397.1	396.9	-0.2
161420	At Yordy Bridge Road	69171	19855UR1	385.4	385.2	-0.2
161186	At Yordy Bridge Road	69171	19855UL1	385.3	385.1	-0.2
160896	At Yordy Bridge Road	69171	19855DL4	384.5	385.0	0.4
151527	At Bellgrove Road	74800	19841UR2	382.2	382.0	-0.2
151270	At Bellgrove Road	74800	01573000DL3	380.6	381.0	0.3
151086	At USGS 01573000	74800	n/a	380.5	380.7	0.2
139231	At Blacks Bridge Road	75251	19829UL2	375.9	375.2	-0.7
139134	At Blacks Bridge Road	75251	19829DL3	375.8	374.9	-0.9
123470	At Raccoon Creek	76003	19826DL2	369.9	369.9	0.0
117620	Upstream of Gravel Hill Road	77656	19825UR2	367.6	367.6	0.0
115769	Downstream of Gravel Hill Road	77656	19825DL3	367.4	367.4	0.0
83866	At Manada Creek	91939	UL161532	353.4	353.0	-0.4
82596	At Manada Creek	96900	UR161531	352.5	352.5	0.0
80429	At USGS 01573560	96900	n/a	352.5	351.7	-0.8
76890	Downstream of Hershey Road	96900	16261UR1	351.5	351.2	-0.3
74977	At Hanover Street	96900	16261DR3	350.5	350.5	-0.1

Table 2.17: Calibration Results to Lee in September 2011 in Swatara Creek_Calibration Plan (Continued)

HEC-RAS XS	Location	Flow (cfs)	HWM ID	Observed WSE (ft. NAVD88)	Computed WSE (ft. NAVD88)	Difference (ft.)
54889	Upstream of Duke Street	100112	16263UR1	340.2	339.4	-0.8
54231	Downstream of Duke Street	100112	16263DR3	340.3	340.7	0.4
47128	At Beaver Creek	100112	16259UR2	336.7	336.1	-0.6
45615	Upstream of Bridge Road	104819	16161UR2	335.3	336.2	0.9
45020	Downstream of Bridge Road	104819	16161DL3	335.3	335.7	0.4
44887	Upstream of U.S. Route 322	104819	16161DL4	335.0	335.2	0.2
43607	Downstream of U.S. Route 322	104819	16108DR4	333.5	333.0	-0.5
39256	At Fidddlers Elbow Road	104819	16215UR1	332.4	331.8	-0.6
39159	At Fidddlers Elbow Road	104819	16215DR3	332.3	332.0	-0.4
21084	Upstream of U.S. Route 283	74299*	16104UL1	315.4	316.2	0.8
20686	Upstream of U.S. Route 283	74299*	16104UL2	315.8	315.9	0.1
19945	Downstream of U.S. Route 283	74299*	16104DL3	314.6	314.7	0.1
14163	Between Vine Street at PA Turnpike	74590*	TPKUL1	311.4	311.4	0.0
12225	Hoffer Street area	74590*	TPKDR3	310.8	310.5	-0.3
11501	Hoffer Street area	76038*	TPKDR4	310.7	310.5	-0.2
9625	At Harrisburg Pike	76038*	16100UR2	310.0	309.5	-0.5
9494	At Harrisburg Pike	76038*	16100DR3	309.9	309.1	-0.8
4784	Upstream of Grubb Street	76471*	16115UR1	304.5	305.1	0.6
3446	At USGS 01573600	76471*	16115UL1	302.9	302.4	-0.5

* *Includes upstream flow loss from Indian Echo Caverns and Karst Features and Quarries*

Figure 2.13: Calibration to More Frequent, Smaller Storm Events in Swatara Creek_Calibration Plan

