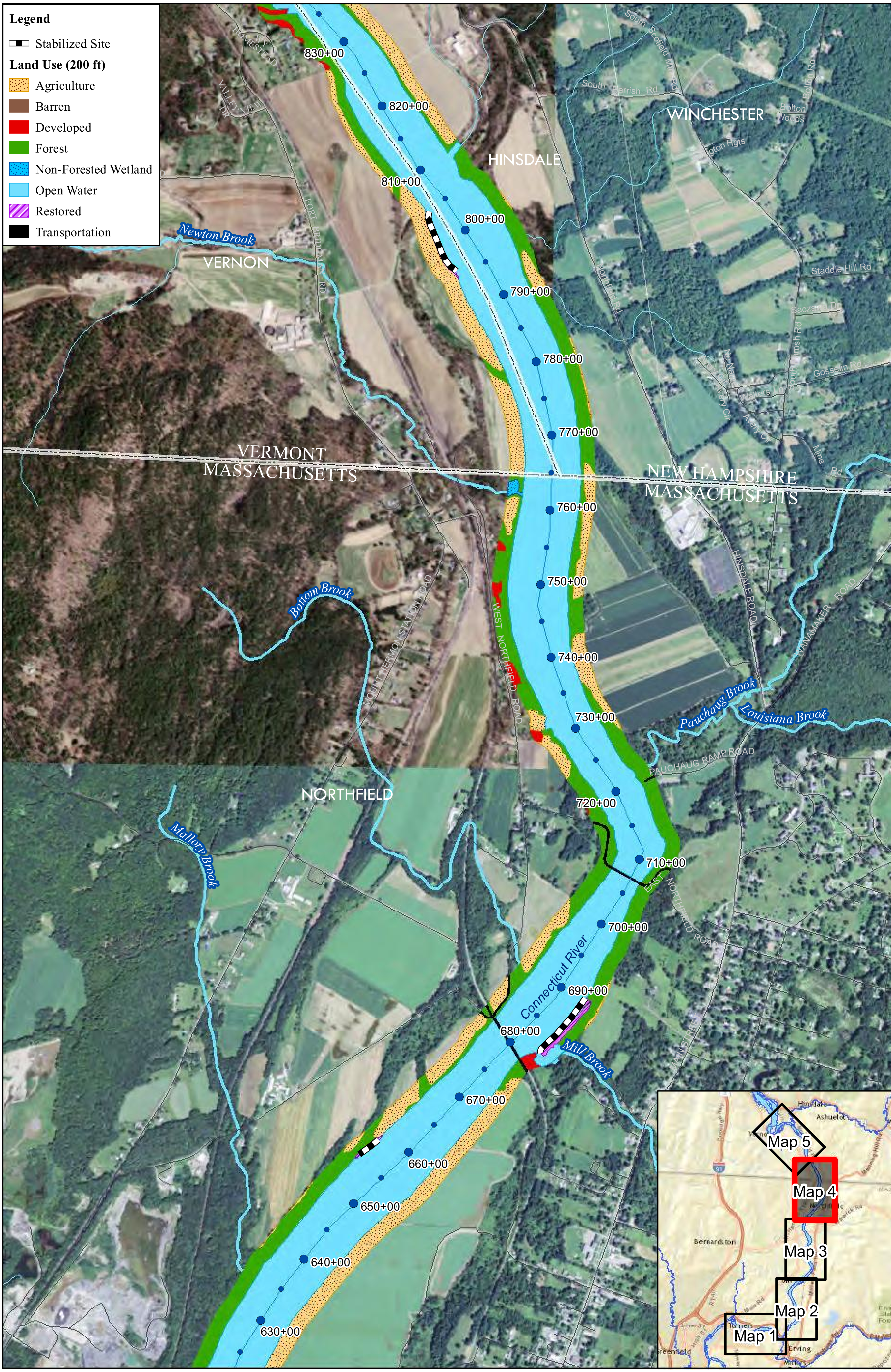

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Figure 5.5.4-1:
Turners Falls Impoundment
Land-use (2013 FRR)
Map 4

N

0 625 1,250 2,500 Feet

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,

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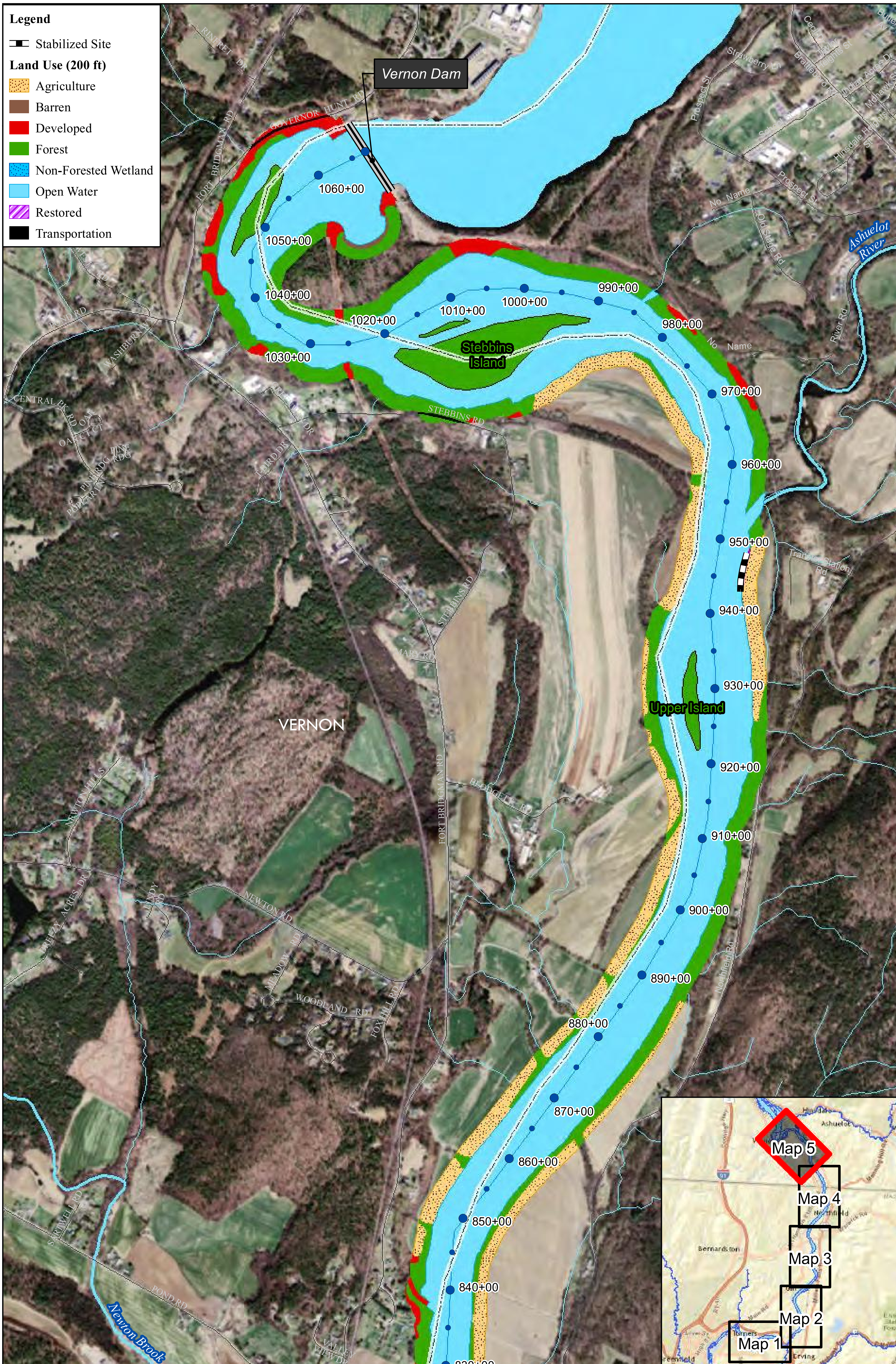


FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 625 1,250 2,500 Feet

Figure 5.5.4-1:
Turners Falls Impoundment
Land-use (2013 FRR)
Map 5

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS,

Path: W:\gis\studies\3_1_2\maps\final_report\figure_5_5_4-1.mxd

Figure 5.5.4-2 Agricultural development on the terraces of the Turners Falls Impoundment

Figure 5.5.4-3: Erosion Adjacent to Agricultural Land-use

Figure 5.5.4-4: Irrigation on agricultural field adjacent to the Connecticut River and Location on Google Earth, Photo 48

Figure 5.5.4-5: Irrigation pumping from the Connecticut River and Location on Google Earth, Photo 255

Figure 5.5.4-6a: Irrigation pumping from the Connecticut River, Photo 359

Figure 5.5.4-6b: Irrigation pumping from the Connecticut River, Photo 364

Figure 5.5.4-6c: Location of Photos 359 and 364 (Google Earth)

Figure 5.5.4-7: Ponding on agricultural fields from rainfall event, September 30, 2015 (a)

Figure 5.5.4-8: Ponding on agricultural fields from rainfall event, September 30, 2015 (b)

Figure 5.5.4-9: Ponding on agricultural fields from rainfall event, September 30, 2015 (c)

Figure 5.5.4-10: Ponding on agricultural fields from rainfall event, September 30, 2015 (d)

Figure 5.5.4-11: Ponding on agricultural fields from rainfall event, September 30, 2015 (e)

Figure 5.5.4-12: Ponding on agricultural fields from rainfall event, September 30, 2015 (f)

Figure 5.5.4-13: Ponding on Agricultural Fields from Rainfall Event, September 30, 2015 (g)

Figure 5.5.4-14: Erosion adjacent to seasonal Camp 2-W

Figure 5.5.4-15: Development thinning or removing riparian vegetation

5.5.5 Ice

Ice can cause damage to riverbanks and effect erosion processes in a number of ways, including:

- During break-up when moving ice can impact or push against and gouge into the bank disrupting or dislodging segments of the bank;
- Damaging or removing vegetation as it is moving along the bank shearing off or scraping against vegetation; and
- Ripping roots out of the ground when vegetation frozen into the ice is pulled up when the ice begins to move during break-up

For decades (since the early 1970s) when VY began using the Connecticut River for cooling water there has been little ice formation. With the decommissioning of this facility at the end of 2014, water temperatures in the Connecticut River downstream of VY have decreased; thus, increasing the potential presence of ice in the TFI. As discussed in Section 4.2.11, in order to account for the fact that ice may play a more significant role in riverbank erosion processes in the future a number of additional analyses were conducted. The results of these analyses are presented in this section.

5.5.5.1 TFI Photo Documentation – Winter 2015/2016

Photos were taken on eight occasions during the winter of 2015/2016 (December 15, 2015 to March 8, 2016) at eight locations spanning the geographic extent of the TFI to document ice conditions (Figure 4.2.11-1). The goal of the photo monitoring was to observe: (1) when sheet ice developed; (2) during formation of sheet ice; (3) during ice break-up; and (4) after ice break-up occurred. The winter of 2015/2016 was unseasonably mild and did not produce significant ice formation in the TFI. Documentation of ice conditions (or lack thereof) during the winter 2015/2016 are found in Volume III (Appendix J).

In preparation for the 2015-2016 ice season, some photographs were taken of ice conditions that occurred the preceding winter (2014-2015) when conditions were more conducive to the formation of ice. Examples of this effort are presented in Figures 5.5.5.1-1 through 5.5.5.1-10. The full set of photos are included in Volume III (Appendix J). While much of the river in the TFI was covered with ice during the winter of 2014-2015, ice break-up was uneventful and no significant damage or erosion was noted after the ice had melted in the spring of 2015.

Staff from USGS in Vermont and New Hampshire indicated in discussions with FirstLight that they have observed that ice typically does not cause erosion if the ice simply melts in place without significant break-up and if ice floes moving down river causing ice jams and impacting the banks do not occur. If, on the other hand, there is significant break-up, ice floes moving down river with the potential for ice jams that are pushed against and scrape along the banks; then such an event could potentially cause erosion and damage to the riverbanks. Ice formation and accompanying freeze/thaw cycles can weaken the soil matrix by developing cracks and spalling of the soil surface; however, the process of ice break up plays the most significant role in determining the potential for erosion caused by ice.

Figure 5.5.5.1-1: Barton Cove 1/5/2015

Figure 5.5.5.1-2: Barton Cove 3/3/2015

Figure 5.5.5.1-3: Northfield Mountain Tailrace 1/5/2015

Figure 5.5.5.1-4: Northfield Mountain Tailrace 3/3/2015

Figure 5.5.5.1-5: Route 10 Bridge 1/5/2015

Figure 5.5.5.1-6: Route 10 Bridge 1/5/2015

Figure 5.5.5.1-7: Route 10 Bridge 3/3/2015

Figure 5.5.5.1-8: Route 10 Bridge 3/3/2015

Figure 5.5.5.1-9: Pauchaug Boat Launch 1/5/2015

Figure 5.5.5.1-10: Pauchaug Boat Launch 3/3/2015

5.5.5.2 Analysis of Available Historic Ice Information

TransCanada was contacted to conduct database research of available ice information on upstream reaches of the Connecticut River. Primarily this information focused on the Vernon, Bellows Falls, and Wilder Impoundments, but some information from the TFI was also found. Additional research into USACE Cold Regions Research and Engineering Laboratory (CRREL) information on ice was also conducted. As part of this research, a trip was made to TransCanada's Bellows Falls office where TransCanada staff had organized files in boxes for review. Hundreds of individual documents were reviewed and numerous files scanned which contained relevant information. A list of the scanned files and associated type of information is provided in Volume III (Appendix J). Included in the TransCanada files were several documents, papers, and reports regarding ice from CRREL.

Much of the information contained in the TransCanada files consisted of photographs of ice jams, ice damage and erosion that occurred as a result of ice. One of the earliest set of photos from TransCanada showing ice was taken in 1915 at Brattleboro, VT (Figure 5.5.5.2-1), which is located in the Vernon Impoundment and just downstream of the West River confluence. Ice had moved a boat house adjacent to the river and ice had been forced over the riverbanks causing damage to trees as shown in Figures 5.5.5.2-2 and 5.5.5.2-3.

Sets of photographs showing ice found in the TransCanada files include the following years: 1915, 1935, 1940, 1941, 1942, 1943, 1945, 1946, 1959, 1968, 1989, 1992, and 1994. Figure 5.5.5.2-4 provides an example of historic ice photos taken in 1915. In addition to a number of sets of photographs of ice, some data was also available in the TransCanada files including ice thickness at several locations along the river. An example of such data is shown in Figure 5.5.5.2-5. Another example of the type of ice data that are available is found in Figure 5.5.5.2-6. Similar types of data were found in the TransCanada files for the following years: 1940, 1944, 1945, 1946, 1948, 1951, 1952, 1953, 1955, 1956, 1957, and 1958. While some observations, are available before and after these years, actual measurements of ice in the available files were concentrated in the 1940s and 1950s. In addition, maps of the extent of ice were occasionally developed based on observations along the river (Figure 5.5.5.2-7). A review of the files also found that tributaries to the Connecticut River are a significant contributor of ice. When ice jams occur, they form as a result of constrictions or shallow areas associated with tributaries.

The fact that ice can and has caused significant damage and erosion to riverbanks and riparian vegetation is clearly documented photographically as shown in various images from TransCanada. One of the years when ice data, notes, and photographs were all taken during ice formation and after it had melted was 1946. This set of information provides insight into ice observations (Figure 5.5.5.2-8), ice photographs (Figures 5.5.5.2-9 through 5.5.5.2-11), ice measurements (Figure 5.5.5.2-12), and damage to riverbanks caused by ice (Figures 5.5.5.2-13 through 5.5.5.2-20). While photographs were either not taken or not available from reaches farther downstream along the Connecticut River in 1946; notes of observations clearly document that ice moved through the river farther downstream, including the TFI (Figure 5.5.5.2-21).

Damage to riverbanks near Cornish, NH in 1946 look very similar to what was observed farther downstream in the Bellows Falls Impoundment in the study conducted by Simons & Associates, 1992, *"Analysis of Bank Erosion at the Skitchwaug Site in the Bellows Falls Pool of the Connecticut River."* The destruction of vegetation and the jagged nature of the top of bank in 1946 (Figure 5.5.5.2-22) following the ice event that year look similar to the lack of vegetation and ice pushed into the banks in 1992 (Figure 5.5.5.2-23). We believe the impacts at this location in 1992 were similar to that depicted in the 1946 photo.

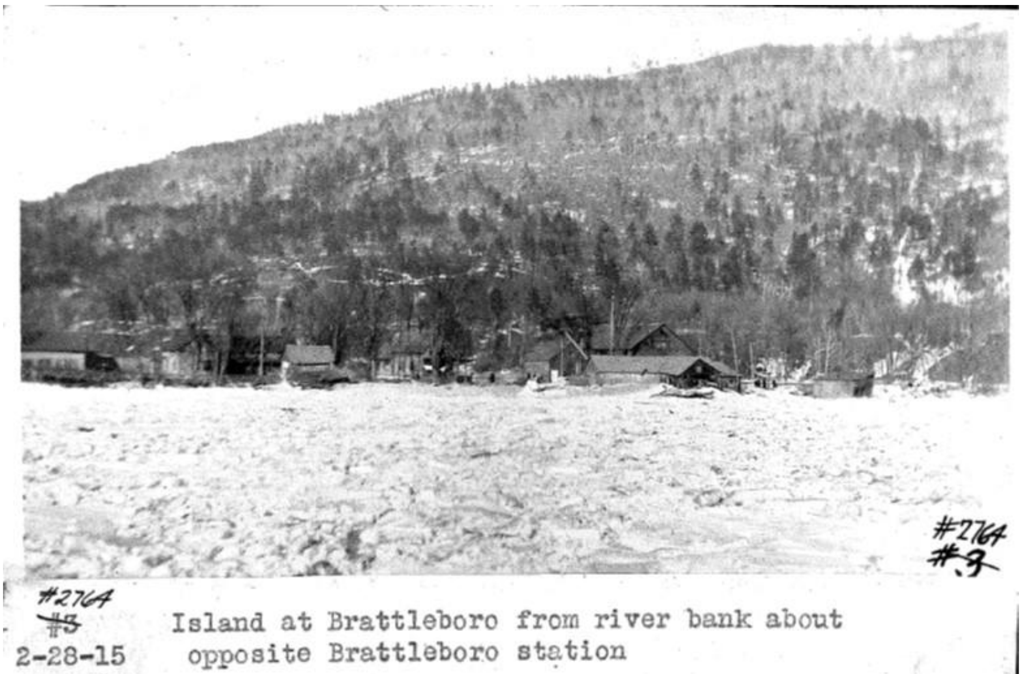


Figure 5.5.5.2-1 Ice on the Connecticut River at Brattleboro, VT – 1915 (TransCanada)

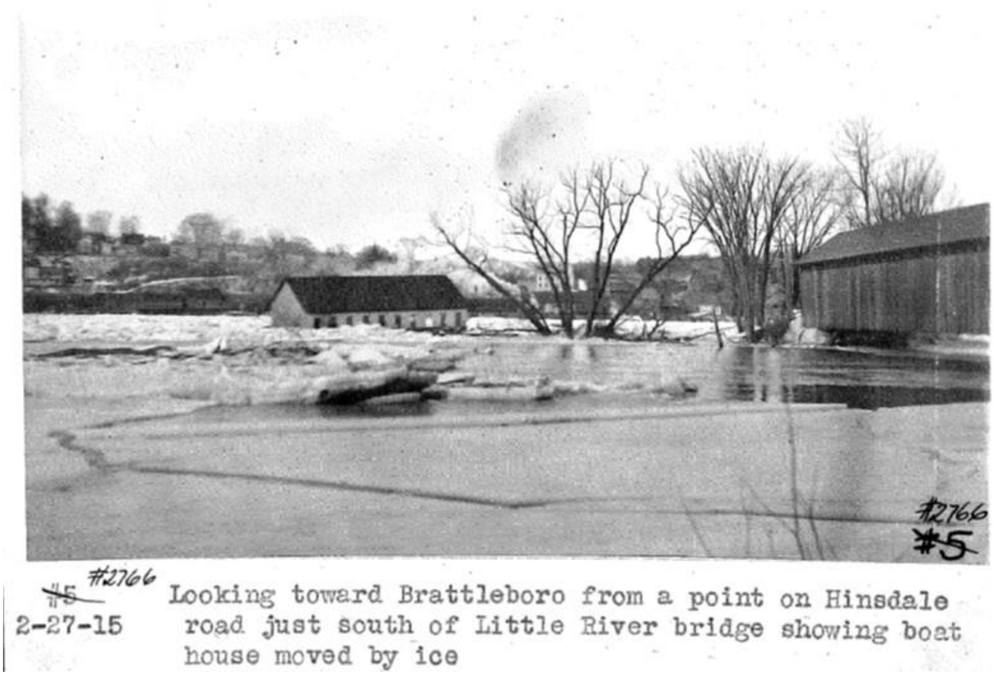


Figure 5.5.5.2-2 Connecticut River Boat House Moved by Ice – 1915 (TransCanada)

Figure 5.5.5.2-3 Ice along riverbanks showing damage to trees, 1915 (after TransCanada)

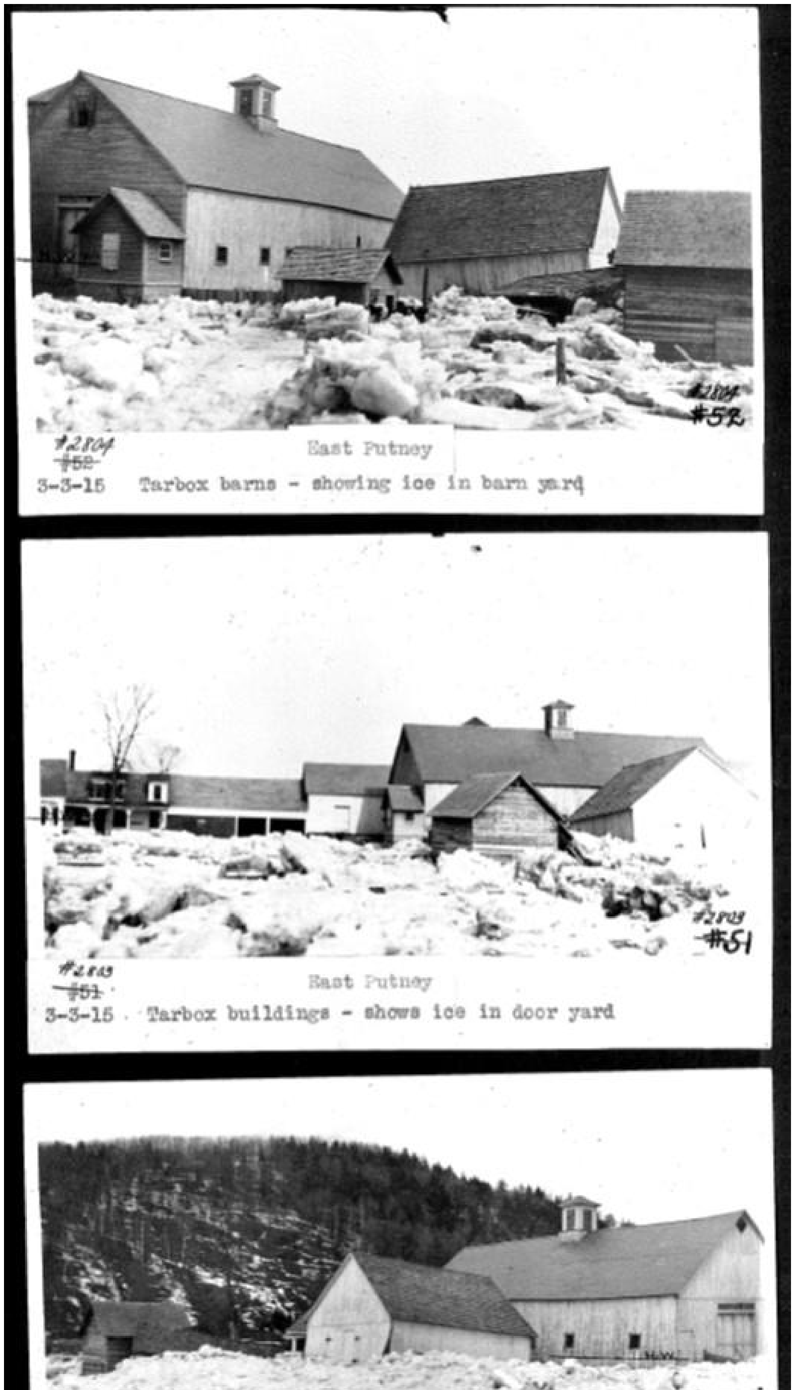


Figure 5.5.5.2-4 Ice at East Putney – 1915 (TransCanada)

ICE MEASUREMENTS

Taken Jan. 30, 1945 by E. E. Fuller.

Location	Vt. side	Middle	N. H. side
Log Yard	50' out 13-1/2"	10"	50' out ice. 8" good ice - 6" snow
Line Crossing	100' out 17"	12-1/2"	75' out 13"
Cheshire Bridge 600' above	100' out 13"	10-1/2"	75' out 11-1/2"
Vershire Camps 3000' above	50' out 11-1/2"	16"	75' out 15"
Ascutney Bridge	50' out 19-1/2"	17-1/2"	50' out 22"
Cone Meadows	75' out 15"	20-1/2"	75' out 18-1/2"

There is a lead about 150 yards long and 20' wide at the Island below Windsor.

Small opening in center of River below the brook at Blood Eddy.

Small lead in the center of the River opposite the mouth of Big Sugar.

Figure 5.5.5.2-5 Example of Ice Measurements – 1945 (TransCanada)

CONNECTICUT RIVER

1946 ICE SURVEY

WELLS RIVER TO WILDER, VERMONT

Index.	River Mileage above Wilder	No. 1 Test Hole	No. 2 Test Hole	No. 3 Test Hole	No. 4 Test Hole	Average.	Location.
		(Thickness of Ice in Inches)					
1	46.6	37	28½	25½	27	29½	Ingalls Eddy.
2	43.9	23½	16	21	19	19-7/8	Ox-Bow off Chas. Dodge Prop.
3	42.2	34	19	17½	17½	22	Middle of Ox-Bow, Newbury.
4	39.3	37½	17½	18	17½	22-5/8	Newbury Bridge, upstream side.
5	36.5	29	14	17	16	19	S. Newbury Bridge downstream.
6	34.0	28½	16	17	24½	21½	Roaring Brook downstream.
7	32.8	20	17	16	25	19½	Off Judson Clark property.
8	29.0	28½	14½	16	17½	19-1/8	Piermont Bridge downstream.
9	27.8	(No measurements - road drifted)					Off M. A. Jenkins property.
10	26.0	26½	15½	23	18	20-3/4	Orford-Piermont Town Line.
11	24.0	22	13½	15½	12½	15-7/8	Adjacent to Jas. Cummings prop.
12	21.5	26	22½	14	14	19-1/8	Orford Bridge downstream.
13	18.0	28	12	17	20½	19-3/8	Clay Brook upstream at Town Line.
14	15.2	30½	20½	16	23	22½	No. Thetford Bridge upstream.
15	13.1	24	14	20	21	19-3/4	E. Thetford-Lyme Bridge down.
16	10.3	30½	23½	15½	13	20-5/8	Above Huggetts Island.
17	8.2	11	9½	13	10½	11	Kendall R.R. Station.
18	6.0	22½	13	14	11	15-1/8	Above Island at Camp Brook.
19	3.0	31½	23	19½	18½	23-1/8	Above Hanover Bridge.
20	2.4	24	18½	14	18	18-5/8	Above Mink Brook.
21	1.4	(No readings due to wind and cold.)					Chase Island.
22	.9	30	18	15	21½	21-1/8	Wilder Pond above boom piers.
Average		27.2"	17.3"	17.2"	18.3"	20"	

Note: River mileages are taken from River Print R-1661$\underline{10}$ and zero mileage is at the proposed New Wilder Dam Site.

Figure 5.5.5.2-6 Example Ice Survey (TransCanada)

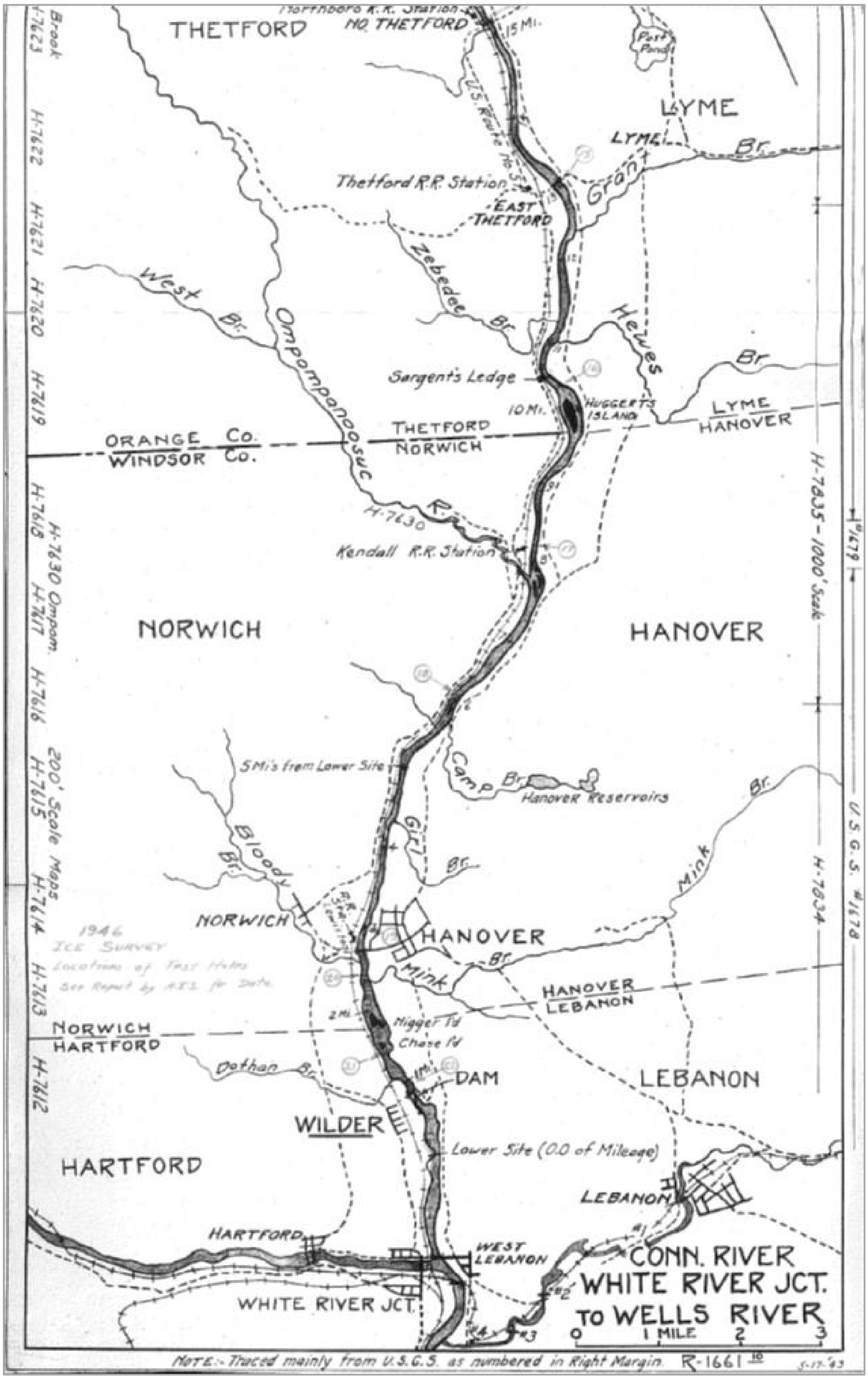


Figure 5.5.5.2-7 Map of Ice Survey and Test Holes – 1946 (TransCanada)

Connecticut River Ice

(Field Notes - C. S. Brewer)

Date	Time	Remarks
3-8-46	3:30 P.M.	Signs of little sugar expelling ice.
3-8-46	3:35 P.M.	Slight lead at Blood Eddy - debris may block culvert.
3-8-46	3:45 P.M.	At Rose Gardens lead 75' wide by 1/4 mile long on New Hampshire shore, ice from January movement intact.
3-8-46	4:25 P.M.	Ottauqueechee open between bridge and dam.
3-8-46	4:45 P.M.	On White River Junction R.R. Bridge, no ice movement - open water in Connecticut under highway bridge. W.R. is filled with ice to about 3/4 mile above R.R. bridge across W.R.
3-8-46	5:30 P.M.	Observed ice jam on highway about 2 miles above Hartford on W.R.-road cleared at this time.
3-8-46	7:30 P.M.	Called Bellows Falls and told Pollard that we were at Windsor House and gave him Windsor at 7:20 P.M. W.R. @ 4:00 P.M. = 20.31
3-9-46	7:20 A.M.	At Windsor gauge - hard rain - but no ice movement since last night.
3-9-46	7:30 A.M.	Clearing sky - rain stopped.
3-9-46	8:30 A.M.	Talked to A.S.Walker and got W.R. readings 7$\frac{48}{A}$ = 20.81 8$\frac{05}{A}$ = 19.33. Instructions are to watch Windsor for this slug.
3-9-46	11:10 A.M.	Started to rain and blow at Windsor.
3-9-46	11:45 A.M.	Stopped raining.
3-9-46	1:30 P.M.	Shore lead on Vt. side running more briskly and boiling over on channel ice - <u>ice cracked for few seconds.</u>
3-9-46	4:45 P.M.	Ice started moving - whole river in motion.
3-9-46	5:00 P.M.	Head of previous jam now at Windsor.
3-9-46	5:10 P.M.	Ice motion stopped.
3-9-46	5:15 P.M.	Ice across road North of bridge on N.H. side at Pole #16 Tree on bank scarred and spiked at water high mark.
3-9-46	5:30 P.M.	High water mark 37" below top of sewer behind garage of old toll house on Vt. shore.

