Letter of Map Revision (LOMR) Application

Exeter, New Hampshire

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October 2017

Table of Contents

List of Tables

1

Executive Summary

The Town of Exeter, New Hampshire retained VHB to determine the revised regulatory floodplains and flood profiles of the Exeter River and Little River resulting from the removal of the former Great Dam located immediately north (downstream) of the High Street bridge over the Exeter River in Exeter, New Hampshire. In additional to the dam removal, this revision includes impacts from recent bridge replacements along the Little River at Court Street and Linden Street. This document and appendices summarize the methods, data, and results of the hydraulic study to support a Letter of Map Revision (LOMR) reflecting this change.

The study area for this analysis covers the entire reach of the Exeter River in Exeter, New Hampshire, along with a portion of the Little River No. 1, a tributary that is influenced by backwater from the Exeter River. Currently, these areas are represented on the effective Flood Insurance Rate Map (FIRM) panels as AE zones with Base Flood Elevations (BFEs) and a designated regulatory floodway. Figure 1 provides an overview of the study area.

VHB has determined that this LOMR would impact a total of seven (7) Flood Insurance Rate Map (FIRM) panels in Rockingham County, New Hampshire, all with the effective date of May 17, 2005:

- 33015C0401E
- 33015C0402E
- 33015C0403E
- 33015C0404E
- 33015C0406E
- 33015C0408E
- 33015C0382E

The LOMR will revise the regulatory floodway, 1-percent annual exceedance (100-year) floodplain, 0.2-percent annual exceedance (500-year) floodplain, and 1-percent annual exceedance probability (100-year) Base Flood Elevation (BFE) along a 7.7-mile long reach of the Exeter River from the confluence at the Squamscott River to the Pickpocket Dam. It will revise the same regulatory items for the Little River No. 1, a tributary of the Exeter River, along a 2.4-mile reach extending from its confluence with the Exeter River to the crossing under Brentwood Road (NH Route 111A).

This analysis predicts that the extent of flooding along the Exeter River will be reduced along a 6-mile stretch upstream of the Great Dam location, reducing the 1-percent BFE by up to 3.0 feet and reducing the width of the 1-percent floodplain by up to 1,230 feet within the study limits. Model analysis also predicts that the extent of flooding along the Little River No. 1 will be reduced along the 1.5-mile stretch influenced by backwater from the Exeter River, reducing the 1-percent BFE by up to

2.5 feet and reducing the width of the 1-percent floodplain by up to 580 feet within the study limits. Upstream of the Exeter River's backwater influence, the model predicts an increase in the 1-percent BFE by up to 3.3 feet and an increase in the 1-percent floodplain by up to 370 feet from the current Effective study. This increase is a result of improved hydrology and topography for the Little River study area. The 1-percent floodplain increases are located primarily in low-lying undeveloped wetland areas upstream of the Boston & Maine Railroad crossing, but some resident homes would be affected by the change. Approximately 12 houses along Hilton Avenue and Alter Street are now partially located within the 1-percent floodplain.

The current Effective Flood Insurance Study (FIS) for Rockingham County, New Hampshire has the effective date of May 17, 2005; the FIS indicates that the hydrologic and hydraulic analysis in the Town of Exeter was completed in 1980. There is currently a Preliminary FIS for Rockingham County with the effective date of February 24, 2016; this Preliminary FIS includes a revised hydrologic and hydraulic analysis of the Exeter River performed by the United States Geological Survey (USGS) in 2011. VHB coordinated with Eleanore Pitney and Alex Sirotek, FEMA reviewers, to confirm the best modeling approach to accommodate the future transition from the Effective to Preliminary FIS; documentation of this coordination is included in Appendix J. The model development, study area and tie-in locations of this analysis have been set to ensure a logical and consistent tie-in to both the current Effective FIS and Preliminary FIS flood maps and profiles.

Figure 1 Limits of Study

2

MT-2 Forms

Form 1 – Overview and Concurrence

Form 2 – Riverine Hydrology and Hydraulics (Exeter River and Little River)

Form 3 – Riverine Structures (Exeter River and Little River)

3

Introduction

The Town of Exeter, New Hampshire retained VHB to determine the regulatory floodway, 1-percent floodplain, and Base Flood Elevations (BFEs) along the Exeter River and Little River in Exeter, New Hampshire shown in Figure 1. This document presents VHB's analysis and results.

In 2016, the Town of Exeter demolished and removed the Great Dam located in the center of Exeter's downtown business district. The dam did not meet safety regulations required for low-hazard dams and the New Hampshire Department of Environmental Services (NHDES) had issued a Letter of Deficiency to the Town of Exeter on July 25, 2000. Furthermore, the dam represented a barrier to upstream fish passage and did not provide any flood storage or mitigation value as a "run-of-the-river" dam. VHB prepared a study analyzing options to address the safety deficiency entitled *Great Dam Removal Feasibility and Impact Analysis* (VHB 2013). Based in part on the findings of this study, and after consultation with NHDES, the Town of Exeter decided to remove the Great Dam and return the Exeter River to a free-flowing river upstream of the dam

Prior to removal, the Great Dam was a reinforced concrete run-of-the-river dam originally constructed in the 1830s with the latest version built in 1914. The dam consisted of a spillway, a fish ladder including a small lower dam (or "weir") structure, a low-level outlet, and a penstock. The dam was approximately 136 feet long by approximately 16 feet high, when measured from its highest point to the streambed at its downstream face. The 2016 removal project eliminated the entire existing dam weir structure in the channel, including the fish ladder and lower dam. The former head works and penstock were kept in place along the northeast bank. Dam removal also entailed reshaping the river channel within the footprint of the existing dam and immediately upstream and downstream.

