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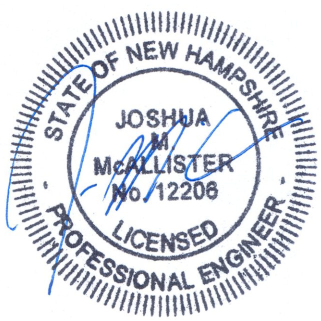
H&H ANALYSIS SUMMARY REPORT

HART'S LOCATION FLOODPLAIN MAPPING PROJECT
PHASE II
HART'S LOCATION, NEW HAMPSHIRE

Prepared for:
FB Environmental Associates
&
Town of Hart's Location

January 31, 2023



Prepared by:
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Project #2020-063

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I. INTRODUCTION

A. Background

HEB Engineers, Inc. (HEB) was contracted by FB Environmental Associates (FBE) to provide a field survey, as well as to carry out hydrologic and hydraulic analyses necessary to produce floodplain maps for the Saco River through the Town of Hart's Location. These maps will be used to define and enforce the Town's Floodplain Conservation District Ordinance. Eventually, the data may be submitted for formal review and acceptance by the Federal Emergency Management Agency (FEMA) into the National Flood Insurance Program (NFIP). This project was funded by the Clean Water State Revolving Fund, which is administered by the New Hampshire Department of Environmental Services (NHDES). This is the second phase of this project, the first phase was completed in June 2021.

This report has been produced to serve as the backing document for the data produced by HEB through hydrologic and hydraulic analyses. It will summarize the project approach and methodology, as well as data utilized and generated. As such, the data can be accessed and incorporated into future studies, including, but not limited to additional floodplain mapping efforts or review and acceptance by FEMA and the NFIP.

All of the data compiled, employed, or generated by HEB for floodplain mapping have been saved in a folder titled "Hart's Location Floodplain Mapping Data (HEB Jan. 2023)", which will be provided as a project deliverable to FBE and the Town of Hart's Location. Throughout this report, data files will be referenced using their respective locations within this folder.

B. HEB Scope of Work

The HEB Scope of Work for this project was divided into four main phases, as follows:

Phase 005: Data Preparation and Study Planning

Under Phase 005, HEB gathered background data and information necessary to proceed with subsequent phases of the project. This included attendance at project kickoff meetings, coordination with project partners to finalize project goals, the compilation and evaluation of existing data resources and guidelines, and the preparation of a survey plan to guide fieldwork.

Phase 006: Field Survey

Field Survey consisted of GPS and total station topographic survey necessary to supplement LiDAR data available for the area. The survey was completed for the main channel of the Saco River from the Saco's crossing of NH Route 302, shortly upstream of the Saco River's confluence with the Dry River (the upper extent of the field survey during the previous phase of this project), to Saco Lake. Fieldwork also included relevant hydraulic features

Phase 007: Hydrologic and Hydraulic Study

HEB's Phase 007 included the gathering of relevant hydrologic data summarizing flood discharge estimates, as well as the production of a functioning hydraulic model that depicted the extent of flooding, primarily during the 1-percent annual chance flood event, for the study reach.

Phase 008: Project Reporting

Project Reporting included the provision of data necessary to produce standalone floodplain maps, as well as that required for the inclusion of a floodplain layer in the Town's online GIS platform. Further, this report was written to summarize work completed by HEB and to facilitate the potential transfer of data and model components for eventual FEMA review.

II. WORKFLOW AND PROJECT IMPLEMENTATION

A. Data Preparation and Study Planning

The project was commenced during the summer of 2022 with a thorough information gathering and research process. HEB compiled and reviewed relevant FEMA resources and guidelines and evaluated potential applications of existing hydrologic data. These resources, as well as pre-survey site visits and a desktop review of river features and terrain, were used to develop a map of river cross-sections to be surveyed with GPS and total station equipment.