Figure 5.5.5.2-8 Connecticut River Ice Observations and Field Notes (TransCanada)

Figure 5.5.5.2-9 Connecticut River at White River Junction, VT – March 8, 1946 (TransCanada)

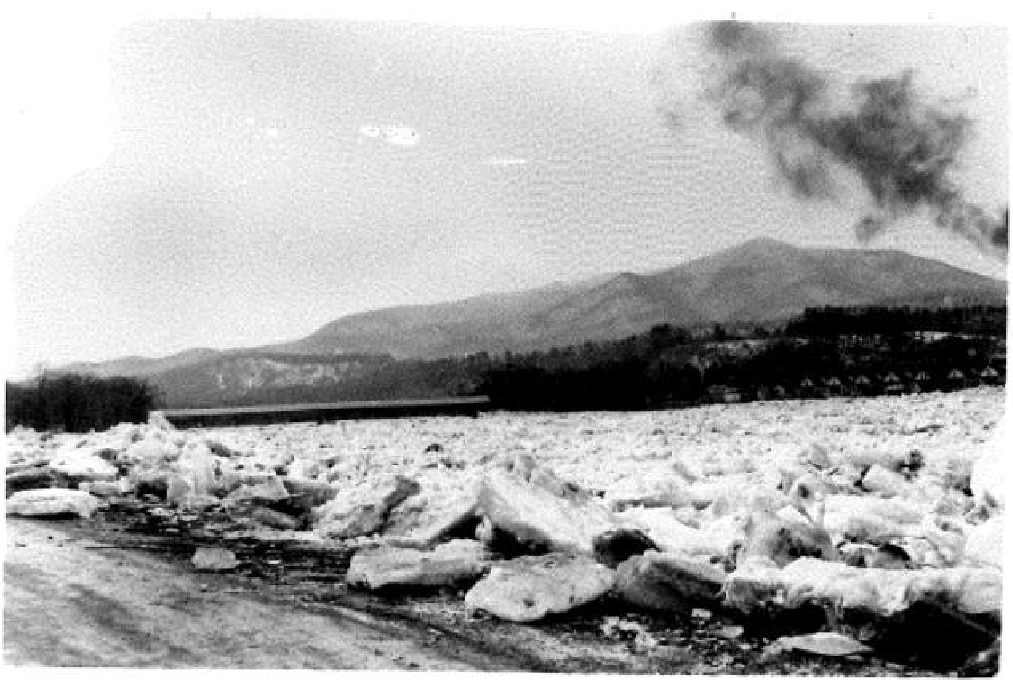


Figure 5.5.5.2-10 Connecticut River Downstream of Windsor Bridge – March 10, 1946 (TransCanada)

Figure 5.5.5.2-11 Connecticut River at Windsor Bridge – March 10, 1946 (TransCanada)

CONNECTICUT RIVER

1946 ICE SURVEY

WELLS RIVER TO WILDER, VERMONT

Index.	River Mileage above Wilder	No. 1 Test Hole	No. 2 Test Hole	No. 3 Test Hole	No. 4 Test Hole	Average.	Location.
		(Thickness of Ice in Inches)					
1	46.6	37	28½	25½	27	29½	Ingalls Eddy.
2	43.9	23½	16	21	19	19-7/8	Ox-Bow off Chas. Dodge Prop.
3	42.2	34	19	17½	17½	22	Middle of Ox-Bow, Newbury.
4	39.3	37½	17½	18	17½	22-5/8	Newbury Bridge, upstream side.
5	36.5	29	14	17	16	19	S. Newbury Bridge downstream.
6	34.0	28½	16	17	24½	21½	Roaring Brook downstream.
7	32.8	20	17	16	25	19½	Off Judson Clark property.
8	29.0	28½	14½	16	17½	19-1/8	Piermont Bridge downstream.
9	27.8	(No measurements - road drifted)					Off M. A. Jenkins property.
10	26.0	26½	15½	23	18	20-3/4	Orford-Piermont Town Line.
11	24.0	22	13½	15½	12½	15-7/8	Adjacent to Jas. Cummings prop.
12	21.5	26	22½	14	14	19-1/8	Orford Bridge downstream.
13	18.0	28	12	17	20½	19-3/8	Clay Brook upstream at Town Line.
14	15.2	30½	20½	16	23	22½	No. Thetford Bridge upstream.
15	13.1	24	14	20	21	19-3/4	E. Thetford-Lyme Bridge down.
16	10.3	30½	23½	15½	13	20-5/8	Above Huggetts Island.
17	8.2	11	9½	13	10½	11	Kendall R.R. Station.
18	6.0	22½	13	14	11	15-1/8	Above Island at Camp Brook.
19	3.0	31½	23	19½	18½	23-1/8	Above Hanover Bridge.
20	2.4	24	18½	14	18	18-5/8	Above Mink Brook.
21	1.4	(No readings due to wind and cold.)					Chase Island.
22	.9	30	18	15	21½	21-1/8	Wilder Pond above boom piers.
Average		27.2"	17.3"	17.2"	18.3"	20"	

Note: River mileages are taken from River Print R-1661 10 and zero mileage is at the proposed New Wilder Dam Site.

Figure 5.5.5.2-12 Ice Survey, Connecticut River (TransCanada)

Figure 5.5.5.2-13 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

Figure 5.5.5.2-14 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

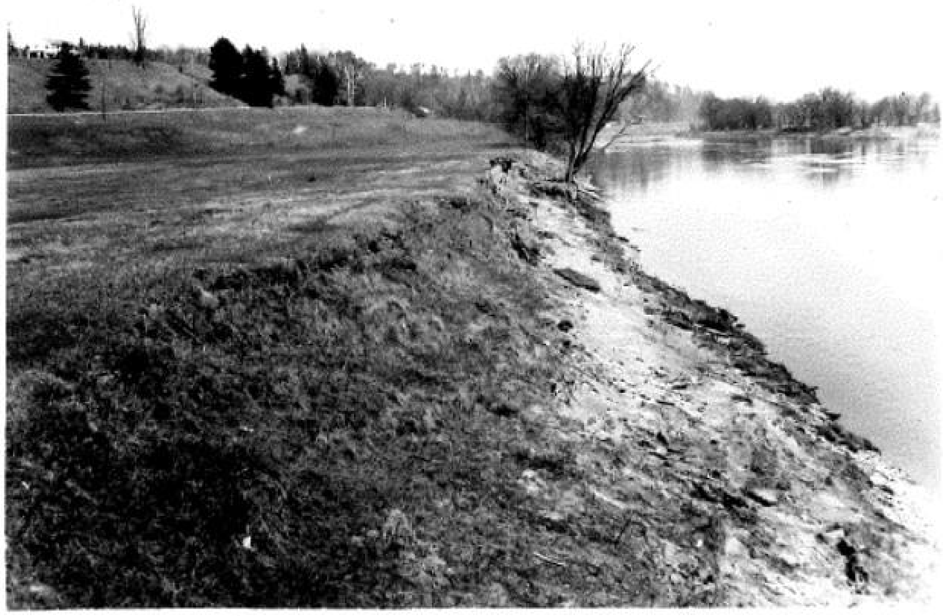


Figure 5.5.5.2-15 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

Figure 5.5.5.2-16 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

Figure 5.5.5.2-17 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

Figure 5.5.5.2-18 Connecticut River near Windsor, VT – April 24, 1946 (TransCanada)

Figure 5.5.5.2-19 Connecticut River near Cornish, NH – April 23, 1946 (TransCanada)

Figure 5.5.5.2-20 Connecticut River near Windsor, VT – April 23, 1946 (TransCanada)

NOTES OF THE 1946 SPRING RUNOFF
By P. C. Pray-In Boston Office

3/8/46 Friday

Observations from French King Bridge reveal breakup in vicinity of Bridge. River just above Turners Falls pond unbroken. No disturbance at Meadow Bridge. Northfield Shell Bridge, there is no disturbance.
Vernon Tail Race cleaned out to line crossing.
No leads from side brooks on Vernon Pond. At Route 9 bridge, there is unbroken ice.
Salmon - Canoe - E. Putney, brook beds are cut open.
Connecticut River cleaned from Bellows Falls tail Race to just below Cobb Br. - ice is gathered here.

Monday, Mar. 11-46

Lake went from Gilman to Cannan and ice intact and too solid to go out. From West Stewartston up, river is clear of ice, due to Pittsburg flow.

Simmonds reports ice in Wilder Basin too solid to move out on present flows. Ice has lifted in some places and some evidence of water pressure but no movement.

A. S. W. called - no change in ice conditions.-J.A.C. to Hadley.

Mr. Nullish called - gave him temps and ppt. from 3-8-46 - 3-11-46 at 15 M. F. He commented on Montague City having turned over and Springfield still rising. I told him Vernon turned over between 3-10-46, 4:00 P.M. and 3-11-46, 8:00 A.M. and that would bear out Montegue and Springfield might be expected to turn over a little later. He commented on some trouble at the Northampton. Hadley Bridge but seemed to have no details, other than dyke work was done. He said he presumed it was the White River ice that had jammed up at Hadley and caused only a little trouble. I pointed out that the White River ice had not got down that far and that it had not passed B. F. or was not quite past Windsor.

C.R.B.-P.C.P

C.R.Bliss reports ice moving in Conn. River below Vernon, passing under Schell Bridge about 2:45 P. M., 3-12-46. He then went back over meadow, down Gill Road and across French King. Main body passed thru meadow while there and it appears that the river is clear from Vernon tail race to French King Br.

Figure 5.5.5.2-21 Notes of the 1946 Spring Runoff (TransCanada)

C.R.B.-P.C.P C.R.Bliss reports ice moving in Conn. River below Vernon, passing under Schell Bridge about 2:45 P. M., 3-12-46. He then went back over meadow, down Gill Road and across French King. Main body passed thru meadow while there and it appears that the river is clear from Vernon tail race to French King Br.

2:30 P. M. Informed Col. Dalton that ice was passing over Vernon dam. Flows had not increased. This was not an unusual thing, but we were keeping him informed as we said. He asked how soon it would get down river and this was answered by saying it had to go thru Turners Falls pond, etc., before getting to Whateley and we were not familiar with river timing down the river. He replied by saying he would say about 18 hours.

Friday, 3-15-46 About 12:00 Noon Vernon reported they had lost the remaining 300' of their boards and that ice in the Vernon Pond had started out.

Figure 5.5.5.2-21 Notes of the 1946 Spring Runoff (TransCanada) continued

Figure 5.5.5.2-22 Connecticut River near Cornish, NH – April 25, 1946 (TransCanada)

Figure 5.5.5.2-23 Ice-Riverbank Interaction in Bellows Falls Impoundment – 1992 (TransCanada)

5.5.5.3 Analysis of the Effects of Ice

A review of the effect of ice on rivers was published in the Journal of Cold Regions Engineering, *"Review of Alluvial-channel Responses to River Ice,"* (Ettema, 2002). The review acknowledges that general concepts regarding the interaction between ice and rivers are understood to some degree but much remains for further study and analysis. The review discusses the fact that riverbanks are weakened due to ice-related processes.

One such ice-related process that is discussed is freeze-thaw. The report states that, freeze-thaw dynamics *"may locally weaken bank soils* (Ettema, 2002)*."* Water is found in at least some of the pore spaces between soil particles in riverbanks. During sufficiently cold weather (in terms of temperature and duration), some of the water in riverbanks can freeze. As water freezes it expands thereby loosening soil particles, causing an expansion of the space between particles, or causing cracks in the soil matrix. Additional water can find its way into larger spaces and with additional freeze-thaw cycles more disruption of the soil matrix can occur. In cold climates, freeze-thaw can adversely affect riverbank stability allowing flow-related forces or gravity to have an enhanced erosive effect on riverbanks.

Inspection of riverbanks during winter conditions sometimes reveals cracks in the bank that may be related to freeze-thaw. Cracks that form as a result of this dynamic encourage more water to infiltrate into the crack because there is less resistance to flow than through the general soil matrix. As a result of subsequent freeze-thaw cycles, cracks in the soil may grow and eventually could lead to pieces of sediment breaking loose (spalling) and falling or sliding down the riverbank slope. Figure 5.5.5.3-1 shows ice on the river as well as icicles hanging down the riverbank, which is indicative of water moving through the riverbank and freezing. Figure 5.5.5.3-2 is an example of the small cracks forming in riverbanks that may be due to freeze-thaw. No actual data exist that allows quantification of the effect of freeze-thaw cycles on riverbank stability in the TFI. Freeze-thaw is a natural process that is primarily influenced by weather and climatic cycles and is not considered a primary factor in riverbank erosion processes in the TFI, nonetheless it is likely to contribute to riverbank instability to some lesser degree.

Another phenomenon discussed in R. Ettema, 2002 was that ice may cause erosion to riverbanks by abrasion or gouging. The review specifically noted that "*during heavy ice runs resulting from ice-cover breakup or ice-jam release, large pieces of ice potentially may gouge and abrade channel banks. There exists significant evidence showing that ice runs may substantially affect riverbank morphology (Marusenko 1956; Hamelin 1979; Smith 1979; U.S. 1983; Doyle 1988; Wuebben 1995; Uunila 1997)"* (R. Ettema, 2002). Ice flowing downstream, or being forced into the banks, was clearly seen in historic and recent photographs shown previously in this report (see Figures 5.5.5.2-1 through 5.5.5.2-4, 5.5.5.2-9 through 5.5.5.2-11, and 5.5.5.2-23). Damage associated with these ice events can be observed in previous figures (Figure 5.5.5.2-13, 5.5.5.2-15 through 5.5.5.2-18, and 5.5.5.2-22 through 5.5.5.2-23).

Ice also has an adverse effect on riparian vegetation (as shown in previously referenced Figure 5.5.5.2-14, 5.5.5.2-19, and 5.5.5.2-20). As noted in R. Ettema, 2002:

> *"Ice-run gouging and abrasion have an important, though as of yet not quantified, effect on riparian vegetation that, in turn, may affect bank erosion and channel shifting. Where ice runs occur with about annual frequency, riparian vegetation communities have difficulty getting established. Ice abrasion and ice jam flooding may suppress certain vegetation types along banks . . . possibly exacerbating bank susceptibility to erosion. This aspect of river ice has yet to be further investigated."*

The effects of ice on riparian vegetation were investigated on the Platte River in Nebraska. A comprehensive vegetation demography study was conducted over a period of numerous years where thousands of seedlings were tagged and tracked through stages of germination, establishment, and growth; as well as numerous modes of mortality including scour, desiccation, ice, and inundation. W.C. Johnson, a vegetation biologist, was the primary investigator of the vegetation demography studies. S&A provided hydrologic and hydraulic support and then utilized the data to develop computer models simulating the interaction between rivers and riparian vegetation. Additional information about this study can be found in the reports: *Analysis of Ice Formation on the Platte River (S&A, 1990a); Physical Process Computer Model of Channel Width and Woodland Changes on the North Platte, South Platte and Platte Rivers* (S&A, 1990b); and *Calibration of SEDVEG Model Based on Specific Events from Demography Data* (S&A, 2002).

A summary of aspects of this work was presented in *"Physical History of the Platte River in Nebraska: Focusing upon Flow, Sediment Transport, Geomorphology, and Vegetation,"* (S&A, 2000). The report found that ice frequently formed along the Platte River during the winter with the ability to remove or damage vegetation as it breaks up and begins to move downstream. Seedling mortality was observed to be highest in the winter due to the fact that ice can block flow and raise river stage, cause sediment movement, and physically damage living vegetation. Mortality rates were observed to be as high as 98% due to ice. The vegetation monitoring studies presented clear evidence of the significant impact ice-scour has in controlling vegetation in the Platte River (S&A, 2000).

While these studies focused on relatively early stages of life from germination through several years old, it confirms the concept in R. Ettema, 2000 regarding the adverse effects of ice on riparian vegetation. It provides a reasonable explanation of why eroded segments of river found in the Vernon and Bellows Falls Impoundments in 1997 remain in the same eroded state in 2008 and; in contrast, significant establishment and growth of new riparian vegetation has been observed in the TFI in both the 2008 and 2013 FRRs where no significant ice formed due to VY.

Although data pertaining to the forces that ice imposes on riverbanks or riparian vegetation is not available, it is evident that ice forces are larger than those imposed by the flow alone as documented photographically and descriptively where trees being snapped off by ice are described and damage to vegetation is readily observed. Figure 5.5.5.3-3 shows ice damage to riparian vegetation along a forested riverbank of the Connecticut River in the Bellows Falls Impoundment. The photograph shows scarring of trees and downed or leaning trees that might have been damaged by the ice. Ice can remove significant vegetation along segments of the river exposing the banks to the erosive forces of water without protective vegetation. Ice may also damage or stress vegetation such that it can die or be weakened such that the vegetation provides reduced or limited protection against erosion.

A number of reports have been published over time investigating the impacts of ice on erosion processes along the banks of the Connecticut River. One such paper was developed by CRREL and included conducting analysis of historic ice events on the Connecticut River. This analysis focused on the reach of river in the vicinity of Windsor, VT where the Cornish-Windsor Bridge is located. In a paper entitled, *"Dynamic Ice Breakup Control for the Connecticut River near Windsor, Vermont,"* M.G. Ferrick, Lemieux, G.E., Weyrick, P.B., and Demont, W.(1988), information is given regarding historic ice events in this part of the river. As the report states, this bridge *"is the longest covered bridge in the United States and has significant historical value."* The report then cites historic ice events that have damaged or destroyed this bridge.

> *Initially constructed in 1796, the Cornish-Windsor covered bridge was destroyed by the Connecticut River in the spring of 1824, in 1849, and again on 3-4 March 1866 (Childs 1960). The loss of the third bridge in 1866 was specifically attributed to ice breakup. The present structure was constructed in 1866 at a higher elevation above the river than previous bridges. Rawson (1963) reports that ice jam floods damaged this bridge in the spring of 1925, 1929, 1936 and 1938, and significant damage from ice impacts occurred again on 14 March 1977. The water levels associated with ice damage to the bridge also caused flood damage in Windsor, Vermont.*

In their analysis, CRREL characterized ice events into three categories of breakup since it is during the process of ice breakup when most damage occurs. Table 5.5.5.3-1 summarizes CRREL's assessment of ice breakup and associated damage to the bridge. CRREL defined the various categories of ice breakup with the following discussion (Ferrick, *et al*., 1988):

- The first group of events (1927, 1929, 1945, 1968, and 1981) exhibited high discharge with only gradual variations, and concurrent ice movement over a period of several days. A gradual and simultaneous breakup at several locations characterizes reduced energy gradient breakup behavior. The breakup was in an advanced stage when the peak discharge occurred, and water levels were generally moderate.

- The events in the second group (1946, 1964, and 1979) each included the formation of a persistent upstream ice jam. The eventual release of the White River ice jam in 1964 produced the highest water levels since at least the 1920s at White River Junction, Vermont. . . This short-duration, extremely high flow input was not supplemented by a rising Connecticut River and experienced significant attenuation prior to arriving at Windsor. In 1946 and 1979 ice jams near the Connecticut River gaging station persisted for about 35 and 48 hr, respectively. The delay of ice from the White River and upstream reach of the Connecticut River provided an opportunity for breakup downstream to proceed with a smaller ice volume, effectively increasing the channel capacity.

- The third group of events (1925, 1936, 1938, and 1977) includes most years of reported bridge damage and the highest water levels at Windsor. In each case an abrupt White River rise deposited large quantities of ice in the Connecticut River. The intact and competent ice on the Connecticut River then began to fail as the discharge continued to increase rapidly, and the breakup traveled downstream. The largest quantities of ice together with a high peak discharge produce the highest river levels at breakup.

According to the *"Flood of March 1936"* (Grover, 1937), the 1936 flood was the result of a warm, moisture-laden front which moved into and stalled over New England resulting in increased temperatures and heavy rainfall during the period March 11-13. For most of the Connecticut River watershed, this was a two-peak event. The first peak (as discussed in this section) was due to a rain-on-snow and ice jam event in mid-March while the second peak was more of a rain caused event later in March. Rainfall amounts as much as 5 inches were reported in some areas of New Hampshire. The combination of heavy rain and melting snow resulted in flooding throughout New England, including on the Connecticut River. The movement of ice, including ice jams and breaks, resulted in significant damage along the Connecticut River. An example of the magnitude of damage occurred at the Holyoke Dam where an ice jam formed above the dam resulting in the Connecticut River cutting a new channel on the east side of the river to get around the dam. Once the ice jam broke, over 9 ft. of water passed over the dam shearing off a 1,000 ft. wide by 5 ft. high section of the dam (Grover, 1937).

CRREL's analysis of historic ice events utilized climatic data including temperature and precipitation during the "warm period" in categorizing and understanding these events. Through this process, the 1936 event was evaluated to have a breakup category of 3 (the highest level where ice damage occurs with a combination of high flow and large quantities of competent ice), with a #1 ranking in terms of peak flow and a #3 ranking in terms of cold. Regarding precipitation during the warm period, no ranking was given but it was one of the highest listed in Table 5.5.5.3-1 with only 2 years having higher values.

Table 5.5.5.3-1: Assessment of Ice Break-up and Associated Damage to the Cornish-Windsor Bridge (CRREL)

Year	Peak flow date of breakup event	Peak daily avg. discharge		Discharge rank	Hydrothermal melting (m^3/s-days)	Freezing (ºC) days	Cold rank	Melting ºC-days through peak Q	Precip. in warm period (cm)	Breakup category
		(ft^3/s)	(m^3/s)							
Reported bridge damage										
1925	12-Feb	36,000	1020	6	100	625	20	18.3	0.20	3
1929	24-Mar	31,100	881	11	4600	445	48	28.1	0.69	1
1936	13-Mar	45,100	1280	1	600	790	3	20.0	4.80	3
1938	25-Mar	34,800	985	8	1900	585	26	56.8	0.05	3
1977	14-Mar	43,100	1220	2	900	741	7	59.4	3.89	3
No reported bridge damage										
1927	20-Mar	34,000	963	9	3900	580	29	59.7	0.53	1
1945	22-Mar	40,200	1140	3	4600	712	12	50.6	2.62	1
1946	9-Mar	31,000	878	12	800	744	6	34.4	2.92	2
1964	6-Mar	35,000	991	7	400	618	23	24.7	4.14	2
1968	22-Mar	34,000	963	9	2100	736	8	36.7	3.73	1
1979	7-Mar	40,000	1130	4	1000	671	18	37.5	6.48	2
1981	21-Feb	38,400	1090	5	4500	565	31	43.9	1.52	1
1986	27-Jan	19,700	558	28	100	641	19	0.0	6.99	2

Figure 5.5.5.3-1 Icicles Hanging from Upper Bank

Figure 5.5.5.3-2 Cracks in a Riverbank Potentially Associated with Freeze-Thaw

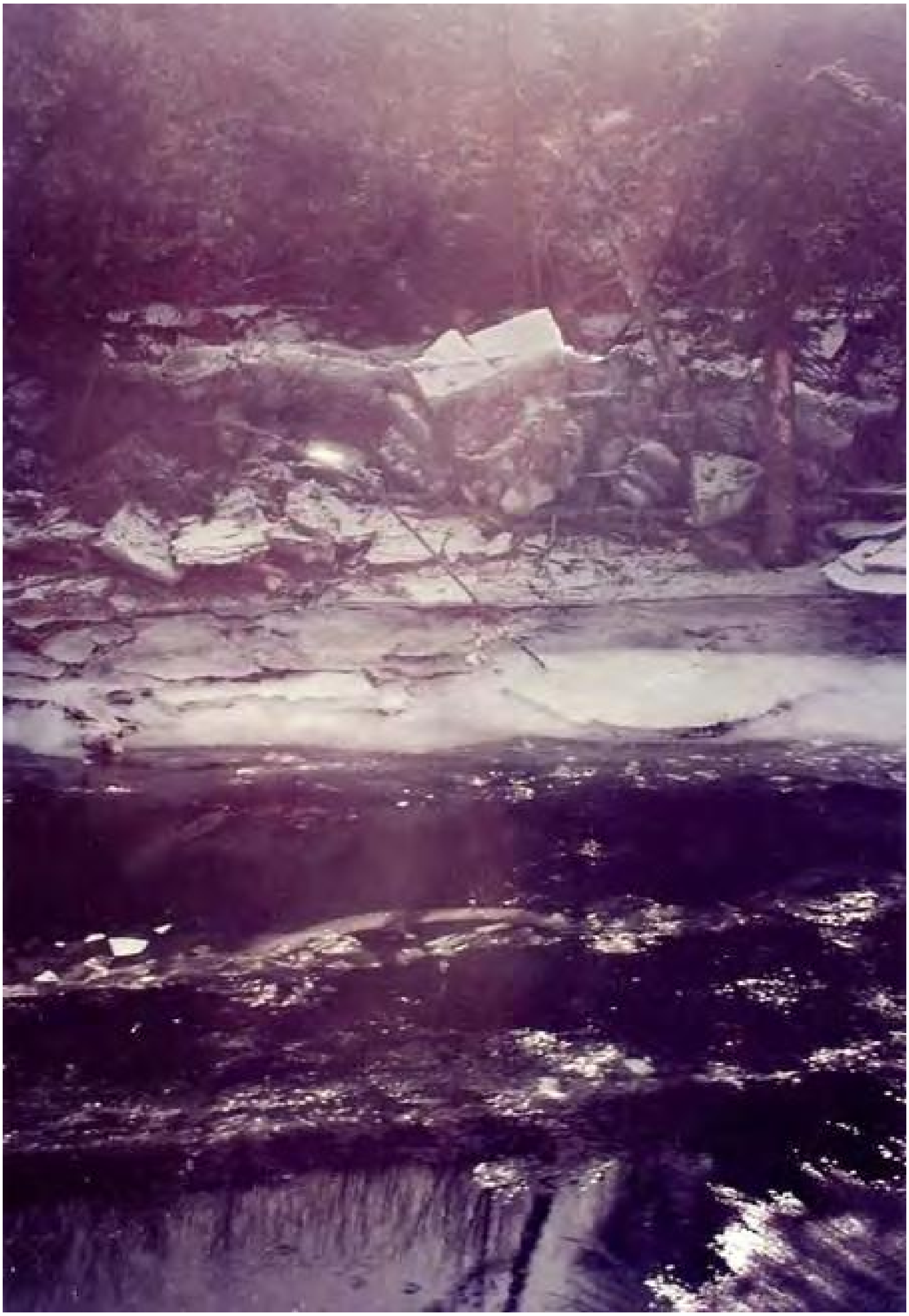


Figure 5.5.5.3-3 Ice Damage to Riparian Vegetation in the Bellows Falls Impoundment – 1992

5.5.5.4 Correlations between Ice and Temperature

The RSP Addendum outlining the study of ice calls for correlations between ice formation and breakup to be developed. As such, the correlation process begins by evaluating years of data where the greatest amount of information exists in order to determine what type of correlations are possible given the specific types of information available. Weather data for this analysis was obtained from monitoring stations in Amherst, MA; Vernon, VT; Keene, NH; and Hanover, NH. Table 5.5.5.4-1 provides an overview of the available information.

A considerable volume of material was found to be available for 1946 regarding ice. Available information includes photographs of ice and damage to riverbanks and vegetation after ice out, ice measurements and notes on observations, a map where ice measurements were taken, and notes of high flow during the spring runoff. In addition, air temperature and flow data are available. Information from January 7-12, 1946 does not discuss ice formation, but rather a thaw and ice movement at various locations. This indicates that ice formed prior to January 7, 1946 since there was an early winter thaw and ice movement event. Ice measurements were taken in February (15-19), with the next set of information being notes discussing ice break up and movement starting on March 8-14 and later in the spring. The minimum and maximum air temperatures at Amherst, MA, Vernon, VT, Keene, NH and Hanover, NH for December 1, 1935 through March 31, 1936 are displayed on Figures 5.5.5.4-1 through 5.5.5.4-4. Table 5.5.5.4-2 provides information correlating ice related events to days on the figures.

All of these graphs show a very similar pattern over time. The graphs of temperature over time indicate that since there was an ice thaw and movement event on January 7-12 (38-41), ice formed before this time; likely during the time when temperatures were low between days 21 – 25. For days 21 – 25, the minimum daily temperatures were primarily between 0 and 10°F with one day below zero (Amherst). The maximum daily temperatures for these days were in the teens and twenties and therefore below freezing. During the January thaw (days 38 – 41), minimum daily temperatures were at or above 30° and maximum daily temperatures ranged from 40 to 50°. During March (days 98-99 and 104-108), the minimum daily temperatures again rose above 30° with maximum temperatures rising into the 50's to over 70° for the days when ice breakup and movement were occurring. Similar temperature patterns were observed at Vernon, Keene, and Hanover.

The fact that ice must have formed when minimum temperatures ranged from below zero up to 10° with maximum daily temperatures less than 30°; and that ice thawed and began breaking up and moving occurred when minimum temperatures were above 30° with maximum temperatures into the 40s, 50s or significantly higher is not surprising.

Another known year with ice data occurred in the winter of 1943/1944. Graphs of temperature over time were prepared for these same stations (Figures 5.5.5.4-5 through 5.5.5.4-8). For the winter of 1943/1944, again no specific information is given regarding ice formation. Available information discusses some ice "shoving" and movement on February 8-10. Ice had to have formed before this time, probably on days 11 through 17 (December 11-17). Additional cold periods occurred through the winter, but as previously mentioned there was some type of ice movement on February 8-10 (days 70-72). The temperature data show a relatively warm period on days 50-60 and another small spike in temperature on about day 69. Minimum daily temperatures dropped again on approximately days 60-80. Notes indicate ice breakup on March 14-17 (days 105-108) and March 26 through April 1 (days 117-123). Minimum daily temperatures during this time period approached and sometimes exceeded freezing and daily maximum temperatures started getting into the 40° to over 60° range. Again, no specific information is available for this year regarding ice formation and ice melt/breakup provides a simple look at a complex issue given that other hydrologic variables of precipitation and flow must be considered.

Ice formation, melting/break-up, and potential ice jam flooding are dictated by climatic conditions that govern these processes. Similar to the CRREL study, climatic data were summarized over the period record to compare and correlate conditions that caused the ice related flooding of 1936 and other years to the rest of the historic record using the Amherst, MA weather station. Ice formation is governed by the number of days that are below freezing or colder during the winter months. Ice melting/break-up is governed by temperatures above freezing in the early spring. Potential flooding is governed by the amount of precipitation that occurs during the early spring concurrently with ice melt as well as snow melt. Table 5.5.5.4-3 summarizes these key data for the historic period. Columns 2-5 are the number of days during the winter months (from December of the preceding year through March of the current year) when the minimum daily temperature is less than 32°, 20°, 10° and 0°F. Columns 6 and 7 are average maximum daily temperature during March and the total precipitation for March (inches). There is an indication of ice occurring in the last column based on the scanned files from TransCanada. The same information is provided for Vernon, VT, Keene, NH and Hanover, NH in Tables 5.5.5.4-4 through 5.5.5.4-6. For the stations that go back into the 1800s, it is noted that 1896 is a year with significant numbers of cold days coupled with one of the larger values of precipitation in March.

For those years where the TransCanada files indicated ice on the Connecticut River, the maximum, average and minimum numbers of days below the selected temperatures are summarized in Table 5.5.5.4-7 through 10 for these four stations. For years when ice formed (as indicated by the TransCanada files and other information) the number of days below the various temperature ranges (<32°, <20°, <10°, <0°) when ice was indicated shows the types of temperature conditions that form ice. These summaries provide a general correlation of the range of temperature conditions under which ice historically formed on the Connecticut River. Ice formation could be expected during those years when ice observations were not available or for future prediction when the number of days below the various levels of temperatures falls within the ranges when ice was documented to have occurred as shown by this summary correlation.

It is instructive to compare temperature and flow conditions for some ice events for which some erosion information is available. The number of days below the various temperature levels for 1936 and 1946 are summarized in Table 5.5.5.4-11. 1936 had the fewest number of days <32° but somewhat above average number of days <20° through <0°. 1946 ranged from slightly below to somewhat above average number of days for the range of temperatures compared to all years indicated as having ice, but did not approach the maximum number of days in any temperature category. Regarding ice break up, the average maximum temperature in March for both 1936 and 1946 were above average, with 1946 actually being the maximum average March temperature. March precipitation for 1936 was well above average and near the maximum while for 1946, March precipitation was near the minimum for all ice years. Referring back to CRREL's evaluation of various ice events, 1936 was ranked in the maximum damage category while 1946 was in the middle or 2nd of the 3 levels of ice/break up events.

Given that 1936 resulted in devastating flooding and damage caused by flooding associated with ice, it can be assumed that a repeat of similar climatic conditions could potentially cause similar results. During the winter of 1936 there were 47 days of minimum temperatures less than 10ºF and 25 days of minimum temperatures less than 0ºF at Vernon. This caused significant ice formation. The average maximum temperature during March was 50ºF and there was 8.45 inches of precipitation which combined to cause melting/break-up of ice and sufficient flow in the river to cause ice-jam flooding and associated flooding and damage. The same information is available at the other weather stations. The question then becomes how unusual were the combination of climatic conditions in 1936 and could they be expected to recur in the future.

At Keene, NH, which has a record of climatic data from 1893 to 2016, the number of days less than 10ºF ranged from 19 to 55, averaging 39.3. The number of days less than 0ºF ranged from 0 to 38, averaging 17.9. Conditions in 1936 were above average in terms of numbers of days below the range of various temperatures but are exceeded several times during the more than 100 year period of available data. In terms of number of days less than 10ºF, 1936 ranks 2nd highest. For the number of days less than 0°, 1936 ranks 3rd highest. Based on the Hanover data, 1936 ranks 7th highest number of days <10ºF and 3rd highest

<0ºF. Conditions that caused formation of ice during 1936 were somewhat unusual, but not the most extreme. Regarding melting/break-up which is dictated by warmer temperatures, during March of 1936 the average maximum temperature was 50ºF (at Keene). This temperature was exceeded 4 times plus during the 1893-2016 record. March precipitation during 1936 totaled 7.60 inches which ranked first for the period of record. At Hanover, 1936 March precipitation ranked 2nd, but was significantly smaller (5.63 inches compared to 9.25 inches) than 1896. While 1936 ranks in the upper ranges regarding cold during the winter and a warm, wet spring; 1896 stands out as a significant ice event along with a number of other years for which no records of ice exist but for which ice is indicated based on the tables showing numbers of days for which temperatures are below the range of selected values. There are numerous years in these tables that exceed the number of days below 10° or 0° from 1936 for which there was no ice indicated. There are numerous years where ice was indicated with fewer cold days than years with no indication of ice. This indicates that the available record of ice is incomplete.

While 1936 represents the greatest flood of record, the individual climatic conditions leading to this event are not extreme and are within the realm of possibility to repeat. Consideration must also be given to the fact that ice related issues causing erosion occur during climatic conditions that occur much more frequently than just 1936 as documented in the CRREL analysis (Ferrick, *et al*, 1988) as well as numerous ice surveys and photographic documentation presented in this section. These conditions can now extend farther downstream through the TFI as a consequence of the closure of VY, as it had in the past.

The variation in temperature at Keene, NH, in terms of the number of days <10° and <0° as well as the average March maximum temperature is shown in Figure 5.5.5.4-9. March precipitation over the available period of record (1893 – 2016) is presented in Figure 5.5.5.4-10. These data plotted over time do not reveal any significant temporal trends.