With the completion of the Great Dam removal and Exeter River restoration project, the Town of Exeter is updating its flood mapping to reflect the reduced flood elevations and floodplain extents.

Study Area Description

The study area of this analysis includes the reaches of the Exeter River and its tributary, the Little River, that were impacted by the backwater from the impoundment created by the former Great Dam in Exeter, New Hampshire. Both rivers are studied by detailed methods in the Effective Flood Insurance Study (FIS) for Rockingham County, New Hampshire, effective date May 17, 2005. The study area is depicted on seven (7) Flood Insurance Rate Map (FIRM) Panels for

Rockingham, New Hampshire; copies of these FIRM panels are included in Appendix C. The seven affected panels are:

- 33015C0401E (effective date of May 17, 2005)
- 33015C0402E (effective date of May 17, 2005)
- 33015C0403E (effective date of May 17, 2005)
- 33015C0404E (effective date of May 17, 2005)
- 33015C0406E (effective date of May 17, 2005)
- 33105C0408E (effective date of May 17, 2005)
- 33015C0382E (effective date of May 17, 2005)

The study area of the Exeter River extends from the downstream limits of detailed study where it terminates at the Squamscott River to the Pickpocket Dam, located approximately 7.7 miles upstream; this area corresponds to the area bounded by published cross-sections A through Z in the Effective FIS. For the Little River, the study area extends from the confluence with the Exeter River to the upstream limits of detailed study at the Route 111A (Brentwood Road) crossing, located approximately 2.4 miles upstream. This area corresponds to the area bounded by published cross-sections A through Q in the Effective FIS.

Regulatory Floodplains and Special Flood Hazard Areas

The regulatory floodplain, commonly referred to as the 100-year floodplain, is defined as the area subject to 1-percent probability of flooding in any given year. Regulatory floodplains are defined within communities that participate in the National Flood Insurance Program (NFIP) and are represented on FIRMs.

The regulatory floodplains of both the Exeter River and the Little River are categorized as Zone AE. The Zone AE designation indicates that the floodplain is delineated using the results of a detailed FIS with defined Base Flood Elevations (BFEs). An additional special flood hazard area mapped as Zone X represents areas subject to flooding during the 0.2-percent-annual-chance or greater flood event (500-year event). This hydraulic study proposes to update the BFEs and floodplains for both rivers to reflect the removal of the Great Dam in Exeter, New Hampshire.

Regulatory Floodway

A regulatory floodway is defined for the Exeter River and for the Little River. The hydraulic study presented in this application does not propose to change the Exeter River regulatory floodway compared to the Preliminary FIS. However, because the Preliminary FIS floodway is different from the Effective FIS floodway, this application does change the regulatory floodway compared to the Effective FIS. For the Little River model, VHB matched the floodway from the Effective FIS where feasible. However, to reflect the updated HEC-RAS model incorporating improved hydrology and topographic data, this study proposes to change the regulatory floodway for the Little River. The floodway width will remain unchanged except for the section between published cross-sections E (1,500 feet upstream of Court Street) and H (railroad crossing). The floodway widens to 125 feet between published cross-

sections E and F, and widens to 190 feet between published cross-sections G and H. A revised floodway table is included in Appendix H, and detailed HEC-RAS floodway results are included in the HEC-RAS model results in Appendix B.

Exeter River

The Exeter River rises in Chester, New Hampshire, and flows approximately 33 miles to downtown Exeter. There, it becomes a tidal river and a primary tributary to Great Bay; the tidal river is called the Squamscott River. The Great Dam location was immediately upstream of the limit of tidal influence, and impounded the Exeter River about 4.5 miles upstream. The watershed of the Exeter River covers approximately 107 square miles, including substantial portions of the towns of Brentwood, Chester, Danville, East Kingston, Exeter, Fremont, Kensington, Kingston, Raymond and Sandown. The watershed also includes small portions of five additional towns: Candia, Derry, Epping, Hampstead and Hampton Falls.

Within the study area, the Exeter River is depicted on FIRM Panels 33015C0401E, 33015C0402E, 33015C0403E, 33015C0404E, 33015C0406E, 33105C0408E, and 33015C0382E.

Little River No. 1

The Little River is a tributary to the Exeter River; it rises in Brentwood, New Hampshire and flows approximately 7 miles to the confluence. Its watershed covers approximately 16 square miles in the towns of Exeter and Brentwood. The Effective FIS indicates that the confluence of the Exeter River and Little River is located 0.6 miles upstream of the former Great Dam location, and that backwater from the Exeter River extends upstream to the Kingston Road crossing, approximately 2 miles upstream from the confluence.

The study area of Little River extends from the confluence with the Exeter River to the crossing at Brentwood Road (NH Route 111A) in Exeter, New Hampshire. This upstream limit is consistent with the limit of detailed study of the Little River in the Effective FIS.

Within the study area, the Little River is depicted on FIRM Panels 33015C0401E and 33015C0402E.

Methods and Documentation

The hydrologic and hydraulic analyses presented in this document are performed in a manner consistent with standard engineering practices and requirements for a Letter of Map Revision (LOMR) to FEMA.

- Section 3 describes the study area
- Section 4 describes the hydrologic analysis
- Section 5 describes the hydraulic analysis and results

- Appendix A presents the StreamStats technical information used for the hydrologic study
- Appendix B presents the results of the HEC-RAS model hydraulic study
- Appendix C presents the effective FIRMs and the annotated (proposed) FIRMs applicable to the project site
- Appendix D presents the topographic Work Map, which provides supporting technical data relevant to the hydraulic analysis
- Appendix E presents a data disk that contains the technical data used to develop this hydraulic analysis including the hydrologic model, the hydraulic model, and ESRI GIS and AutoCAD mapping files
- Appendix F presents the base map survey data including record plans and as-built drawings for structures included in the study.
- Appendix G presents the effective and proposed flood profiles for the Exeter River and Little River No. 1
- Appendix H presents the effective and proposed floodway table for the Little River No. 1.
- Appendix I presents documentation associated with public notices
- Appendix J presents a summary of pre-application coordination with FEMA to verify the approach and methodology for this study.