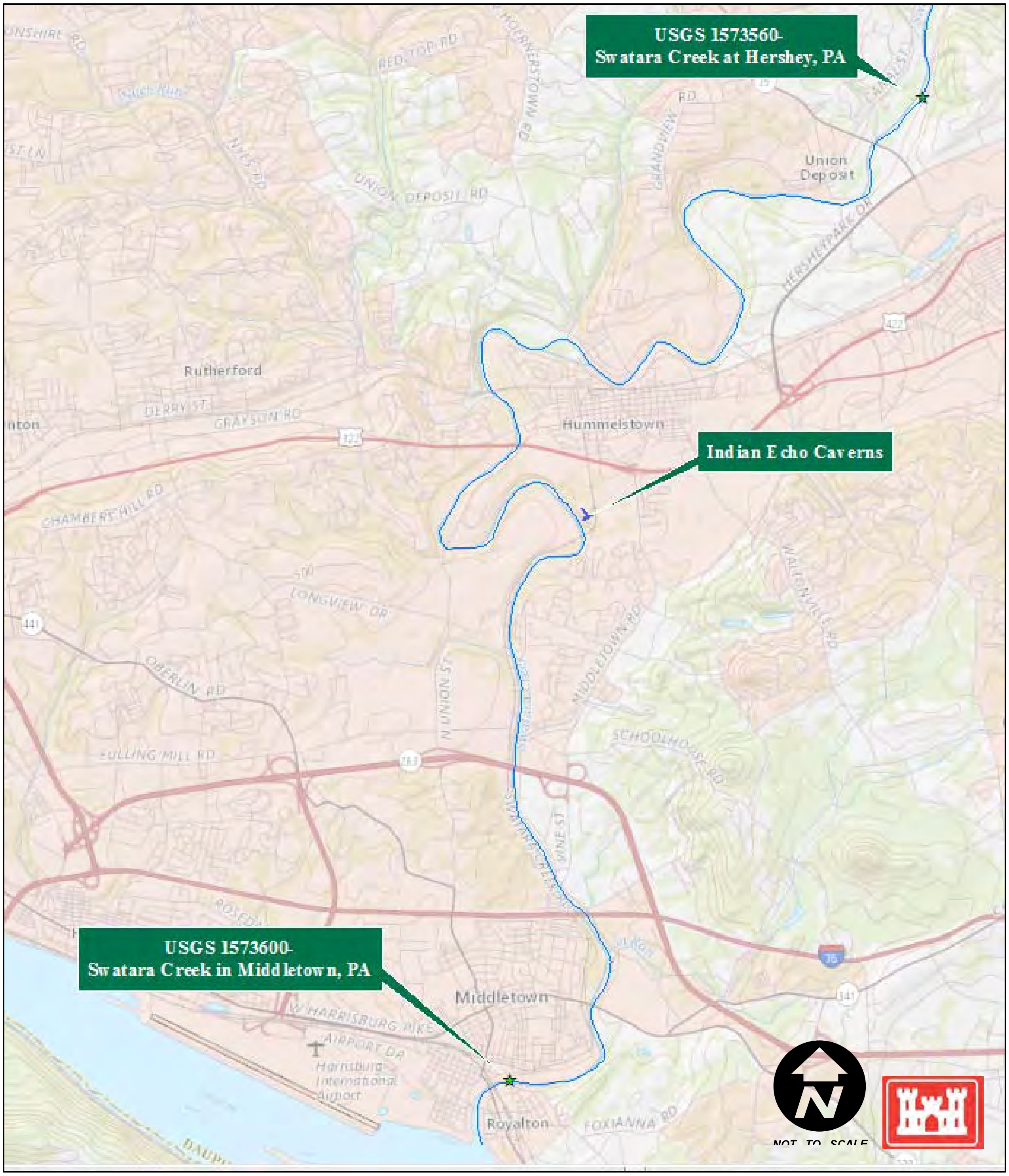


Table 2.18: Calibration Results for More Frequent, Smaller Flood Events in Swatara Creek_Calibration Plan

26-February 2016 Storm (Approximately 2-year Storm)						
HEC-RAS XS	Location	Flow (cfs)	Stage (ft.)	Observed WSE (ft. NAVD88)	Computed (ft. NAVD88)	Difference
80429	USGS 1573000-Hershey	10300	7.8	333.1	333.3	0.2
3446	USGS 1573600-Middletown	n/a	9.9	288.4	288.3	-0.1
6-March 2008 Storm (Approximately 5-year Storm)						
HEC-RAS XS	Location	Flow (cfs)	Stage (ft.)	Observed WSE (ft. NAVD88)	Computed (ft. NAVD88)	Difference
80429	USGS 1573000-Hershey	17400	11.1	336.3	336.3	0.0
3446	USGS 1573600-Middletown	n/a	14.8	293.4	293.4	0.0

2.4.4. Existing-Conditions Plan

The existing-conditions plan in this project was developed by using the calibrated geometry in the Swatara Creek_Calibration plan and using the project DEM (instead of the 2008 PASDA DEM) for the lateral structure at 38900 (Fiddlers Elbow North Quarry). The existing-conditions plan therefore includes channel, overbank, and bridge data current to Spring 2017, as well as the lateral structures at 60590 (Hummelstown Quarry), 38900 (Fiddlers Elbow North Quarry), and 33200 Indian Echo Caverns and Karst Features).

A summary of the results for the 1-percent annual chance flood and a comparison to the effective FIS values (at the time of this project) for the same reach is shown in Table 2.19.

Table 2.19: Existing-Conditions Results and Comparison to Effective FIS

HEC-RAS XS	County	Effective FEMA XS	1-percent annual chance flood elevation (ft. NAVD88)		Difference (ft.)
			Effective FEMA	Existing-Conditions	
279488	Schuylkill	XS 116 in the GG3 HEC-RAS model	486.5	486.7	0.2
239996	Lebanon	AS	448.4	450.4	2.0
239399	Lebanon	AR	447.5	450.2	2.7
237966	Lebanon	AQ	444.2	445.1	0.9
237480	Lebanon	AP	442.5	444.6	2.1
235973	Lebanon	AO	438.8	439.5	0.7
234710	Lebanon	AN	435.8	437.2	1.4
233208	Lebanon	AM	435.5	434.0	-1.5
232347	Lebanon	AL	435.0	433.7	-1.3

229806	Lebanon	AK	432.3	432.0	-0.4
228716	Lebanon	AJ	429.1	431.6	2.5
226790	Lebanon	AI	426.2	429.2	3.0
224005	Lebanon	AH	424.8	427.1	2.3
223334	Lebanon	AG	424.3	424.9	0.6
222852	Lebanon	AF	423.3	425.0	1.7
221154	Lebanon	AE	420.5	421.9	1.4
218850	Lebanon	AD	419.2	422.2	3.0
217005	Lebanon	AC	418.4	421.7	3.3
216143	Lebanon	AB	417.8	421.4	3.6
215160	Lebanon	AA	416.4	421.0	4.6
214321	Lebanon	Z	415.2	416.8	1.6
213343	Lebanon	Y	414.4	416.5	2.1
212533	Lebanon	X	414.2	416.1	1.9
210822	Lebanon	W	412.9	416.0	3.1
209598	Lebanon	V	412.9	415.9	3.0
208209	Lebanon	U	412.6	415.3	2.7
207227	Lebanon	T	411.8	415.0	3.2
199870	Lebanon	S	407.1	411.9	4.8
199743	Lebanon	R	406.5	408.8	2.3
198550	Lebanon	Q	406.1	409.6	3.5
198439	Lebanon	P	402.6	404.6	2.0
196380	Lebanon	O	401.4	403.8	2.4
193872	Lebanon	N	400.1	402.8	2.7
188739	Lebanon	M	399.6	400.0	0.4
186566	Lebanon	L	398.5	398.9	0.4
184879	Lebanon	K	397.9	398.2	0.3
181988	Lebanon	J	397.4	396.4	-1.0
179390	Lebanon	I	396.8	394.9	-1.9
178114	Lebanon	H	396.3	394.1	-2.2
177478	Lebanon	G	395.4	393.0	-2.4
176111	Lebanon	F	394.8	392.3	-2.5
174240	Lebanon	E	394.4	391.3	-3.1
125030	Lebanon	D	366.1	367.6	1.5
122904	Lebanon	C	364.6	366.7	2.1
121524	Lebanon	B	362.8	365.5	2.7
117407	Lebanon	A	361.9	364.6	2.7
109133	Dauphin	CU	357.7	362.4	4.7
108515	Dauphin	CT	357.6	362.4	4.8
107957	Dauphin	CS	357.5	362.2	4.7
106066	Dauphin	CR	357.0	361.7	4.6