These graphic and tabular correlations between known existence of ice and break up of ice yield the expected conclusion that ice forms when it is sufficiently cold and it breaks up when it is sufficiently warm. Due to the fact that actual ice formation data were not available (since those collecting the data and observations were focused on ice break up rather than ice formation), no specific criteria can be developed for ice formation. While ice does not necessarily form every year, whenever ice does form in the winter; as surely as night follows day, ice which forms in the winter melts in the spring (noting that spring in this context is considered to be based on climatic season rather than strictly the calendar). The fact ice necessarily melts in the spring of every year following the formation of ice from the previous winter (under the recent historic climatic regime); complicates the development of specific criteria regarding the consequences of ice break up as this is further complicated by the influence of precipitation, snow melt, and flow. More detailed analysis, beyond the scope of this investigation, would be required to develop more complex and specific criteria regarding ice break up that were not outlined in the study addendum. The general correlation, however, from the summary tables provides guidance as to the potential for damaging ice break up.

Table 5.5.5.4-1 Weather and Temperature Data Analyzed

Station	Weather Data Availability	Temperature Data
Amherst, MA	1893-2015	1893-2015
Vernon, VT	1893-1998	1912-1998
Keene, NH	1893-2016	1893-2016
Hanover, NH	1884-2016	1895-2016

**Columns for temperature data were included in the data files but contained no temperature data*

Table 5.5.5.4-2 Correlation of ice related events to dates (days), 1946

Date (day)	Observation
January 7-12 (38-41)	January thaw – ice thaw, breakup and movement
February 15-19 (77-78)	Ice measurements taken
March 8-9 (98-99)	Ice breakup and movement
March 14-18 (104-108)	Ice breakup and movement

Table 5.5.5.4-3 Summary of climatic data – Amherst, MA 1930-2015

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1893	81	56	33	12	40	3.25	
1894	101	59	26	8	51	1.45	
1895	114	73	36	15	40	2.62	
1896							x
1897	99	59	24	7	44	3.31	
1898	91	46	25	9	50	1.18	
1899	108	62	26	9	40	6.96	
1900	105	61	22	4	39	6.11	
1901	85	52	23	4			
1902	88	50	18	5	51	5.47	
1903	92	49	25	10	53	5.58	
1904	114	80	51	21	40	4.48	
1905	112	84	48	15	44	3.66	
1906	106	55	24	7	37	3.92	
1907	104	69	37	17	45	1.82	
1908	107	59	22	9	44	2.86	
1909	104	51	18	2	41	3.01	
1910	104	54	22	12	51	1.37	
1911	110	69	26	2	42	3.8	
1912	107	66	35	14	41	5.7	
1913	87	38	14	3	48	6.3	
1914	106	56	30	15	42	5.52	
1915	108	48	19	6	43	0.12	
1916	113	71	26	8	37	3.97	
1917	103	60	29	8	42	4.09	
1918	115	83	50	25	47	2.91	
1919	101	36	10	3	48	4.22	
1920	112	79	49	17	45	2.9	
1921	89	47	17	5	53	3.57	
1922	107	58	32	10	45	5.34	
1923	113	82	48	20	40	2.28	
1924	101	49	22	6	44	1.05	
1925	98	50	23	6	50	4.62	x
1926	102	65	24	2	38	3.95	
1927	107	63	34	8	36	2.62	x
1928	105	54	21	3	42	1.17	
1929	98	49	18	3	47	3.2	x
1930	68	35	16	4	43.3	3.95	
1931	105	55	23	7	44.2	3.79	
1932	98	43	7	0	39.8	4.24	
1933	99	32	13	2	39.3	4.79	
1934	114	74	43	20	40.9	3.6	
1935	102	63	30	13	45.4	1.48	x
1936	88	63	40	12	49.6	7.04	x
1937	98	34	6	0	39.4	3.38	
1938	102	53	20	3	47.5	2	x
1939	103	58	18	1	38.9	4.49	

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1940	109	71	28	3	37.4	5.58	x
1941	108	70	24	3	39	1.63	x
1942	97	44	23	5	48.1	7.89	x
1943	111	57	30	11	41.4	3.07	x
1944	106	65	32	5	41.1	4.36	x
1945	105	63	34	11	56.2	2.16	x
1946	100	62	37	8	57.5	1.6	x
1947	111	53	17	1	42.6	3.29	
1948	111	72	42	15	46.2	2.92	x
1949	92	35	11	1	48.5	1.67	
1950	98	48	16	9	41	2.67	
1951	93	37	14	5	45	5.13	x
1952	100	44	12	5	44.1	3.17	x
1953	91	32	3	0	46.2	8.24	x
1954	97	32	18	5	46.1	3.93	
1955	104	42	11	1	42.4	4.39	x
1956	106	59	16	6	37.1	4.94	x
1957	101	46	18	7	47.1	1.55	x
1958	99	40	21	6	43.9	2.62	x
1959	113	70	33	7	44.4	2.83	x
1960	104	44	11	0	36.5	3.32	
1961	106	77	52	29	42.9	3	
1962	107	63	36	8	45.1	1.84	
1963	116	76	50	27	44.1	3.61	
1964	113	63	44	13	47.2	2.71	x
1965	118	74	33	17	42.6	1.1	
1966	105	59	24	5	44.7	2.93	
1967	109	64	33	11	42.1	3.27	
1968	107	63	36	15	48.9	4.47	x
1969	108	67	36	5	44.3	1.97	
1970	110	74	41	24	44.2	3.52	
1971	114	68	39	18	43.3	2.53	
1972	107	54	30	6	43.6	4.85	
1973	96	40	20	5	52.6	3.45	
1974	106	55	20	11	46.6	4.34	
1975	102	53	17	6	45.5	3.97	
1976	102	57	33	12	51	2.15	
1977	102	70	46	12	54	5.88	x
1978	110	70	34	13	43.2	2.65	
1979	72	38	18	8	49.6	3	x
1980	100	62	26	1	41.2	6.42	
1981	106	65	41	18	47.3	0.24	x
1982	117	72	37	17	46.6	2.26	
1983	95	47	19	8	43	4.95	
1984	108	60	28	16	38.9	3.68	
1985	103	52	26	5	53	2.65	
1986	107	63	30	5	50.5	3.69	x
1987	110	59	29	11	50.4	4.58	
1988	102	52	27	11	49.5	2.13	

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1989	106	66	22	3	50	2	x
1990	94	63	25	7	53	3.13	
1991	98	36	8	2	51.2	4.73	
1992	105	72	27	1	41.7	3.25	x
1993	113	67	30	9	42.5	5.44	
1994	110	78	55	29	43.2	5.6	x
1995	93	54	17	6	48.1	1.68	
1996	112	70	42	18	42.7	2.19	
1997	94	50	9	4	42.1	3.19	
1998	95	44	8	0	47.8	4.53	
1999	105	48	20	5	46.1	4.82	
2000	98	57	31	12	51.9	3.82	
2001	118	79	39	6	41.2	6.16	
2002	105	40	7	0	46.7	3.8	
2003	110	77	51	23	47.9	2.83	
2004	106	64	26	12	48.2	2.11	
2005	110	62	30	15	42.7	3.13	
2006	110	54	17	3	46.4	0.5	
2007	100	55	26	1	43.8	5.01	
2008	116	58	21	4	43	6.04	
2009	112	66	34	14	45.7	4.2	
2010	101	48	18	0	52.5	5.78	
2011	112	70	32	12	44.7	5.33	
2012	90	31	7	0	55.2	1.45	
2013	111	48	11	5	43.6	1.82	
2014	114	80	43	16	39.7	4.25	
2015	110	79	44	24	39.3	1.77	x

**Note that the indication of ice is incomplete in these scanned files; since for example, there was ice in 2015 and not in the files as well as numerous other years where the files did not contain ice information, yet temperatures were colder than for some years in the files where ice was observed.*

Table 5.5.5.4-4 Summary of climatic data – Vernon, VT 1912-1998

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1912	102	58	33	18	39	5.29	
1913	80	36	6	1	46	6.31	
1914	97	55	27	14	42	2.77	
1915	106	58	19	6	40	0.09	
1916	114	78	35	14	36	1.74	
1917	113	66	35	18	40	2.63	
1918	115	80	60	40	44	1.61	
1919	103	47	13	8	45	4	
1920	107	79	46	19	46	2.09	
1921	82	46	18	4	53	8.23	
1922	111	60	41	14	41	4.8	
1923	110	82	52	27	38	2.01	
1924	94	50	25	5	41	0.74	
1925	101	61	41	15	44	4.55	x
1926	111	73	45	13	34	2.52	
1927	92	55	31	7	52	1.75	x
1928	103	59	24	5	43	2.07	
1929	89	53	21	5	51	2.43	x
1930	70	50	26	8			
1931	95	50	15	4	46	3.86	
1932	55	29	10	4	43	3.65	
1933	108	47	18	6	40	4.94	
1934	112	76	47	31	44	2.65	
1935	107	74	49	23	48	1.54	x
1936	97	67	47	25	50	8.45	x
1937	111	74	23	0	39	3.74	
1938	111	80	41	14	47	1.89	x
1939	115	79	51	20	38	4.04	
1940	118	85	52	28	38	4.38	x
1941	105	79	45	22	38	1.6	x
1942	111	57	38	14	47	5.67	x
1943	118	76	45	28	40	3.03	x
1944	117	83	57	18	40	4.6	x
1945	111	82	54	36	54	1.95	x
1946	110	77	57	26	42	3.11	x
1947	117	77	42	13	46	2.79	
1948	116	89	64	40			x
1949	0	0	0	0		1.88	
1950	0	0	0	0		3.15	
1951	52	19	11	4	43	5.01	x
1952	114	75	39	13	43	2.82	x
1953	106	61	22	0	46	8.35	x
1954	114	45	28	12	46	3.79	
1955	116	72	23	4	42	4.46	x
1956	117	82	41	17	39	4.36	x
1957	114	73	32	16	48	1.71	x

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1958	114	73	32	16	46	1.99	x
1959	121	98	60	36	44	4.21	x
1960	117	77	37	4	38	2.36	
1961	112	87	66	42	44	3.09	
1962	114	73	50	25	45	1.84	
1963	112	83	54	32	44	3.16	
1964	117	83	46	25	45	3.81	x
1965	117	70	36	18	43	1.54	
1966	115	62	32	12	45	3.57	
1967	114	80	50	23	40	2.84	
1968	111	79	52	18	45	4.32	x
1969	112	76	40	16	42	2.41	
1970	114	91	53	27	42	3.69	
1971	121	80	54	26	42	3.11	
1972	113	69	44	20	39	5.77	
1973	106	53	31	17	48	4.65	
1974	111	61	33	14	43	4.83	
1975	111	66	30	13	42	3.38	
1976	109	68	39	18	47	3.18	
1977	112	77	51	20	49	6.59	x
1978	109	75	45	25	43	2.71	
1979	104	70	40	16	49	3.3	x
1980	108	68	42	4	43	5.62	
1981	107	74	50	26	45	0.73	x
1982	116	80	48	23	42	2.97	
1983	95	50	23	7	45	6.08	
1984	105	61	38	18	39	5.19	
1985	109	63	32	6	49	3.74	
1986	110	82	42	11	47	4.68	x
1987	111	72	35	10	48	2.46	
1988	112	73	35	16	47	2.76	
1989	114	70	24	3	45	2.62	x
1990	107	71	39	19	49	3.51	
1991	105	49	18	5	47	3.9	
1992	106	70	32	2	42	4.16	x
1993	110	62	32	7	41	5.45	
1994	104	69	43	22	42	5.11	x
1995	97	50	18	4	44	2.35	
1996	120	82	46	19	43	2.29	
1997	70	36	10	2	43	3.65	
1998	103	39	8	2	47	4.05	

Table 5.5.5.4-5 Summary of climatic data – Keene, NH 1893-2016

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1893	85	65	42	21	40	1.97	
1894	112	66	40	12	48	1.21	
1895	116	87	50	29	37	1.89	
1896	112	77	46	19	35	6.19	x
1897	113	73	41	18	41	4.08	
1898	102	59	30	13	49	0.97	
1899	111	73	46	20	39	6.02	
1900	113	78	43	14	37	4.28	
1901	115	74	45	20	41	4.61	
1902	102	65	45	13	50	3.86	
1903	99	66	39	19	52	4.67	
1904	118	90	63	32	40	2.21	
1905	117	92	65	36	43	2.73	
1906	113	73	39	17	37	3.4	
1907	109	79	55	26	45	1.68	
1908	113	74	38	16	44	2.67	
1909	110	69	29	11	40	2.15	
1910	110	66	36	21	51	1.02	
1911	116	74	48	17	41	3.55	
1912	107	75	43	25	40	4.64	
1913	101	51	25	7	49	5.76	
1914	112	70	51	23	42	4.05	
1915	112	74	28	14	42	0.04	
1916	116	82	44	21	37	2.78	
1917	114	72	46	19	42	2.97	
1918	119	92	66	40	46	1.95	
1919	104	60	22	6	48	4.93	
1920	112	88	57	32	46	4.21	
1921	100	54	29	12	54	3.94	
1922	113	70	45	24	45	5.24	
1923	115	86	53	34	40	2.01	
1924	111	63	35	15	42	1.13	
1925	103	66	38	23	49	4.18	x
1926	108	79	44	19	38	2.44	
1927	106	72	44	18	48	1.61	x
1928	104	62	30	6	42	1.99	
1929	106	63	27	10	46	3.59	x
1930	100	65	31	12	45	4.49	
1931	112	69	36	21	43	3.99	
1932	111	61	26	3	39	3.21	
1933	106	55	26	6	39	4.18	
1934	116	84	58	34	43	2.18	
1935	109	78	55	27	45	1.29	x
1936	104	69	53	30	50	7.6	x
1937	110	62	26	2	39	3.71	

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1938	108	70	33	11	48	1.47	x
1939	107	68	42	19	37	3.87	
1940	117	82	49	22	38	3.67	x
1941	108	76	39	12	39	1.42	x
1942	103	49	30	11	47	5.4	x
1943	113	66	33	22	41	2.36	x
1944	112	76	48	16	48	4.01	x
1945	105	70	37	18	56	1.91	x
1946	103	68	39	16	58	0.98	x
1947	110	59	26	7	42	3.36	
1948	112	82	50	26	46	2.93	x
1949	100	50	20	8	48	2.01	
1950	104	62	38	15	41	2.25	
1951	99	46	28	7	44	5.07	x
1952	105	58	26	10	43	2.46	x
1953	103	51	19	0	46	6.6	x
1954	100	49	19	7	46	3.7	
1955	109	61	21	5	42	4.1	x
1956	112	74	38	14	39	4.85	x
1957	110	62	31	14	47	2.84	x
1958	106	48	31	11	45	2.35	x
1959	117	89	50	23	44	3.65	x
1960	111	61	29	6	37	3.27	
1961	111	78	55	36	45	2.25	
1962	111	64	40	22	47	1.36	
1963	117	79	51	33	46	2.33	
1964	115	71	44	23	46	3.7	x
1965	110	75	36	19	42	1.34	
1966	106	60	31	14	46	2.54	
1967	109	66	45	17	41	2.14	
1968	107	69	45	21	48	4.18	x
1969	109	72	36	16	41	2.11	
1970	111	78	50	26	42	3.14	
1971	118	78	42	22	41	2.87	
1972	109	66	34	20	39	5.11	
1973	103	51	28	15	48	3.09	
1974	108	64	25	11	42	4.31	
1975	111	52	23	10	41	2.67	
1976	110	66	39	15	48	2.81	
1977	107	70	47	23	52	4.98	x
1978	117	78	47	23	42	1.77	
1979	101	65	35	19	49	3.23	x
1980	105	62	37	10	45	5.53	
1981	102	73	44	26	46	0.66	x
1982	82	59	40	17	44	2.43	
1983	90	52	23	10	45	4.01	
1984	108	61	34	18	39	3.17	
1985	100	62	32	13	49	2.85	
1986	106	72	34	15	47	4.39	x

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1987	109	63	32	11	48	1.61	
1988	108	64	35	11	46	1.78	
1989	109	67	29	6	45	2.17	x
1990	105	74	34	16	50	3.01	
1991	109	56	22	4	45	3.47	
1992	114	82	48	21	40	3.68	x
1993	116	86	49	23	41	4.86	
1994	115	86	54	38	41	4.68	x
1995	106	67	28	10	46	2.59	
1996	114	77	48	30	41	1.74	
1997	108	66	32	8	40	3.66	
1998	110	59	23	7	46	3.79	
1999	112	68	29	16	44	4.1	
2000	106	62	39	21	50	2.86	
2001	110	56	14	0			
2002	86	69	47	26	45	3.95	
2003	109	74	43	15			
2004	115	73	41	23	47	1.28	
2005	113	64	34	7	42	4.57	
2006	107	67	42	8	44	1.18	
2007	117	81	32	12	44	3.47	
2008	114	84	45	21	42	5.62	
2009	110	58	23	9	45	3.31	
2010	114	83	45	16	50	5.39	
2011	98	48	14	5	43	5.33	
2012	112	60	22	9	54	1.56	
2013	112	85	60	27	43	1.98	
2014	112	85	60	27	38	3.99	
2015	113	84	52	34	39	1.36	x
2016	94	47	15	5	50	3.22	

Table 5.5.5.4-6 Summary of climatic data – Hanover, NH 1895-2016

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1895	116	84	46	26	35	1.99	
1896	108	78	45	21	33	9.25	x
1897	109	73	47	23	39	3.05	
1898	101	65	38	18	48	1.17	
1899	115	80	58	32	35	5.34	
1900	115	87	60	25	35	3.69	
1901	118	85	58	25	37	3.72	
1902	106	77	48	22	47	3.8	
1903	100	70	47	26	51	4.9	
1904	119	92	68	42	38	1.71	
1905	115	100	79	43	42	2.51	
1906	112	82	50	22	34	2.19	
1907	117	87	69	39	42	2.08	
1908	111	81	48	23	41	1.24	
1909	111	84	51	16	38	2.07	
1910	110	73	42	24	48	0.92	
1911	120	95	70	32	49	3.3	
1912	115	84	54	31	38	3.23	
1913	105	60	28	11	47	6.02	
1914	107	76	52	35	39	4.35	
1915	112	83	39	15	38	0.03	
1916	117	84	48	22	36	3.01	
1917	112	80	53	29	40	2.4	
1918	121	95	76	46	42	1.44	
1919	121	95	76	46	44	3.41	
1920	115	89	64	34	43	3.39	
1921	104	62	31	16	50	4.12	
1922	112	83	54	30	41	4.61	
1923	118	93	62	42	37	2.41	
1924	108	74	45	22	42	0.78	
1925	108	77	54	30	47	2.95	x
1926	111	86	58	29	35	1.65	
1927	111	78	54	21	45	0.88	x
1928	111	75	41	18	39	1.97	
1929	107	72	35	14	42	1.91	x
1930	109	73	42	18	41	2.87	
1931	113	67	38	18	43	1.98	
1932	107	67	30	4	36	3.24	
1933	112	56	18	6	37	3.4	
1934	116	89	69	39	40	1.9	
1935	112	78	61	34	42	1.43	x
1936	100	70	56	35	47	5.63	x
1937	115	70	29	5	35	3.49	
1938	112	76	48	16	44	1.37	x
1939	112	81	51	24	35	2.36	

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1940	119	88	59	27	37	3.9	x
1941	113	85	54	23	36	2.03	x
1942	113	60	34	20	44	4.16	x
1943	117	78	47	30	37	1.75	x
1944	120	87	65	38	37	2.94	x
1945	109	79	55	25	53	1.57	x
1946	107	75	56	29	56	1.26	x
1947	115	76	42	21	40	2.43	
1948	118	91	65	43	44	2.41	x
1949	104	60	28	7	43	1.7	
1950	107	76	41	14	36	3.01	
1951	103	56	29	10	39	4.07	x
1952	110	64	41	18	40	2.07	x
1953	100	59	31	7	43	4.98	x
1954	108	63	29	17	40	3.54	
1955	113	69	34	11	39	2.83	x
1956	116	80	45	20	36	4.44	x
1957	110	70	39	17	43	1.47	x
1958	110	54	36	18	43	2.09	x
1959	118	91	61	32	41	3.16	x
1960	116	66	34	11	35	2.37	
1961	115	82	60	31	42	2.2	
1962	114	70	47	25	44	2.65	
1963	115	77	48	28	42	2.5	
1964	114	79	47	25	42	4.67	x
1965	86	68	42	20			
1966	106	72	36	15	42	2.45	
1967	113	80	52	25	37	1.39	
1968	108	75	56	34	45	3.28	x
1969	114	74	48	21	39	2.04	
1970	111	87	49	32	40	2.55	
1971	116	82	54	23	39	3.35	
1972	112	75	50	27	38	3.89	
1973	111	57	38	20	48	2.13	
1974	110	67	33	15	40	3.27	
1975	111	67	35	14	37	2.09	
1976	115	79	46	19	44	3.49	
1977	110	79	55	27	49	4.03	x
1978	114	88	61	30	40	1.68	
1979	99	70	44	25	45	1.73	x
1980	103	67	43	13	42		
1981	101	68	47	25	46	0	x
1982	116	75	49	26	43	2.27	
1983	105	58	30	12	43	4.74	
1984	99	67	40	18	35	5.19	
1985	107	72	40	16	47	2.75	
1986	111	81	62	29	47	2.27	x
1987	112	69	46	20	48	2.57	
1988	114	67	43	23	45	1.04	

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)	Ice indicated by TransCanada files*
	<32°	<20°	<10°	<0°			
1989	115	82	43	19	42	2.43	x
1990	108	78	49	29	48	2.45	
1991	99	48	27	9	43	2.1	
1992	111	78	47	19	39	2.59	x
1993	112	82	49	23	41	5.57	
1994	115	76	49	30	40	3.46	x
1995	72	47	25	11	46	2.79	
1996	108	75	38	16	42	1.87	
1997	105	61	33	7	39	4.59	
1998	78	41	20	5	45	2.54	
1999	67	38	23	9	42	4.09	
2000	100	54	28	18	48	2.98	
2001	110	82	34	7	38	5.56	
2002	106	49	17	4	43	3.46	
2003	110	82	55	31	44	2.15	
2004	115	74	44	18	44	1.15	
2005	111	77	45	14	39	4.1	
2006	109	59	23	5	41	1.84	
2007	105	66	39	14	41	3.13	
2008	114	71	31	7	40	4.59	
2009	110	78	43	15	44	2.96	
2010	103	47	18	6	50	4.66	
2011	106	76	36	14	40	3.61	
2012	99	48	17	4	53	1.77	
2013	104	49	24	7	43	1.18	
2014	103	73	48	23	36	3.93	
2015	109	81	47	25	39	0.8	x
2016	86	39	16	6	50	2.63	

Table 5.5.5.4-7 Temperature and precipitation statistics (Amherst, MA) for years having ice based on TransCanada files

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)
	<32°	<20°	<10°	<0°		
Minimum	72	32	3	0	36	0.24
Mean	102.7	58.5	28.3	8.5	45.8	3.61
Maximum	113	79	55	29	57.5	8.24

Table 5.5.5.4-8 Temperature and precipitation statistics (Vernon, VT) for years having ice based on TransCanada files

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)
	<32°	<20°	<10°	<0°		
Minimum	52	19	11	0	38	0.7
Mean	107.8	72.4	41.4	17.7	45.0	3.8
Maximum	121	98	64	40	54	8.45

Table 5.5.5.4-9 Temperature and precipitation statistics (Hanover, NH) for years having ice based on TransCanada files

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)
	<32°	<20°	<10°	<0°		
Minimum	99	54	29	7	33	0
Mean	110.5	75.3	48.5	24.2	42.5	2.84
Maximum	120	91	65	43	56	9.25

Table 5.5.5.4-10 Temperature and precipitation statistics (Keene, NH) for years having ice based on TransCanada files

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)
	<32°	<20°	<10°	<0°		
Minimum	99	46	19	0	35	0.66
Mean	108.2	69.5	39.3	17.9	45.4	3.44
Maximum	117	89	55	38	58	7.60

Table 5.5.5.4-11 Temperature and precipitation statistics (Vernon, VT) for 1936 and 1946

Year	No. Days below Temperature Threshold				March Temperature (average max, °F)	March Precipitation (in.)
	<32°	<20°	<10°	<0°		
1936	97	67	47	25	50	8.45
1946	117	77	57	26	42	3.11