LOMR Filing Fees

The revised flood analysis in this LOMR is a result of the removal of the Great Dam in Exeter, New Hampshire. The dam removal was performed as a habitat restoration project to restore upstream passage for diadromous fish and to improve water quality downstream of the dam by returning the Exeter River to a free-flowing state. Funding for the project was provided in part by federal and state grants from the New Hampshire State Conservation Committee Conservation Grant Program, the National Oceanic and Atmospheric Administration (NOAA) Coastal Ecosystem Resiliency Program, and the New Hampshire Department of Environmental Services (NHDES) Coastal Program and Aquatic Resource Mitigation Fund.

In accordance with the Homeowner Flood Insurance Affordability Act of 2014 (Public Law 113-89, section 22), a requester shall be exempt from submitting a review or processing fee for a request for a Flood Insurance Rate Map (FIRM) change based on a project where: (1) the primary purpose is habitat restoration; and (2) where the project is funded in whole or in part with Federal or State funds. This exemption includes projects for dam removal, culvert redesign or installation or the installation of fish passage. This project meets both of these requirements and therefore is exempt from a LOMR filing fee.

4

Hydrology

Hydrology for the current Effective FIS (May 17, 2005) is based on regional peak discharge and frequency formulas (USGS 1978). The hydrologic analysis for both the Exeter River and the Little River was originally performed for the 1981 Town of Exeter FIS and has not been updated. No river gage data was available for either river at the time of the analysis.

The Preliminary FIS (February 24, 2016) updated hydrology for the Exeter River based on hydrologic analysis from the 2013 Coastal Study Update. Hydrology was based on log-Pearson Type III analysis of USGS gage 01073587, located in the town of Brentwood upstream of the study area, and supplemented with data from the former USGS gage 01073500. Discharges were adjusted for downstream stream locations based proportional to relative watershed areas. However, hydrology for the Little River remained unchanged from the original 1981 analysis.

For this LOMR, VHB adopted the hydrology from the Preliminary FIS; although this represents a change from the Effective FIS hydrology, it does not represent a new hydrologic analysis. However, VHB did perform a new hydrologic analysis for the Little River.

Comparison to Effective and Preliminary FIS Hydrology

VHB reviewed the contributing watershed areas and hydrology for both the Exeter River and Little River as they compared to the values published in the Effective FIS and Preliminary FIS. The United States Geological Service (USGS) maintains a stream gage on the Exeter River in Brentwood (USGS 01073587), but there is no current or historic gage data available for the Little River. For each river, VHB calculated the contributing watershed area and estimated peak discharge rates by regression analysis. VHB applied regression equations and methodology published in USGS Scientific Investigations Report 2008-5216, "Estimation of flood discharges at selected recurrence intervals for streams in New Hampshire" (Olson, S.A., 2009), using the USGS Streamstats 4.0 program. Results for of the regression analysis for the Exeter River were comparable to the Preliminary FIS values, but for the Little River the contributing watershed area was calculated to be nearly 15% greater than the area given in the Effective FIS, and peak discharge rates for the 1-percent-annual-chance flood were calculated to be over 75% greater than those given in the Effective FIS.

Table 1 provides a comparison of the calculated watershed areas at selected locations in the study area:

Table 1. Comparison of Watershed Areas

Location	2005 Effective FIS Watershed Area (mi^2)	2016 Preliminary FIS Watershed Area (mi^2)	2017 VHB Watershed Area (mi^2)
	Exeter River		
At High Street Bridge	114.6	107	107.3
Upstream of Little River	100.8	--	91.1
Upstream of Great Brook	89.9	--	76.4
Pickpocket Dam	73	74.1	74.1
	Little River No. 1		
Confluence with Exeter River	13.9	13.9	15.8

Sources: FIS watersheds from 2005 Effective FIS and 2016 Preliminary FIS. 2017 VHB watersheds calculated with StreamStats 4.0 (USGS): https://streamstats.usgs.gov/ss/

Little River Hydrology

Given the discrepancy in watershed area and calculated peak discharge rates between the Effective FIS and VHB regression analysis, this study proposes to revise the hydrology for the Little River.

Based on the contributing watershed characteristics, VHB calculated peak discharge rates for the 10-, 2-, 1-, and 0.2-percent-annual-chance flood events for the Little River based on regional peak and frequency regression equations developed by the USGS in 2009. There is no gage data available for the Little River

The contributing watershed to the Little River is calculated to be 15.8 square miles, of which 11.27% is wetlands and 5.57% is impervious cover. The watershed has a mean basin slope of 2.98% and the main channel of the river has a mean stream slope of 10.1 feet per mile. All values were calculated with the USGS StreamStats 4.0 program using GIS data for New Hampshire; the detailed StreamStats report is included in Appendix A.