FEMA Resources and Relevance to Project Approach

With the understanding that the data produced through this project might eventually be submitted for inclusion in the National Flood Insurance Program, HEB reviewed relevant FEMA guidelines and protocols to ensure data was gathered and analyzed accordingly and to the extent practicable. FEMA documents reviewed during the Data Preparation and Study Planning phase include, among others:

- Flood Insurance Study (FIS) for Carroll County, New Hampshire (Effective: March 19, 2013)
- Guidance for Flood Risk Analysis and Mapping, General Hydraulics Considerations
- Guidance for Flood Risk Analysis and Mapping, Hydraulics: One-Dimensional Analysis
- Guidance for Flood Risk Analysis and Mapping, Hydraulics: Two-Dimensional Analysis
- Guidance for Flood Risk Analysis and Mapping, Mapping Base Flood Elevations on Flood Insurance Rate Maps

The most important conclusion drawn from the procedures outlined in these documents was that a one-dimensional (1-D) steady-state hydraulic model, utilizing discharge estimates generated through United States Geological Survey (USGS) regression equations, is the most common and appropriate technique utilized for producing a Flood Insurance Rate Maps (FIRM) under the FEMA NFIP, given the characteristics of study reach (e.g. size, development, slope, hydraulic features, etc.) Further, the Flood Insurance Study for Carroll County assisted in developing the limits of the study reach.

FEMA guidance documents are saved in the project deliverables folder (Path: Reference Materials\FEMA Guidance Documents and Resources)

Existing Hydrologic Data

No stream gages currently exist in the upper reaches of the Saco River to provide historical records of flood events through Hart's Location. Due to the distance upstream from the nearest existing gauges, located at the River Street Bridge in Bartlett, New Hampshire (USGS 010642505) and in Conway, New Hampshire (USGS 01064500), and relative watershed sizes; data from gauges could not be utilized to calculate and/or calibrate hydrologic data.

LiDAR Data Compilation

HEB accessed and compiled LiDAR topography data using the New Hampshire Statewide Geographic Information System Clearinghouse (NH GRANIT). It was confirmed that all necessary data were available for the study area. HEB utilized LiDAR hillshade imagery to determine the appropriate location, orientation, and spacing of river cross-sections to provide bathymetric topography that is otherwise obscured in LiDAR datasets. The data covering the project area was captured on May 20, 2017.

Survey Plan

A plan of proposed river cross-sections was developed for use by HEB surveyors in the field. As discussed previously, the survey was necessary to provide bathymetric data for the main channel of the Saco River and its major tributaries. LiDAR topography, as is the case with the data available for Hart's Location, typically does not accurately depict areas that were obscured by water during its production, resulting in a flat elevation at river sections with significant water depth present. Cross-sections were mapped and surveyed in a manner that would allow for interpolation of channel bathymetry and subsequent merging of this channel information with the LiDAR data available for the larger floodplain and surrounding areas (Path: Survey Data\Survey Sections Plan on USGS Topo.pdf).

Field Review of Survey Plan

The HEB hydraulic modeler and survey crew lead reviewed proposed cross-section locations along the study reach prior to the commencement of the survey. Exact cross-section locations and the overall goals of the survey were discussed. Potential approaches to the survey of particular sections were evaluated, such as the effectiveness and efficiency of GPS and/or total station survey based on aspects and surrounding vegetation or obstructions.

B. Field Survey

The field survey for this phase began in August of 2022 and was completed in November of 2022. In total, fifty-four (54) cross-sections were surveyed in and along the Saco River. Survey data was also gathered for hydraulic features including two (2) bridges along NH Route 302 and the Willey Pond Dam. Additional information, including recent 2017 survey information, was provided for the area around the Willey Pond Dam by David Krause from the State of New Hampshire.

A traverse network consisting of 49 main points, with secondary control spurs as needed in and adjacent to the riverbed were established with a total station from the nearest primary control point. Section data was gathered using a total station. After the survey, a total of seven primary survey control points were identified along the project corridor. Multiple redundant static GPS observations were taken between these seven control points and incorporated NGS/NHDOT benchmarks "207-0010," "207-0030," "207-0050," and "207-0060." The traverse network observations were adjusted using Least-Squares methods with Carlson SurvNET software was performed in order to finalize the coordinates and elevations of the river section data.