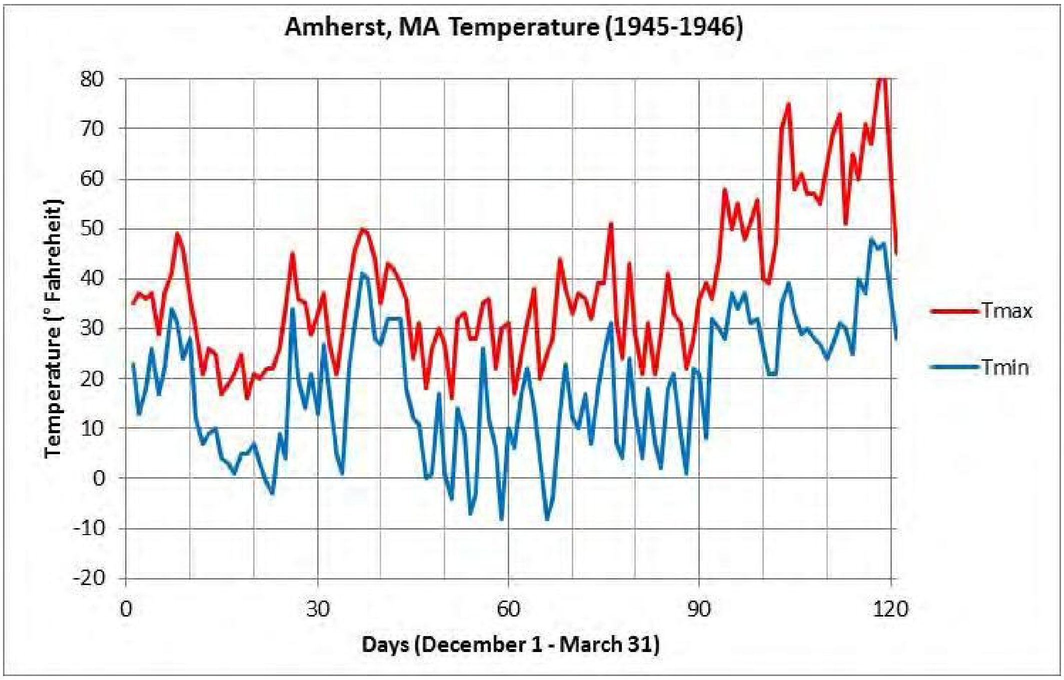


Figure 5.5.5.4-1 Temperatures at Amherst, MA December 1, 1945 – March 31, 1946

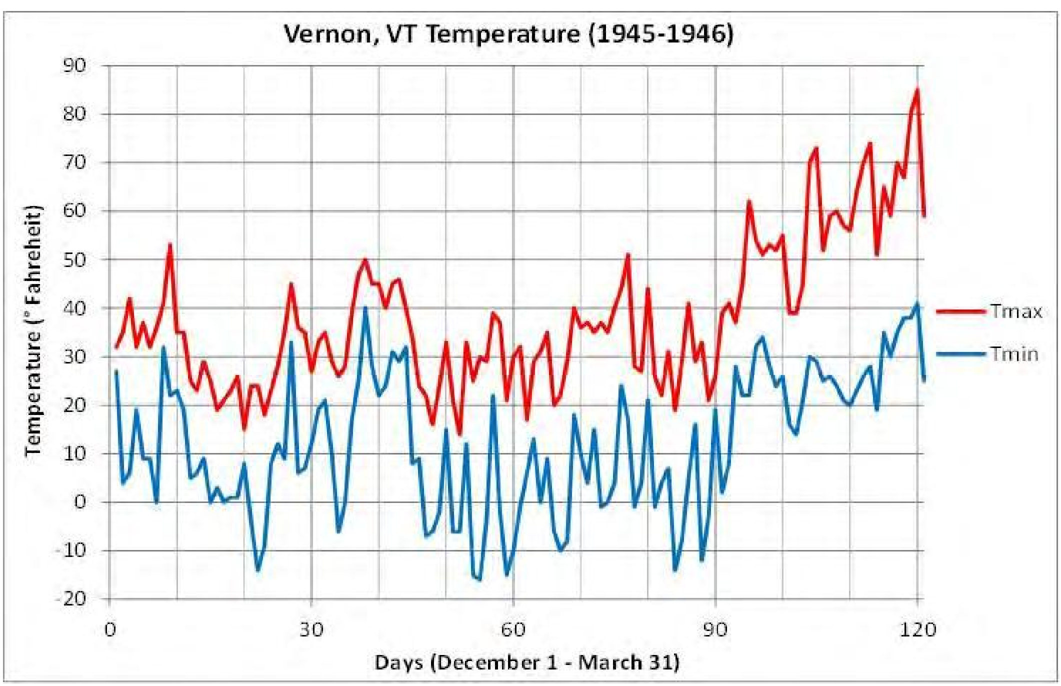


Figure 5.5.5.4-2 Temperatures at Vernon, VT December 1, 1945 – March 31, 1946

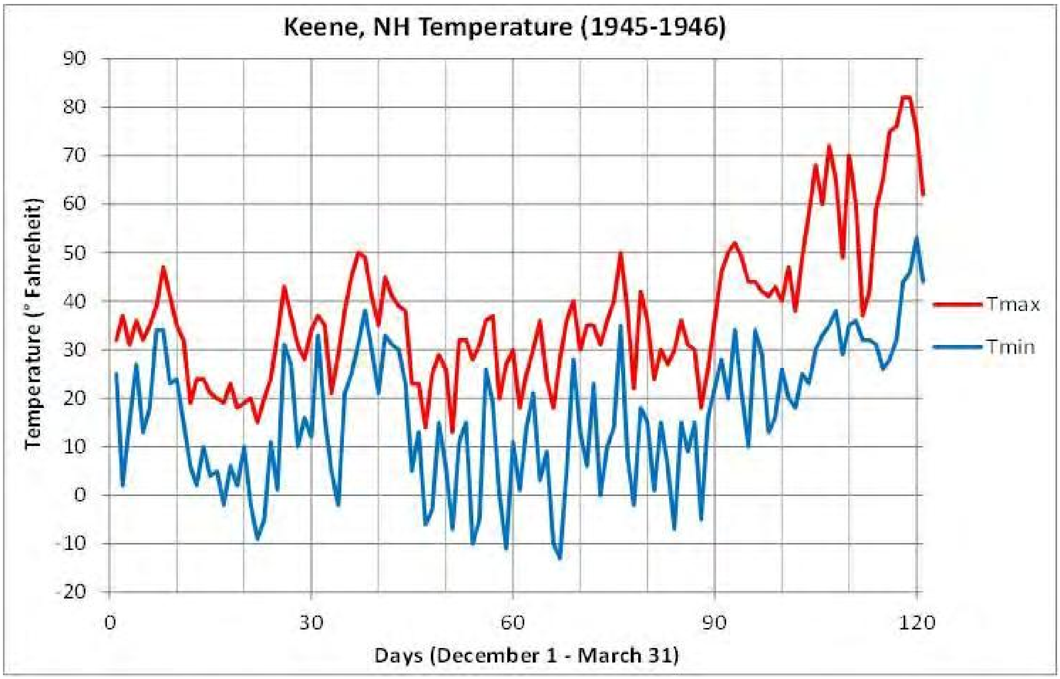


Figure 5.5.5.4-3 Temperatures at Keene, NH December 1, 1945 – March 31, 1946

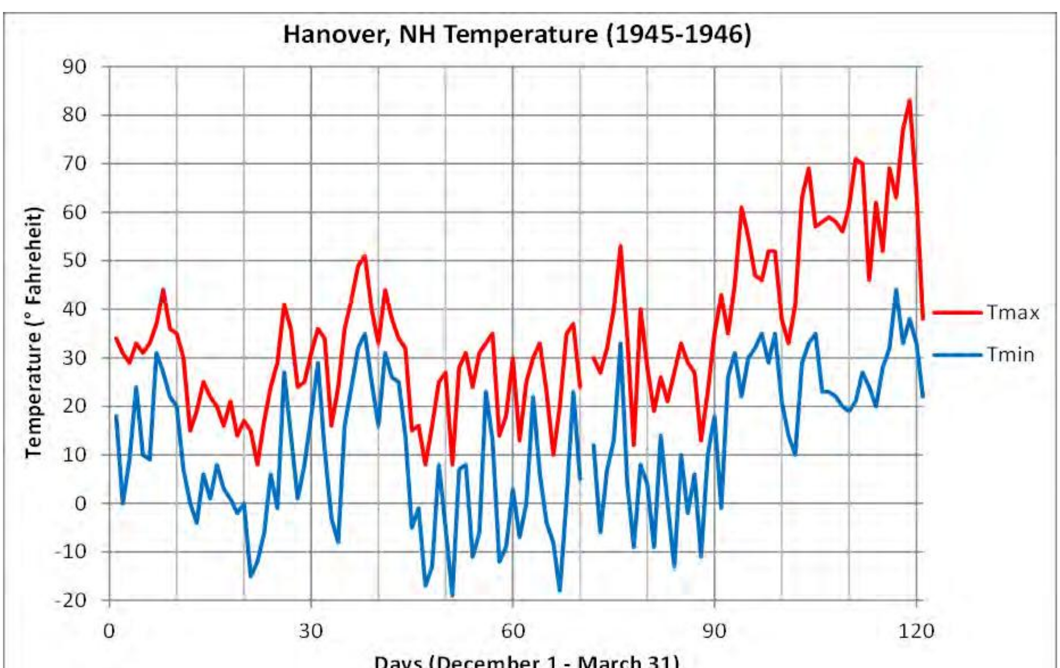


Figure 5.5.5.4-4 Temperatures at Hanover, NH December 1, 1945 – March 31, 1946

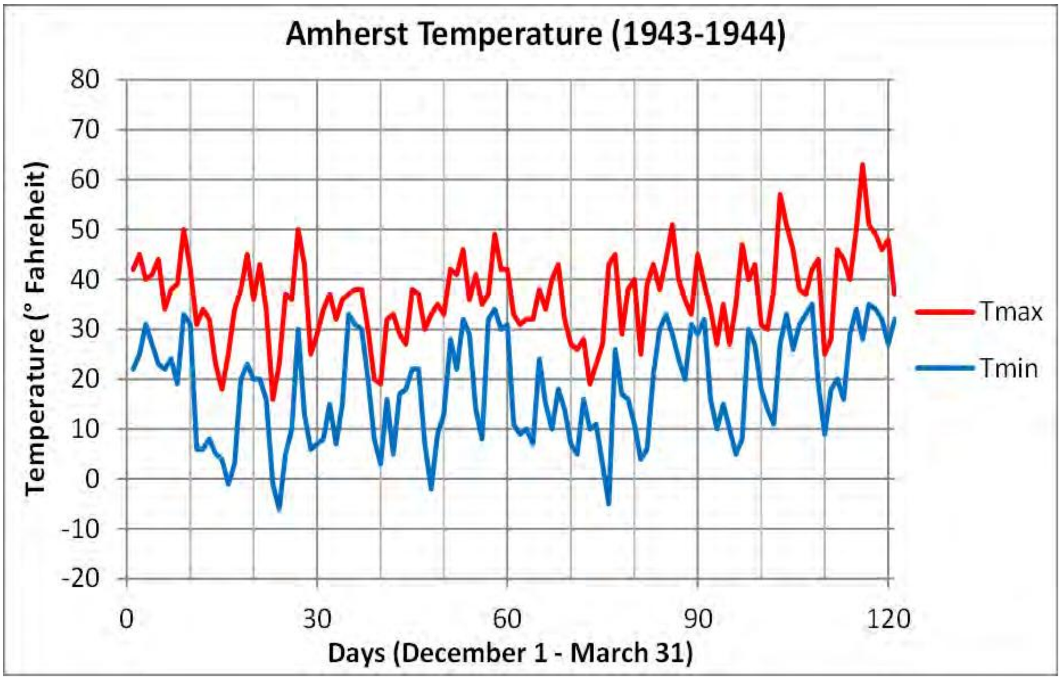


Figure 5.5.5.4-5 Temperatures at Amherst, MA December 1, 1943 – March 31, 1945

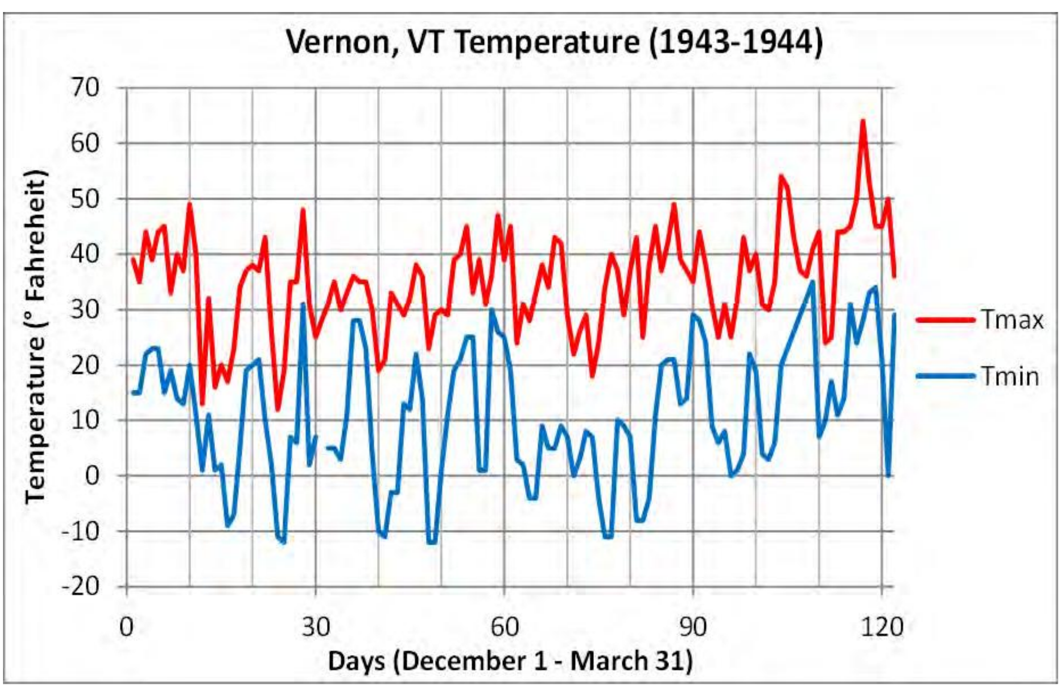


Figure 5.5.5.4-6 Temperatures at Vernon, VT December 1, 1943 – March 31, 1944

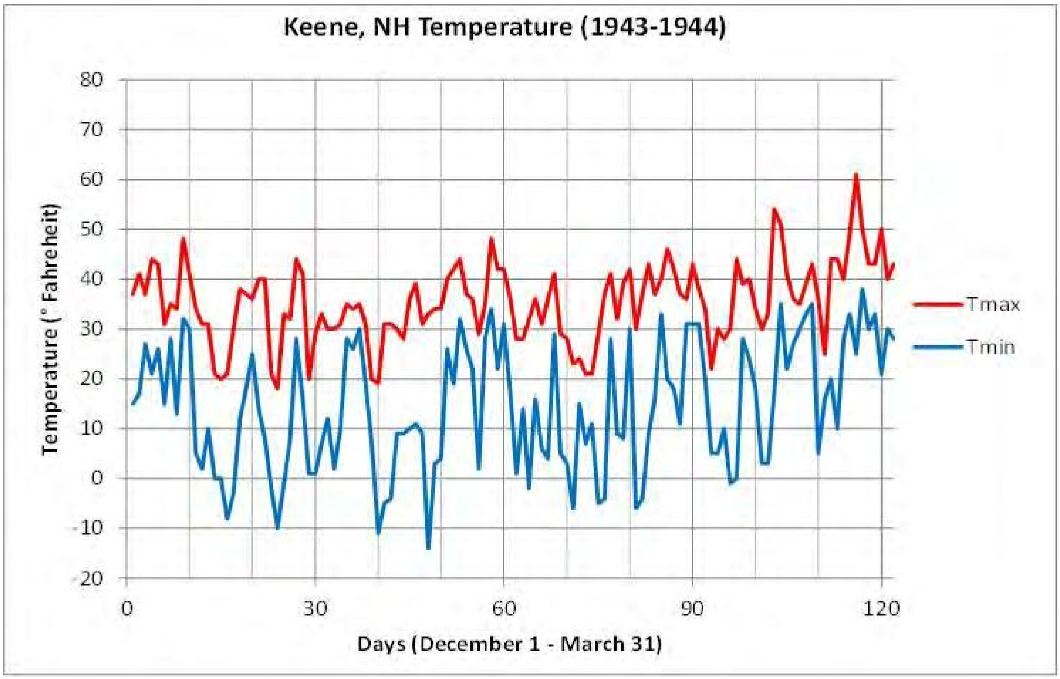


Figure 5.5.5.4-7 Temperatures at Keene, NH December 1, 1943 – March 31, 1944

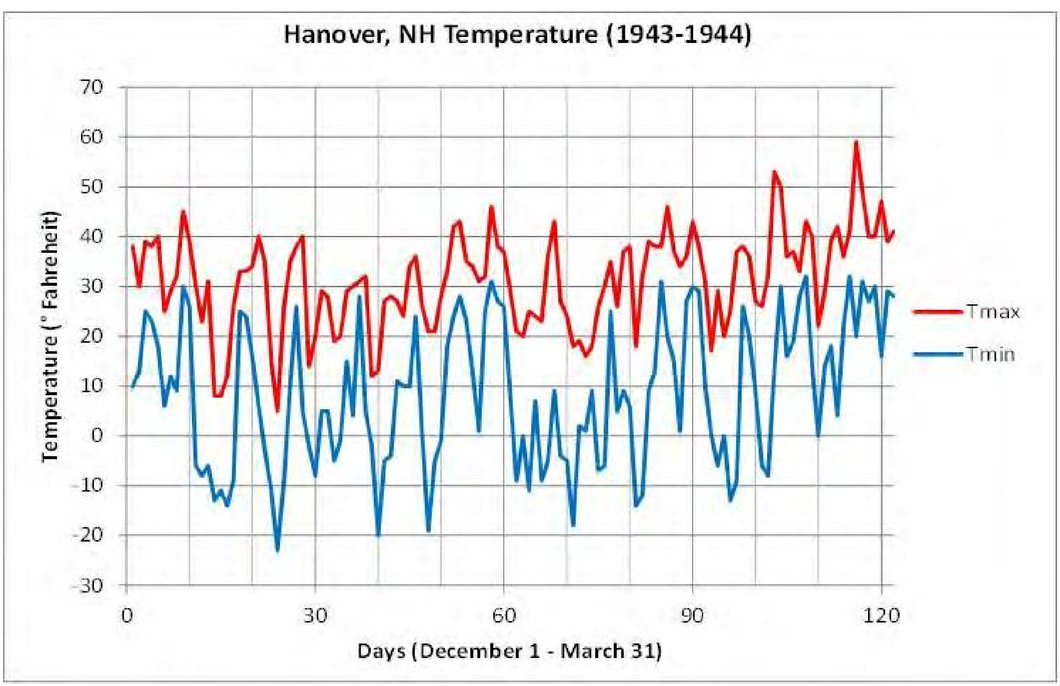


Figure 5.5.5.4-8 Temperatures at Vernon, VT December 1, 1943 – March 31, 1944

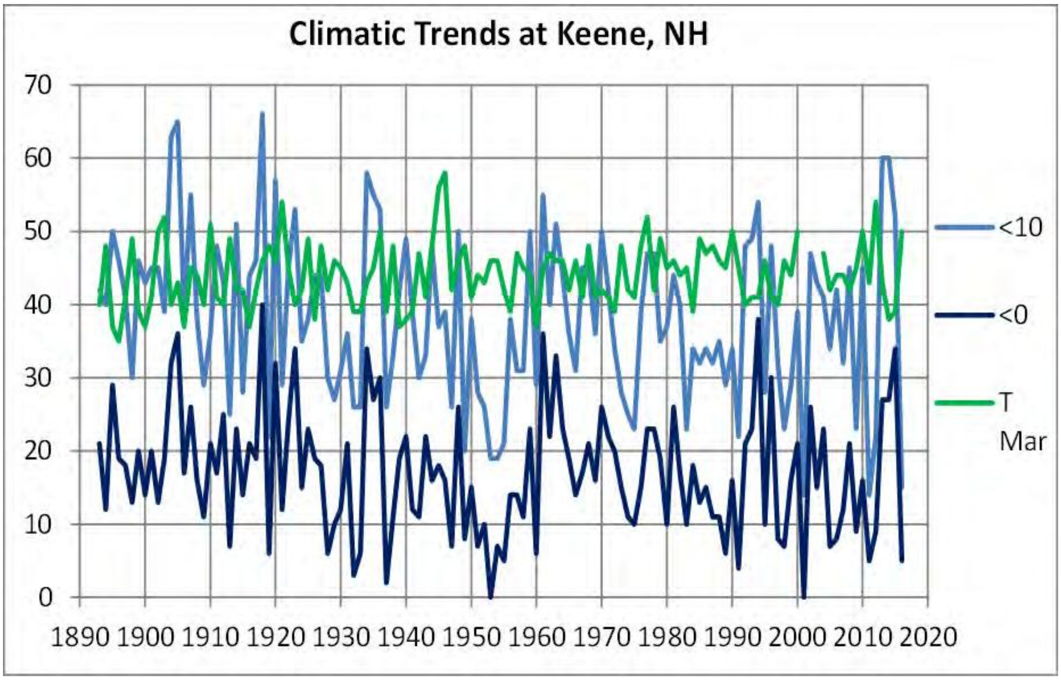


Figure 5.5.5.4-9. Climatic trends – Keene, NH

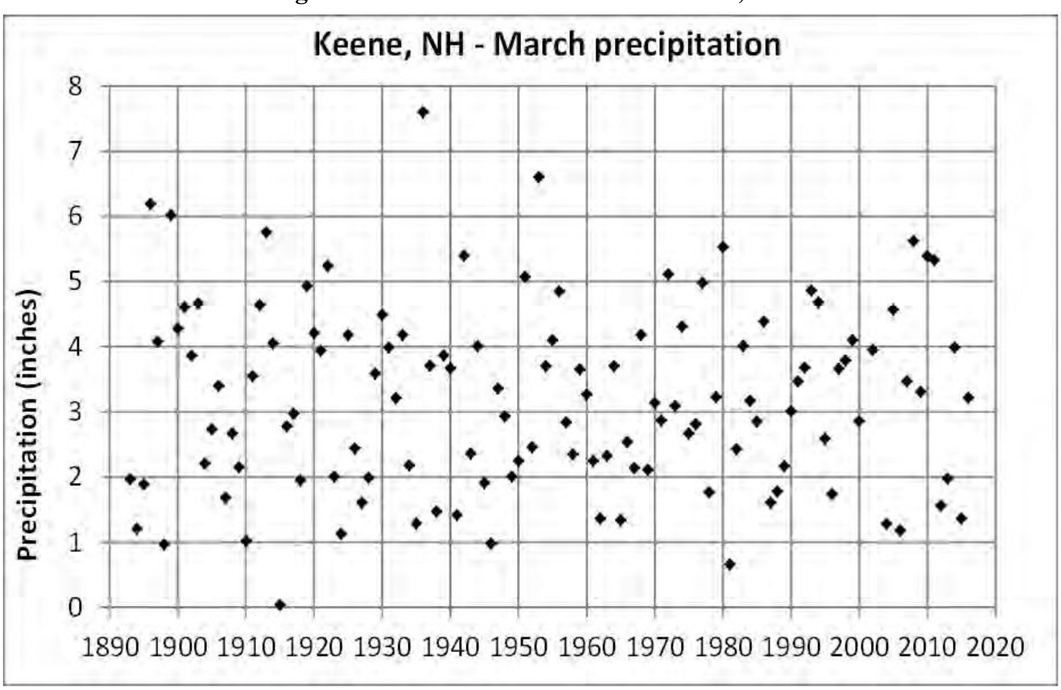


Figure 5.5.5.4-10 March precipitation – Keene, NH

5.5.5.5 Discussion of Key Questions, Summary, and Conclusions

The key questions before all those interested in understanding the causes of erosion in the TFI are: to what extent might erosion due to ice have occurred in the past, what were the effects of VY, and now that VY is no longer operating – to what extent might ice impact the riverbanks in the future. Much can be learned in answering these key questions by evaluating and analyzing the available information and applying scientific inductive and deductive processes to the available information.

While most photographs related to ice and riverbank conditions after ice events are concentrated in reaches of the Connecticut River upstream of Vernon Dam, some information exists regarding ice in the TFI and farther downstream. In the notes of the 1946 Spring Runoff (Figure 5.5.5.2-21), the following statements were made:

> 3/8/1946 – *Observation from French King Bridge reveal breakup in vicinity of bridge. River just above Turners Falls pond unbroken. No disturbance at Meadow Bridge. Northfield Schell Bridge, there is no disturbance.*
>
> 3/11/1946 – *some trouble at the Northampton. Hadley Bridge but seemed to have no details…. presumed it was the White River ice that had jammed up at Hadley and caused only a little trouble.*
>
> 3/12/1946 – *C.R. Bliss reports ice moving in Conn. River below Vernon, passing under Schell Bridge about 2:45 P.M., 3-12-46. He then went back over meadow, down Gill Road and across French King. Main body passed thru meadow while there and it appears that the river is clear from Vernon tailrace to French King Br.*

Another wave of ice was discussed later in the notes passing over Vernon Dam and through the TFI:

> *Informed Col. Dalton that ice was passing over Vernon dam…He asked how soon it would get down river and this was answered by saying it had to go thru Turners Falls Pond, etc., before getting to Whateley and we were not familiar with river timing down the river.*
>
> 3/15/1946 – *About 12:00 Noon Vernon reported they had lost the remaining 300' of their boards and that ice in the Vernon Pond had started out.*

The fact that there is significant information related to ice in the Vernon, Bellows Falls and Wilder Impoundments is due to the power companies' historic focus on these impoundments and does not necessarily indicate that ice is historically more prevalent in the upstream reaches or that there was a lack of ice in the TFI. The fact that ice formed and flowed through the TFI is confirmed by the 1946 observations (in a year that is near the average for ice related temperature conditions) and is supplemented by previous observations of ice and significant damage occurring even farther downstream than Turners Falls.

Historic accounts provide background information regarding the fact that ice events cause erosion along the Connecticut River. An account of the 1896 flood (Charles Thayer) stated the following about what he observed.

> *I thought someone fired off a gun over across the river, but in a minute it began roar, crash, snap, crackle, bang. The fog was so thick that I couldn't see the riverbank but pretty soon it lifted and we could see the trees go down like cornstalks, as the big cakes of ice struck them.*
>
> *In the afternoon we went down to Titans Pier to see the ice go fast. It did go fast with a vengeance and so did the hencoops, trees, barrels, beams, and such. The noise was enough to make you deaf.*

Titans pier is a rock formation on the Connecticut River near Northampton, MA; downstream of the TFI. This account provides observations of ice moving down river shearing off trees and destroying adjacent structures accompanied by deafening noise. This observation demonstrates that historically ice has flowed farther downstream than the TFI.

The CRREL report categorized the 1936 flood as the highest level of damage due to ice breakup. Erosion damage due to the 1936 event is similar to damage shown on the 1946 photographs (Figure 5.5.5.5-1). Field (2007) discussed erosion resulting from the 1936 flood in the form of avulsions in the TFI. He stated that *"The flood of 1936 spread across the floodplain with sufficient force to scour a new channel 20 feet deep across Moose Plain around Schell Bridge in part the result of floating debris that had accumulated under the bridge."* Since ice was a significant factor in the 1936 event, it is likely that ice was the primary component of the floating debris observed at the Schell Bridge (especially since there are only two widely spaced bridge piers at a narrow section of the river where there is also a sharp bend and a significant mid-channel bar downstream of Schell Bridge, see Figure 16 from Field). Ice jams frequently occur as a result of constrictions, bends, and shallow areas of a river where ice floes are restricted. An avulsion occurs when a river abandons (or partially abandons) an existing river channel and forms a new channel through a process of rapid erosion (see Figure 5.5.5.5-2). Field described several avulsion channels that resulted from rapid and significant erosion as a result of floods such as the 1936 flood. Potential erosion scars from the flood of 1936 are visible on a 1939 aerial photograph (Figure 5.5.5.5-3).

The notes from 1946 and the information presented from the 1936 event show that ice has affected the TFI. Historic accounts from 1896 discuss the dramatic effect of ice farther downstream on the Connecticut River near Northampton. In addition to this direct evidence, there is additional information to be considered regarding the condition of riverbanks in the TFI before the influence of VY.

An eroded bank affected by ice is shown in the 1946 photograph in Figure 5.5.5.5-4. This photograph is similar to photographs of eroded banks in the TFI adjacent to an agricultural field downstream of Vernon Dam taken the same time of year (April) in 1913 (Figure 5.5.5.5-5 and 5.5.5.5-6). The reach of the Connecticut River in the TFI downstream of Vernon Dam shows a farm on the *"Vermont side,"* or right bank (Figure 5.5.5.5-7) which may be the area depicted in the previous figures (Figures 5.5.5.5-5 and 5.5.5.5-6). The river in the vicinity of this field is shown in a 1929 aerial photograph (Figure 5.5.5.5-8). The bank along this field is eroded and devoid of riparian vegetation (as is the opposite bank near the downstream tip of Stebbins Island). Ice events occurred in 1866, 1896, 1915, 1925 and 1929. It is possible that these ice events played a significant role in the eroded condition of this riverbank as shown in the 1913 photos and in the 1929 aerial photograph since such erosion is typical of what has been observed on photos showing ice damage. The eroded condition of this reach of the river continues on the aerial photograph taken in 1952 (Figure 5.5.5.5-8), but by the 2008-2010 aerial imagery, a narrow zone of riparian vegetation had become established in this same part of the river.

This area of the river was noted in the 2008 FRR when it was compared to the 1998 image showing that this area was naturally revegetating and becoming more stable over time. These photos, as well as a photo from 2013 show this area over the past 15 years (Figures 5.5.5.5-9 through 5.5.5.5-14). The comparison over time, from 1998 through 2013, show increasing vegetation over this period indicating increasing riverbank stability in this area of the river and significant improvement compared to the barren, eroded conditions seen in the 1929 and 1952 photographs. Other areas that were eroded and lacked riparian vegetation, but now support a zone of riparian vegetation through natural stabilization processes were documented in Section 2.3.4. Documentation of the establishment and growth of new riparian vegetation is provided in Volume III (Appendix J).

As shown by the analysis of historic aerial photographs (Section 2.3), numerous areas of significant erosion were evident in the TFI in the 1950s and 1960s. The study comparing riverbank erosion along the Connecticut River (*"Riverbank Erosion Comparison along the Connecticut River,"* Simons & Associates, 2012) concluded that the segment of river with the greatest extent of eroding riverbanks is the un-impounded northern reach, erosion sites have been stabilizes in the TFI with evidence of natural stabilization, and during the same period of time erosion sites in other impoundments (Bellows Falls, Vernon, and Holyoke) have continued eroding. Given this, the question can and should be raised as to what extent ice may play in the disparate erosion responses occurring in various reaches of river.

Erosion is more extensive in the reaches of river upstream of the TFI (3 times more extensive in the un-impounded reach compared to the TFI based on S&A, 2012). The un-impounded reach does not experience hydropower water level fluctuations but is not dammed and hence somewhat steeper and flows at higher velocities. It is farther north with a potentially somewhat colder climate and has experienced numerous episodes of ice throughout recent history. Historic aerial imagery taken prior to the construction and beginning of operation of both VY and Northfield Mountain which occurred in the 1970s, show that there were significant areas of erosion in the TFI during these years. As a result of VY operations (1972-2014), the TFI has experienced warmer water and very limited episodes of ice. In recent years, segments of river within the TFI have experienced natural stabilization processes with increased vegetation (see 2008 and 2013 FRRs). In contrast, observations in 1998 and 2008 showed that riverbank segments that were eroded over this time period remain in essentially the same eroded condition in Vernon and Bellows Falls Impoundments where the effects of ice has continued (S&A, 2012). Due to the fact that (1) numerous severely eroded areas (consistent with erosion observations in upstream reaches due to ice) were present before 1972 in the TFI; (2) natural stabilization processes have been ongoing in the TFI in recent years during a period of limited ice; and (3) erosion is greatest in a reach of river that is impacted by ice and the TFI has not been significantly affected by ice for a period of more than 30 years it can be concluded that ice plays a significant role as a cause of erosion and lack of ice has played a role in the natural stabilization processes.

The effect of ice is further evaluated by comparing erosion that occurred during 1946 and 2011 in both the TFI and upstream impoundments. The flow hydrographs (at Montague) for these two years are presented in Figure 5.5.5.5-15. The peak flow for 1946 occurred during March with a maximum mean daily flow of 67,000 cfs. There was also a peak flow in March of 2011 of 58,800 cfs. While flows during the remainder of 1946 did not exceed the March peak, there were several higher peak flows during 2011 including a peak of 82,500 cfs in April and 118,000 cfs (mean daily) in August due to Tropical Storm Irene. Flows were much higher in 2011 compared to 1946, with multiple high peaks including the highest peak flow in recent years. If high flows alone caused the most significant erosion, it would be expected that erosion during 2011 would be significantly greater than 1946. Riverbanks were observed by boat in 2011 just after the peak flow due to Tropical Storm Irene. In traveling through the TFI in 2011 only a couple of areas of erosion were observed. Examples of erosion that occurred due to the high flow event in 2011 are shown in Figures 5.5.5.5-16 and 5.5.5.5-17. These areas of erosion are relatively small. In contrast, erosion during 1946 as shown in previous set of figures (Figures 5.5.5.2-13 through 5.5.5.2-20) as well as Figure 5.5.5.5-18, below, is much greater than erosion observed in 2011.

The contrast between extensive and dramatic erosion due to ice in 1946, despite much lower peak flows, compared to quite limited erosion due to a much higher peak flow in 2011 is dramatic. Erosion due to ice is much greater and more extensive than erosion due to a much higher peak flow event without ice.

While the erosion photos from 1946 are quite dramatic and severe, the question of whether this erosion is due to ice or perhaps high flow should be considered. The previously presented photos in 1946 showed ice floes in the river and ice pushing up, into and over the riverbanks on March 8th and 10th, 1946 (Figures 5.5.5.2-9 through 5.5.5.2-11). A series of photos were taken shortly thereafter on April 23rd through 25th, 1946 (Figures 5.5.5.2-13 through 5.5.5.2-20 and 5.5.5.2-22). These photos show the eroded banks and damaged vegetation with evidence of ice gouging and scarring of trees as a result of ice. This combination of ice survey data, photographs of ice on the river, followed by photos of riverbank damage about a month after the ice event show that ice and associated damage was the focus of this set of information. The peak flow of 71,000 cfs (at Montague) in 1946 is below the long-term (1904-1960) average peak flow (97,600 cfs). For a number of years prior to 1946, the peak flows were likewise quite low (Table 5.5.5.5-1).

The fact that an effort was made to document riverbank conditions immediately after the ice event of 1946, coupled with flow data showing that for a period of 6 consecutive years from 1941 through 1946 peak flows were below average; indicate that the eroded and damaged condition of the riverbanks and riparian vegetation shown in the April 1946 photographs resulted primarily from ice.

The observations of the significance of damage to riverbanks due to ice compared to high flow on the Connecticut River is supported by studies on other rivers. The importance of ice as a cause of erosion was discussed in an analysis of erosion on the Missouri River in Montana (Simon *et al*., 1999):

> *The cycle of river-ice formation, presence, and breakup affects bank erosion, sediment transport, and channel morphology in numerous ways. The mechanisms whereby river ice locally may accelerate bank erosion and change in channel morphology are as follows:*

- Elevated ice-cover level;
- Elevated flow rates after freeze up;
- Local scour in regions of locally high flow velocity at ice accumulations or flow
- Deflected by ice accumulations;
- Ice-run gouging and abrasion of channel banks and bars;
- Channel avulsion attributable to ice jams; and,
- Ice-cover influence on bank-material strength and bank stability.

> *Two of the most important issues regarding streambank erosion along the Missouri River in the study reach are pore-water pressure effects from sustained high flows, ice-related effects, and the direct effects of an ice cover.*

While quantitative analysis of the effect of ice on riverbank erosion is not possible with the available information (since riverbank surveys in the TFI occurred during a period of no ice and no known historic cross-section surveys are available over a period of years at upstream reaches), observations of ice on the Connecticut River (from photographs, notes, ice data, temperature and climatic data, flow data, and direct observations of ice), analysis of ice on other rivers (Platte, and Missouri) all strongly indicate that ice has the potential to be one of the dominant primary causes of erosion, on a level similar to or even greater than high flow events, in the TFI.

Another important question of interest is to what extent water level fluctuations may adversely affect young riparian or other vegetation when the TFI is covered with ice. During the winter of 2014/2015, as shown in Figures 5.5.5.1-2, 5.5.5.1-4, 5.5.5.1-7, 5.5.5.1-8, and 5.5.5.1-10 (taken on March 3, 2015), ice formed on the Connecticut River through much of the TFI. Photographs taken on January 5, 2015 showed that there was some ice on the river but that most of the river was open water (Figures 5.5.5.1-3, 5.5.5.1-5, 5.5.5.1-6 and 5.5.5.1-9). Based on these photographs, the river may have been covered with ice later in January or February and then into March. As indicated in the literature, ice may adversely affect riparian vegetation. It has been clearly demonstrated that when ice breaks up rapidly, potentially jams, and moves downstream in floes; riparian vegetation including trees can be sheared off, otherwise severely damaged or scarred. In addition, young riparian vegetation may be impacted by ice in the earliest stages of life including establishment and survival from the seedling to sapling phase of growth (Ettema, 2002). As noted in R. Ettema, 2002:

> *Where ice runs occur with about annual frequency, riparian vegetation communities have difficulty getting established. Ice abrasion and ice jam flooding may suppress certain vegetation types along banks…possibly exacerbating bank susceptibility to erosion.*

High seedling mortality was further documented in (S&A, 2000).

> *In Johnson's report (1994a), he states that, "seedling mortality is usually highest in winter". In both the Johnson reports covering 1993-94 and 1994-95, he concludes with essentially the same information, "seedling mortality is usually highest in the winter associated with ice; ice is an effective mortality factor because it can block flow and raise river stage, cause sediment movement,*

and physically damage living vegetation". Johnson recorded mortality rates as high as 98 percent due to ice. Furthermore, he states that "ice remains the only factor with much potential to kill older seedlings, at least within the flow ranges that we have experienced during the course of this study."

In the TFI with the continual fluctuations due to hydropower operations, there could be some adverse impact primarily on young vegetation when ice moves up and down with the water level fluctuations. Water level fluctuations are shown during February and March of 2015 at the Northfield Mountain Tailrace in Figures 5.5.5.5-19 and 5.5.5.5-20. During these months, daily water level fluctuations ranged from approximately 1 to 3 feet with fluctuations over a week's time as large as approximately 5 feet. Overall water levels during this time period ranged from about El. 179 to 185 feet. This range of fluctuation which occurred during February and March of 2015 is considered as being typical of Northfield operations.

Photographs were taken later in 2015 showing riverbank vegetation focusing on aquatic, herbaceous and young woody riparian vegetation. Figure 5.5.5.5-21 shows a maple seedling that survived the winter ice of 2014/2015 (Note that maples seeds drop in the fall of the year as can be seen lying on the ground in this photograph that was taken in September). Figure 5.5.5.5-22 shows cottonwood seedlings/saplings that are 2 or more years old and survived the winter ice of 2014/2015. Ice-out in 2015 did not include a significant break-up event as the ice essentially melted in place. The fact that seedlings and other vulnerable vegetation, which can be seen in these photographs taken later in 2015, survived the 2014/2015 winter ice demonstrates that the typical water level fluctuations which occurred when ice covered the TFI during this winter did not cause significant adverse impacts to even the most sensitive vegetation. Observations of ice in 2014/2015 and subsequent observation of vegetation later in the year suggest that ice cover which experiences typical water level fluctuations and that subsequently melts without a significant break up event does not cause significant damage to young riparian vegetation in the TFI.

Several key points regarding ice are made based on photographs, aerial photographs, notes, measurements and observations of ice on the Connecticut River:

- Ice has caused erosion of riverbanks and damage to riparian vegetation on the Connecticut River as documented by photographs, observations and measurements from the 1800s to the present, upstream of Vernon Dam;

- Ice both destroys riparian vegetation and limits its establishment and growth as demonstrated by various analyses and observations (and has been quantitatively demonstrated by vegetation demography studies, analysis and computer modeling that ice plays a *"significant, if not dominant"* role in removing and limiting riparian vegetation on the Platte River). As shown in the erosion causation study, riparian vegetation plays a significant role in riverbank stability;

- Ice has been observed flowing through the TFI as well as downstream on several occasions along with damage likely due to ice jam flooding and an avulsion in 1936 in the vicinity of the Schell Bridge;

- Eroded riverbanks and lack of riparian vegetation has been documented in the TFI before VY that is similar to the condition of riverbanks eroded by ice in reaches upstream of Vernon Dam as documented by historic aerial and ground photographs;

- Areas that were eroded and lacked riparian vegetation in the TFI have been experiencing a natural stabilization process and associated increase in vegetation as documented by aerial photographs taken over time when VY was in operation and little ice occurred. Riparian vegetation and aquatic vegetation have been increasing in the TFI as documented by the 2008 and 2013 FRR's and subsequent observations;

- The river upstream of Vernon Dam has experienced more significant erosion over recent decades than the TFI as documented in *"Riverbank Erosion Comparison along the Connecticut River,"* Simons & Associates, 2012):

> Several erosion sites were identified and photographed in the Bellows Falls, Vernon, Turners Falls, and Holyoke Impoundments in 1997, and again in 2008. All of the erosion sites in 1997 in the Bellows Falls and Holyoke Impoundments and all but one of the 1997 erosion sites in the Vernon Impoundment remain in essentially the same state of erosion when photographed in 2008, many of which are significant in both size and severity.

These observations are consistent with: (1) the scientific literature regarding the adverse effects of ice; (2) studies on other rivers which show that ice plays a significant role in causing erosion (on the same order of magnitude as high flows) and a significant, if not dominant, role in riparian vegetation processes; and (3) the fact that ice has affected the Connecticut River upstream of VY on an ongoing basis over centuries of time but that the effects of ice were essentially eliminated for the period from the early 1970s until the end of 2014 in the TFI due to the operation of VY. Given that VY has ceased operation and will no longer warm the waters of the TFI, ice is expected to once again affect riverbanks and riparian vegetation in the TFI as dictated by climatic and hydrologic processes as has been seen in other areas along the river (Figures 5.5.5.5-23 and 5.5.5.5-24).

Conclusions

Ice has the potential to be a naturally occurring dominant primary cause of erosion in the TFI in the future given the right climatic and hydrologic conditions. Furthermore, based on (1) the results of the ice analysis conducted as part of this study; (2) observations made during the 2014/2015 winter when ice formed over much of the TFI; and (3) the results of the various hydrologic analyses previously discussed it appears unlikely that Project operations will exacerbate the impact of ice on erosion processes. The most significant erosion associated with ice is due to ice break-up, floes, and jams and the corresponding damage which occurs as the ice scrapes along the bank while moving downstream. Based on analysis of historic information, these processes occur as a result of moderate to high flows which typically exceed the high flow threshold previously discussed (i.e. 37,000 cfs). At flows greater than 37,000 cfs (or 17,130 cfs in the upper reach) hydropower operations typically have minimal hydrologic impact in the TFI. While ice is the ultimate cause of erosion in these instances, it is not until sufficiently high flows persist for damage to the riverbanks to occur. This is a naturally occurring process independent of hydropower operations.

Sheet ice can also impact riverbank stability by scraping along the bank when water levels fluctuate. As previously demonstrated from the results of the various hydrologic analyses, for the vast majority of the time the water surface (and therefore the ice) rests on the lower riverbank. In the TFI, the lower bank is typically a flat, beach like feature with minimal to no vegetation or erosion. It is not until the water surface (and therefore the ice) reaches the upper bank that erosion could potentially occur. It is typically not until flows approach or exceed the natural high flow threshold that the water level reaches the upper bank. As such, based on the results of the hydrologic analyses conducted, it is unlikely that water level fluctuations associated with typical hydropower operations could result in ice damage to the banks.

These processes were observed during the winter/spring of 2014/2015 when ice formed over much of the TFI. During this time Northfield Mountain operated in a typical manner. Water levels at the Northfield Mountain Tailrace fluctuated approximately 1 to 4 feet on a daily basis, with an average of about 2 feet, and about 5 feet over a week's time through the winter and early spring. For the vast majority of the time the water level rested, and fluctuated, on the lower bank. Based on observations of ice through this period, these fluctuations did not cause ice break-up or floes as the ice persisted into March. There was no significant ice break-up event and ice primarily melted in place, probably partly due to inflow from Vernon not exceeding 17,130 cfs until April 4^{th}. Observations of the riverbank later in the year did not exhibit damage due to ice erosion and young riparian vegetation (seedlings and saplings) that had been established prior to the winter of 2014/2015 were observed at various locations in the TFI. Typical Project operations and associated water level fluctuations did not appear to cause or exacerbate ice related erosion or damage.