The Effective FIS only provides peak discharges for a single location along the Little River, at the confluence with the Exeter River. This study does not propose to add any additional discharge locations to the model. Table 2 provides a summary comparing Effective FIS discharges to the calculated peak discharges at this location:

Table 2. Comparison: Peak Discharges, Little River (All Locations)

Flood Event	Effective FIS Peak Q (cfs)	2017 VHB Q (cfs)
10-Year (10%)	345	574
50-Year (2%)	528	914
100-Year (1%)	624	1,100
500-Year (0.2%)	874	1,560

Sources: Effective discharges from 2005 Effective FIS. VHB discharges calculated with regional regression equations from Olson, S.A., 2009, "Estimation of flood discharges at selected recurrence intervals for streams in New Hampshire": U.S. Geological Survey Scientific Investigations Report 2008-5206, using the StreamStats 4.0 program (USGS)

Peak Discharge Rates Summary

As noted above, this study incorporates peak discharge rates from two sources: the Preliminary FIS (for the Exeter River) and regression analysis (for the Little River). The Preliminary FIS includes discharge tables for both the Exeter River and the Exeter River (Town of Exeter); this study only uses the values for the Exeter River (Town of Exeter). Table 3 below provides a summary of the peak discharge rates used in the model; discharge rates adapted from the Preliminary FIS are in italics:

Table 3. Summary of Peak Discharges Used in Model (cfs)

Location	10-Year (10%)	50-Year (2%)	100-Year (1%)	500-Year (0.2%)
	Exeter River:			
At High Street Bridge	*2,910*	*4,740*	*5,690*	*8,350*
At Confluence with Little River	*2,905*	*4,730*	*5,670*	*8,330*
At Confluence with Great Brook	*2,510*	*4,080*	*4,890*	*6,430*
At Linden St. Bridge	*2,240*	*3,650*	*4,370*	*6,430*
At Confluence with Perkins Brook	*2,230*	*3,630*	*4,360*	*6,410*
At Pickpocket Dam	*2,210*	*3,590*	*4,310*	*6,330*
	Little River:			
At Confluence with Exeter River	574	914	1,100	1,560

Notes: Discharges in italics are unchanged from the 2016 Preliminary FIS.

Sources: Exeter River discharge rates are from the 2016 Preliminary FIS. Little River discharges calculated with regional regression equations from Olson, S.A., 2009, "Estimation of flood discharges at selected recurrence intervals for streams in New Hampshire": U.S. Geological Survey Scientific Investigations Report 2008-5206, using the StreamStats 4.0 program (USGS)

5

Hydraulic Analysis and Results

VHB used HEC-RAS version 5.0.3 to simulate flood profiles along the Exeter River and Little River, producing three hydraulic models: (1) a duplicate-effective model representing the Effective FIS study; (1) a pre-project model representing the Preliminary FIS study prior to removal of the Great Dam; and (3) a post-project model representing current conditions with the dam removed. The duplicate-effective model is included as a HEC-2 printout; owing to the differences in calculation methodology between HEC-2 and HEC-RAS, VHB used the original HEC-2 model results instead of generating a new HEC-RAS model. These HEC-2 printouts are included in Appendix B.

HEC-RAS Model Limits

On February 24, 2016, FEMA issued a revised Preliminary FIS for Rockingham County. This preliminary study includes a revised hydrologic and hydraulic analysis of the Exeter River in the Town of Exeter, including the entire study area of this LOMR. Given that there is no firm schedule for the Preliminary FIS to become Effective, this LOMR is intended to modify both the current Effective FIS and the Preliminary FIS when it becomes effective in the future. The study limits of this analysis have been selected to provide a smooth tie-in to both the Effective FIS and Preliminary FIS.

The model limits for the Exeter River extend from the downstream limits of detailed study where it terminates at the Squamscott River to the Pickpocket Dam, located approximately 7.7 miles upstream; this area corresponds to the area bounded by published cross-sections A through Z in the Effective FIS and in the Preliminary FIS. The downstream limit of detailed study represents the limits of tidal action from the Squamscott River. The downstream tie-in point for this LOMR is the location where the Exeter River flood profile intersects the Squamscott River stillwater flood elevation; this location will vary slightly when tying in to the Effective FIS compared to the Preliminary FIS.

For the Little River, the study limits extend from the confluence with the Exeter River to the upstream limits of detailed study at the Route 111A (Brentwood Road) crossing, located approximately 2.5 miles upstream. This area corresponds to the area bounded by published cross-sections A through Q in the Effective FIS, and represents the full extent of the Little River studied by detailed methods in the Effective FIS. The Preliminary FIS did not update the hydraulic model for the Little River, but did re-delineate floodplains incorporating updated topographic data.

Data Collection

VHB based this study on existing hydraulic models from FEMA, supplemented with detailed topographic and survey data. The following lists these data sources:

1. Exeter River and Little River HEC-2 model printouts dated August 1977, provided by the FEMA Engineering Library.
2. 2011 Exeter River Flood Study HEC-RAS 4.0 model dated December 19, 2011, created by the USGS NH/VT Water Science Center, provided by FEMA.
3. 2011 USGS Survey Topographic LiDAR: LiDAR for the North East, 1m resolution Digital Elevation Model (DEM) with bare earth vertical accuracy of 15.0cm, vertical datum NAVD88 (feet) provided by the NOAA Office for Coastal Management (OCM).
4. As-built Plan in Exeter, NH, dated October 5, 2016 and prepared by Millennium Engineering, Inc. The plan shows channel bathymetry and bank topography in the vicinity of the Great Dam following removal of the dam and fish weir/ladder.
5. Record Drawing plan "Town of Exeter, New Hampshire, Linden Street, Little River Bridge Replacement," dated January 2016 and prepared by CMA Engineers. The plan shows the geometry of the replacement bridge for Linden Street over the Little River.
6. Issued for Construction plan "Town of Exeter, New Hampshire, Court Street, Little River Bridge Replacement," dated June 2017 and prepared by CMA Engineers. The plan shows the geometry of the replacement bridge for Court Street over the Little River.