Survey points were processed into an AutoCAD file for comparison with the originally planned cross-section locations on a periodic basis. In general, while minor adjustments were made for some sections to better accommodate conditions encountered in the field, the surveyed sections aligned well with the plan developed as part of Phase 006 (Path: Survey Data\AutoCAD Files\2020-063-Survey 2022.dwg).

The horizontal datum used is NH State Plane Coordinate System NAD83(2011)(Epoch:2010.0000) and the vertical datum is NAVD88.

C. Hydrologic and Hydraulic Study

HEB completed both the hydrologic data gathering and the hydraulic modeling during this phase. Hydrologic data was gathered to estimate flood discharge estimates and hydraulic modeling was conducted to determine flooding extents through the project reach.

Hydrologic Calculations

A hydrologic analysis was conducted to summarize flood discharge estimates at the point of confluence for major tributaries as well as other key points along the Saco River in Hart's Location, NH. Discharge estimates for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance (2-year through 500-year) flood events were calculated for each location. The nearest discharge gages, located in Conway, NH (USGS Gage #01064500) and at River Street in Bartlett, NH (USGS Gage #010642505), both have watersheds more than 1.5 times that of any point along the study reach. For this reason, data from existing gages could not be used to estimate flood discharges. Standard regression equations, from the USGS StreamStats application, we utilized to estimate flood discharges for relevant events.

Hydraulic Model

A 1-D steady-state hydraulic model was developed using the Hydrologic Engineering Center's River Analysis System (HEC-RAS). As confirmed by relevant guidance documents, this modeling approach and software are widely accepted and commonly utilized for producing a FEMA Flood Insurance Study and corresponding FIRMs. In particular, this methodology is appropriate for a study reach in which there are relatively few hydraulic features, diversion structures, or associated flow losses, and the overbank areas are largely undeveloped. As such, and with the appropriate geometric characterization of the study reach, a sufficient level of accuracy can be achieved through the creation of a comprehensive model and the application of properly calculated discharge estimates.

Projection
The projection used for the hydraulic model was the New Hampshire State Plane Coordinate System (NAD83, US Feet). Several mapping layers were imported into the RAS Mapper module for reference throughout the project, including a merged LiDAR dataset for the entirety of the study reach. National Hydrography Dataset (NHD) flow paths and satellite imagery were also imported.

Survey Data Export and Incorporation
Survey data points corresponding with each surveyed cross-section were exported from AutoCAD to HEC-RAS in the form of shapefiles. These shapefiles were then utilized to create georeferenced cross-sections under an initial HEC-RAS geometry file. Elevation data was added to these cross-sections within HEC-RAS, based on the survey data, to define the main channel bathymetry of the Saco River and Dry River. An HEC-RAS terrain was generated based on this bathymetric data and an interpolated surface along the channel between surveyed cross-sections.

The bathymetric terrain was then stitched with the merged LiDAR terrain to create a composite terrain representing both the channel bathymetry and the overbank/floodplain areas, as well as surrounding landforms and topography. A review of the composite terrain in RAS Mapper depicts some minor discrepancies (e.g. differences between the top of bank location for the survey and LiDAR data). However, the main channel bathymetry appears to accurately represent the full depth of the Saco River and, overall, provides a consistent transition to LiDAR-based floodplains.

Model Geometry
Using the composite terrain, a new HEC-RAS geometry was developed to characterize the study reach and contributing areas. A river channel line was digitized for the main channel of the Saco River. The Saco River geometry begins at the upstream limit of the previous phase of this project (Saco River Station 0) and ends just downstream of Saco Lake (Saco River Station 28626). Numerous cross-sections were drawn to better define complex areas within the model. Cross-sections were digitized at both the surveyed cross-section locations and at points in between, making use of the interpolated channel bathymetry. Bank stations were defined along these main river channels, along with flow paths at the extent of the apparent floodplain for each section.