103960	Dauphin	CQ	356.3	359.2	2.9
103385	Dauphin	CP	356.1	358.5	2.3
101546	Dauphin	CO	352.7	357.5	4.8
100310	Dauphin	CN	352.3	357.3	5.0
99721	Dauphin	CM	351.8	357.0	5.2
98939	Dauphin	CL	351.7	356.3	4.6
97903	Dauphin	CK	350.9	355.4	4.4
96208	Dauphin	CJ	350.4	354.6	4.2
94307	Dauphin	CI	349.7	353.7	4.0
93502	Dauphin	CH	349.0	353.3	4.3
92457	Dauphin	CG	348.7	352.8	4.1
90840	Dauphin	CF	347.8	352.0	4.2
89441	Dauphin	CE	347.5	351.3	3.8
88496	Dauphin	CD	347.2	350.8	3.6
87001	Dauphin	CC	346.9	350.0	3.0
83145	Dauphin	CB	345.9	348.7	2.8
81782	Dauphin	CA	345.7	348.2	2.5
80429	Dauphin	BZ	345.5	347.8	2.3
78479	Dauphin	BY	345.3	347.5	2.2
77692	Dauphin	BX	344.6	347.3	2.7
77285	Dauphin	BW	344.4	347.1	2.7
76890	Dauphin	BV	344.3	347.2	2.9
76561	Dauphin	BU	344.1	347.2	3.1
76255	Dauphin	BT	343.8	347.1	3.3
74977	Dauphin	BS	343.6	346.7	3.1
74584	Dauphin	BR	343.5	346.8	3.3
73566	Dauphin	BQ	343.1	346.6	3.5
70708	Dauphin	BP	342.4	345.8	3.4
68637	Dauphin	BO	341.8	345.4	3.6
67038	Dauphin	BN	340.6	344.5	3.9
64004	Dauphin	BM	339.9	343.9	4.0
63196	Dauphin	BL	339.8	342.9	3.1
60959	Dauphin	BK	339.2	342.3	3.1
60180	Dauphin	BJ	338.6	341.1	2.5
58049	Dauphin	BI	337.0	339.4	2.4
56888	Dauphin	BH	336.6	339.3	2.7
56716	Dauphin	BG	336.5	338.2	1.7
56319	Dauphin	BF	335.8	337.9	2.1
55760	Dauphin	BE	334.4	336.4	2.0
54688	Dauphin	BD	334.3	336.9	2.6
54451	Dauphin	BC	334.5	337.3	2.8

54231	Dauphin	BB	332.5	337.1	4.6
53838	Dauphin	BA	332.2	336.4	4.2
53169	Dauphin	AZ	332.2	336.5	4.3
52571	Dauphin	AY	331.9	336.6	4.7
52056	Dauphin	AX	331.2	336.5	5.3
50713	Dauphin	AW	330.1	336.2	6.1
49847	Dauphin	AV	329.7	334.5	4.8
49483	Dauphin	AU	329.3	334.6	5.3
48070	Dauphin	AT	327.9	333.7	5.8
47369	Dauphin	AS	327.9	333.8	5.8
46313	Dauphin	AR	326.7	331.9	5.2
45393	Dauphin	AQ	326.5	331.7	5.2
45165	Dauphin	AP	326.2	331.5	5.3
44754	Dauphin	AO	326.0	330.7	4.7
44329	Dauphin	AN	326.0	329.4	3.4
43607	Dauphin	AM	325.3	329.7	4.3
41721	Dauphin	AL	324.3	329.1	4.8
40021	Dauphin	AK	323.9	328.4	4.5
38940	Dauphin	AJ	323.4	327.3	3.8
37860	Dauphin	AI	322.4	326.1	3.6
37134	Dauphin	AH	321.8	324.0	2.2
35441	Dauphin	AG	320.9	323.7	2.7
33400	Dauphin	AF	319.2	319.9	0.7
30227	Dauphin	AE	316.4	317.5	1.1
29127	Dauphin	AD	315.1	317.0	1.9
27284	Dauphin	AC	314.1	316.2	2.1
25493	Dauphin	AB	313.3	315.1	1.8
23778	Dauphin	AA	312.2	314.2	2.0
22079	Dauphin	Z *(LOMR 15-03-0854P)*	311.8	312.7	0.9
21511	Dauphin	Y *(LOMR 15-03-0854P)*	311.7	313.3	1.6
21084	Dauphin	X *(LOMR 15-03-0854P)*	311.5	313.1	1.6
20686	Dauphin	W *(LOMR 15-03-0854P)*	311.3	312.8	1.5
19945	Dauphin	V	310.3	311.9	1.6
18804	Dauphin	U	310.0	311.3	1.3
17273	Dauphin	T	309.5	310.9	1.4
15177	Dauphin	S	307.9	309.7	1.7
14163	Dauphin	R	307.7	308.8	1.1
13428	Dauphin	Q	307.2	308.5	1.3
12729	Dauphin	P	306.7	308.0	1.3
12225	Dauphin	O	306.3	307.9	1.6
11028	Dauphin	N	306.2	307.5	1.3