Unless noted otherwise, VHB retained the Preliminary FIS model cross-section geometry upstream of the Great Dam for the purposes of hydraulic modeling and SHFA delineation.

Duplicate Effective Models

The duplicate effective model is a reproduction of the Effective FIS flood profile. The results of the model are used to demonstrate that the duplicate effective model is consistent with the effective FIS flood profiles. To meet the FEMA requirement for acceptance as a duplicate-effective model, the results must match the effective FIS within a tolerance of 0.5 feet.

VHB requested and received from the FEMA Engineering Library the HEC-2 model printouts of the Exeter River and Little River; these HEC-2 models were used to develop the BFEs in the Effective FIS. Copies of these HEC-2 model inputs and results are included in Appendix B. Model results support the conclusion that the models obtained from FEMA are consistent with the profiles published in the FIS. Table 4 provides a summary of the results at selected locations in the model; a full table of results is included in Appendix B.

Table 4. Duplicate-Effective Model WSE Results

Location and FIS Published Cross Section	HEC-2 Station[1]	Effective FIS 100-year WSE[2] (ft NGVD29)	Duplicate-Effective 100-year WSE (ft NGVD29)	Difference (ft)
Exeter River:				
DS Limit of Study[4]	--	6.9	6.9	0.00
A – US of String Bridge	300050	11.8	11.82	-0.02
D – DS of High St.	300100	30.4	30.38	0.02
E – US of High St.	300121	31.1	31.14	-0.04
G – US of Gilman St.	300143	31.7	31.67	0.03
H – Confluence of Little River	300160	31.7	31.73	-0.03
J – Confluence of Great Meadows Brook	300180	32.4	32.36	0.04
L – DS of Court St.	300210	32.9	32.89	0.01
M – US of Court St.	300230	33.5	33.45	0.05
N – US of Linden St.	300233	34.6	34.57	0.03
R – US of railroad	300273	36.2	36.19	0.01
V – US of Kingston Rd.	300303	42.9	42.88	0.02
X – DS of Cross Rd.	300330	50.6	50.6	0.00
Y – DS of Pickpocket Dam	300334	59.2	59.42	-0.22
Location and FIS Published Cross Section	**HEC-2 Station[1]**	**Effective FIS 100-year WSE[2,3] (ft NGVD29)**	**Duplicate-Effective 100-year WSE[3] (ft NGVD29)**	**Difference (ft)**
Little River No. 1:				
A – DS limit of study	310010	31.7	31.7	0.00
D – US of Court St.	310030	31.7	31.7	0.00
F – DS of Linden S.	310050	31.7	31.7	0.00
G – US of Linden St.	310055	31.7	31.7	0.00
J – US of railroad	310073	31.7	31.7	0.00
M – US of Kingston Rd	310012	31.7	31.7	0.00
P – DS of dam	310127	40.4	40.41	-0.01
Q – US limit of study	310132	47.5	47.47	0.03

Notes: 1. HEC-2 stationing is from HEC-2 model and does not correspond to river station.
2. Effective FIS WSE values from floodway data tables in 2005 FIS
3. Little River WSEs through published section M are from Exeter River backwater.
4. Exeter River WSE at DS limit of study is from Squamscott River backwater.

Sources: Effective FIS WSEs are from 2005 Effective FIS, Duplicate-Effective WSEs are from HEC-2 printouts provided by FEMA Engineering Library.

Pre-Project Models

The pre-project models represent conditions immediately prior to the removal of the Great Dam in 2016.

For the Exeter River, this study uses the model prepared by USGS in 2011 for the Preliminary FIS. This model replaced the Effective FIS model sections with new georeferenced sections, added additional intermediate sections, and updated structure geometry at bridges and dams. For this analysis, VHB used the HEC-RAS model dated 12/19/11 from by the University of New Hampshire (UNH) provided by FEMA. VHB did not make any edits or revisions to this HEC-RAS model other than a slight adjustment to ineffective flow area stations at the Court Street bridge crossing. Table 5 provides a comparison of the pre-project model to the results of the Preliminary FIS. Please note that this only includes the Exeter River, as the Preliminary FIS does not include a revised model for the Little River.

Table 5. Pre-Project Model WSE Results vs. Preliminary FIS

Location and FIS Published Cross Section	HEC-RAS Station[1]	Preliminary FIS 100-year WSE[2] (ft NAVD88)	Pre-Project 100-year WSE (ft NAVD88)	Difference (ft)
Exeter River:				
A – DS Limit of Study	5	7.0[3]	7.0[3]	0.0
D – DS of High St.	489	27.9	27.85	-0.05
E – US of High St.	847	30.4	30.38	-0.02
G – US of Gilman St.	2672	30.9	30.90	0.0
H – Confluence of Little River	3856	30.9	30.93	0.03
J – Confluence of Great Meadows Brook	10969	31.0	31.01	0.01
L – DS of Court St.	24399	31.4	31.18	-0.22
M – US of Court St.	24483	31.5	31.34	-0.16
N – US of Linden St.	26908	33.0	32.85	-0.15
R – US of railroad	32012	34.1	34.02	-0.08
V – US of Kingston Rd.	39795	45.7	45.70	0.0
X – DS of Cross Rd.	40651	54.8	54.77	-0.03
Y – US Limit of Study	40770	58.2	58.18	-0.02

Notes:
1. HEC-RAS stationing is based on river station and does not correspond to HEC-2 model.
2. Elevations are from Preliminary FIS Floodway Data Table for Exeter River (Town of Exeter)
3. Exeter River WSEs through published section A are from Squamscott River backwater.

For the Little River, VHB modified the duplicate-effective model to create a pre-project model in the following ways:

- Digitized duplicate effective HEC-2 model cross-section geometry and georeferenced the locations of the 17 published cross-sections, 4 bridges, and one in-line structure (dam).