Although a quantitative analysis of the impact of ice as a cause of erosion was not possible given weather conditions during the monitoring period and the available historic data, the results of the analyses which were conducted indicate that ice has the potential to be a naturally occurring dominant cause of erosion in the TFI in the future if the right climatic and hydrologic conditions persist. Available information and observations indicate that Project operations do not cause an ice break-up event to occur, as ice break-up events occur as a result of climatic and hydrologic conditions (i.e. moderate to high flows, rapid melting, and rainfall) which are independent of Project operations.

Table 5.5.5.5-1 Peak Flows immediately preceding and including 1946 (Connecticut River at Montague)

Year	Peak Flow
1941	46,300
1942	70,600
1943	71,100
1944	69,600
1945	85,600
1946	71,000

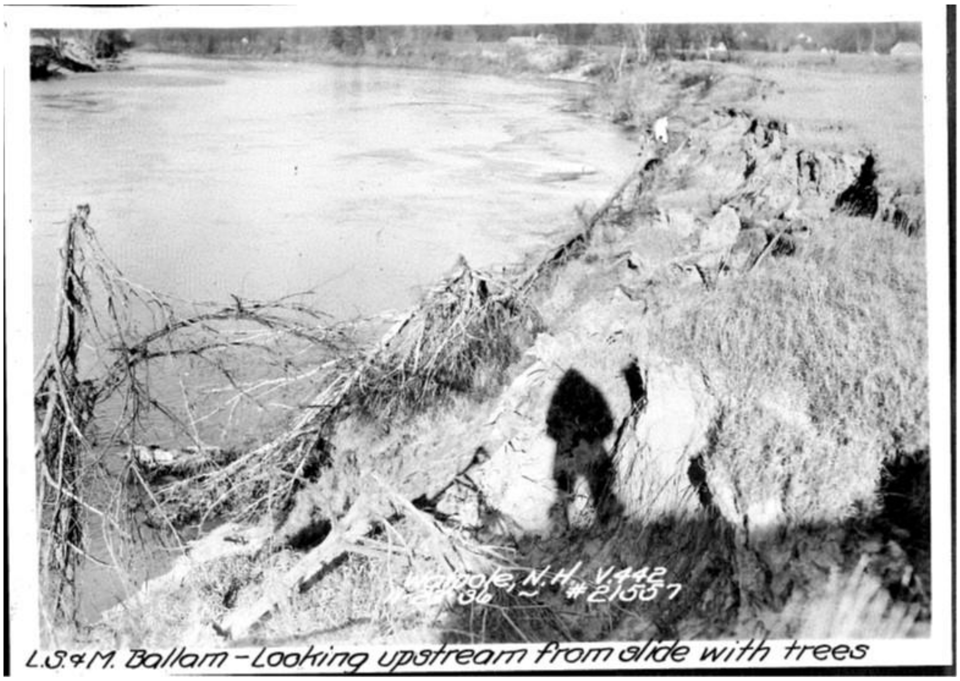


Figure 5.5.5.5-1 Erosion Damage – 1936 Flood

Figure 5.5.5.5-2 Abandoned Avulsion Channel – 1936 Flood (Field, 2007)

Figure 5.5.5.5-3 Aerial Photo Showing Erosion Scars on Floodplain - 1939

Figure 5.5.5.5-4 Connecticut River near Windsor, VT – April 28, 1946 (TransCanada)

Figure 5.5.5.5-5 Eroded Bank in Turners Falls Impoundment Downstream of Vernon Dam – April 5, 1913 (TransCanada)

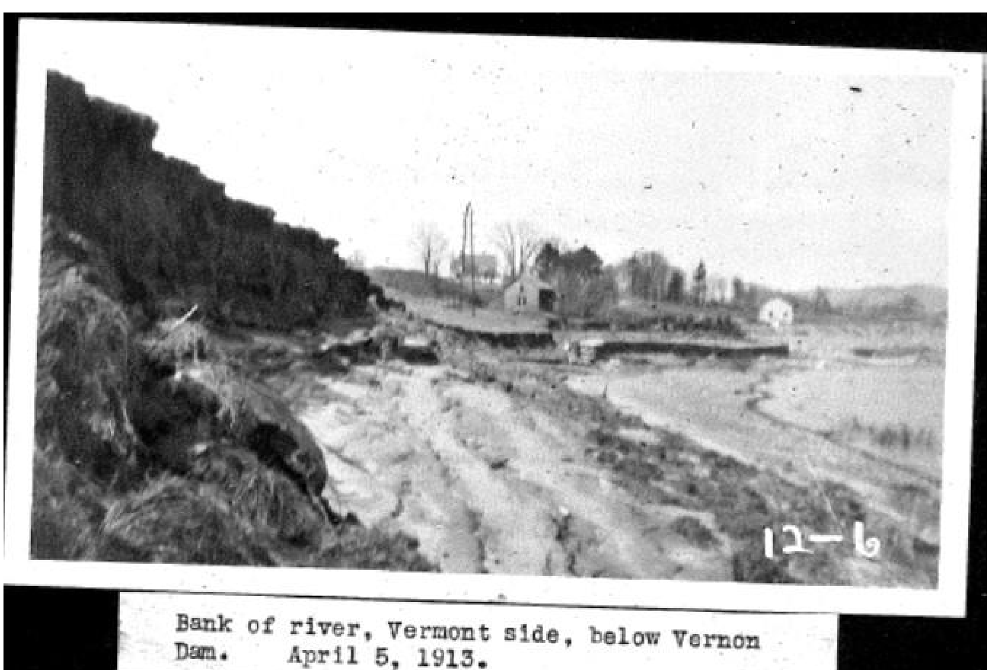


Figure 5.5.5.5-6 Eroded Bank in Turners Falls Impoundment Downstream of Vernon Dam – April 5, 1913 (TransCanada)

Figure 5.5.5.5-7 Connecticut River Downstream of Vernon Dam (Google Earth)

Figure 5.5.5.5-8 Field Downstream of Vernon Dam – 1929

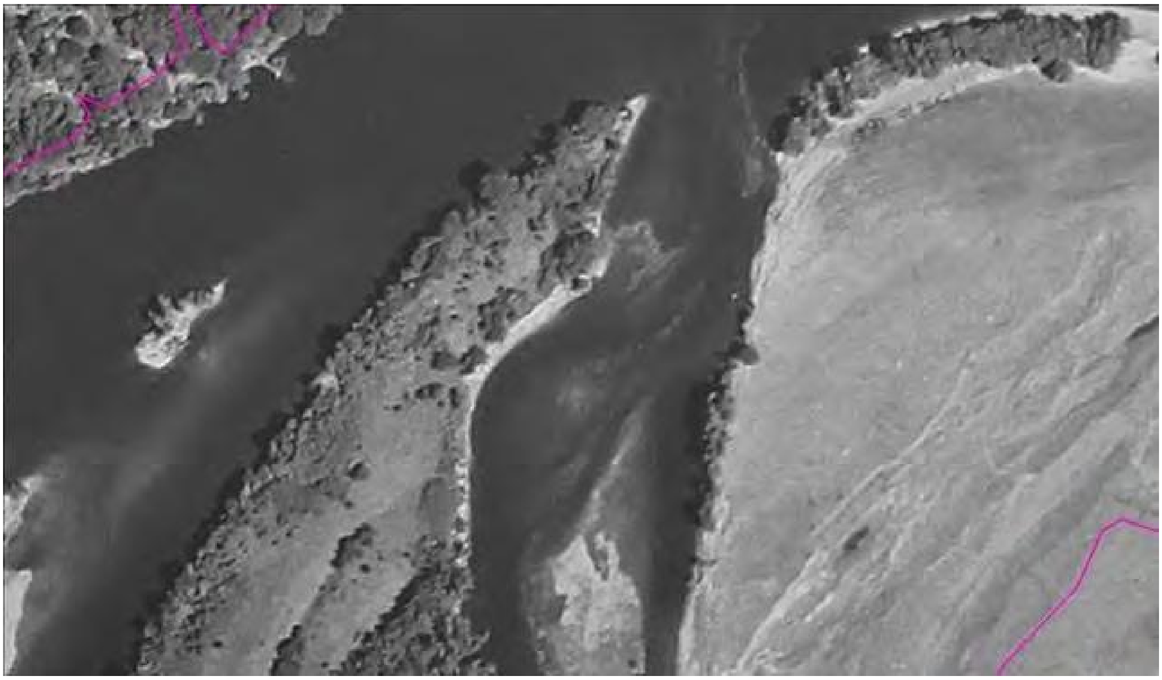


Figure 5.5.5.5-9 Field Downstream of Vernon Dam – 1952

Figure 5.5.5.5-10 Field Downstream of Vernon Dam – 2008-2010

Figure 5.5.5.5-11 Right Bank Near Downstream End of Stebbins Island – 1998

Figure 5.5.5.5-12 Right Bank Near Downstream End of Stebbins Island – 2008

Figure 5.5.5.5-13 Right Bank near Downstream End of Stebbins Island – 2013

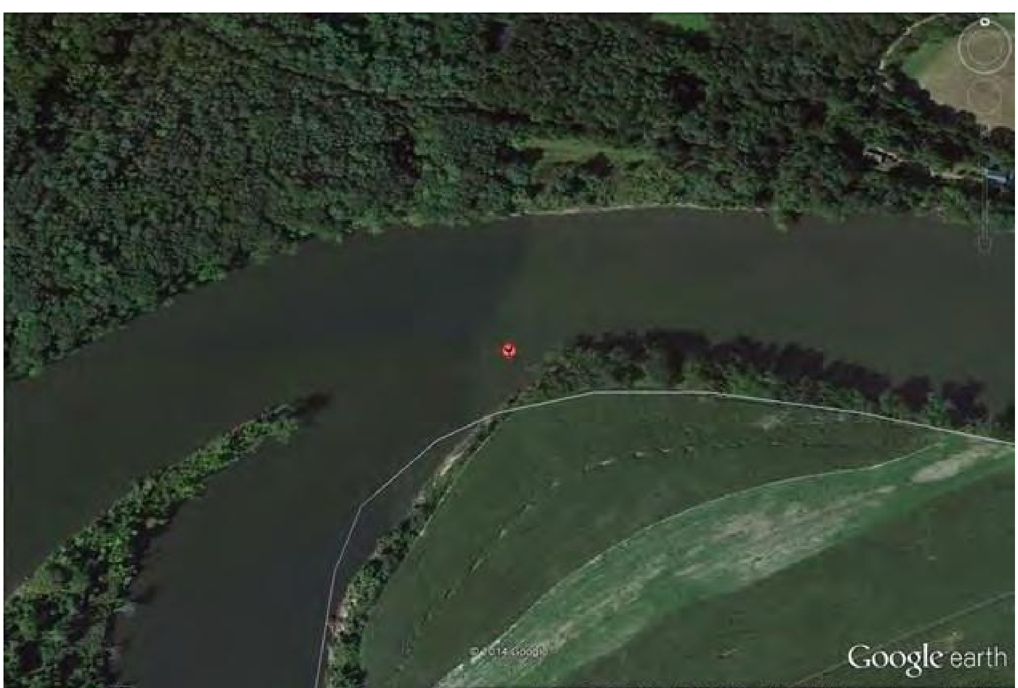


Figure 5.5.5.5-14 Location of Photos Taken Downstream of Stebbins Island (Google Earth)

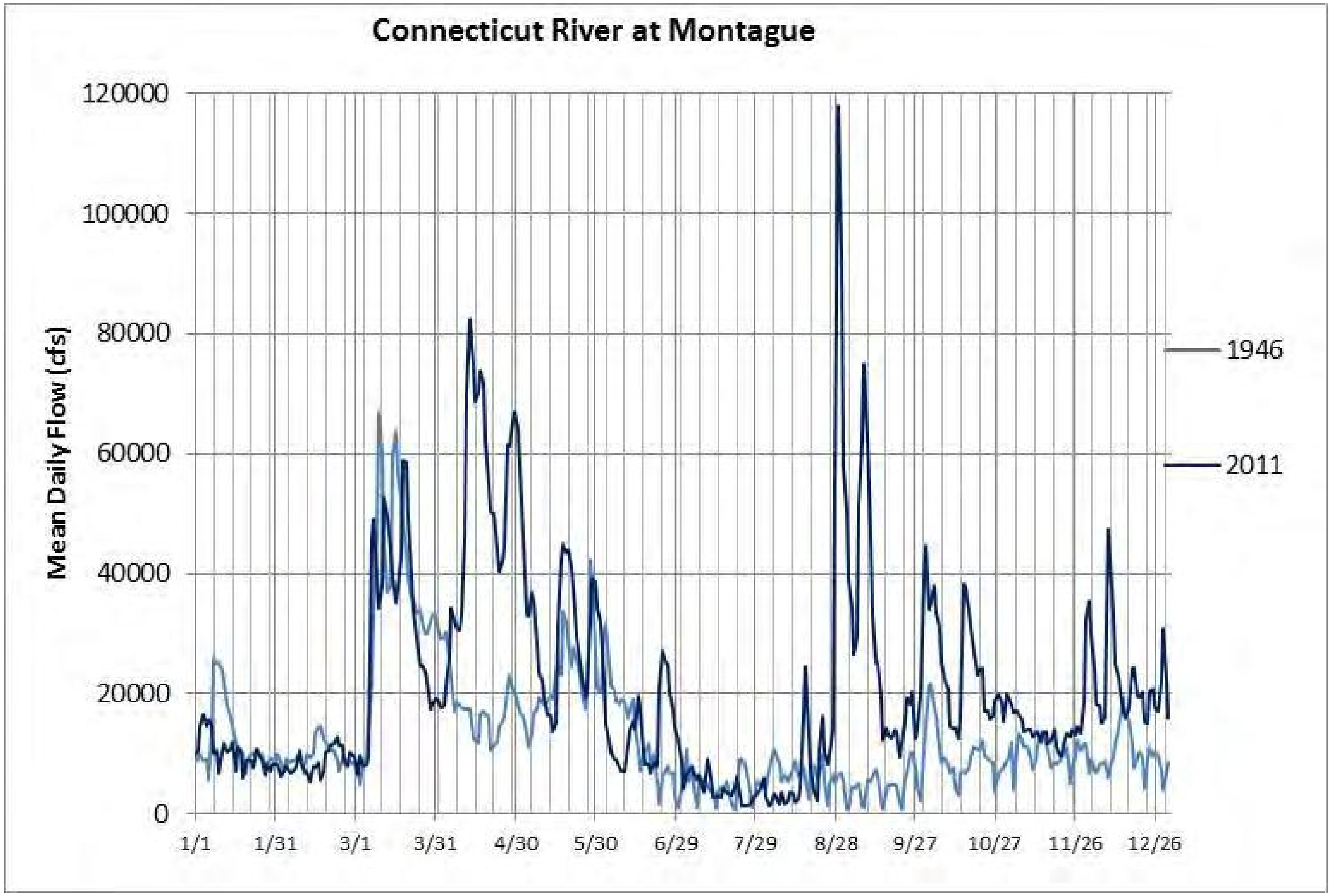


Figure 5.5.5.5-15: Connecticut River at Montague, MA – 1946 and 2011 (USGS)

Figure 5.5.5.5-16 Erosion Due to High Flow in 2011

Figure 5.5.5.5-17 Erosion Due to High Flow in 2011

Figure 5.5.5.5-18 Erosion in 1946 Due to Ice (TransCanada)

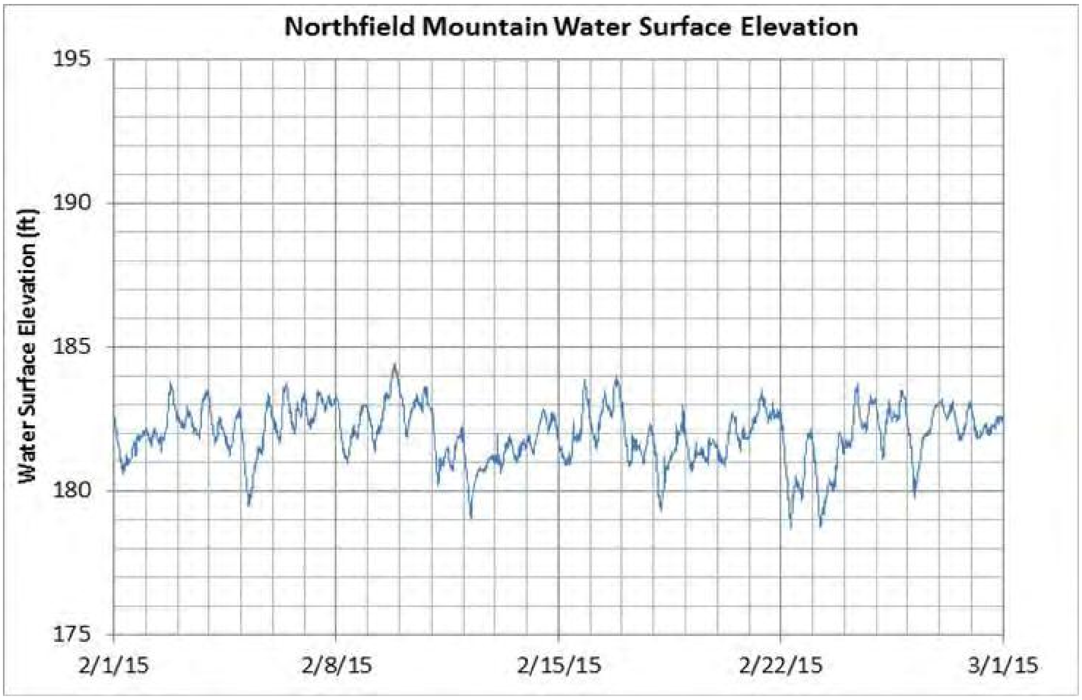


Figure 5.5.5.5-19 Water Level Fluctuations at Northfield Mountain Tailrace, February 2015

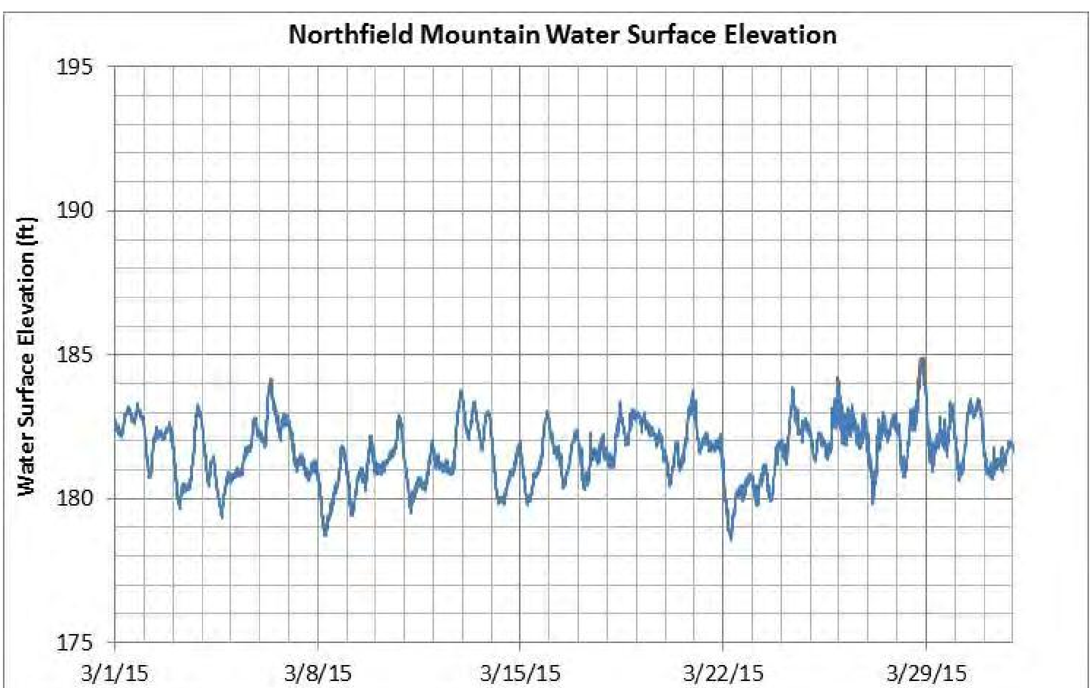


Figure 5.5.5.5-20: Water Level Fluctuations at Northfield Mountain Tailrace, March 2015

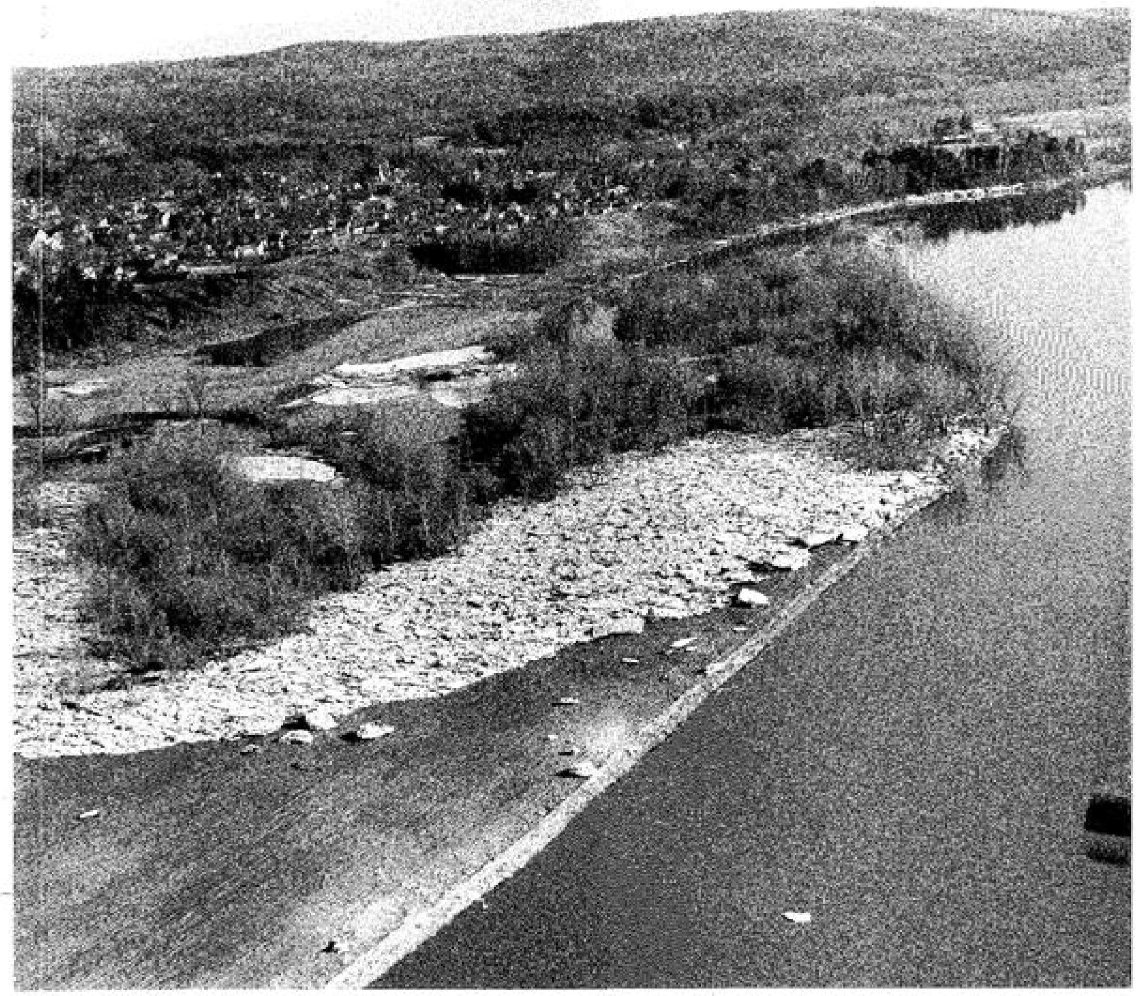
Figure 5.5.5.5-21: Maple seedling (9/28/2015)

Figure 5.5.5.5-22: Cottonwood seedlings (9/28/2015)

A - 3

March 25, 1968 - Eroded banks on N.E.P. property just north of Gray banks.

Figure 5.5.5.5-23 Ice and erosion damage, 1968



A - 15

Evidence of low bank erosion opposite Charlestown.

Figure 5.5.5.5-24 Ice and erosion damage, 1968

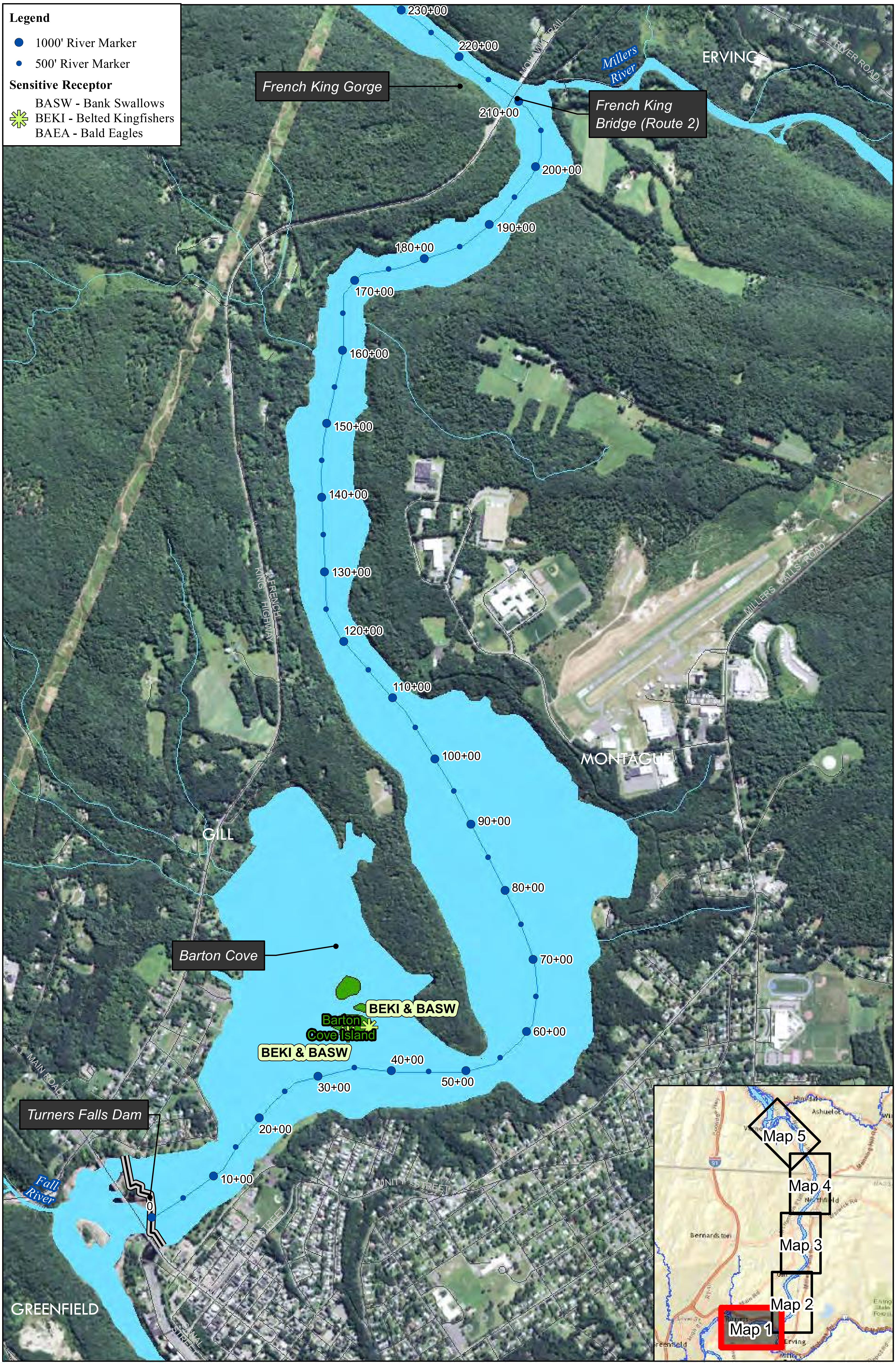
5.5.6 Animals

Animals cause damage to riverbanks in a number of ways. Animal trails leading to the river can create concentrated runoff that cause gullies to form along the trail. Removal or damage to vegetation above ground reduces the protective effect against erosion that vegetation offers which, in turn, can result in root damage and decrease in the binding effect that roots have on the soil matrix. Burrowing of animals or birds into the riverbank can also create disturbance to the riverbank or can create points where seepage may more easily develop resulting in concentration of such flows down the riverbank slope and corresponding erosion.

As part of the 2013 FRR, the locations of sensitive receptors found along or near the TFI riverbanks were mapped. A sensitive receptor was defined as important wildlife habitat located at or near the riverbank. Many wildlife features were observed during this survey including bank swallow and belted kingfisher nesting sites and bald eagle nest and perch sites. Of particular interest to this study were the bank swallow and belted kingfisher nesting sites since they are reliant on eroding banks for habitat. Belted kingfishers and bank swallows excavate cavities to use as nests in sheer banks lacking vegetation and containing appropriate soil conditions. Figure 5.5.6-1 depicts the locations of the sensitive receptors identified during the 2013 FRR. An example of a bank swallow nesting site is found in Figure 5.5.6-2.

Along agricultural fields, paths are frequently created by animals traveling between fields and the river. Examples of this activity are shown in Figure 5.5.6-3 and again in Figures 5.5.6-4 through 5.5.6-12. Figure 5.5.6-13 shows the location where each of the photos in Figures 5.5.6-4 through 5.5.6-12 were taken. At the agricultural field found in Figures 5.5.6-4 through 5.5.6-12 it was observed that there were a number of animal paths over the length of the field. Based on the width of the riparian zone adjacent to this particular field, the animal paths were found where the riparian zone was narrow while no animal paths were observed where the riparian zone was wider.