10119	Dauphin	M	305.8	307.2	1.4
8278	Dauphin	L	304.3	305.8	1.4
7345	Dauphin	K	303.4	304.9	1.5
6497	Dauphin	J	302.4	302.1	-0.3
5160	Dauphin	I	301.5	301.1	-0.4
3916	Dauphin	H	298.8	300.8	2.0

2.4.5. Floodway Analyses

A floodway encroachment analysis was completed for Swatara Creek for the project hydraulic study reach. Because lateral structures were used in the model, the floodway flows would differ from the existing-conditions flows as the floodplain becomes encroached, because more flow would be pushed into the flow loss areas. Therefore, a separate geometry file was prepared for the floodway analysis in which the optimization option for the lateral structures were disabled, and a separate flow file for the floodway analysis was created which contained the discharge (optimized) results from the existing-conditions model. This assured that the floodway plan used the same flow values as the optimized existing-conditions plan, which accounts for flow losses.

Using equal conveyance reduction, Method 4 in HEC-RAS and a target water surface elevation of 1.0 ft. was used to initially locate the encroachment stations in the floodway plan. These encroachment stations were then imported into Method 1 and manually adjusted in order to (1) achieve a surcharge between 0.0-1.0 ft. and (2) maintain a floodway width that creates a smooth transition between cross-sections. Table 2.20 shows the results of the floodway analysis and a comparison with the effective floodway widths (at the time of this project).

Table 2.20: Existing-Conditions Floodway Widths and Comparison to Effective FIS

HEC-RAS XS	County	Effective FEMA XS	Floodway Width (feet)		Difference (ft.)
			Effective FEMA	Existing-Conditions	
239996	Lebanon	AS	265	246	-19
239399	Lebanon	AR	208	268	60
237966	Lebanon	AQ	157	305	148
237480	Lebanon	AP	182	162	-20
235973	Lebanon	AO	576	518	-58
234710	Lebanon	AN	905	851	-54
233208	Lebanon	AM	1356	1344	-12
232347	Lebanon	AL	1111	1124	13
229806	Lebanon	AK	1053	1069	16
228716	Lebanon	AJ	852	958	106
226790	Lebanon	AI	658	591	-67
224005	Lebanon	AH	770	910	140
223334	Lebanon	AG	784	561	-223
222852	Lebanon	AF	650	739	89
221154	Lebanon	AE	354	385	31
218850	Lebanon	AD	973	992	19

217005	Lebanon	AC	782	1112	330
216143	Lebanon	AB	914	1043	129
215160	Lebanon	AA	541	559	18
214321	Lebanon	Z	412	418	6
213343	Lebanon	Y	570	788	218
212533	Lebanon	X	865	773	-92
210822	Lebanon	W	964	1836	872
209598	Lebanon	V	1507	2101	594
208209	Lebanon	U	1210	873	-337
207227	Lebanon	T	1196	1537	341
199870	Lebanon	S	263	174	-89
199743	Lebanon	R	253	147	-106
198550	Lebanon	Q	786	517	-269
198439	Lebanon	P	720	517	-203
196380	Lebanon	O	716	840	124
193872	Lebanon	N	819	1170	351
188739	Lebanon	M	725	747	22
186566	Lebanon	L	980	1070	90
184879	Lebanon	K	929	899	-30
181988	Lebanon	J	871	913	42
179390	Lebanon	I	880	808	-72
178114	Lebanon	H	434	683	249
177478	Lebanon	G	576	599	23
176111	Lebanon	F	482	519	37
174240	Lebanon	E	559	688	129
125030	Lebanon	D	812	1079	267
122904	Lebanon	C	700	816	116
121524	Lebanon	B	538	595	57
117407	Lebanon	A	1609	1992	383
109133	Dauphin	CU	710	821	111
108515	Dauphin	CT	776	964	188
107957	Dauphin	CS	827	954	127
106066	Dauphin	CR	795	1025	230
103960	Dauphin	CQ	774	987	213
103385	Dauphin	CP	565	717	152
101546	Dauphin	CO	740	949	209
100310	Dauphin	CN	835	878	43
99721	Dauphin	CM	596	766	170
98939	Dauphin	CL	556	561	5
97903	Dauphin	CK	398	508	110
96208	Dauphin	CJ	491	629	138