- Converted elevations from NGVD29 to NAVD88 vertical datum by subtracting 0.76 feet. Conversion factor for study area latitude/longitude determined using US National Geodetic Survey VERTCON program (https://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html); this conversion is consistent with NAVD88 elevations given in the Preliminary FIS.
- Added 28 new intermediate cross-sections between the published cross-sections at locations where downstream reach lengths between cross-sections exceeded 500 feet.
- Updated overbank geometry for all cross-sections using 2011 USGS LiDAR DEM topography to replace the original 1977 model geometry.
- Updated bridge deck profiles using 2011 USGS LiDAR for bridge crossings where the HEC-2 model had incorporated special bridge routines with no high chord elevations.
- Added ineffective flow areas and manning's n values to new cross-sections.
- Between Published Cross-Sections A and C, updated channel bathymetry from bathymetric survey performed in 2010, the same bathymetric survey data used in the Preliminary FIS HEC-RAS model.
- Adapted channel bathymetry in new cross-sections from the original HEC-2 model by interpolating channel elevations between published cross-sections.
- Updated peak flow rates to apply the revised hydrology as discussed in the previous section.

Bridge structure geometries were preserved from the duplicate effective model. The pre-project model assumes normal depth for the downstream boundary condition at the confluence with the Exeter River, applying an average stream channel slope of 0.00073ft/ft. For locations where the model indicates a water surface elevation (WSE) lower than the Exeter River WSE at the confluence, the WSE elevations are assumed to be controlled by backwater from the Exeter River and have been adjusted to be equal to that of the Exeter River at the confluence.

The Topographic Work Map (Appendix D) illustrates the locations of the new cross sections for the Little River. Model results provide water surface elevations along the Exeter River and Little River. Table 6 provides a summary of the results at selected locations in the model; a full table of results is included in Appendix B. Please note that because the published station locations for the Preliminary FIS do not correspond precisely to the river station for published station locations for the Effective FIS, the actual WSE difference at a specific location may be greater or less than the values listed in this table.

Table 6. Pre-Project Model WSE Results

Location and FIS Published Cross Section	HEC-RAS Station[1]	Effective FIS 100-year WSE[2] (ft NAVD88)	Preliminary FIS 100-year WSE[3] (ft NAVD88)	Pre-Project 100-year WSE (ft NAVD88)	Change vs. Effective (ft)
		Exeter River:			
A[4] – DS Limit of Study	5	6.9[5]	7.0[5]	7.0[5]	0.1
D – DS of High St.	489	29.5	27.9	27.85	-1.6
E – US of High St.	847	30.3	30.4	30.38	0.1
G – US of Gilman St.	2672	30.9	30.9	30.90	0.0
H – Confluence of Little River	3856	30.9	30.9	30.93	0.0
J – Confluence of Great Meadows Brook	10969	31.5	31.0	31.01	-0.5
L – DS of Court St.	24399	32.1	31.4	31.18	-0.9
M[4] – US of Court St.	24483	32.5	31.5	31.34	-1.2
N – US of Linden St.	26908	33.7	33.0	32.85	-0.9
R – US of railroad	32012	35.4	34.1	34.02	-1.4
V – US of Kingston Rd.	39795	42.1	45.7	45.70	3.6
X – DS of Cross Rd.	40651	49.8	54.8	54.77	5.0
Y – US Limit of Study	40770	58.4	58.2	58.18	-0.2

Location and FIS Published Cross Section	HEC-RAS Station[1]	Effective FIS 100-year WSE[2] (ft NAVD88)	Preliminary FIS 100-year WSE[3] (ft NAVD88)	Pre-Project 100-year WSE (ft NAVD88)	Change vs. Effective (ft)
			Little River No. 1:		
A – DS limit of study	318	30.9[6]	30.9[6]	30.93[6]	0.03
D – US of Court St.	2676	30.9[6]	30.9[6]	30.93[6]	0.03
F – DS of Linden S.	5241	30.9[6]	30.9[6]	30.93[6]	0.03
G – US of Linden St.	5375	30.9[6]	30.9[6]	30.93[6]	0.03
J – US of railroad	8149	30.9[6]	30.9[6]	32.48[6]	+1.58
M – US of Kingston Rd	10367	30.9	31.0	33.67	+2.67
P – DS of dam	12766	39.6	39.7	39.23	-0.37
Q – US limit of study	12907	46.7	46.8	46.86	+0.16

Notes: 1. HEC-RAS stationing is based on river station and does not correspond to HEC-2 model.
2. Elevations are from Effective FIS Floodway Data Table for Exeter River (Town of Exeter)
3. Elevations are from Preliminary FIS Floodway Data Table for Exeter River (Town of Exeter)
4. These published sections correspond to different locations in the 2005 Effective FIS: published section A is US of String Bridge; published section M is DS of Linden Street
5. Exeter River WSEs through published section A are from Squamscott River backwater.
6. Little River WSEs through published section J are from Exeter River backwater.

Sources: Effective FIS WSEs are from 2005 Effective FIS, Pre-Project WSEs for Exeter River are from Preliminary FIS HEC-RAS model provided by UNH, Pre-Project WSEs for Little River are from the pre-project HEC-RAS model developed by VHB.