While the types of animal activities discussed above have been observed to occur along the riverbanks of the TFI, they are found only in a few discrete areas along the river.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 625 1,250 2,500 Feet

Figure 5.5.6-1
Sensitive Receptor Locations
Map 1

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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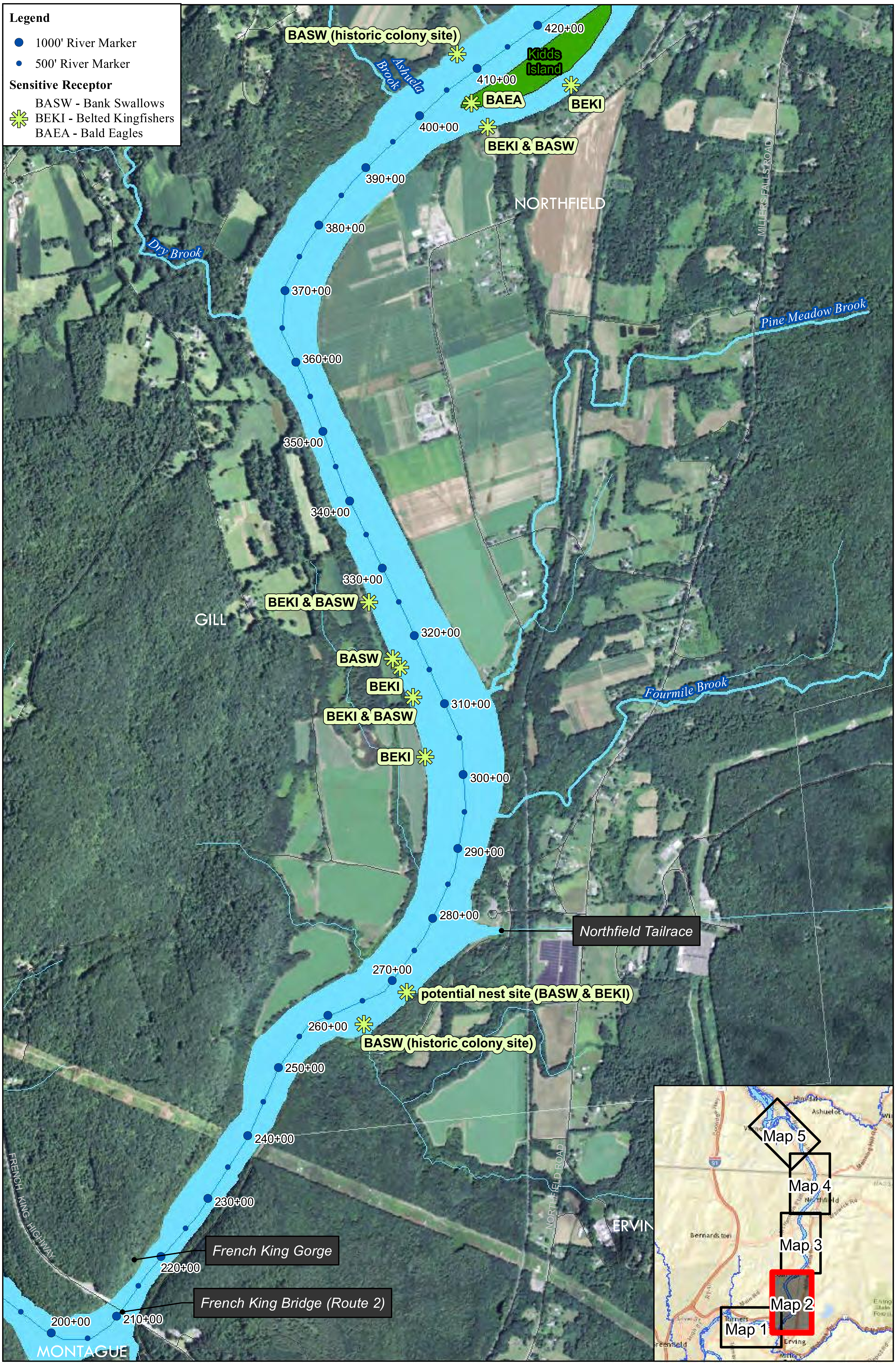

FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
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Turners Falls Hydroelectric Project No. 1889
STUDY 3.1.2

N

0 625 1,250 2,500 Feet

Figure 5.5.6-1
Sensitive Receptor Locations
Map 2

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
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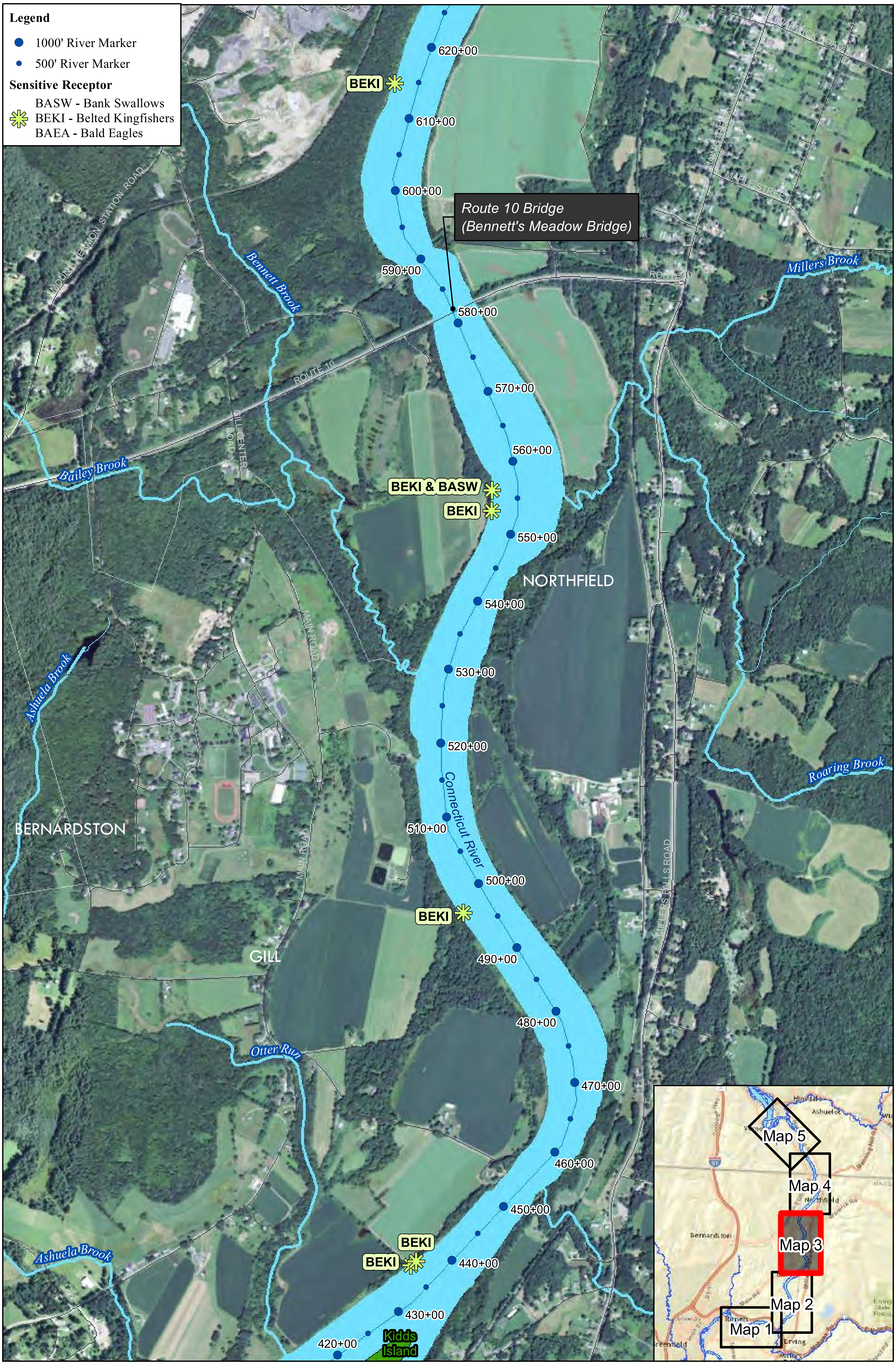

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STUDY 3.1.2

Figure 5.5.6-1
Sensitive Receptor Locations
Map 3

0 625 1,250 2,500 Feet

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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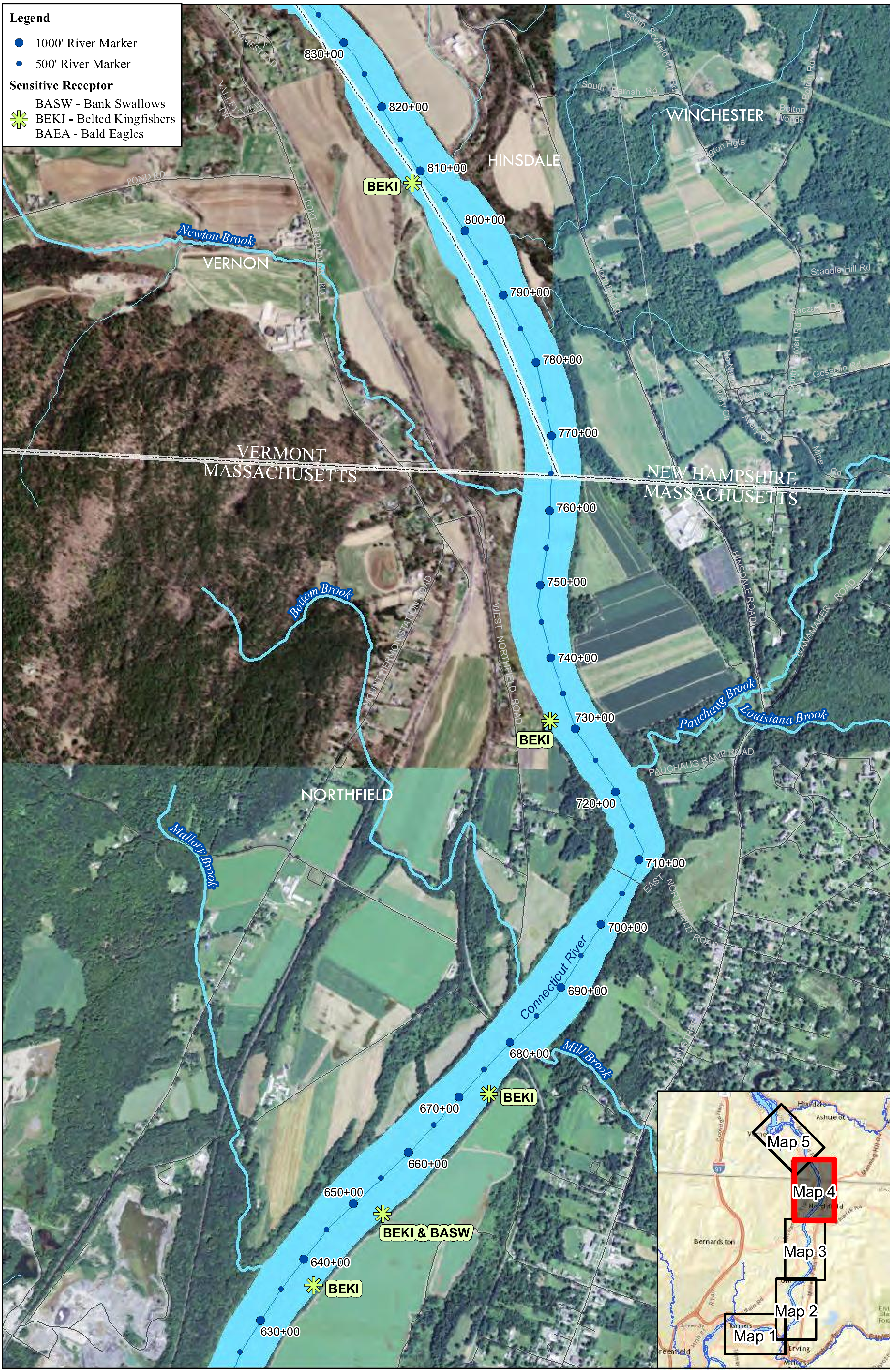

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 625 1,250 2,500 Feet

FirstLight Power Resources

Figure 5.5.6-1
Sensitive Receptor Locations
Map 4

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 625 1,250 2,500 Feet

Figure 5.5.6-1
Sensitive Receptor Locations
Map 5

FirstLight Power Resources

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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Figure 5.5.6-2: Bank swallow nests – Flagg erosion site near Kidds Island, Turners Falls Impoundment

Figure 5.5.6-3: Cattle using riverbank area along Connecticut River – Flagg erosion site near Kidds Island, Turners Falls Impoundment

Figure 5.5.6-4: Animal path from river to field, Photo 101

Figure 5.5.6-5: Animal path from river to field, Photo 109

Figure 5.5.6-6: Animal path from river to field, Photo 117

Figure 5.5.5-6-7: Animal path from river to field, Photo 119

Figure 5.5.6-8: Animal path from river to field, Photo 120

Figure 5.5.6-9: Animal path from river to field, Photo 124

Figure 5.5.6-10: Animal path from river to field, Photo 128

Figure 5.5.6-11: Animal path from river to field, Photo 130

Figure 5.5.6-12: Animal path from river to field, Photo 135

Figure 5.5.6-13: Location of Animal Paths along Field

6 SUMMARY EVALUATION OF THE CAUSES OF EROSION

As discussed in Section 3, potential primary and secondary causes of erosion that may be present in the TFI were originally identified in the RSP and then evaluated as part of this study. The original list of potential causes included:

Potential Primary Causes of Erosion

- Hydraulic shear stress due to flowing water
- Water level fluctuations due to hydropower operations
- Boat Waves
- Land management practices and anthropogenic influences
- Ice

Potential Secondary Causes of Erosion

- Animals
- Wind waves
- Seepage and piping
- Freeze-thaw

Based on the results of BSTEM and the supplemental analyses previously discussed, the dominant (>50% at any location) and contributing (5-50% at any location) primary causes of erosion were identified at each detailed study site and then extrapolated throughout the TFI. Dominant and contributing causes were classified as being either due to: (1) natural high flows[43]; (2) natural moderate flows[44]; (3) Northfield Mountain Project operations; (4) Vernon Project operations; (5) Turners Falls Project operations; (6) boat waves; or (7) ice. To be consistent with the terminology for the primary causes of erosion defined in the RSP, the following correlations were identified:

- **Natural high and moderate flows** included both hydraulic shear stress due to flowing water and naturally occurring water level fluctuations as determined by BSTEM and supplemental analyses;

- **Northfield Mountain, Turners Falls, and Vernon Project Operations** included both hydraulic shear stress due to flowing water and water level fluctuations associated with hydropower operations as determined by BSTEM and supplemental analyses;

- **Boats** included the impact of boat waves on bank erosion as determined by BSTEM and supplemental analyses;

- **Land management practices and anthropogenic influences** included geospatial analysis of land management practices and anthropogenic influences to the riparian zone associated with land-uses classified as Agriculture or Developed; and

- **Ice** included historic analysis of ice formation and break-up in the TFI, impoundments upstream of the TFI, and other river systems. Observations of ice formation and break-up in the TFI during the winter 2014/2015 were also analyzed.

[43] Defined as flows greater than 17,130 cfs in hydraulic reach 4 (upper) and greater than 37,000 cfs in reaches 3 (middle), 2 (Northfield Mountain), and 1 (lower).
[44] Defined as flows between 17,130 cfs and 37,000 cfs in hydraulic reaches 3, 2, and 1. Moderate flows were not a factor in hydraulic reach 4 given the high flow threshold of 17,130 cfs.

The results of the various analyses found that naturally occurring high flows were the dominant primary cause of erosion in the TFI, followed by boat waves, and Vernon operations. Northfield Mountain or Turners Falls Project operations were not found to be a dominant primary cause of erosion at any riverbank segment in the TFI. The dominant primary causes of erosion followed a clear spatial pattern with Vernon Project operations being the dominant cause from Vernon Dam to downstream of detailed study site 11L, natural high flows from downstream of detailed study site 11L to upstream of Barton Cove, and boat waves from upstream of Barton Cove to Turners Falls Dam. The findings of this analysis are summarized below based on relative percentage of total TFI riverbank length:

Dominant Primary Cause of Erosion	% of Total Riverbank Length	Total length (ft.)	Total length (mi.)
Natural High Flows	78%	175,900	33
Boat waves	13%	30,800	6
Vernon Operations	9%	20,200	4
Northfield Mountain Operations	0%	0	0
Turners Falls Operations	0%	0	0
Ice	I	I	I

I = Indeterminate

As observed in the table, the impact of ice on erosion processes could not be quantified as it was not a cause of erosion that was examined in BSTEM. Through discussions with the USGS in NH and VT it was noted that ice typically does not cause erosion if the ice simply melts in place without significant break-up and if ice floes moving down river causing ice jams and impacting banks do not occur. This is consistent with the findings of the historic analysis conducted and with observations made during field monitoring which occurred during the 2014/2015 winter when much of the TFI was frozen over but the ice simply melted in place during the late winter, early spring of 2015. If, on the other hand, there is significant break-up, ice floes moving down river with the potential for ice jams that are pushed against and scrape along the banks; then such an event could potentially cause erosion and damage to the riverbanks.

Analysis of historic ice information and observations made in the TFI, upstream impoundments (Vernon, Bellows Falls, and Wilder), and other river systems (both impounded and un-impounded) provided valuable insights into what could potentially occur in the TFI in the future as ice formation becomes more likely due to the closure of VY. Analysis of historic data found that ice has caused severe erosion under the right conditions (i.e., severe break-up, ice floes, and ice jams) and has contributed to bank instability which can eventually lead to erosion. In addition to directly causing erosion these processes can also greatly effect riverbank vegetation thus also impacting the stability of the bank. Ice formation and accompanying freeze-thaw cycles may also weaken the soil matrix by developing cracks and spalling of the soil surface; however, the process of break-up plays a more significant role in erosion processes.

Erosion due to ice would be expected when temperatures are sufficiently cold (when the number of days are below the various temperature levels when ice historically occurred as presented in Section 5.5.5), combined with an ice breakup event of significant spring rainfall and/or high spring flow when ice is on the river. This combination of events has nothing to do with hydropower operations and to the extent that ice causes erosion, this further reduces the relative impact of hydropower operations on erosion, which is already very small. Although hydropower operations are not anticipated to exacerbate the impacts of ice on erosion, based on the findings of the historic analysis conducted it is likely that ice has the potential to be a natural, dominant cause of erosion in the TFI in the future given the right climatic conditions.

Analysis of contributing primary causes of erosion (i.e., >5% but <50% of erosion at a given site), found that the majority of riverbank segments in the TFI did not have a contributing primary cause. Natural high flows were such a dominant factor in erosion processes that no other contributing primary causes were identified at the majority of riverbank segments. At riverbanks segments that did have contributing primary causes of erosion, boat waves were found to be the most common followed by naturally occurring moderate flows, natural high flows, and Northfield Mountain operations. Turners Falls or Vernon operations were not found to be a contributing primary cause of erosion at any riverbank segment in the TFI. Riverbank segments that exhibited contributing causes of erosion were limited to the Upper (high flows); Northfield Mountain (moderate flows), Northfield Mountain operations, and boats); and Lower (moderate flows and boats) hydraulic reaches. The findings of this analysis are summarized below based on relative percentage of total TFI riverbank length:

Contributing Primary Cause of Erosion	% of Total Riverbank Length[45]	Total length[46] (ft.)	Total length (mi.)
None	68%	153,400	29
Boats	16%	36,000	7
Natural Moderate Flows	10%	23,200	4
Natural High Flows	9%	20,200	4
Northfield Mountain Operations	4%	8,600	1.5
Vernon Operations	0%	0	0
Turners Falls Operations	0%	0	0
Ice	I	I	I

I = Indeterminate

Land management practices or anthropogenic influences were found to be a potential contributing cause of erosion at 44% of the TFI riverbanks (101,000 ft. or 19 mi.). These segments were localized to areas where the land-use adjacent to the riverbank was classified as Developed or Agriculture and the riparian buffer was 50 ft. or less.

While evidence of some secondary causes of erosion were observed at limited, localized segments in the TFI the majority of the secondary causes were found to be insignificant. Analysis of the potential secondary causes of erosion found that:

[45] Note that since moderate flows and boat waves are contributing causes of erosion at a number of the same riverbank segments, the total percentage for contributing causes does not equal 100%. In other words, given that a riverbank segment can have more than one contributing cause of erosion, the percentages do not add to 100%.
[46] Rounded to the nearest 100 ft. or 0.5 mi.

- As noted in the RSP, **Animals** can be both a potential primary and/or secondary cause of erosion. Cattle grazing to the river's edge or the removal or trampling of vegetation resulting from animal trails leading to the river are potential land management or anthropogenic factors which were evaluated as potential primary causes of erosion. These activities can lead to runoff issues, gullying, and damage to the soil matrix which all contribute to bank instability. Wild animals and birds (potential secondary cause) can also contribute to bank instability and erosion; an example of which are animals that burrow into riverbanks which may lead to concentrated points of seepage or direct damage to the bank.

- The impacts of animal activity, both from an anthropogenic and natural perspective, in reducing riparian vegetation are typically limited to a number of localized areas throughout the TFI. Observed animal pathways are typically on the order of a couple feet wide or narrower and may exist at a spacing of every few hundred feet along agricultural fields. The contributions of anthropogenic influences were taken into consideration in the analysis of land-use and land management practices. Sensitive receptors, such as burrows, were identified during the 2013 FRR and were found to be scattered throughout the TFI at a number of localized areas. While animal activity, both anthropogenic and naturally occurring, may potentially contribute to erosion processes at limited, localized areas (e.g., riverbanks adjacent to agricultural fields with narrow riparian buffers) it was not found to be a significant factor in erosion processes throughout the TFI.

- **Wind waves** were generally not found to be a factor in erosion processes throughout the TFI. Wind waves in the TFI are relatively small because the wind cannot act over a significant length of open water (fetch) since the river lies at the bottom of a valley protected on both sides by mountains.

- In the lower bank area, a few limited, localized areas of **seepage** were identified flowing over the lower bank or beach in the TFI. The observed lower bank seepage did not appear to cause significant erosion or sloughing in the adjacent upper riverbank areas. Limited seepage and piping were also observed in localized areas of upland erosion that are unrelated to riverbank processes. In these areas, limited riverbank erosion may occur where such features carve through the upper riverbank and eventually reach the river; however, evidence of this was not prominent at the detailed study sites. Given this, seepage and piping were not found to be a significant factor in erosion processes throughout the TFI.

- **Freeze-thaw** activity was analyzed based on historic information obtained from TransCanada as well as research conducted on other rivers. Freeze-thaw can potentially contribute to bank instability and erosion if the right conditions are present. Based on the research conducted as part of this study it was determined that while freeze-thaw has the potential to contribute to bank instability, it is not believed that freeze-thaw would be a significant factor in erosion processes in the TFI.

Given that the secondary causes of erosion had minimal to no impact on riverbank erosion processes, the remaining discussion in this section focuses on the dominant and contributing primary causes of erosion. The following sections provide detailed descriptions of how the summary statistics previously discussed were calculated.

6.1.1 Summary of Results: Site Specific Causes of Erosion

The results of the BSTEM modeling runs were used to analyze and evaluate primary causes of erosion, including: hydraulic shear stress due to flowing water, water level fluctuations due to hydropower operations, boat waves, and to some extent land management practices (i.e. riverbank vegetative conditions).

From this analysis dominant and contributing causes of erosion were identified and bank erosion rates were calculated at the 25 detailed study sites. In this section discussion is focused on determining the causes of bank erosion under current or "existing" conditions at the 25 detailed study sites. Thus, post-restoration conditions and not pre-restoration conditions are considered in this dataset for those sites that have been restored.

Bank Erosion Rates

To interpret causes and contributing factors to bank erosion, detailed study sites that have had measureable/significant rates of bank erosion were first identified. Rather than arbitrarily selecting a threshold value to determine what a "significant" rate of erosion is, a distribution of annualized rates of current bank-erosion rates was developed to determine the erosion rate that represents the lowest 5% of those rates. This resulted in a threshold of value 0.163 ft^3/ft/y. Of the five sites falling below this threshold, only 4L and 10L represent a non-restored condition.

Overall, values of current conditions ranged from 0.0 ft^3/ft/y at two post-restoration sites (10R and 6AL) to 8.61 ft^3/ft/y at Site 5CR with a median value of 2.22 ft^3/ft/y. Mean-annual erosion rates were broken into six classes to obtain a measure of the central 50% and the upper and lower 5% of the distribution. These are shown along with the sites that fall into each class in Table 6.1.1-1.

Dominant and Contributing Causes of Erosion

Based on the results provided in Section 5.4 and using current erosion rates, a matrix of dominant and contributing causes, contributing factors, and contributing processes was developed for the detailed study sites (Table 6.1.1-2). The results of this matrix were then overlaid on aerial imagery to geographically show the dominant and contributing causes of erosion, contributing factors, and contributing processes found at each site throughout the TFI (Figures 6.1.1-1 & 6.1.1-2). In addition to identifying the causes, factors, and processes associated with erosion at each detailed study site the figures also include color coded symbols for the six classes of current, average-annual erosion rates.

As demonstrated in the matrix and figures, four different causes of erosion are listed that have specific effects on hydrologic and hydraulic conditions that affect bank processes. These include both "natural" and human-induced effects, including (in no particular order):

- High flows;
- Northfield Mountain Project operations;
- Vernon operations; and
- Boats

To be consistent with the terminology for the primary causes of erosion defined in the RSP, sites classified as having High Flows as a cause of erosion refer to hydraulic shear stresses and naturally occurring water level fluctuations at flows in excess of the hydraulic capacity of Vernon Dam (17,130 cfs in the upper impoundment reach) and in excess of 37,000 cfs in the three lower-impoundment reaches (due to additional inputs from Northfield Mountain). Sites classified as having Boats as a cause of erosion indicate the impact of boat waves on bank erosion. Land management practices (i.e. riverbank vegetative conditions) were analyzed as contributing factors in BSTEM.

Also included in the matrix were contributing factors, including:

- High, steep bank;

- Minimal vegetation;
- Land use practices; and
- Seepage/piping

Finally, the contributing processes included in the matrix are those that are typical in bank erosion and that were modeled within the BSTEM framework. These include:

- Hydraulic erosion (of surficial materials);
- Geotechnical erosion (failure by gravity of *in situ* materials); and
- Wave erosion

To justify the selection of a particular cause and factor for a given site and condition, a quantitative rule set was developed that was based on analysis of the BSTEM results. Most importantly, for a cause to be considered as *Dominant*, it needs to have been responsible for at least 50% of the erosion at the site. This information is obtained directly from the modeling results. For example, for High Flows to be a *Dominant* cause, more than 50% of the erosion would have to occur at a flow rates greater than 17,130 cfs (for the upper impoundment) or 37,000 cfs (for the middle, NFM and lower-impoundment reaches) as determined from the high-flow analysis. For Northfield Mountain Project Operations to be listed as a Dominant cause, the S1 minus Baseline erosion rate would need to make up at least 50% of the Baseline erosion rate. The same procedure is used as a criteria for waves but in this case the comparison is between the "Waves On" and "Waves Off" scenarios under the Baseline Condition. For a cause to be considered as Contributing, the effect had to be responsible for at least 5% of the bank-erosion rate. This is similar to the justification used above to determine the minimum threshold by which to consider causes of bank erosion.

Selection of contributing factors is based on empirical evidence and observations of conditions at each of the sites along with interpretation of the results of the modeling runs. Assigning Contributing Processes is based on: (1) analysis of BSTEM output which provides for individual erosion volumes by the hydraulic-erosion sub model and by the geotechnical sub-model, and (2) in the case of waves, comparison between "Waves On" and "Waves Off" erosion rates.

Role of Northfield Mountain and Turners Falls Project Operations and Other Factors on Bank-Erosion Rates

Based on the delineation of hydraulic reaches which were defined by differences in energy grade slopes (as discussed in Section 5.4.1) it can be observed that there are seven (7) detailed study sites that lie within the Northfield Mountain Reach, located between stations 27,000 and 41,000. Sites within the Northfield Mountain Reach include:

- 119BL;
- 7L;
- 7R;
- 8BL;
- 8BR;

- 87BL; and
- 75BL

Although technically not included in this reach because of its generally flatter energy slopes, Sites 6AL and 6AR at station 41,750 are still in the vicinity of the reach. The effects of Northfield Mountain Project operations on bank erosion would, therefore, be expected to show at the sites in closest proximity to the tailrace. Based on the criteria defined above for selection of the causes of bank erosion, Project operations are not a *Dominant* cause of current bank erosion at any of the sites (Table 6.1.1-2). Project operations are, however, a Contributing cause at Sites 8BL and 8BR, represented by existing and post-restoration conditions, respectively. For conditions prior to restoration at Site 8BR, Project operations were deemed a *Dominant* cause of bank erosion at this location, but this has been limited by the subsequent restoration work there. Site 8BL with its greater vegetative cover and flatter bank slope was more resilient. At none of the other detailed study sites are Northfield Mountain Project operations deemed to even be a Contributing cause.

Results show that a small amount of erosion at site 7L (station 37,500) can be attributed to Northfield Mountain operations but this amount (3.9%) falls below the threshold value of 5% to be considered a Contributing cause. Site 7R has less than half the erosion rate as 7L and the Dominant cause is High Flows. The difference between sites 7R and 7L can be attributed to the fact that Site 7L has banks that are taller and steeper. The same goes for Site 119BL, approximately 13,000 feet upstream of Northfield Mountain, where about 1.5% of the bank erosion can be attributed to Project operations while the Dominant cause is High Flows. No adverse effect is seen at sites 87BL and 75BL.

With the exception of the sites in the lower TFI (9R, 12BL and BC-1R) where boat waves are the Dominant cause of bank erosion and the uppermost site (11L) just downstream from Vernon Dam where Vernon Operations control bank erosion, the Dominant cause of bank erosion at the remainder of the detailed study sites is High Flows (Table 6.1.1-2). This is discussed in detail in Section 5.4.2 and supported with the figures and tables provided in Section 5.4.3.

To delineate the relative contributions of each of the causes at a given site, results of the BSTEM simulations were used. The procedure to quantify this included the following steps:

- Determine amount of bank erosion due to Northfield Mountain Project operations by subtracting the bank-erosion rate under the S1 scenario from the bank-erosion rate under Baseline Conditions;
- Determine the contribution from Boat waves by subtracting the bank-erosion rate for the Baseline Condition with "waves off" from the bank-erosion rates of with "waves on";
- Take the percentage of bank-erosion resulting from high flows (using either the 17,130 or 37,000 cfs threshold depending on the site location in the TFI), multiply that by the amount eroded under Baseline Conditions to obtain the amount of erosion by high flows; and
- For contributions due to Vernon operations and moderate flows, the contributions from Northfield Mountain Project operations, boat waves and high flows were summed and subtracted from the bank-erosion rates under Baseline Conditions.

Percent contributions are then calculated relative to the total bank-erosion rate under Baseline Conditions with waves on.

In regard to Turners Falls operations, a modified extrapolation approach was employed in Reach 1 to determine to what extent, if any, Turners Falls Project operations were a cause of erosion. When compared to the rest of the TFI, Reach 1 has unique and varied geomorphic characteristics. The upper portion of the reach includes the French King Gorge which is very narrow, lined with bedrock, and serves as the hydraulic control for the mid and upper portion of the TFI at high flows. Just downstream of the French King Gorge is the confluence of the Millers River. From this point, the middle portion of the reach is more riverine before transitioning to a wider, more lake-like section upstream of the entrance to Barton Cove and continuing to the Turners Falls Dam. Given the unique geomorphic characteristics of this reach, combined with there being detailed study sites only in the lake-like portion and not the more riverine portion, the modified extrapolation approach was required in order to determine the contributions, if any, of Turners Falls Project operations on erosion.

Based on a combination of BSTEM and hydraulic model results combined with supplemental geomorphic and hydraulic analyses it was determined that in the upper portion of the reach the causes of erosion are similar to those found at Site 75BL where high flows are the dominant cause of erosion with moderate flows and boats as contributing causes. In the middle, riverine portion of the reach high flows are the dominant cause of erosion with boats as a contributing cause. While in the lower, lake-like portion of the reach boats were the dominant cause of erosion with no contributing causes. Based on the results of this analysis, it was determined that Turners Falls Project operations are not a dominant or even contributing cause of erosion in the TFI. This approach is discussed in more detail in Section 6.1.2.

As for contributing factors to bank erosion, bank height and steepness are important as they help determine the downslope, gravitational component of the failure process. The lower and flatter the bank, the less likely it is to fail. With riparian vegetation, less vegetative cover means less root reinforcement provided to the slope. The land use factor refers to banks where cultivation goes to the top-bank edge or where there is no vegetative cover on the top bank surface. This category was also used to include unique flow conditions in the channel associated with anthropogenic influences. An example of this is the flow deflection from piers of the Route 10 Bridge towards Site 5CR. Although piping was not observed at any of the sites, seepage was observed at Sites 21R and 26R. Tension cracks are often evidence of recent or imminent bank collapse. During collection of the hydraulic- and geotechnical-resistance data at the 25 detailed study sites, field crews did not observe tension cracks along bank-top edges.

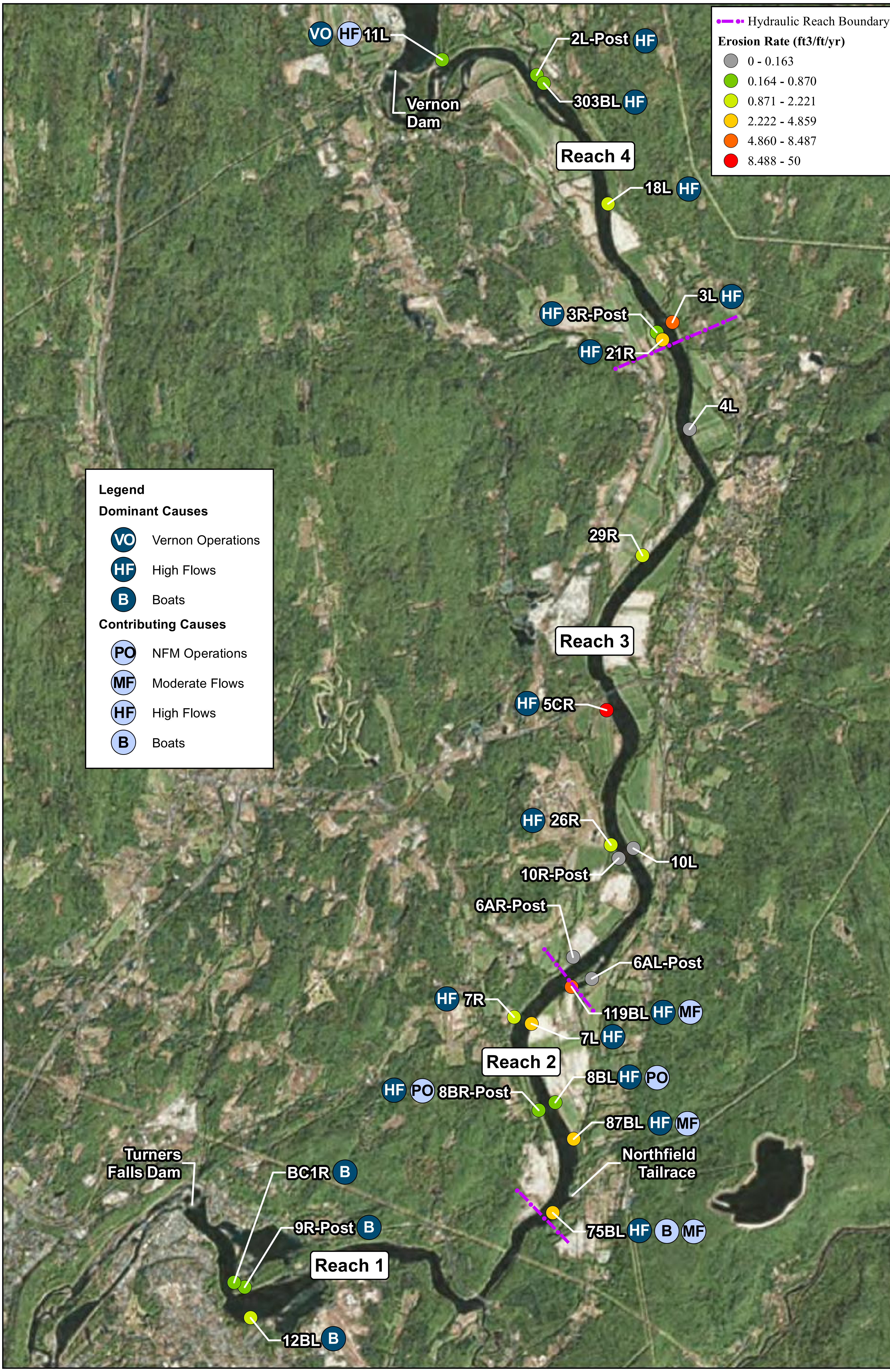
Table 6.1.1-1: Distribution of Mean Annual Erosion Rates by Site

Mean Annual Erosion Rate Classes	Corresponding Erosion Rate ($ft^3/ft/y$)	Number of Detailed Study Sites	Detailed Study Sites
0-5%	<0.163	5	4L, 10L, 10R, 6AL, 6AR
6-25%	0.164 – 0.87	8	11L, 2L, 303BL, 3R, 8BL, 8BR, 9R, BC-1R
26-50%	0.88 – 2.22	5	18L, 29R, 26R, 7R, 12BL
51-75%	2.23 – 4.86	4	21R, 7L, 87BL, 75BL
76-95%	4.87 – 8.49	2	3L, 119BL
96-100%	>8.49	1	5CR

Table 6.1.1-2: Matrix of Causes of Bank Erosion and Contributing Factors at the 25 Detailed Study Sites

Site	Station	Dominant Causes				Contributing Causes				Contributing Factors				Contributing Processes		
		NFM Project Operations	High Flows	Vernon Operations	Boats	NFM Project Operations	High Flows	Moderate Flows	Boats	High, Steep Bank	Minimal Vegetation	Land Use	Seepage/Piping	Hydraulic Erosion	Geotechnical Erosion	Wave Erosion
11L	100000			X			X			X				X		
2L - Pre	94500		X								X	X		X	X	
2L - Post	94500		X									X		X		
303BL	94000		X							X	X			X		
18L	87000		X							X	X			X	X	
3L	79500		X											X	X	
3R-Pre	79500		X							X	X			X	X	
3R-Post	79500		X											X		
21R	79250		X							X	X		X	X		
4L	74000	-	-	-	-	-	-	-	-					X		
29R*	66000	Failure occurs at first time step due to severely undercut bank, cannot determine primary cause								X	X				X	
5CR	57250		X							X	X	X**		X	X	
26R	50000		X							X	X		X	X		
10L	49000	-	-	-	-	-	-	-	-					X		
10R-Post	49000	-	-	-	-	-	-	-	-							
6AL-Pre	41750		X							X	X			X		
6AL-Post	41750	-	-	-	-	-	-	-	-	X						
6AR-Post	41750	-	-	-	-	-	-	-	-	X		X		X		
119BL	41000		X					X		X	X			X	X	
7L	37500		X							X	X			X	X	
7R	37500		X							X				X		
8BL	32750		X			X				X				X		
8BR-Pre	32750	X					X			X	X			X	X	
8BR-Post	32750		X			X				X				X		
87BL	30750		X					X		X				X	X	
75BL	27000		X					X	X	X	X			X	X	X
9R-Pre	6750				X		I			X	X			X		X
9R-Post	6750				X		I			X				X		X
12BL	6500				X		I			X				X	X	X
BC-1R	4750				X		I			X				X		X