Bank stations allow the software to differentiate between channel flow and overbank flow, for which different Manning's Roughness Coefficients are defined. In general, based on on-site visits and photo documentation, Manning's Roughness Coefficient for the Saco River channel was defined in the range of 0.045 – 0.055. This range corresponds to mountainous streams with bed sediments composed primarily of cobbles and large boulders, and no vegetation in the channel. The overbank areas for most cross-sections in the model geometry were assigned a Manning's Roughness Coefficient of 0.110 – 0.120, a range that corresponds to a healthy wooded floodplain with some brush and downed trees. Floodplain areas consisting of large wetland areas were assigned a Manning's Roughness Coefficient of 0.060 – 0.100, a range that corresponds to light brush and trees to medium to dense brush. Overbank areas that consist primarily of impervious roadway corridors were assigned a Manning's Roughness Coefficient of 0.015, a value that corresponds to paved surfaces with minimal roughness. For cross-sections and floodplains that contained significant channelized flow (i.e. downstream of the northernmost NH Route 302 bridge, where significant flow mixing occurs and multiple well-developed side channels exist), a horizontal variation in Manning's Roughness Coefficient was applied. Photos used to estimate Manning's Roughness Coefficient can be viewed in the project deliverables folder (Path: Hydraulic Data\Photos Used for Determination of Manning's).

Three stream-crossing structures were included in the model geometry to assess their effect on flood elevations on the Saco River. These included two (2) NH Route 302 bridges (Saco River Station 4403 and Saco River Station 24723) and the Willey Pond Dam (Saco River Station 17182). Expansion and contraction coefficients for the cross-sections on either side of these structures were set to 0.3 and 0.5 respectively.

Steady Flow Data
In general, discharge estimates calculated at various points along the Saco River were applied to the model geometry as "Flow Change Locations". Flow change locations were intended to account for significant inflows from the largest tributaries to the Saco River through the study reach including Kedron Brook, Wiley Brook, and Flume/Silver Cascade. Additional flow change locations were included to account for smaller unnamed tributaries and the growth of the Saco River drainage area between significant tributaries.

Discharge estimates for the 10-, 2-, 1-, and 0.2-percent annual chance flood events were added to the Steady Flow data file based on hydrologic calculations carried out for the project. Note that these events are referred to interchangeably with their common names as follows:

- 10-percent annual chance, 10-year storm/flood/discharge
- 2-percent annual chance, 50-year storm/flood/discharge
- 1-percent annual chance, 100-year storm/flood/discharge
- 0.2-percent annual chance, 500-year storm/flood/discharge

Boundary conditions for stream reaches inform the model as to the conditions that contribute from upstream or exist directly downstream of the modeled area. Boundary conditions are entered as part of the Steady Flow data. A normal depth boundary condition was chosen and represented by the bed slope of the Saco River at the downstream extent of the current study reach (0.014723).

Geometry Review and Refinement
After developing a functioning hydraulic model for the study area, HEB conducted a thorough review and refinement of geometric components to ensure flows were simulated appropriately and water surface elevations were depicted accurately. This process was carried out with a focus primarily on the accurate depiction of the 100-year floodplain. Cross-sections were edited in order to better represent the direction of flow at any point along the respective stream reach. Artificial levees were placed based on the review of specific areas and the determination that flood elevations did not overtop certain features to result in divided flow. These artificial levees force 100-year flood elevations to overtop diversion structures or natural high ground prior to indicating inundation in low-lying areas behind them.

Additional cross-sections were added as necessary to further refine the model and to account for any terrain features that may have impacted results. Initial model results were reviewed and evaluated by multiple HEB staff and were presented to project partners and the client for feedback and discussion.

Model Calibration
Several pieces of information and data were considered to assess the accuracy of the hydraulic model:

Qualitative Review with Project Partners
Overall project review was conducted by project partners before initial delivery to the client. This review focused on methodology and critical areas within the study area.

Comparable Techniques to Previous Phase
During the previous phase of this project, completed in 2021 just downstream of this report's study area, careful analysis of obtained documented high-water marks for recent large storm events was carried out. Comparison of hydraulic model results to these documented high water marks showed a close correlation between model results and documented storm event flooding extents and water surface elevations. These correlations helped confirm that the techniques used in the model were effective and accurate.

Significant effort was taken during this phase of the project to obtain similar documented high-water mark information, but due to the remote location of the study area and the lack of residences and/or businesses, no information was available.