94307	Dauphin	CI	673	770	97
93502	Dauphin	CH	470	526	56
92457	Dauphin	CG	503	596	93
90840	Dauphin	CF	481	938	457
89441	Dauphin	CE	557	805	248
88496	Dauphin	CD	719	820	101
87001	Dauphin	CC	735	831	96
83145	Dauphin	CB	784	1096	312
81782	Dauphin	CA	749	906	157
80429	Dauphin	BZ	953	1132	179
78479	Dauphin	BY	1068	1169	101
77692	Dauphin	BX	755	1016	261
77285	Dauphin	BW	784	1031	247
76890	Dauphin	BV	1049	1442	393
76561	Dauphin	BU	1032	1424	392
76255	Dauphin	BT	1008	1285	277
74977	Dauphin	BS	1042	1092	50
74584	Dauphin	BR	826	1244	418
73566	Dauphin	BQ	807	1215	408
70708	Dauphin	BP	817	1042	225
68637	Dauphin	BO	673	933	260
67038	Dauphin	BN	374	658	284
64004	Dauphin	BM	828	997	169
63196	Dauphin	BL	828	633	-195
60959	Dauphin	BK	351	371	20
60180	Dauphin	BJ	572	368	-204
58049	Dauphin	BI	405	265	-140
56888	Dauphin	BH	353	278	-75
56716	Dauphin	BG	284	260	-24
56319	Dauphin	BF	278	306	28
55760	Dauphin	BE	258	308	50
54688	Dauphin	BD	317	325	8
54451	Dauphin	BC	405	434	29
54231	Dauphin	BB	486	506	20
53838	Dauphin	BA	764	730	-34
53169	Dauphin	AZ	960	1034	74
52571	Dauphin	AY	847	1208	361
52056	Dauphin	AX	1143	1209	66
50713	Dauphin	AW	822	794	-28
49847	Dauphin	AV	482	579	97
49483	Dauphin	AU	472	589	117

48070	Dauphin	AT	291	627	336
47369	Dauphin	AS	600	393	-207
46313	Dauphin	AR	754	1006	252
45393	Dauphin	AQ	611	1042	431
45165	Dauphin	AP	593	1025	432
44754	Dauphin	AO	464	485	21
44329	Dauphin	AN	557	386	-171
43607	Dauphin	AM	378	344	-34
41721	Dauphin	AL	654	824	170
40021	Dauphin	AK	556	670	114
38940	Dauphin	AJ	464	496	32
37860	Dauphin	AI	284	299	15
37134	Dauphin	AH	273	290	17
35441	Dauphin	AG	291	295	4
33400	Dauphin	AF	257	284	27
30227	Dauphin	AE	308	381	73
29127	Dauphin	AD	277	223	-54
27284	Dauphin	AC	294	302	8
25493	Dauphin	AB	368	293	-75
23778	Dauphin	AA	515	484	-31
22079	Dauphin	Z *(LOMR 15-03-0854P)*	400	357	-43
21511	Dauphin	Y *(LOMR 15-03-0854P)*	639	950	311
21084	Dauphin	X *(LOMR 15-03-0854P)*	653	748	95
20686	Dauphin	W *(LOMR 15-03-0854P)*	729	636	-93
19945	Dauphin	V	794	579	-215
18804	Dauphin	U	1076	598	-478
17273	Dauphin	T	874	1126	252
15177	Dauphin	S	564	573	9
14163	Dauphin	R	982	820	-162
13428	Dauphin	Q	659	597	-62
12729	Dauphin	P	687	826	139
12225	Dauphin	O	911	914	3
11028	Dauphin	N	1193	1390	197
10119	Dauphin	M	1644	1775	131
8278	Dauphin	L	645	1177	532
7345	Dauphin	K	395	697	302
6497	Dauphin	J	321	367	46
5160	Dauphin	I	422	568	146
3916	Dauphin	H	248	540	292

2.4.6. Profiles

The FEMA RASPLOT Program (Version 3.0) was used to complete flood profiles Swatara Creek. Minor drawdowns in water surface elevations were automatically corrected in RASPLOT. Backwater elevations from the Susquehanna River were not included on the profiles. Profiles are located in Appendix G.

2.4.7. Upstream Tie-In

As noted in Section 1.1, the upstream limit of the hydraulic modeling in this project ties into a HEC-RAS model completed by GG3 Joint Venture for FEMA in February 2013 under Task Order HASFE03-12-J-0008 of Contract No. HASFE03-08-D0007 (Reference 1).The results of this project impacts the upstream study reach in three ways: (1) the XS stations need to be re-numbered in order to be in the distance, in feet, upstream of the confluence with the Susquehanna River. XS 279488 in this projects model is the same as XS 116 in the GGS HEC-RAS model. Therefore, a distance of 279372 would need to be added to the GG3 HEC-RAS model stations; (2) the upstream HEC-RAS model should use “known water surface elevation” as the downstream boundary condition from this projects model (instead of normal depth) and (3) the current project updated the flow estimates for the GG3 reach, which would impact water surface elevations for the entire reach.

A revised HEC-RAS model for the upper reach, incorporating these changes, is provided for FEMA in the deliverables for this project. Tables showing the changes in water surface elevations as a result of these revisions is provided in Appendix H.

2.4.8. Potential Conditions Scenario

A “potential-conditions” plan was developed in this project (SwataraCreek_PotentialConditions). This was developed as a tool for local floodplain managers to assess the potential flooding, especially in areas downstream of Hummelstown, should changes (natural or man-made) in the watershed occur that result in the reduction or elimination of flood losses to the Indian Echo Caverns, karst features, or quarries.

For the quarries, the Fiddlers Elbow North Quarry has already had improvements made to prevent flooding of the quarry, but those improvements have eliminated an estimated 4.3-percent of flow losses during a 1-percent annual chance flood event (100-year). Table 2.21 outlines the flow losses from the calibration plan, which reflects conditions during Lee in September 2011, and it also shows the flow losses in the existing-conditions plan, and how watershed changes can occur that will impact the flow downstream of Hummelstown and water surface elevations extending further upstream of Hummelstown.

Anticipated changes could include the removal or alteration to the Hummelstown Quarry that could minimally impact less frequent, higher flow events. Other changes that could cause the potential-conditions scenario to come to fruition would be changes to the karst features, such as underground changes that could block passageways of water or reduce storage capacity of underground karst features. In addition, another potential scenario, which would have a low probability of occurrence, would be two significant events occurring days apart where the underground storage areas would not have the opportunity to drain back into Swatara Creek to replenish the storage capacity.