Post-Project Models

The post-project model represents existing conditions since the removal of the Great Dam in 2016. The only difference between the pre-project model and post-project model is the removal of the Great Dam and associated fish weir in downtown Exeter, New Hampshire. VHB modified the pre-project model to create the post-project model in the following ways:

- Removed the Great Dam and downstream fish weir inline structures
- Re-aligned the two cross sections immediately upstream and downstream of the removed fish weir to be perpendicular to the river channel
- Added three intermediate sections between the String Bridge and High Street bridge
- Updated channel bathymetry for cross-sections 330 through 565 based on as-built survey prepared by Millenium Engineering, Inc. and dated October 5, 2016.
- Updated ineffective flow area elevations at the Court Street (Route 108) crossing to accurately model overbank flow over the roadway approaches for post-dam-removal water surface elevations.
- Updated geometry for the Court Street and Linden Street bridges to reflect the replacement bridges constructed by the Town of Exeter in 2016 and 2017. Bridge and channel geometry at the bridge crossings were adapted from design and record plans prepared by CMA Engineering.

The Topographic Work Map (Appendix D) illustrates the locations of the new and revised cross sections where the Great Dam was removed. Model results provide water surface elevations along the Exeter River and Little River. Table 7 provides a summary of the results at selected locations in the model; a full table of results is included in Appendix B.

Table 7. Post-Project Model WSE Results

Location and FIS Published Cross Section	HEC-RAS Station[1]	Effective FIS 100-year WSE (ft NAVD88)	Pre-Project 100-year WSE (ft NAVD88)	Post-Project 100-year WSE (ft NAVD88)	Pre- vs. Post-Difference (ft)
			Exeter River:		
A – DS Limit of Study	5	6.9[1]	7.0[1]	7.0[1]	0.0
D – DS of High St.	489	29.5	27.85	19.93	-7.9
E – US of High St.	847	30.3	30.38	27.37	-3.0
G – US of Gilman St.	2672	30.9	30.90	28.39	-2.5
H – Confluence of Little River	3856	30.9	30.93	28.49	-2.4
J – Confluence of Great Meadows Brook	10969	31.5	31.01	28.77	-2.2
L – DS of Court St.	24399	32.1	31.18	29.05	-2.1
M[4] – US of Court St.	24483	32.5	31.34	29.84	-1.5
N – US of Linden St.	26908	33.7	32.85	32.18	-0.7
R – US of railroad	32012	35.4	34.02	33.65	-0.4
V – US of Kingston Rd.	39795	42.1	45.70	45.70	0.0
X – DS of Cross Rd.	40651	49.8	54.77	54.76	0.0
Y – US Limit of Study	40770	58.4	58.18	58.19	0.0

Location and FIS Published Cross Section	HEC-RAS Station	Effective FIS 100-year WSE (ft NAVD88)	Pre-Project 100-year WSE (ft NAVD88)	Post-Project 100-year WSE (ft NAVD88)	Pre- vs. Post-Difference (ft)
			Little River No. 1:		
A – DS limit of study	318	30.9[2]	30.93[2]	28.48[2]	-2.45
D – US of Court St.	2676	30.9[2]	30.93[2]	28.48[2]	-2.45
F – DS of Linden S.	5241	30.9[2]	30.93[2]	28.48[2]	-2.45
G – US of Linden St.	5375	30.9[2]	30.93[2]	28.48[2]	-2.45
J – US of railroad	8149	30.9[2]	32.48[2]	32.48[2]	0.00
M – US of Kingston Rd	10367	30.9	33.67	33.66	-0.01
P – DS of dam	12766	39.6	39.23	39.23	0.00
Q – US limit of study	12907	46.7	46.86	46.86	0.00

Notes: 1. Exeter River WSEs through published section A are from Squamscott River backwater.
2. Little River WSEs through published section J are from Exeter River backwater.

Sources: Effective FIS WSEs are from 2005 Effective FIS, Pre-Project WSEs for Exeter River are from Preliminary FIS HEC-RAS model provided by UNH, Pre-Project WSEs for Little River are from the pre-project HEC-RAS model developed by VHB.

Model Framework

Manning's "n": values and Adjustments

Manning's "n" is an empirically derived coefficient representing the roughness or friction applied to the flow by the channel. The model maintains the same "n" values from the 2016 Preliminary FIS model for the Exeter River; for the dam removal area and for the Little River, VHB applied Manning's "n" values consistent with the Preliminary FIS model:

- For stream channels, VHB used Manning's "n" values ranging from 0.025 to 0.055. For overbank areas, VHB used "n" values ranging from 0.065 to 0.08.
- Smooth-bottomed, open pond channel are represented by n=0.025.
- Well-defined, winding natural stream channels with some pools and shoals with some weeds and stones are represented by n=0.035
- The reconstructed stony, coarse-bottomed stream channel in the dam removal is represented by n=0.04.

- Poorly-defined, meandering natural stream channels with extensive vegetation and weeds are represented by n=0.045 to n=0.055
- Lightly to moderately vegetated overbank areas, including open wetlands with grass or shrub vegetation, are represented by n=0.065 to 0.07.
- Wooded overbank areas with dense tree canopies are represented by n=0.08.

Expansion and Contraction at Bridges and Culverts

For the Exeter River, VHB preserved coefficients from the Preliminary FIS model. For the Little River, VHB assigned expansion and contraction coefficient values of 0.1 and 0.3, respectively, at most cross-sections. For cross-sections immediately upstream or downstream of a bridge or culvert, VHB assigned coefficient values of 0.3 and 0.5, respectively.

Ineffective Flow Areas

For the Exeter River, VHB preserved ineffective flow areas from the Preliminary FIS model. For the Little River, ineffective areas were added along model cross-sections as ineffective flow areas based on inspection of bridge crossings and the topography of adjacent cross-sections. All ineffective flow areas are considered temporary and are assumed to become effective flow areas when the flood profile exceeds the elevation assigned to the ineffective flow area.