The same modeling techniques used during the first phase of the project were utilized during this phase as well, and the model was frequently reviewed for errors and/or unlikely results. Because the modeling during this phase of the project was conducted in the same manner as in the first phase, and because the first phase modeling closely correlated with known large storm event high-water marks, it is assumed that this phase's model is similarly accurate to the previous phase's. Should high-water mark evidence for this portion of the river be obtained at any point in the future, it could be used to confirm this assumption.

Comparison During Smaller Storm Event

HEB was able to visit the study area on December 23, 2022 during a storm event. Based on data from the gage at River Street in Bartlett, NH (USGS Gage #010642505), it is assumed that this storm event was between a 2-year and 5-year event (approximately 3.7-year event at the gage location). Although this is a significantly smaller storm event, and although exact storm frequency and peak timing is difficult to determine, photos from this visit confirmed that the model generally properly modeled water surface elevations and flood extents during smaller-sized events. The photos below depict water surface elevations and flooding extents around 3:30 PM on December 23, 2022.

Photo 1: Photo looking upstream from NH Route 302 bridge at Saco River Station 24,723 during December 23, 2022 storm event.

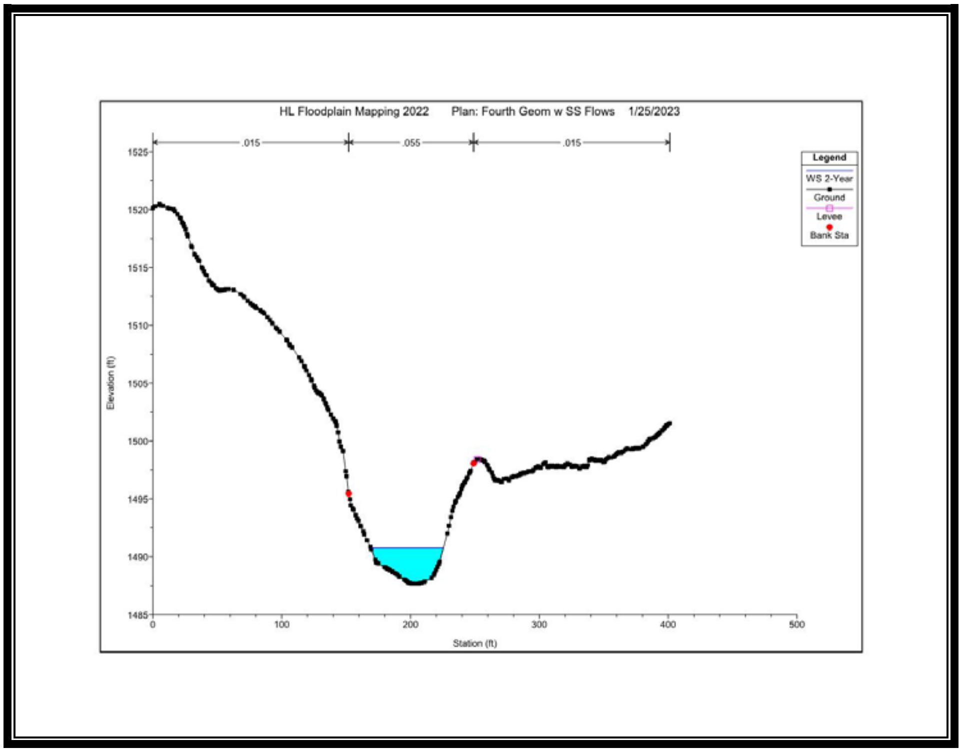

Figure 1: HEC-RAS cross-section just upstream of Route 302 bridge
(Saco River Station 24,822) showing 2-year peak water surface elevation.

Photo 2: Inlet of NH Route 302 bridge at Saco River Station
24,723 during December 2022 storm event.