The potential-conditions plan, therefore, does not include any flow losses via lateral structures. All lateral structures were removed from this plan, and the only other changes to the geometry were adjusting ineffective flow areas to account for bridge overtopping. Flow values from Table 2.9 would be valid in the

Table 2.21: Flow Losses at Lateral Structures

HEC-RAS XS	Lateral Structure	Storm Event	2011- Flow Loss %	Existing Conditions- Flow Loss %
60590	Hummelstown Quarry	10-yr	0.0%	0.0%
		25-yr	0.0%	0.0%
		50-yr	0.0%	0.0%
		100-yr	0.0%	0.0%
		Lee	1.4%	n/a
		500-yr	3.6%	4.1%
38900	Fiddlers Elbow North Quarry	10-yr	0.0%	0.0%
		25-yr	0.0%	0.0%
		50-yr	0.5%	0.0%
		100-yr	4.3%	0.0%
		Lee	11.8%	n/a
		500-yr	13.9%	0.0%
33200	Indian Echo Caverns and Karst Features	10-yr	5.7%	5.7%
		25-yr	12.0%	12.0%
		50-yr	15.9%	15.9%
		100-yr	17.5%	17.5%
		Lee	21.4%	n/a
		500-yr	21.3%	20.2%

potential-conditions plan as no losses from lateral structures would occur. The results of the potential-conditions plan show an increase in 1-percent annual chance flood (100-year) elevations as far upstream as XS 93502 (increase of 0.1 ft.), a maximum increase of 4.7 ft. at XS 33400, with generally an increase of 1.0-2.0 ft. downstream of Fiddlers Elbow Road and 0.1-1.0 feet upstream of Fiddlers Elbow Road. A summary of the results for the 1-percent annual chance flood and a comparison between the effective FIS values (at the time of this project), existing-conditions, and potential-conditions is located in Appendix I, along with a map showing the potential-conditions 1-percent annual chance floodplain.

2.4.9. Quality Assurance Review

The HEC-RAS modeling completed in this investigation was reviewed by the U.S. Army Corps of Engineers-Philadelphia District. A quality control review certification is included in Appendix C of this document. The FEMA CHECKRAS Program was used on the HEC-RAS model to assure the model complied with FEMA specifications.

2.4.10. Exceptions

- Bridge changes over time was not reflected in the different hydraulic models. For example, Duke Street was replaced in Hummelstown in 2015. The existing bridge is in the geometry for the SwataraCreek_Agnes1972 plan even though that bridge was not in place at the time. A review of the bridge changes was conducted and it was determined that the changes would have minimal impact to the modeling or calibration process.

- A low flow weir exists downstream of XS 205885. This weir was visited during the field survey and determined to not significantly impact flooding on Swatara Creek, even during smaller, more frequent flood events. Therefore, this weir was not included in the model.

2.4.11. Conclusions

The USACE HEC-GeoRAS program was used to develop basic input attributes to export to the USACE HEC-RAS (version 5.0.3) program, which calculated water surface elevations for the 10-, 25-, 50-, 100-, 100Plus-, and 500-year floods for Swatara Creek in Dauphin, Lebanon, and Schuylkill Counties, Pennsylvania. The HEC-RAS model includes several plan files developed for the calibration process, and the existing-conditions plan considers flow losses to two quarries and caverns and karst features. A potential-conditions plan was also developed to assist floodplain management in the area, which does not consider flow losses.

2.4.12. Required Hydraulic Data Deliverables

The required deliverables for the hydraulic analysis, shown in Table 2.22, were submitted to the FEMA MIP at:
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload\Hydraulics\2173210
J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload\Hydraulics\2173210
J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload\Hydraulics\2173210

Table 2.22: Hydraulic Data Deliverables

Required Deliverable	Provided	Location	Format
General Project Narrative / Hydraulics Report	Yes	This TSDN, also MIP	PDF
P.E. or PLS Certification	Yes	Appendix A of This TSDN, also MIP	PDF
Hydraulics Metadata	Yes	MIP	XML
Correspondence	Yes	Appendix B of this TSDN, also MIP	PDF
Simulations	Yes	MIP	Input and Output Files - Native Format
Supplemental Data	Yes	MIP	Native Format
Spatial Files	Yes	MIP (S_BFE if applicable, S_Fld_Haz_Ar, S_Gen_Struct, S_HWM if applicable, S_Levee if applicable, S_Profil_Basln,	SHP/pGDB/fGDB

		S_Riv_Mrk, S_Stn_Start, S_Submittal_Info, S_XS)	
FIS Report Files	Yes	This TSDN, also MIP, L_ L_Mannings_N, L_Profil_Bkwtr_El if applicable, L_Profil_Label, L_Profil_Panel, L_Source_Cit, L_Summary_Elevations if applicable, L_XS_Elev, L_XS_Struct	DBF/MDB/GDB
QA/QC	Yes	Appendix C of this TSDN, also MIP	PDF

2.4.13. FIS Report Tables

See Appendix E for the following FIS Report tables required as part of Perform Hydraulic Analyses which are applicable to this study, all of which are derived from data in the FIRM Database:

- Table 2, Flooding Sources Included in this FIS Report
- Table 7, Summary of Hydrologic and Hydraulic Analyses
- Table 14, Roughness Coefficients
- Table 24, Floodway Data
- Table 29, Summary of Contracted Studies Included in this FIS Report

2.5. Perform Floodplain Mapping

The results of the HEC-RAS modeling for Swatara Creek were used to create digital floodplain mapping for the 1-percent annual chance flood, 0.2-percent annual chance flood, and regulatory floodway. The HEC-GeoRAS post-processor and the project DEM were used to delineate the floodplain and floodway boundaries.