Bridges and In-line Structures

VHB preserved the geometry of bridges and in-line structures from the Preliminary FIS for the Exeter River and from the Duplicate-Effective model for the Little River, with the following exceptions:

- For the Exeter River, the Great Dam and downstream fish weir were removed for the post-project model based on as-built survey.
- For the Little River, bridge high chord elevations were adjusted based on 2011 USGS LiDAR topography where the Duplicate-Effective HEC-2 model used the Special Bridge Routine without a set high chord profile.
- For the Little River Post-Project model, the Court Street and Linden Street bridge geometry was updated to reflect the replacement bridges constructed by the Town of Exeter in 2016 and 2017.

Boundary Conditions

The HEC-RAS model assumes subcritical flow for the entire model domain. This assumption is reasonable for the expected conditions in the study area. The downstream boundary condition for the Exeter River is set to critical depth, the same condition used in the Preliminary FIS model. The downstream boundary condition

for the Little River is set to normal depth for a slope of 0.007 ft/ft, the average channel slope for the downstream reach of the river. In both cases, the actual water surface elevation is controlled by backwater from the confluence with the downstream river.

6

Conclusions

The hydraulic analysis performed for this work provides new flood profiles and inundation areas to revise the regulatory floodway, 1-percent annual exceedance (100-year) floodplain, 0.2-percent annual exceedance (500-year) floodplain, and 1-percent annual exceedance probability (100-year) Base Flood Elevation (BFE) for the Exeter River and Little River No. 1 in Exeter, New Hampshire. The hydraulic analysis model incorporates both physical changes (the removal of the Great Dam in Exeter) and improved data (updated hydrologic analysis and topographic data for the Little River No. 1). As a result, the Effective FIS would be changed by the following modifications:

- Exeter River BFE and flood profiles will be lowered by up to 3.0 feet along the 6-mile stretch upstream of High Street resulting from the removal of the Great Dam.
- Exeter River 1-percent and 0.2-percent floodplain extents will decrease along the same reach.
- Little River No. 1 BFE and flood profiles will be lowered by up to 2.5 feet along the 1.5-mile stretch upstream of the confluence with the Exeter River, due to reduced backwater from the removal of the Great Dam.
- Little River No. 1 1-percent and 0.2-percent floodplain extents will decrease along the same reach.
- Little River No. 1 floodway will be increased between published cross-sections E (footbridge between Cross Street and Linden Street) and H (Boston & Maine railroad crossing), as a result of improved hydrology and topographic data.
- Little River No. 1 BFE and flood profiles will be raised, and 1-percent and 0.2-percent floodplains will increase, from the Boston & Maine Railroad crossing to the upstream limit of study as a result of improved hydrology and topographic data.

Detailed HEC-RAS model results are included in Appendix B. Revised floodplain and floodway mapping is depicted in the Annotated FIRM panels in Appendix C and in the Topographic Work Map in Appendix D. Updated flood profiles and floodway tables are included in Appendix G and Appendix H, respectively. A data disk including electronic copies of all GIS shapefiles and HEC-RAS model data is included in Appendix E.

These changes to floodplain mapping would affect 281 parcels in the Town of Exeter, including 34 parcels in the Effective Zone AE (the 1-percent annual chance

floodplain) that would no longer be in the floodplain, and 18 parcels not currently in the Effective Zone AE that would now be in the floodplain. A list of the affected parcels, along with a draft letter to the owners of affected parcels, is included in Appendix I.

7

References

(IS-9) Federal Emergency Management Agency, Managing Floodplain Development through the NFIP, 1998.

(FEMA, 2003) Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, April 2003.

(FEMA 2009) Federal Emergency Management Agency, Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix C, November 2009.

(FEMA 2005) Federal Emergency Management Agency, Flood Insurance Study (Effective) Rockingham County, New Hampshire, May 17, 2005.

(FEMA 2016) Federal Emergency Management Agency, Flood Insurance Study (Preliminary) Rockingham County, New Hampshire, February 24, 2016.

(USACE 2016) U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS 5.0 River Analysis System User's Manual, Davis, California, February 2016.

(USGS 2009) U.S. Department of the Interior U.S. Geological Survey, Scientific Investigations Report 2008-5206, "Estimation of flood discharges at selected recurrence intervals for streams in New Hampshire" by Scott A. Olson, 2009.

(USGS 2011) U.S. Department of the Interior U.S. Geological Survey, New Hampshire/Vermont Water Science Center, Exeter River Flood Study, December 2011.

(USGS 2011) U.S. Department of the Interior U.S. Geological Survey, LiDAR for the Northeast 1-meter resolution digital elevation model, 2011

8

Appendices

Appendix A – Hydrologic Study

Appendix B – HEC-RAS Model Results

Appendix C – Effective and Annotated FIRM Panels

Effective and Annotated FIRM Panels are not bound with the narrative.

See the 26" x 36" Effective and Annotated FIRM Panel plots for the following panels:

- 33015C0382E
- 33015C0401E
- 33015C0402E
- 33015C0403E
- 33015C0404E
- 33015C0406E
- 33015C0408E

Appendix D – Topographic Work Map

Overall and Individual Topographic Work Maps are not bound with the narrative.

See the 24” x 36” Overall and Topographic Work Maps.

Appendix E – Data Disk

Appendix F – Survey Base Maps

Survey Base Maps are not bound with the narrative.

See the following 24” x 36” As-Built Survey plans:

- Court Street Little River Bridge Replacement
- Great Dam Removal
- Linden Street Little River Bridge Replacement

Appendix G – Effective and Revised Flood Profiles

Appendix H – Effective and revised Floodway Tables

Appendix I – Draft Letter to Affected Properties

Appendix J – Pre-Application FEMA Coordination