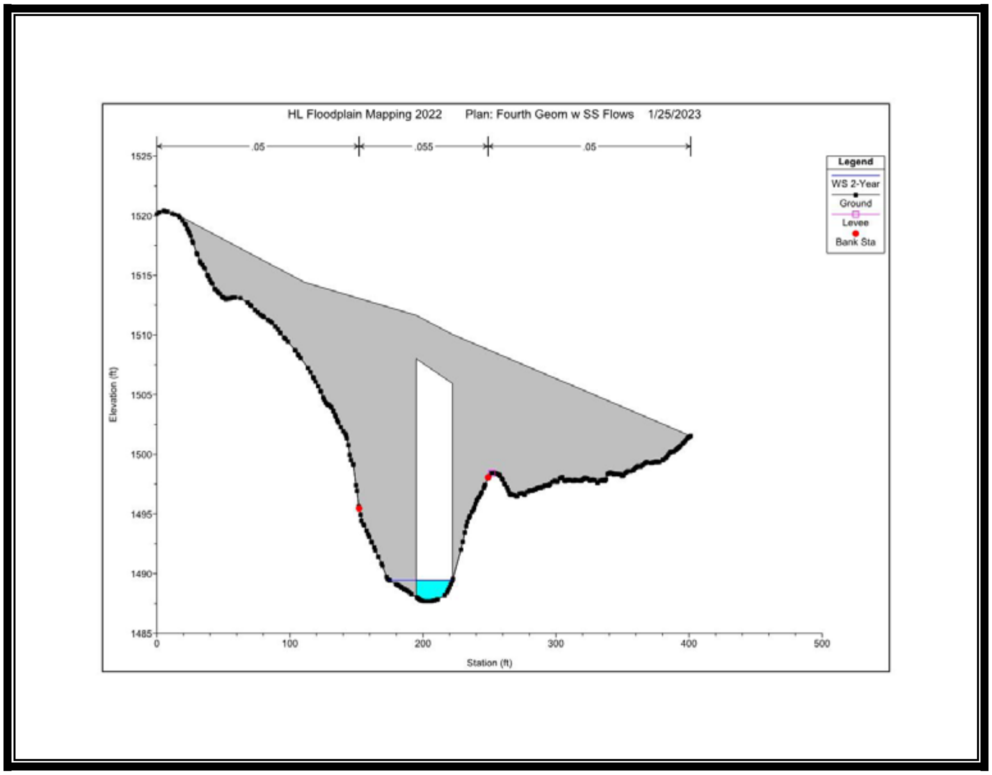

Figure 2: HEC-RAS cross-section of NH Route 302 bridge
(Saco River Station 24,723) showing 2-year peak water surface elevation.

Photo 3: View of Willey Pond Dam at Saco River Station 17,182
during December 23, 2022 storm event.