* Imminent failure ** Issues with hydraulics caused by the Rt. 10 Bridge I = Indeterminate



FirstLight Power Resources

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.625 1.25 2.5 Miles

Figure 6.1.1-1:
Dominant and Contributing Causes of Erosion at each Detailed Study Site

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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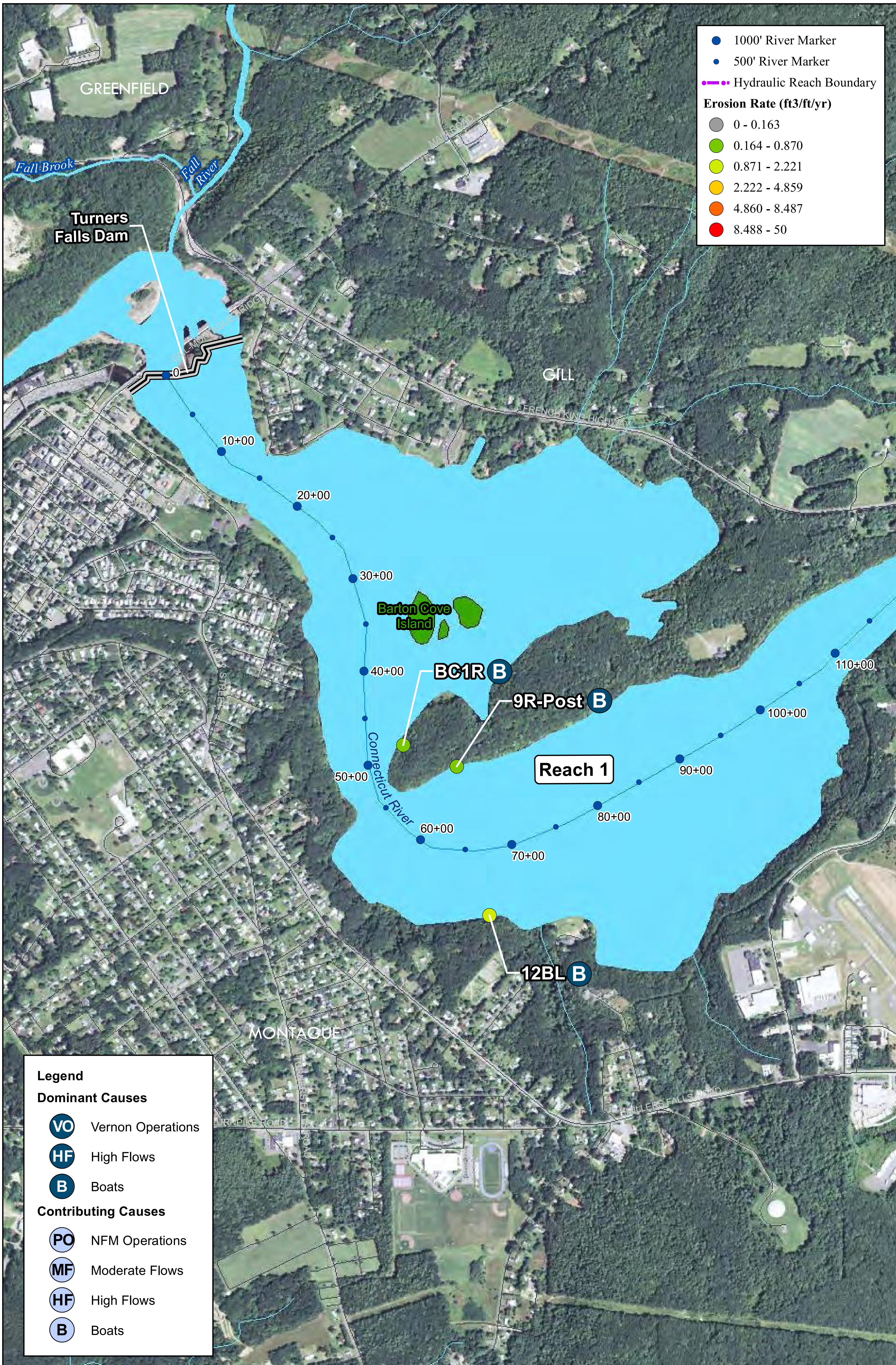

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Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Figure 6.1.1-1:
Dominant and Contributing Causes of Erosion at each Detailed Study Site
Reach 1

N

0 500 1,000 2,000 Feet

FirstLight Power Resources

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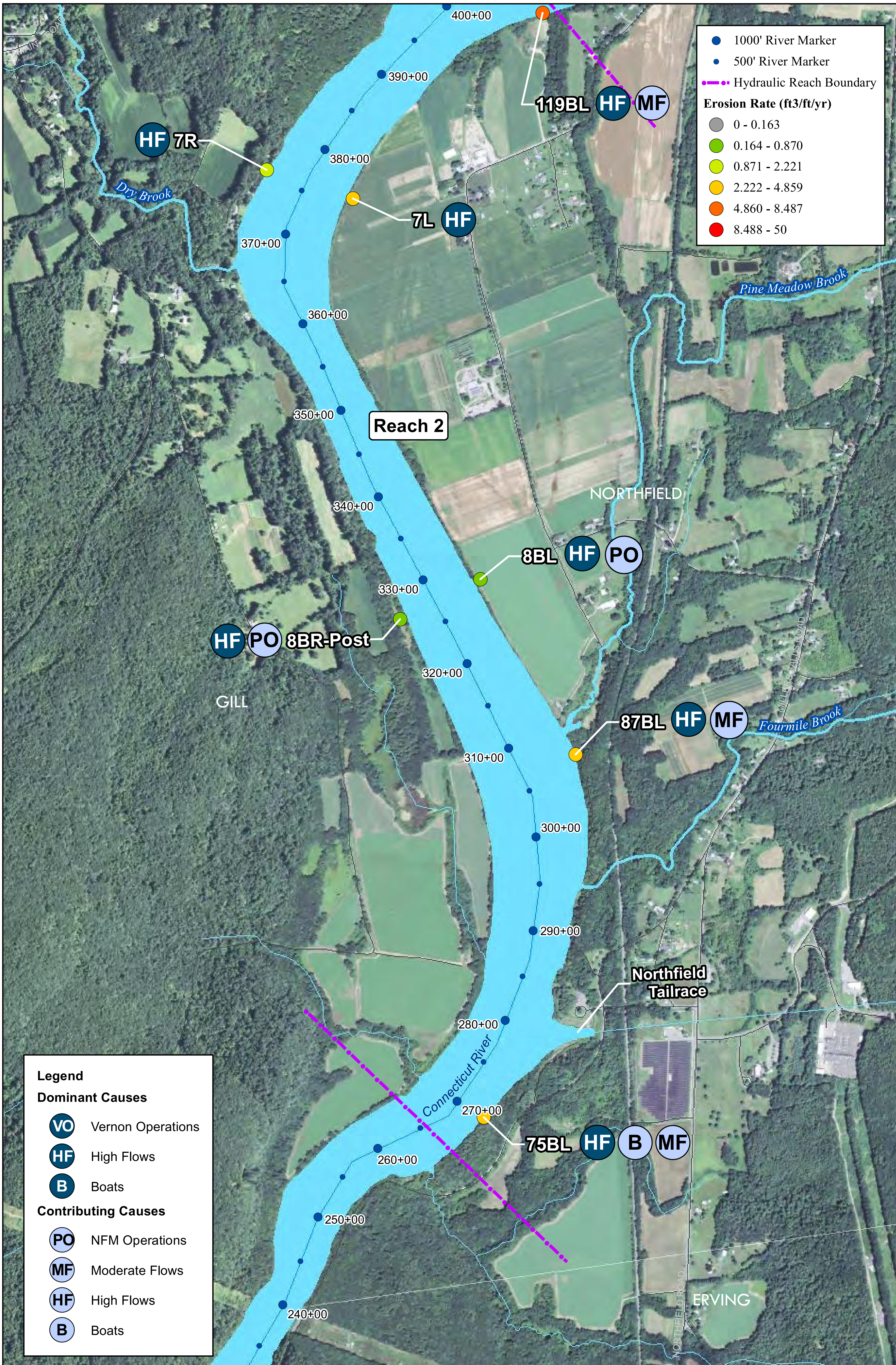

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 500 1,000 2,000 Feet

Figure 6.1.1-1:
Dominant and Contributing Causes
of Erosion at each Detailed Study Site
Reach 2

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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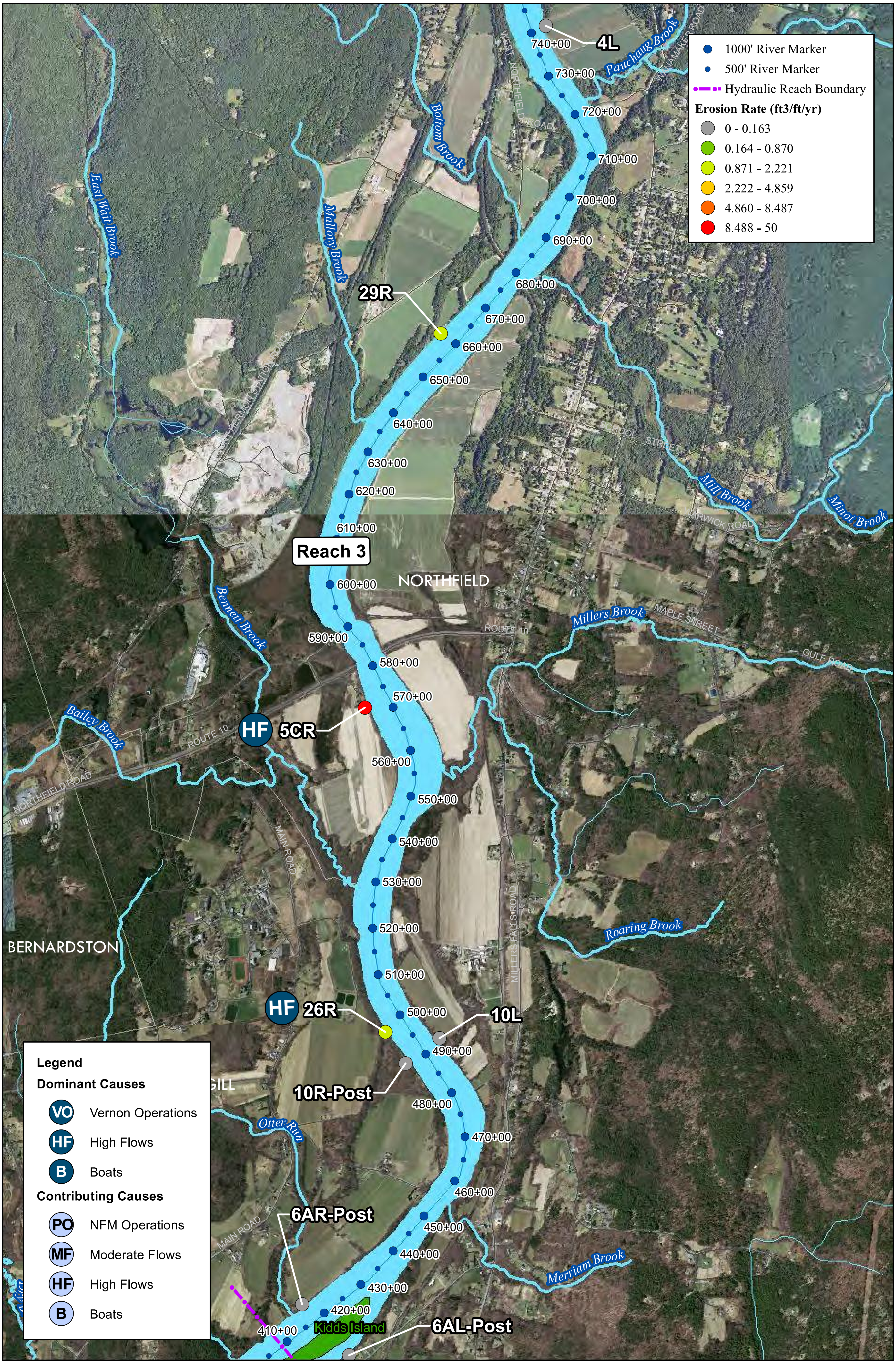

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Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

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N

0 1,000 2,000 4,000 Feet

Figure 6.1.1-1:
Dominant and Contributing Causes of Erosion at each Detailed Study Site
Reach 3

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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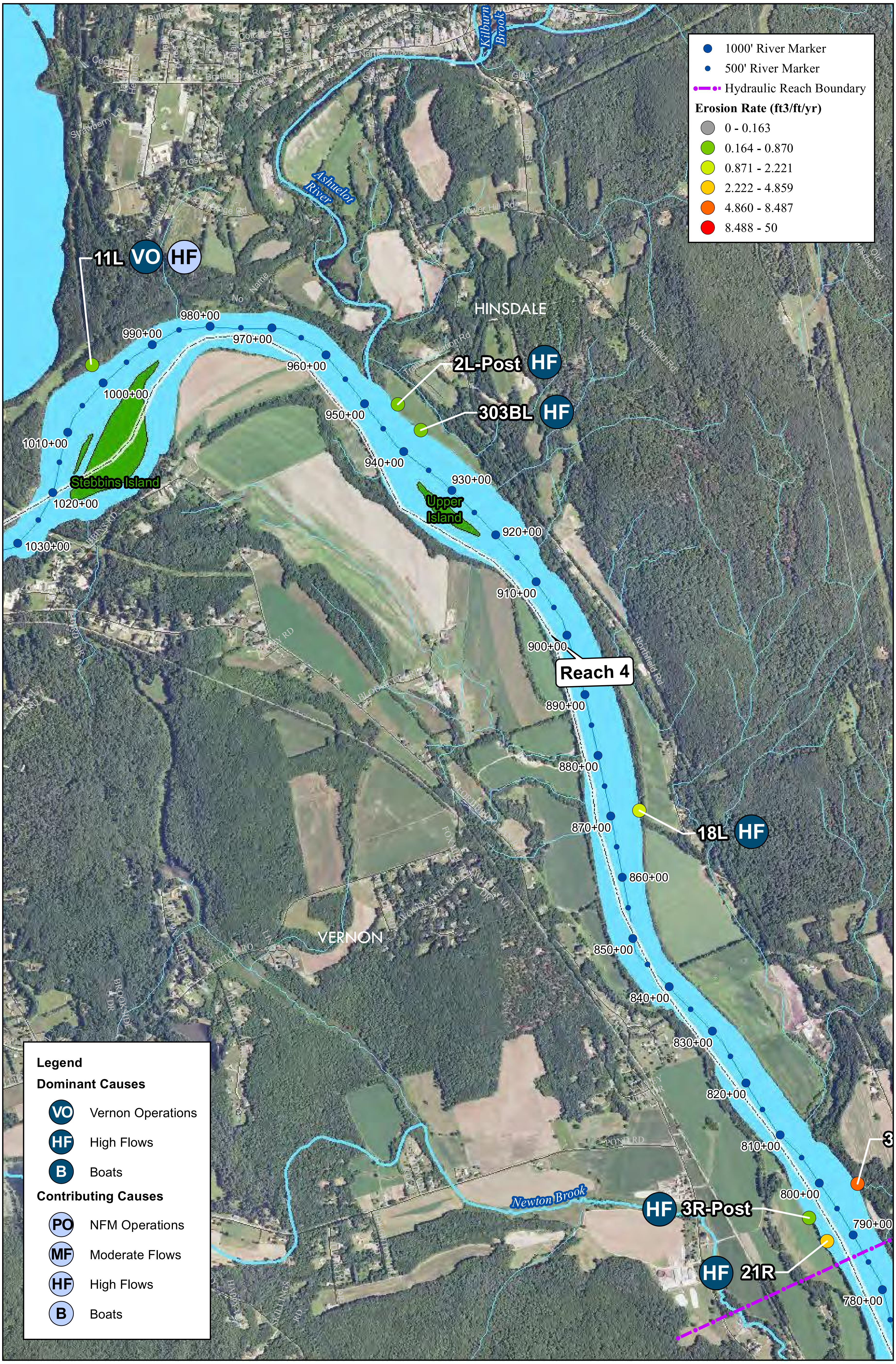

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 750 1,500 3,000 Feet

Figure 6.1.1-1:
Dominant and Contributing Causes of Erosion at each Detailed Study Site
Reach 4

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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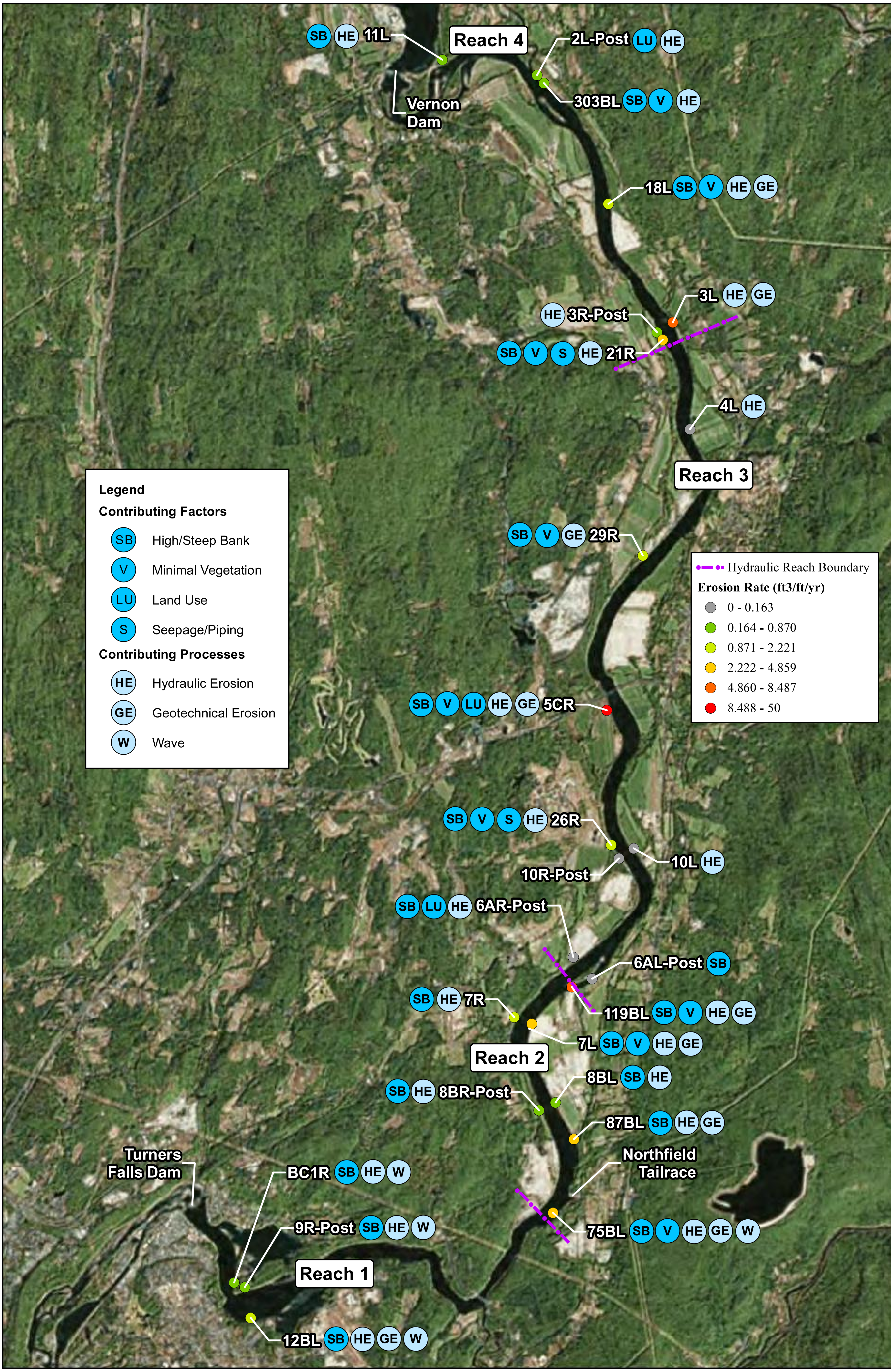

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.625 1.25 2.5 Miles

Figure 6.1.1-2:
Contributing Erosion Factors and Processes at each Detailed Study Site

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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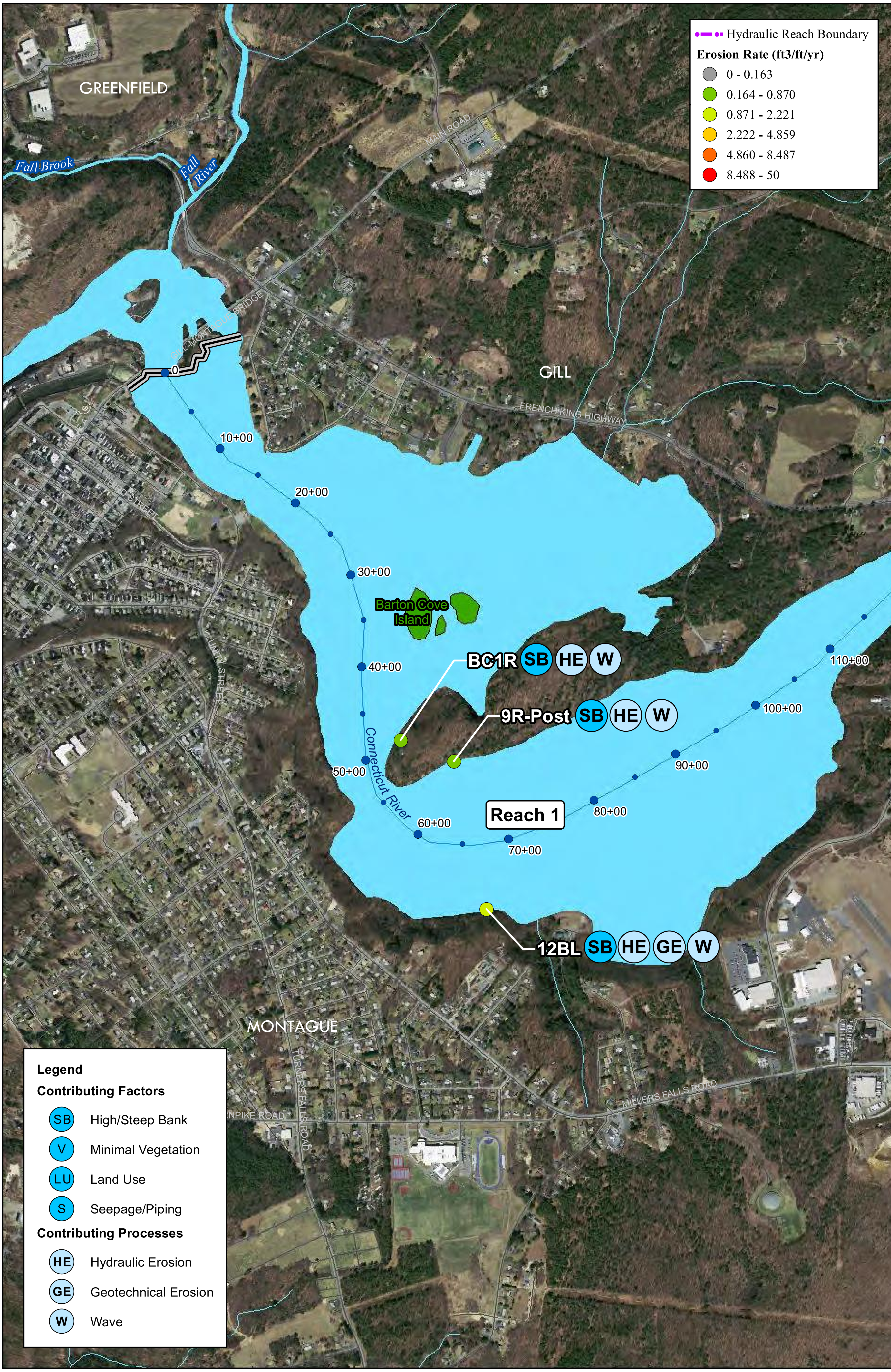

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Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 500 1,000 2,000 Feet

Figure 6.1.1-2:
Contributing Erosion Factors and Processes at each Detailed Study Site
Reach 1

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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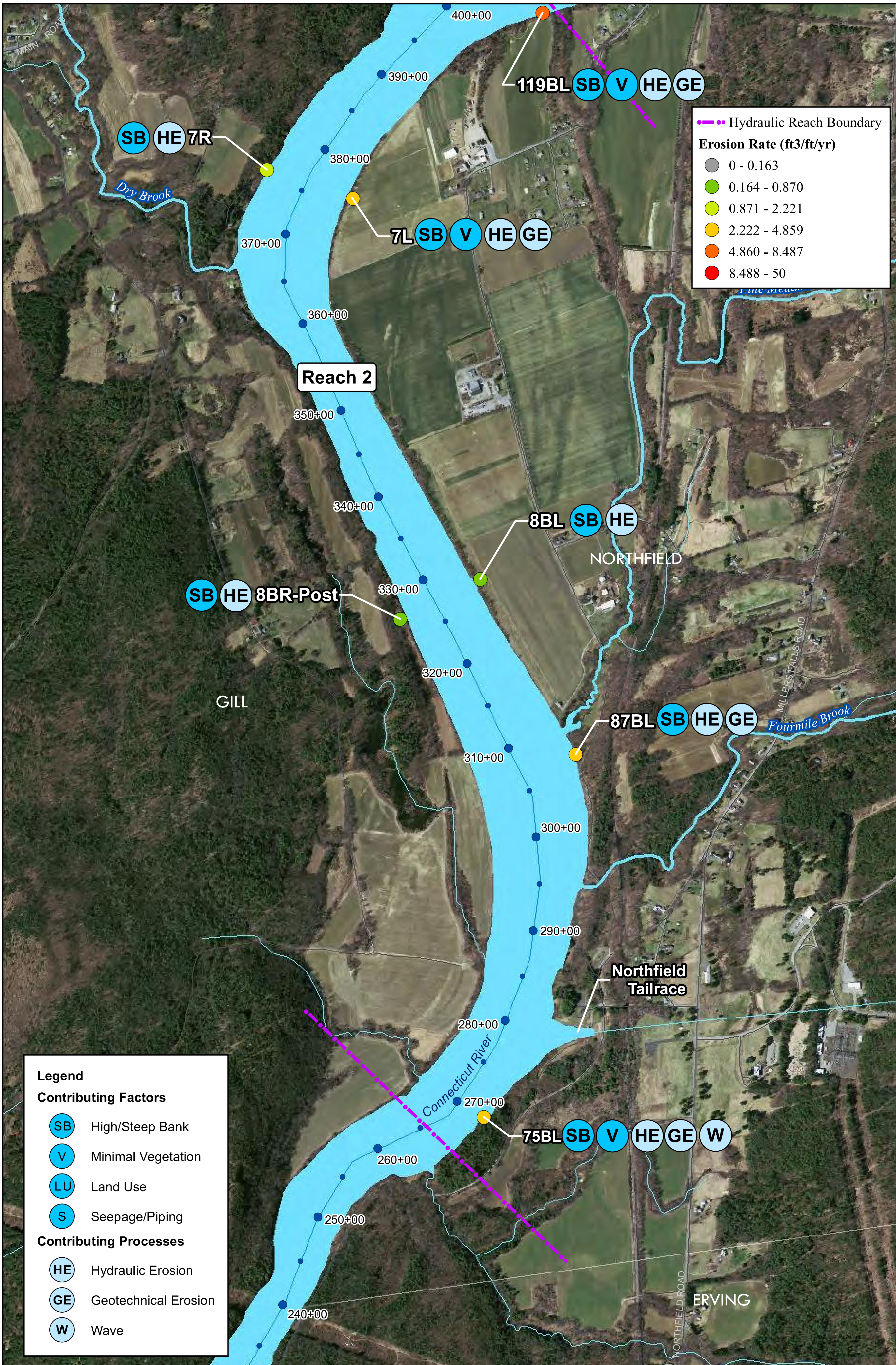

FirstLight Power Resources

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Figure 6.1.1-2:
Contributing Erosion Factors and Processes at each Detailed Study Site
Reach 2

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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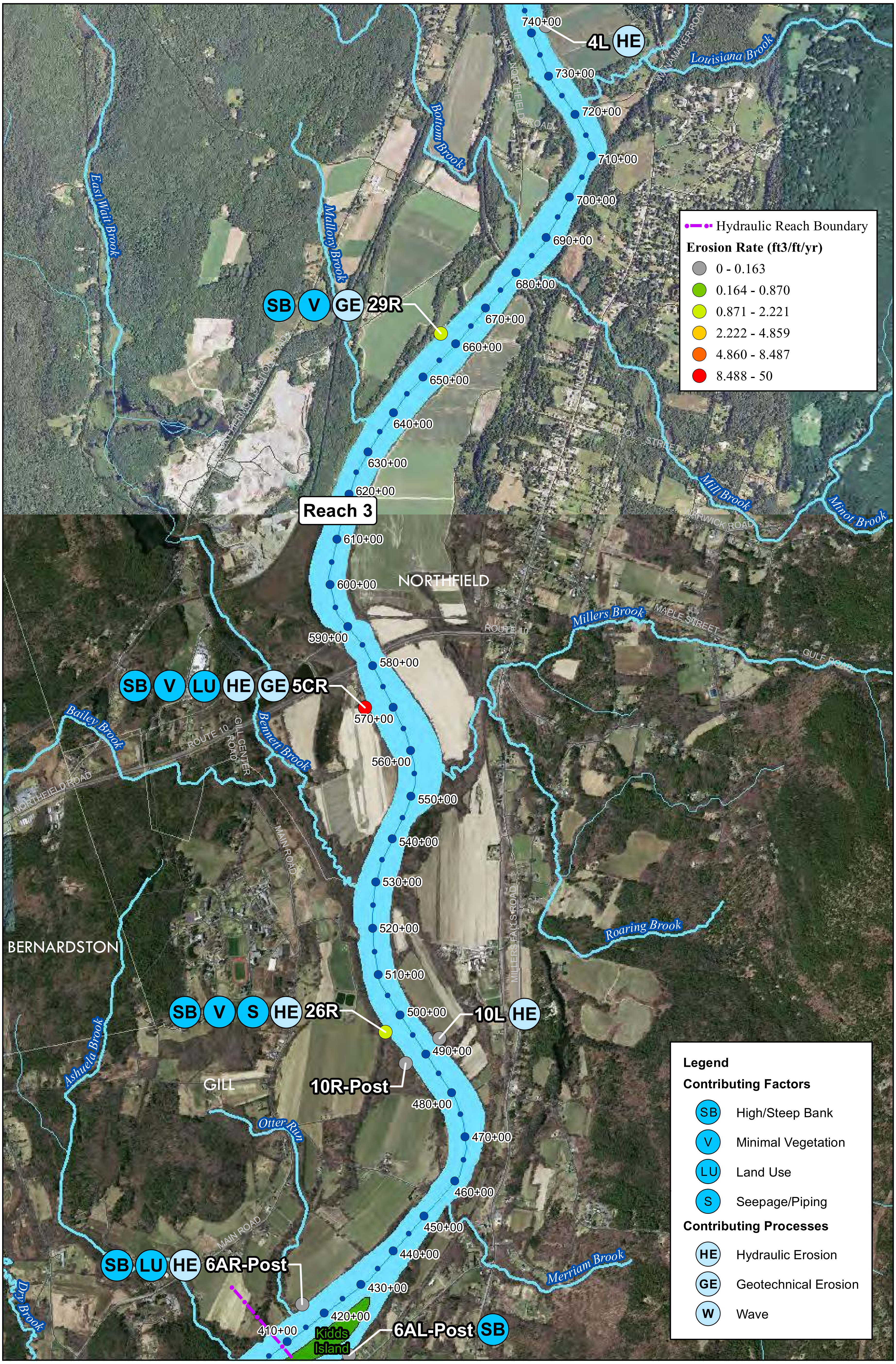

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Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 1,000 2,000 4,000 Feet

Figure 6.1.1-2:
Contributing Erosion Factors and Processes at each Detailed Study Site
Reach 3

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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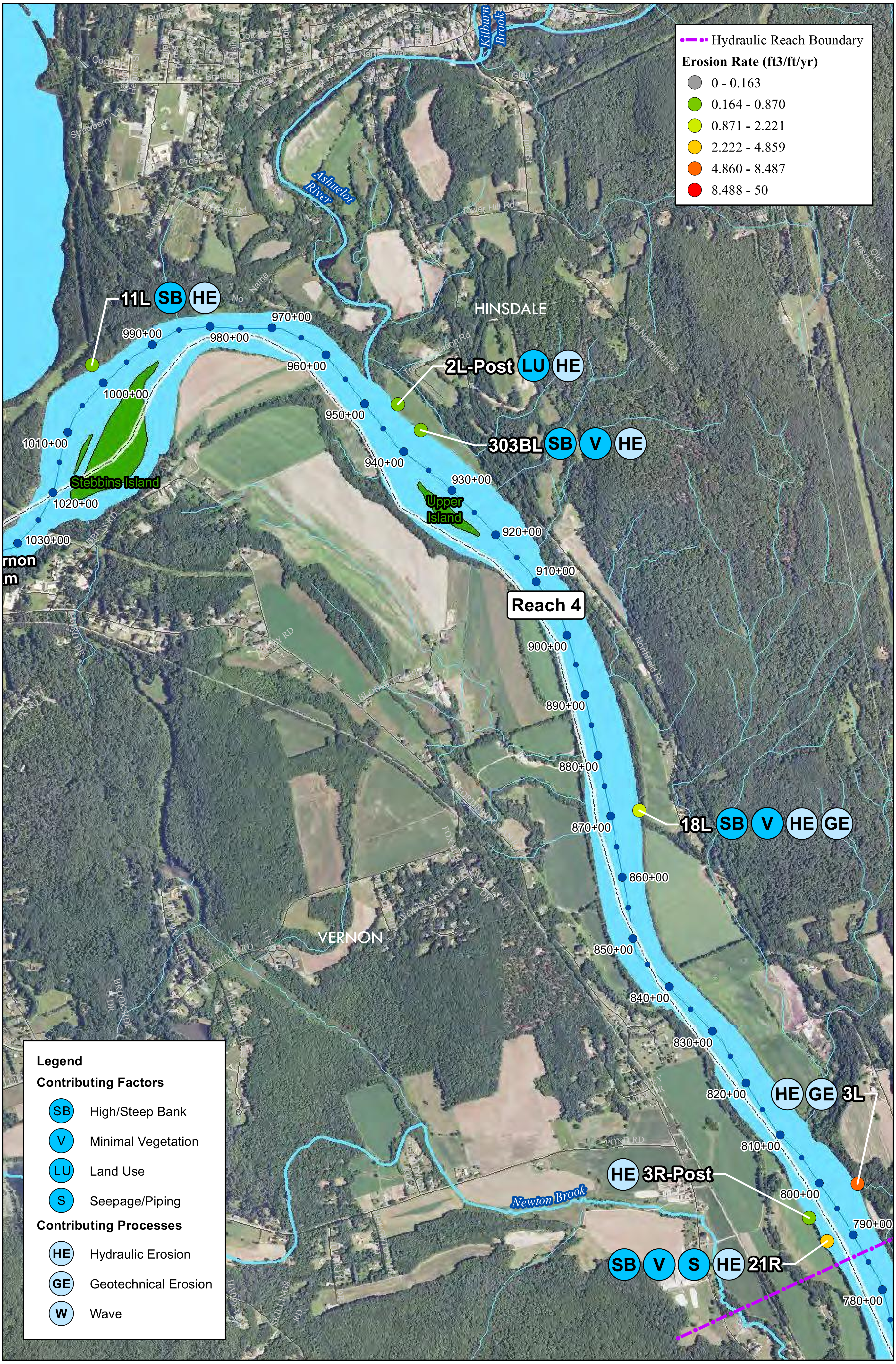

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Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 750 1,500 3,000 Feet

N

Figure 6.1.1-2:
Contributing Erosion Factors and Processes at each Detailed Study Site
Reach 4

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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6.1.2 Summary of Results: Extrapolation across the Turners Falls Impoundment

In accordance with the RSP, after determining the dominant and contributing primary cause(s) of erosion at each detailed study site the BSTEM results, combined with the results of the supplemental analyses, were extrapolated across the TFI. The purpose of this extrapolation was to determine the cause(s) of erosion at each riverbank segment identified in the 2013 FRR. The extrapolation process was a multi-step process that included analysis of the riverbank features, characteristics, and erosion conditions at each segment, the variability of hydraulic forces throughout the TFI, and the adjacent land-use. The end result of this task was the quantification, based on relative percentages, of the dominant and contributing primary cause(s) of erosion at each detailed study site and the TFI overall.