2.5.1. Detailed Study Floodplain Mapping

The entire hydraulic study reach of Swatara Creek was mapped as a detailed study reach with a delineated regulatory floodway using the HEC-GeoRAS post-processor and the project DEM. This study supersedes the detailed flood study (Zone AE) for Swatara Creek in the 8/2/12 FEMA FIS for Dauphin County, Pennsylvania, the detailed flood study (Zone AE) and approximate flood study (Zone A) in the 6/5/2012 FEMA FIS for Lebanon County, Pennsylvania, and the approximate flood study (Zone A) in the 11/19/04 FEMA FIS for Schuylkill County, Pennsylvania.

2.5.2. Backwater Effects Mapping

Although backwater elevations are shown on the profile, backwater from the Susquehanna River was not mapped in this project. The layers created in the mapping process will be forwarded to FEMA for incorporation into the on-going revision to the Dauphin County FIS. The floodplain layer for the Susquehanna River and Swatara Creek will be merged by FEMA's mapping contractor.

2.5.3. Floodway Mapping

The entire hydraulic study reach of Swatara Creek was mapped as a detailed study reach with a delineated regulatory floodway using the HEC-GeoRAS post-processor and the project DEM.

2.5.4. Other Deliverables

Mapping of the other plans included in the HEC-RAS model was completed, but not post-processed (i.e. cleaned up") like the existing-conditions mapping. Therefore, GIS shapefiles are provided for the September 2011 (Lee) flood event, Agnes in 1972, and the potential-conditions plan. These boundaries are not included in the regulatory databases, but are provided as shapefiles on the project disc for FEMA's use.

2.5.5. Exceptions

- The Hummelstown Quarry (Station 60590), which is represented as a lateral structure in HEC-RAS, was not included in the flood mapping. Only the 500-year flood overtops the high ground surrounding the quarry; however, a detailed analysis of the estimated 500-year water surface elevation within the quarry was not conducted. A "Limit of Study" line was placed at this location in the mapping to show that the flooding will enter the quarry, but the quarry is not mapped.

- For large tributaries entering Swatara Creek, cross-sections in HEC-GeoRAS and HEC-RAS were not extended the entire length of the backwater area. This was done to increase the amount of station/elevation points in the effective flood area. Therefore, backwater up these tributaries were mapped outside of HEC-GeoRAS, by using the spatial analyst tool in ArcMap to generate a contour at the backwater elevations. This contour line was then smoothed and merged with the HEC-GeoRAS floodplains to map the backwater flood areas.

2.5.6. Conclusions

The results of the HEC-RAS modeling for Swatara Creek were used to create digital floodplain mapping for the 1-percent annual chance flood, 0.2-percent annual chance flood, and regulatory floodway.

2.5.7. Required Floodplain Mapping Deliverables

The required floodplain mapping deliverables, shown in Table 2.23, were submitted to the FEMA MIP at:
J:\R03\PENNSYLVANIA_42\DAUPHIN_043C\15-03-0142S\SubmissionUpload\Floodplain\2182597
J:\R03\PENNSYLVANIA_42\LEBANON_075C\15-03-0142S\SubmissionUpload\Floodplain\2182597
J:\R03\PENNSYLVANIA_42\SCHUYLKILL_107C\15-03-0142S\SubmissionUpload\Floodplain\2182597

Table 2.23: Floodplain Mapping Deliverables

Required Deliverable	Provided	Location	Format
General Project Narrative	Yes	This TSDN, also MIP Draft FIS Report – Word and PDF	DOCX/PDF
P.E. or PLS Certification	Yes	Appendix A of This TSDN, also MIP	PDF
Floodplain Metadata	Yes	MIP	XML
Correspondence	Yes	Appendix B of this TSDN, also MIP	PDF
Supplemental Data	Yes	MIP Rectified effective maps and any other data that was used to re-create effective profiles and delineations – Native format	Native Format
Spatial Files	Yes	MIP FIRM Database files as described in the FIRM Database Technical Reference Table 2 – SHP/PGDB/fGDB/GML	SHP/pGDB/fGDB
FIS Report Files	Yes	This TSDN, also MIP FIS Tables **(See Appendix E)** FIS text overflow for Principal Flood Problems and Special Considerations (if necessary), FIRM Database files as described in the FIRM Database Technical Reference Table 2	DBF MDB GDB XLS DOCX
QA/QC	Yes	Appendix C of this TSDN, also MIP	PDF

APPENDIX B

Corresponding Stages and WSELs

USGS 1573600: Swatara Creek at Middletown, PA

FIM	Stage (ft)	Elevation (NAVD88)	Flow Input to RAS(cfs)	Flow after Optimization	Condition
1	**2.7**	**285.5**	6320	6320	
2	**3.4**	**286.2**	7598	7598	
3	**4.3**	**287.1**	9301	9301	
4	**4.6**	**287.4**	9794	9794	
5	**5.5**	**288.3**	11597	11597	2YR
6	**5.8**	**288.6**	12113	12113	
7	**6.9**	**289.7**	13996	13996	
8	**7.1**	**289.9**	14463	14463	
9	**8.7**	**291.5**	16951	16951	
10	**10.4**	**293.2**	19514	19453	ACTION (10.0)
11	**10.6**	**293.4**	19909	19808	5YR
12	10.9	293.7	21162	20879	
13	11.1	293.9	22307	21832	FLOOD (11.0)
14	11.5	294.3	25060	24064	
15	11.8	294.6	27420	25900	10YR
16	11.9	294.7	28551	26774	
17	12.3	295.1	32279	29620	
18	12.8	295.6	36236	32596	
19	13.2	296.0	40752	35940	25YR
20	13.6	296.4	45413	39351	
21	14.1	296.9	51516	43852	
22	14.3	297.1	54409	45896	50YR
23	14.5	297.3	57015	47770	
24	15.0	297.8	63077	52737	MODERATE (15.0)
25	15.6	298.4	69444	57626	
26	15.8	298.6	70690	58512	100YR
27	16.3	299.1	76039	61856	
28	16.8	299.6	83113	64504	
29	18.3	301.1	90826	71788	MAJOR (18.0)
30	20.2	303.0	99232	78449	
31	22.2	305.0	109361	85825	
32	22.4	305.2	110884	86542	
33	23.9	306.7	117912	92323	
34	25.0	307.8	127388	98723	
35	24.4	307.2	128423	99455	500YR
36	25.0	307.8	137063	105450	
37	26.4	309.2	147331	111706	125% RATING