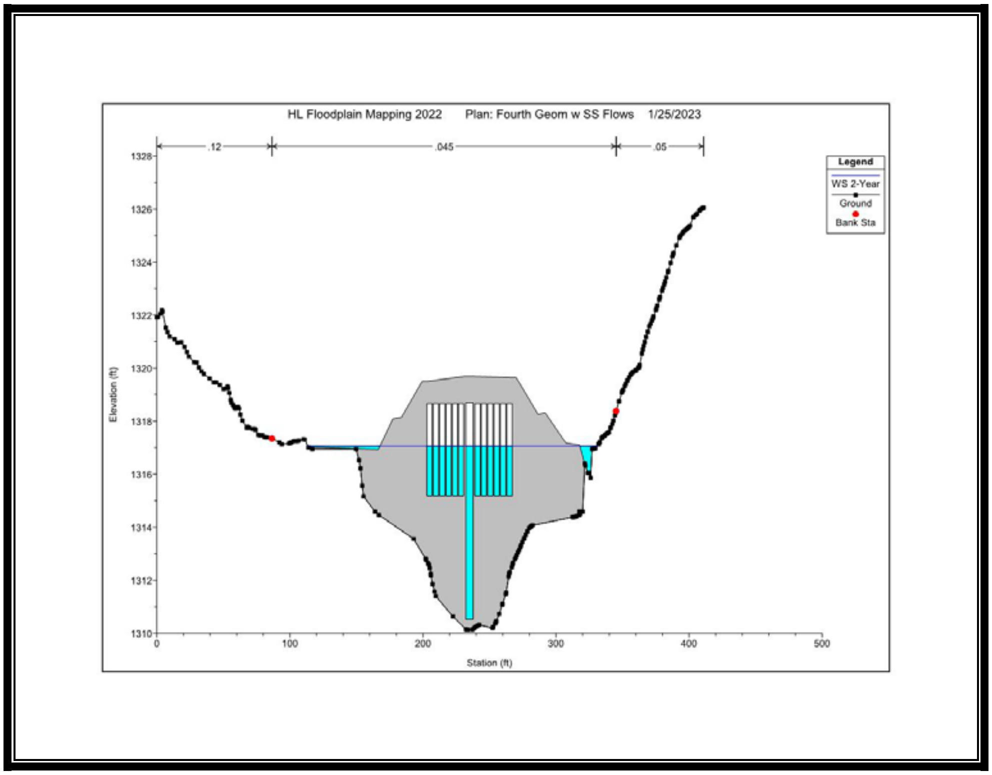

Figure 3: HEC-RAS cross-section of Willey Pond Dam (Saco River Station 17,182) Showing 2-year peak water surface elevation.

II. RESULTS AND MODEL OUTPUTS

Having confirmed the hydraulic model's ability to accurately depict the extent of flooding for the 100-year storm on a macro scale, HEB exported and processed relevant mapping layers for use by FBE and the Town of Hart's Location. These mapping layers include the shapefile for the 100-year storm, water surface elevation contours at 5-foot intervals for the study reach, and main river channel alignments corresponding with modeled profiles. River sections labeled in accordance with FEMA symbology at locations that were field surveyed, exported hydraulic structure data, as well as several other geospatial data, features useful in viewing or constructing the mapping layers. Many of the mapping layers for the project contain attribute data that correspond with the HEC-RAS hydraulic model and/or the final results. All mapping data are saved in the project deliverables folder (Path: Final Mapping Layers).

Processing of mapping data after export from HEC-RAS was largely carried out to display various mapping layers properly and in accordance with typical FEMA flood mapping styles and symbology. Minor edits were made to the inundation boundary layer exported from HEC-RAS in order to remove discrepancies that resulted from inaccurate high ground (i.e. thin terrain walls at the convergence of survey and LiDAR data). Areas that were shown to be inundated but had no connection to upstream or downstream flooded areas were removed. Finally, all islands (i.e. dry areas) smaller than 1000 square feet were removed from the inundation boundaries and considered part of the floodplain area. This reduced the file size and complexity of the floodplain shapefile substantially while removing insignificant patches of dry land from areas that are otherwise entirely inundated.

While the model results are best represented by the saved mapping layers, the 100-year flood profile and corresponding cross-section data are saved in the project deliverables folder (Path: Hydraulic Data\Hydraulic Model Outputs). Further, all relevant HEC-RAS model files have been saved in the project deliverables folder (Path: Hydraulic Data\HEC-RAS Model Files).

III. DISCUSSION AND CONCLUSION

The products of this study represent a useful tool for the Town of Hart's Location in defining and enforcing its Floodplain Conservation District Ordinance. Using the data provided, the Town's ability to prevent hazardous development or activity will be strengthened. Further, the data allow the Town to pursue additional studies of significant tributaries, extend floodplain mapping of the Saco River further into Crawford Notch, carry out floodway analysis, or to further refine the current study through the FEMA validation process.

While the study data are indeed a useful tool, it should be acknowledged that the ultimate interpretation and enforcement of the Floodplain Conservation District Ordinance will be at the discretion of Hart's Location municipal officials. This point is noteworthy in that a typical floodplain map that is accepted by FEMA often has site-specific discrepancies that can be reconciled through formal FEMA appeals (e.g. a Letter of Map Amendment).

Finally, because hydrologic data such as those produced by long-term stream gage records were not available for the upper reaches of the Saco River through Hart's Location, and while peak discharge estimation was carried out in accordance with established and accepted methodology, inherent but minor inaccuracies should be expected. The installation of a streamgage or other means of monitoring precipitation, stage, and discharge relationships for the upper Saco River and/or its tributaries would be highly beneficial in updating the current model's results, and in the accurate prediction of future flooding.

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