No rating curve at this gage. Values from calibrated model. Bold red uncertainty due to backwater conditions.

18 Major
15 Moderate
11 Flood
10 Action

USGS 1573560: Swatara Creek at Hershey, PA

Stage (ft)	Elevation (NAVD88)	Flow (cfs)	Condition
5.4	330.7	5500	*Action at Harper Tavern*
6.0	331.3	6642	ACTION
6.8	332.1	8150	*Flood at Harper Tavern*
7.0	332.3	8598	FLOOD
7.8	333.1	10201	2-YEAR
8.0	333.3	10669	
8.8	334.1	12350	*Moderate at Harper Tavern*
9.0	334.3	12772	
10.0	335.3	14931	MODERATE FLOOD
11.0	336.3	17188	
11.1	336.4	17327	5YR
11.6	336.9	18500	Major at Harper Tavern
12.0	337.3	19546	
13.0	338.3	22000	
13.7	339.0	24120	10YR
14.0	339.3	25148	MAJOR FLOOD
15.0	340.3	28482	
16.0	341.3	32000	
17.0	342.3	35895	25YR
18.0	343.3	40000	
19.0	344.3	44834	
19.5	344.8	47565	50YR
20.0	345.3	49958	
21.0	346.3	55376	
22.0	347.3	61087	
22.2	347.5	62265	100YR
23.0	348.3	67094	
24.0	349.3	73398	
25.0	350.3	80000	200YR
26.0	351.3	87405	
27.0	352.3	95176	
27.2	352.5	96935	LEE
28.0	353.3	103318	
29.0	354.3	111834	
29.1	354.4	112968	500YR
30.0	355.3	120726	
31.0	356.3	130000	125% RATING

USGS 1573000: Swatara Creek at Harper Tavern

Stage (ft)	Elevation (NAVD88)	Flow (cfs)	Condition
7	363.1	4783	ACTION
7.9	364.0	5752	
9	365.1	7174	FLOOD
9.4	365.5	7704	
10.7	366.8	9241	2-YEAR
11.0	367.1	9655	
12	368.1	11020	MODERATE FLOOD
12.3	368.4	11403	
13.4	369.5	13212	
14.4	370.5	15113	
14.5	370.6	15260	5YR
15	371.1	16200	MAJOR FLOOD
15.4	371.5	17118	
16.2	372.3	19116	
16.8	372.9	20870	10YR
17.1	373.2	21703	
17.8	373.9	24323	
18.5	374.6	27190	
19.3	375.4	30323	25YR
19.9	376.0	33500	
20.5	376.6	37205	
20.9	377.0	39538	50YR
21.2	377.3	41331	
21.8	377.9	45531	
22.3	378.4	50047	
22.4	378.5	50999	100YR
22.8	378.9	54949	
23.3	379.4	59888	
23.8	379.9	65217	200YR
24.2	380.3	70573	
24.4	380.5	74000	
24.5	380.6	74814	LEE
25.1	*381.2*	*82500*	
25.8	*381.9*	*88500*	
25.9	*382.0*	*89450*	500YR
26.8	*382.9*	*97000*	
28.0	*384.1*	*107000*	125% RATING AT HERSHEY

Red indicates model use to extend rating curve stages

USGS 1572190: Swatara Creek at Inwood

Stage (ft)	Elevation (NAVD88)	Flow (cfs)	Condition
7.1	433.2	2000	
8.3	434.4	2755	
9.4	435.5	3606	
9.8	435.9	3957	
10.8	436.9	4875	2YR
11.1	437.2	5108	
12.0	438.2	6004	
12.2	438.4	6208	
13.3	439.4	7317	
14.2	440.4	8403	
14.3	440.5	8543	5YR
14.7	440.9	9002	
15.3	441.4	9709	
16.2	442.3	10900	
17.0	443.1	11990	10YR
17.4	443.5	12507	
18.3	444.5	14052	
19.3	445.4	15888	
20.2	446.3	17850	25YR
21.0	447.2	19889	
21.9	448.1	22107	
22.3	448.5	23550	50YR
22.6	448.8	24719	
23.2	449.3	27000	
23.9	450.0	30000	
23.9	*450.0*	*30650*	100YR
25.1	*451.2*	*33200*	
26.3	*452.4*	*36500*	
27.6	*453.7*	*40000*	200YR
28.7	*454.8*	*43000*	
29.7	*455.8*	*46800*	
29.9	*456.0*	*47500*	
30.8	*456.9*	*50300*	
31.6	*457.7*	*54000*	
31.7	*457.8*	*54440*	500YR
32.3	*458.4*	*60000*	
34.2	*460.3*	*67200*	125% RATING AT HERSHEY

Red indicates model use to extentd rating curve stages