The approach presented herein is consistent with not only the requirements of the RSP but also the regulatory goal of MADEP to "*determine through accurate, repeatable, scientifically based mapping and supportive data collection what fraction of the "banks" of the Turners Falls Impoundment (TFI) are susceptible to or experiencing erosion due to repeated wetting and drying of the soil column. In the process, eliminate all other "banks" within the TFI from further study in regards to this issue, including areas in which bedrock predominates; soils/substrates are presently stable; and hardscape stabilization has previously been installed* (October 17, 2013 correspondence)."

Discussion in this section focuses on the extrapolation methodology used to determine the causes of erosion at each riverbank segment throughout the TFI and the results of the extrapolation process.

6.1.2.1 Extrapolation Methodology

As previously mentioned, the extrapolation methodology was a multi-step process that took into consideration TFI riverbank features, characteristics, and erosion conditions, the variability of hydraulic forces throughout the TFI, and the adjacent land-use. Whereas analysis of riverbank features, characteristics, erosion conditions, and adjacent land-use was a relatively straightforward processes, the complex hydraulics of the TFI, including three hydropower projects and natural hydraulic controls, made the extrapolation of the detailed study site results particularly challenging. After much analysis and deliberation it was determined that using the Energy Grade Line Slope, as determined by the HEC-RAS model, would be the most accurate and effective way to identify hydraulic reaches in the TFI and to determine the geographic extent that hydropower operations (i.e., Vernon, Northfield Mountain, or Turners Falls) could have an impact on erosion conditions.

The steps which comprised the extrapolation methodology are outlined below:

1. **Analyze the variability of hydraulic forces throughout the TFI**: Energy Grade Line Slope, as determined by the HEC-RAS model, was used to identify the variability of hydraulic forces throughout the TFI and to determine the geographic extent where a hydropower project could potentially have an impact on riverbank erosion. Analysis of the results of both BSTEM and the various supplemental analyses indicated that hydraulic forces have just as much of an impact, or more in some cases, on erosion as the riverbank features and characteristics do. As such, it is vital to understand the varying hydraulic characteristics of the TFI in order to adequately understand the erosion processes at a given site.

   Due to the hydraulic characteristics of the TFI it is unlikely that a hydropower project can have an impact on erosion processes outside of its hydraulic reach. For example, it is unlikely that Northfield Mountain Project operations can impact erosion processes outside of Reach 2 due to the clear delineation of energy grade line segments throughout the TFI. While a hydropower project can impact water level fluctuations and flow outside of its hydraulic reach, the magnitude of those impacts are so minor that they do not affect the energy grade line slope outside of their given reach. The hydraulic reaches delineated for this study are discussed in Section 5.4.1.1 and shown in Figure 6.1.2.1-1.

The hydraulic reaches were first established by examining the energy grade line slope from the Baseline Condition HEC-RAS run at the 25 detailed study sites. From this initial analysis four hydraulic reaches were clearly identified (Section 5.4.1). In order to determine if the hydraulic reaches identified based on the results of the Baseline Condition modeling run were representative and accurately portrayed the geographic extent of a given hydropower projects impact, the results of the HEC-RAS scenarios were analyzed over a range of flow and operating conditions. The range of flows at each detailed study site were segmented into the following three ranges:

- Flows less than 18,000 cfs[47];
- Flows between 18,000 and 37,000 cfs; and
- Flows in excess of 37,000 cfs.

HEC-RAS scenarios included:

- Baseline Condition: historic conditions, and
- Scenario 1: Northfield Mountain idle

The results of this analysis were then compared against the hydraulic reaches identified from the Baseline Conditions and were deemed to be similar. The end result was a set of four hydraulic reaches based on energy grade line slope which represent the geographic extent of potential erosion impacts due to hydropower operations.

2. **Analyze and review the site specific BSTEM results**: BSTEM results at each of the 25 detailed study sites were reviewed to determine the dominant and contributing causes of erosion at each site. For those sites that were previously restored, both the pre- and post-restoration results were examined.
3. **Analyze riverbank features, characteristics, and erosion conditions**: This step involved a number of incremental sub-steps, including:
    a. Identify the detailed study sites where hydropower operations (i.e., Vernon or Northfield Mountain) were the dominant or contributing cause of erosion;
    b. Identify the riverbank features, characteristics, and erosion conditions at those sites based on the results of the 2013 FRR;
    c. Identify other segments in hydraulic reach 4 (Vernon) or 2 (Northfield Mountain) that have the same features and characteristics. Map the locations of those segments in ArcGIS; and
    d. Compare the locations of those segments identified in Step 3c against (1) the results of the nearest detailed study site, and (2) the hydraulic and geomorphic conditions at that location to determine if the riverbank features and characteristics or hydraulics/geomorphology are the likely factors influencing erosion.
4. **Assign the dominant and contributing causes of erosion to each riverbank segment identified in the 2013 FRR:** This step involved a number of sub-steps, including:

[47] As discussed in Section 5.1, 18,000 cfs was used as the low flow threshold for this analysis as it is slightly higher than the hydraulic capacity of Vernon (17,130 cfs) and also accounts for inflow from TFI tributaries.

   a. Identify sites where hydropower operations from Northfield Mountain or Vernon were found to potentially be a dominant or contributing cause of erosion based on the results from Steps 3c and 3d; and

   b. Extrapolate the results from a given detailed study site, halfway upstream and halfway downstream to the nearest detailed study site. For example, the causes of erosion identified at Site 119BL were extrapolated and assigned to all riverbank segments up to the halfway point upstream to Site 6A and halfway point downstream to Site 7

5. **Conduct supplemental hydraulic and geomorphic analyses in Reach 1 to determine the impact, if any, of Turners Falls Project operations:** due to the unique hydraulic and geomorphic conditions found in Reach 1, conduct a modified extrapolation approach using the results of the BSTEM and hydraulic modeling and 2013 FRR to determine the causes of erosion in this reach and to determine the impact, if any, of Turners Falls Project operations on erosion;

6. **Analyze land-use and width of riparian buffers**: Analyze the land-use and width of riparian buffers found adjacent to the riverbanks throughout the TFI in ArcGIS. Segments where the adjacent land-use is Agriculture or Developed and the riparian buffer width is less than 50 ft. were identified as segments where land management practices are a potential contributing cause of erosion;

7. **Create a map identifying the causes of erosion for each riverbank segment as determined in Steps 4 through 6**; and

8. **Finalize map and calculate summary statistics:** Following completion of Steps 1-7, maps denoting the dominant and contributing primary causes of erosion for every TFI riverbank segment identified during the 2013 FRR will be finalized and the dominant and contributing primary causes will be quantified using relative percentages for the entire TFI.

The results of the extrapolation process are presented in the following section.

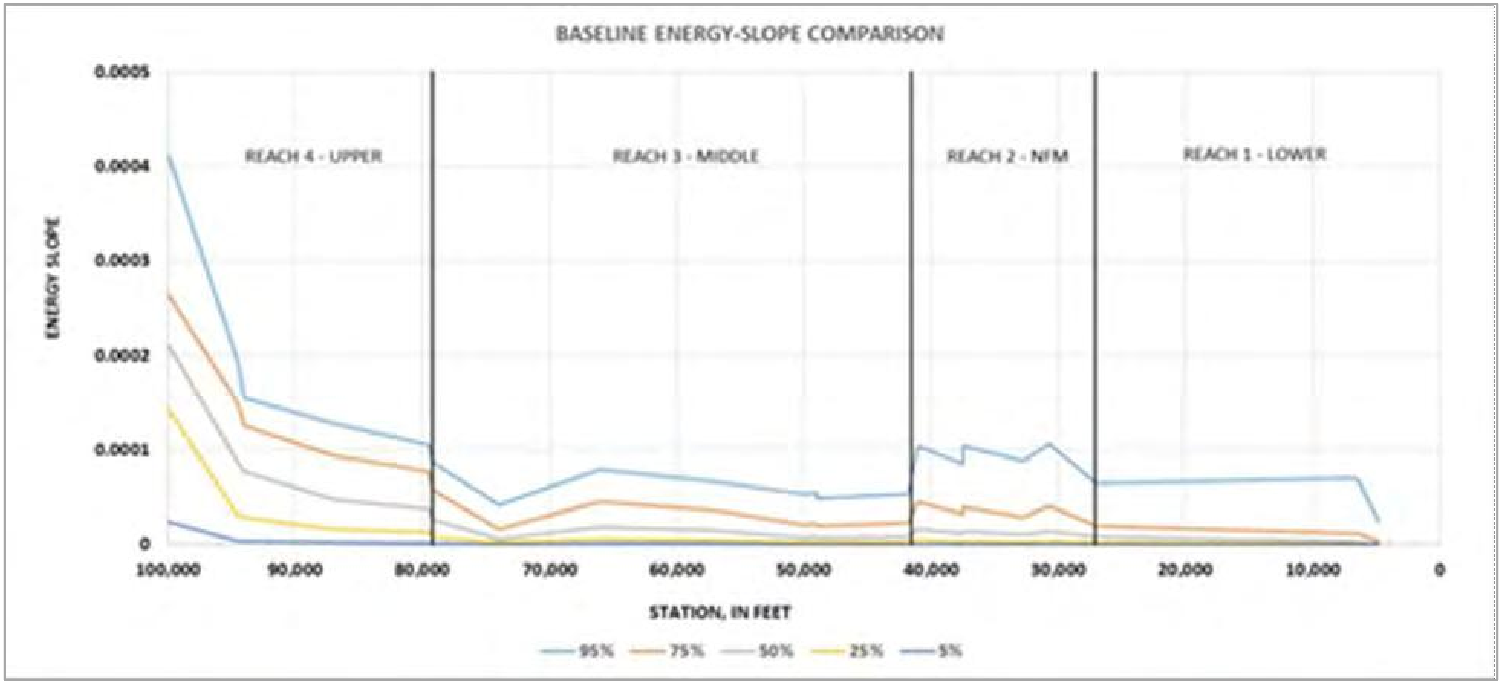


Figure 6.1.2.1-1: Energy slope trends through the Turners Falls Impoundment

6.1.2.2 Extrapolation Results

The multi-step extrapolation process resulted in the classification of the dominant and contributing primary causes of erosion for each riverbank segment identified during the 2013 FRR (excluding islands). The results of each step of the extrapolation process are discussed below.

Step 1: Analyze the variability of hydraulic forces throughout the TFI

The first step in this process was to evaluate if the hydraulic reaches discussed in Section 5.4.1 accurately reflected the geographic extent in which hydropower operations can impact erosion processes. In order to determine this, energy grade line slopes from the supplemental HEC-RAS run discussed in the previous section were compared against the energy grade line slope from the Baseline Condition HEC-RAS run. Figures 6.1.2.2-1 through 6.1.2.2-3 depicts the results of this analysis for the three flow ranges discussed in the previous section.

As observed in the figures, the energy grade line slopes for the supplemental run do not vary appreciably from the results of the Baseline Condition scenario, thus validating the four hydraulic reaches identified from the Baseline Condition HEC-RAS run. Given the clear delineation and characteristics of each hydraulic reach it is unlikely that a hydropower project can have an impact on erosion processes outside of the hydraulic reach in which it is located. While a hydropower project can impact water level fluctuations and flow outside of its hydraulic reach, the magnitude of those impacts are so minor that they do not affect the energy grade line slope outside of their given reach. For example, even though Northfield Mountain operations can impact the water surface elevation in reaches 3 and 4 at flows which exceed the erosion flow threshold at the detailed study sites, the impacts are so negligible that corresponding changes to the energy grade line slope do not occur. Thus, given the hydraulic characteristics of each reach it is unlikely that Northfield Mountain operations can impact erosion processes outside of reach 2. Conversely, it is also unlikely that Vernon operations can impact erosion processes outside of reach 4 or that Turners Falls operations can impact erosion processes outside of Reach 1.

Step 2: Analyze and review the site specific BSTEM results

Once the evaluation of the hydraulic reaches was concluded, focus then turned to analyzing the site specific BSTEM results for the 25 detailed study sites. For those sites where restoration had previously occurred, both the pre- and post-restoration results were reviewed. Table 6.1.2.2-1 provides a summary of these results. Causal determinations for the extrapolation process followed the same criteria discussed in Section 6.1.1. That is, for a cause to be considered dominant it needs to have been responsible for at least 50% of the erosion at the detailed study site. For a cause to be considered contributing, it had to contribute to >5% of the erosion at a site. As shown in Table 6.1.2.2-1 an “X” indicates the cause(s) of erosion, a “-” indicates that erosion was insignificant, and an “I” means indeterminate. The term Qe_{95} is the flow above which 95% of erosion occurred (as determined from the BSTEM results). Since there is no definable stage-discharge relationship in the lower portion of the TFI Qe_{95} was not determined in that reach (as indicated with an “I” in the table). Figures 6.1.1-1 and 6.1.1-2 (from Section 6.1.1) depict the geographic distribution of the various causes of erosion at the detailed study sites.

Step 3: Analyze the riverbank features, characteristics, and erosion conditions

As observed in Table 6.1.2.2-1, only one site (8BR-Pre) was identified as having Northfield Mountain operations be the dominant cause of erosion while two sites (8BL and 8BR-Post) were identified as having Northfield Mountain operations be a contributing cause. Similarly, only one site (11L) was identified as having Vernon operations be the dominant cause of erosion; no sites were found to have Vernon operations be a contributing cause. The corresponding 2013 FRR riverbank segments and their features, characteristics, and erosion conditions for each site mentioned above were identified and summarized (Table 6.1.2.2-2). The riverbank features, characteristics, and erosion conditions associated with Site 11L were then compared against all segments in reach 4 in order to identify segments with common features and characteristics. Given that the features and characteristics found at Site 11L are relatively common of riverbanks in the TFI, 25 segments were identified in reach 4 with common features and characteristics to those found at Site 11L (Figure 6.1.2.2-4). FRR riverbank segments with common features and characteristics which were identified as part of this analysis include:

- 249
- 266
- 282
- 284
- 288
- 289
- 295
- 297
- 312
- 320
- 321
- 324
- 327
- 533
- 542
- 548
- 550
- 553
- 555
- 559
- 563
- 565
- 575
- 583
- 594

A similar analysis was then conducted for Site 8BR-Pre. Due to the fact that 8BR is a restoration site, the riverbank features and characteristics as observed during the 1998 FRR were compared against the features and characteristics identified during the 2013 FRR for all riverbank segments found in reach 2 to determine if similarities exist at other locations within the reach. No riverbank segments were found in reach 2 with the same characteristics as were observed at Site 8BR in 1998. While no riverbank segments were found to be an exact match, three FRR segments were identified as having very similar characteristics – 75, 87, and 109. The only difference between these segments and Site 8BR (1998) was in regard to upper riverbank vegetation where 8BR (1998) was classified as having None to Very Sparse vegetation and FRR segments 75, 87, and 109 were classified as having Sparse vegetation. These three segments total 276 ft. in length, or 0.12% of the total length of TFI riverbanks, and are shown in Figure 6.1.2.2-4.

Finally, the same comparison was then conducted for the features and characteristics at Sites 8BL and 8BR-Post. Based on the results of this comparison, eight FRR segments in reach 2 were identified as having the same features and characteristics as Sites 8BL and 8BR-Post, including:

- 78
- 91
- 92
- 93
- 94
- 101
- 116
- 421

These segments are shown in Figure 6.1.2.2-4.

Step 4: Assign each riverbank segment dominant and contributing causes of erosion

The location of the FRR segments identified above were then analyzed to determine what the likely driving erosion factor would be at each site (i.e. riverbank features and characteristics, hydraulics, geomorphology, or geography) and were compared against the causes of erosion identified at the nearest detailed study site. If based on this analysis, it was determined that the features and characteristics were the likely driving factor in erosion processes the site would be assigned Northfield Mountain or Vernon operations as the dominant or contributing cause of erosion. If, however, it was determined that hydraulics or geomorphology were the driving factor then the site was assigned the cause(s) of the nearest detailed study site (which in some cases was hydropower operations anyway).

For those segments in reach 4 that were located between Vernon Dam and Site 11L, it was determined that Vernon operations was the dominant cause of erosion due to the hydraulics, geomorphology, and BSTEM results at Site 11L. For those segments that were located downstream of Site 11L it was determined that, although the features and characteristics were the same as Site 11L, the causes of erosion would be determined by the results of the nearest detailed study site (which in this case was always high flows with no contributing causes). This determination was made based on the hydraulics, geomorphology, and consistency of BSTEM results across all detailed study sites in reach 4 downstream of Site 11L.

A similar analysis was then conducted for the segments located in reach 2. FRR segments 75 and 109 are approximately 33 and 36 ft. in length and are surrounded by detailed study sites which indicate that high flows are the dominant cause of erosion. Given this, Sites 75 and 109 were classified as having the same causes of erosion as the nearest detailed study site. FRR segment 87 is located at detailed study site 87BL and therefore was assigned the causes of erosion observed at that site as determined by BSTEM. Similar to the rationale for segments 75 and 109, FRR segments 78 and 116 were assigned the causes of erosion found at the nearest detailed study site. All remaining segments were classified as Northfield Mountain being a contributing cause of erosion.

Once the analysis of common riverbank features and characteristics was completed, the remaining riverbank segments identified during the FRR were assigned dominant and contributing causes of erosion based on the results of the nearest detailed study site. The results of the nearest detailed study site were extrapolated halfway upstream and downstream to its neighboring study site. For example, the results found at detailed study site 8BL were extrapolated to all riverbank segments which were located from that site halfway upstream to site 7 and halfway downstream to site 87B such that Site 8BL would be in the middle of all segments which were assigned the same causes as were found at that site. This is demonstrated in later figures.

Step 5: Conduct supplemental hydraulic and geomorphic analyses in Reach 1 to determine the impact, if any, of Turners Falls Project operations

As previously discussed, Turners Falls Project operations can only be a potential cause of erosion in hydraulic reach 1 (lower) due to the hydraulic characteristics of the TFI. Detailed study sites in the lower reach only exist in the vicinity of Barton Cove (12BL) with the nearest upstream study sites located at the Northfield Mountain tailrace (75BL, upstream of the French King Gorge). The geomorphic characteristics of the TFI between the Barton Cove and Northfield Mountain sites varies significantly. Given this, it is not appropriate to do a straight extrapolation from site 75BL to Site 12BL. As such, a modified extrapolation approach was used to determine the causes of erosion in the area between these study sites. The modified approach utilized a combination of BSTEM results, geomorphic assessment, and hydraulic model analysis.

For the upstream and downstream portions of reach 1, the causes of erosion at the nearest detailed study sites were extrapolated to the riverbank segments in these areas. In the upstream portion of the reach, this included the area from just downstream of detailed study site 75BL to the French King Bridge. Given that this area is upstream of, or includes, the French King Gorge, and is composed mainly of bedrock, the hydraulic conditions are the same, or similar, as those found at detailed study site 75BL thus making the extrapolation of the causes found at that site appropriate.

The downstream portion of the reach, from Turners Falls Dam to upstream of the entrance to Barton Cove before the river narrows, is lake-like, has unique geomorphic characteristics when compared to the other portions of the reach, and includes three detailed study sites. The results at the three detailed study sites demonstrate how dominant the effect of boat waves are in causing erosion in this area. As a result of these findings, combined with the unique geomorphic characteristics of this area and that water level fluctuations are limited to a very narrow band, the results of the detailed study sites were extrapolated to the riverbank segments in the downstream portion of the reach. The results of this extrapolation classified all riverbank segments in this area as having boat waves as the dominant cause of erosion with no contributing causes.

In the middle portion of this reach (i.e., from where the river narrows upstream of Barton Cove to the French King Gorge) the results of the hydraulic modeling, combined with the findings of the 2013 FRR, were used to analyze the potential for Turners Falls Project operations to cause erosion. In this section of the TFI, the water surface elevation is normally largely a function of the gate setting by FirstLight at the Turners Falls Dam. The slope of the WSEL is generally flat to the lower part of French King Gorge under most flow conditions. In addition to the flows released to the power canal, FirstLight can release over 130,000 cfs via the bascule and taintor gates at the Turners Falls Dam at the long term median WSEL of 181.3. As a result, there is a not a stage discharge relationship in this part of the TFI as there is upstream of French King Gorge (especially at higher flows). While a reliable stage discharge relationship could not be developed, analysis of water level data during a representative year (2011) was completed to determine the impacts, if any, of Turners Falls operations on erosion.

Based on an extensive set of time-stamped photos collected in associated with the 2013 FRR and corresponding water surface elevation data FirstLight was able to determine the elevation of the lower bank -upper bank transition. Once this elevation was determined, FirstLight could then determine the amount of time that water levels exceeded the top of the lower bank and rested on the silt/sand upper bank as well as the flows at which that occurred. The transition from the lower bank to the upper bank is significant given that, in this area, the lower bank sediment is classified as bedrock or boulders with upper bank sediment classified as silt/sand. The results of the hydraulic model were then used to determine the percentage of time during the modeling period that the water level equaled or exceeded this elevation and at what flow.

This analysis found that for the vast majority of the time the water level rests, or fluctuates, on the bedrock/boulders where erosion due to hydraulic forces is inconsequential. In the event that the water level does rest, or fluctuate, on the silt composed upper bank flows typically exceed the natural high flow threshold (37,000 cfs). In other words, the only time the water level is higher than the bedrock-silt interface, and therefore the only time when erosion could potentially occur, is during naturally occurring high flows. Review of the data during the analysis period (2011) found that only those flows which occurred during Hurricane Irene resulted in water surface elevations exceeding the top of the lower bank. As such, the dominant cause of erosion in this area was classified as high flows. Given that boat waves were found to be the dominant cause of erosion at the downstream study sites and a contributing cause of erosion at Site 75BL, boat waves were also classified as a contributing cause of erosion in this area.

As described above, the results of the modified extrapolation approach employed in Reach 1 indicate that Turners Falls Project operations are not a dominant or even contributing cause of erosion at any riverbank segment in the lower reach. Furthermore, during high flow events water level management at the Turners Falls Dam may actually aid in the prevention of erosion as water levels in the impoundment are typically drawn down to prevent unnecessary spilling.

Step 6: Analyze land-use and width of riparian buffers

Land management practices and associated land-use adjacent to the banks of the TFI were then analyzed to determine to what extent they may be a potential contributing primary cause of erosion. In order to determine this, land-use and width of riparian buffer datasets developed as part of the 2013 FRR were analyzed to identify segments where the adjacent land-use was classified as either Agriculture or Developed and the width of riparian buffer was 50 ft. or less. Based on the results of this analysis, it was found that 249 segments (101,000 ft. or 19 mi.) were identified where land management practices and/or land-use are a potential contributing cause of erosion. These segments are shown in Figure 6.1.2.2-5 and Table 6.1.2.2-3.

Steps 7 and 8: Create a map identifying the causes of erosion and calculate summary statistics

The extrapolation process resulted in a clear classification of the dominant primary causes of erosion throughout the TFI such that Vernon operations were found to be the dominant cause of erosion from Vernon Dam to downstream of Site 11L. From downstream of Site 11L until upstream of the entrance to Barton Cove high flows were found to be the dominant cause of erosion, while from upstream of the entrance to Barton Cove to the Turners Falls Dam boat waves were identified as the dominant primary cause.

Based on the results of the BSTEM analysis, high flows were found to be such a dominant cause of erosion throughout the TFI that the majority of riverbank segments did not have any contributing causes of erosion assigned to them. The relatively limited areas where contributing causes were found included: (1) the area from Vernon Dam to downstream of Site 11L where high flows were a contributing cause; (2) one area in reach 3 where moderate flows were a contributing cause; (3) a few areas in reach 2 where Northfield Mountain operations were a contributing cause; (4) a few areas around the Northfield Mountain tailrace extending to below the French King Gorge where moderate flows and boats were contributing causes; and (5) the middle section in reach 1 from the French King Bridge to upstream of the entrance to Barton Cove where boat waves were a contributing cause.

The results of the extrapolation process are shown in Figure 6.1.2.2-6 and Tables 6.1.2.2-4 and 6.1.2.2-5. As shown in the tables, the dominant and contributing primary causes of erosion were quantified using relative percentages for every TFI riverbank segment identified during the 2013 FRR (excluding islands). It should be noted when reviewing these tables, and the accompanying figure, that ice is not included in these results. Although the results of the analysis discussed in Section 5.5.5 indicate that ice has the potential to be a naturally occurring dominant primary cause of erosion in the TFI given the right climatic and hydrologic conditions, the extent to which ice may impact erosion could not be quantified given the available information.

From review of Figure 6.1.2.2-6 and Tables 6.1.2.2-4 and 6.1.2.2-5, the following is observed:

- Natural High Flows were found to be the dominant primary cause of erosion in the TFI at 78% of all riverbanks, followed by Boat Waves (13%), and Vernon Operations (9%);
- Northfield Mountain operations were not found to be a dominant cause of erosion at any riverbank segment in the TFI;
- Turners Falls Project operations were not found to be a dominant or contributing primary cause of erosion at any riverbank segment in the TFI;
- The majority of the riverbank segments in the TFI (68%) did not have a contributing cause of erosion;

- Boats were a contributing cause at 16% of all riverbank segments followed by moderate flows (10%), High Flows (9%), and Northfield Mountain operations (4%);

- Vernon operations were not found to be a contributing cause of erosion at any riverbank segments; and

- Land management practices were found to be a potential contributing cause of erosion at 44% of all TFI riverbanks.

The riverbank features, characteristics, erosion conditions, and causes of erosion for each riverbank segment identified during the 2013 FRR are found in Volume III (Appendix M).

Table 6.1.2.2-1: Causes of erosion at detailed study sites summarized from BSTEM

Site	Hydraulic Reach	Station	Primary/Dominant Causes					Contributing Causes			
			Project Operations	High Flows	Vernon Operations	Qe_{95} (cfs)	Boats	Project Operations	High Flows	Moderate Flows	Boats
11L	4 - Vernon	100000			X	500			X		
2L - Pre		94500		X		49,906					
2L - Post		94500		X		51,924					
303BL		94000		X		53,194					
18L		87000		X		17,824					
3L		79500		X		37,098					
3R-Pre		79500		X		39,229					
3R-Post		79500		X		36,411					
21R		79250		X		22,928					
4L	3 - Middle	74000	-	-	-	6,991	-	-	-	-	-
29R*		66000	Failure occurs at first time step, cannot determine primary cause(s)								
5CR		57250		X		47,867					
26R		50000		X		43,294					
10L		49000	-	-	-	58,922	-	-	-	-	-
10R-Post		49000	-	-	-	46,944	-	-	-	-	-
6AL-Pre		41750		X		56,264					
6AL-Post		41750	-	-	-	62,287	-	-	-	-	-
6AR-Post		41750	-	-	-	7,051	-	-	-	-	-
119BL	2 - NFM	41000		X		24,796				X	
7L		37500		X		47,731					
7R		37500		X		53,614					
8BL		32750		X		77,997		X			
8BR-Pre		32750	X			64,443			X		
8BR-Post		32750		X		66,504		X			
87BL		30750		X		17,849				X	
75BL		27000		X		33,822				X	X
9R-Pre	1 - Lower	6750				I	X		I		
9R-Post		6750				I	X		I		
12BL		6500				I	X		I		
BC-1R		4750				I	X		I		

Table 6.1.2.2-2: Riverbank Features, Characteristics, and Erosion Conditions for those Sites Identified as having Hydropower Operations as a Cause of Erosion

Detailed Study Site	Hydraulic Reach	Dominant Cause of Erosion	Contributing Cause of Erosion	FRR Segment	Upper Riverbank				Lower Riverbank			Erosion Conditions			
					Slope	Height	Sediment	Vegetation	Slope	Sediment	Vegetation	Types	Indicators of Potential Erosion	Stage	Extent
11L	4	Vernon Operations	None	321	Moderate	High	Silt/Sand	Heavy	Flat/Beach	Silt/Sand	None-Very Sparse	Undercut	None	Stable	None/Little
8BR-Pre[48]	2	Northfield Mtn. Operations	High Flows	421	Overhanging - Vertical	High	Silt/Sand	None to Very Sparse	Flat/Beach	Silt/Sand	None-Very Sparse	Slide	Exposed roots, overhanging bank	Active	Extensive
8BR-Post[49]	2	High Flows	Northfield Mtn. Operations	421	Steep	High	Silt/Sand	Heavy	Flat/Beach	Gravel	None-Very Sparse		None	In process of stabilization	None/Little
8BL	2	High Flows	Northfield Mtn. Operations	92	Steep	High	Silt/Sand	Moderate	Flat/Beach	Silt/Sand	None-Very Sparse	Undercut	Creep/Leaning Trees	Eroded	Some

[48] Riverbank features, characteristics, and erosion conditions for Site 8BR-Pre represent the conditions as observed during the 1998 FRR
[49] Riverbank features, characteristics, and erosion conditions for Site 8BR-Post represent the conditions as observed during the 2013 FRR

Table 6.1.2.2-3: Quantification of Land-use and Land Management Practices as a Potential Contributing Cause of Erosion in the Turners Falls Impoundment

Potential Contributing Cause of Erosion	Hydraulic Reach 1 - Lower				Hydraulic Reach 2 - NFM				Hydraulic Reach 3 - Middle				Hydraulic Reach 4 - Vernon			
	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
Land-use or Land Management Practices[50]	39	16,000	3	7%	40	20,700	4	9%	94	37,200	7	16%	76	27,100	5	12%

Land-use and Land Management Practices as a Contributing Cause of Erosion - Summary

Potential Contributing Cause of Erosion	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
Land-use or Land Management Practices	**249**	**101,000**	**19**	**44%**
Land-use not a factor	344	126,000	24	56%

[50] This includes Agriculture and Developed land-use classifications and areas where riparian buffer widths are 50 ft. or less.

Table 6.1.2.2-4: Quantification of the Dominant Primary Causes of Erosion in the Turners Falls Impoundment

Dominant Cause of Erosion	Hydraulic Reach 1 - Lower				Hydraulic Reach 2 - NFM				Hydraulic Reach 3 - Middle				Hydraulic Reach 4 - Vernon			
	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
Vernon Operations	0	0	0	0%	0	0	0	0%	0	0	0	0%	59	20,200	4	9%
High Flows	86	33,000	6	14.5%	67	28,400	5	13%	208	77,500	15	34%	113	37,000	7	16%
Northfield Mtn. Operations	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
Turners Falls Operations	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
Boats	60	30,800	6	13.5%	0	0	0	0%	0	0	0	0%	0	0	0	0%
TOTAL	**146**	**63,800**	**12**	**28%**	**67**	**28,400**	**5**	**13%**	**208**	**77,500**	**15**	**34%**	**172**	**57,200**	**11**	**25%**

Dominant Primary Causes of Erosion - Summary

Dominant Cause of Erosion	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
High Flows	474	175,900	33	78%
Boats	60	30,800	6	13%
Vernon Operations	59	20,200	4	9%
Northfield Mtn. Operations	0	0	0	0%
Turners Falls Operations	0	0	0	0%

Table 6.1.2.2-5: Quantification of the Contributing Primary Causes of Erosion in the Turners Falls Impoundment

Contributing Cause of Erosion	Hydraulic Reach 1 - Lower				Hydraulic Reach 2 - NFM				Hydraulic Reach 3 - Middle				Hydraulic Reach 4 - Vernon			
	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
Vernon Operations	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
High Flows	0	0	0	0%	0	0	0	0%	0	0	0	0%	59	20,200	4	9%
Moderate Flows	26[51]	11,500	2	5%	26	10,800	2	5%	1	900	<0.5	<0.5%	0	0	0	0%
Northfield Mtn. Operations	0	0	0	0%	20	8,600	1.5	4%	0	0	0	0%	0	0	0	0%
Turners Falls Operations	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
Boats	86	33,000	6	14.5%	10[52]	3,000	0.5	1%	0	0	0	0%	0	0	0	0%
None	60	30,800	6	13.5%	21	9,000	1.5	4%	207	76,600	14.5	34%	113	37,000	7	16%
TOTAL	**172**	**75,300**	**14**	**33%**	**77**	**31,400**	**5.5**	**14%**	**208**	**77,500**	**15**	**34%**	**172**	**57,200**	**11**	**25%**

Contributing Primary Causes of Erosion - Summary

Dominant Cause of Erosion	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total TFI Riverbank Length
None	401	153,400	29	68%
Boats	96	36,000	7	16%
Moderate Flows	53	23,200	4	10%
High Flows	59	20,200	4	9%
Northfield Mtn. Operations	20	8,600	1.5	4%
Vernon Operations	0	0	0	0%
Turners Falls Operations	0	0	0	0%

[51] Note that for hydraulic reach 1, there are 26 segments where moderate flows and boats are contributing causes at the same segment. This effects the summary statistics.

[52] Note that for hydraulic reach 2, there are 10 segments where boats and moderate flows are contributing causes at the same segment. This effects the summary statistics.

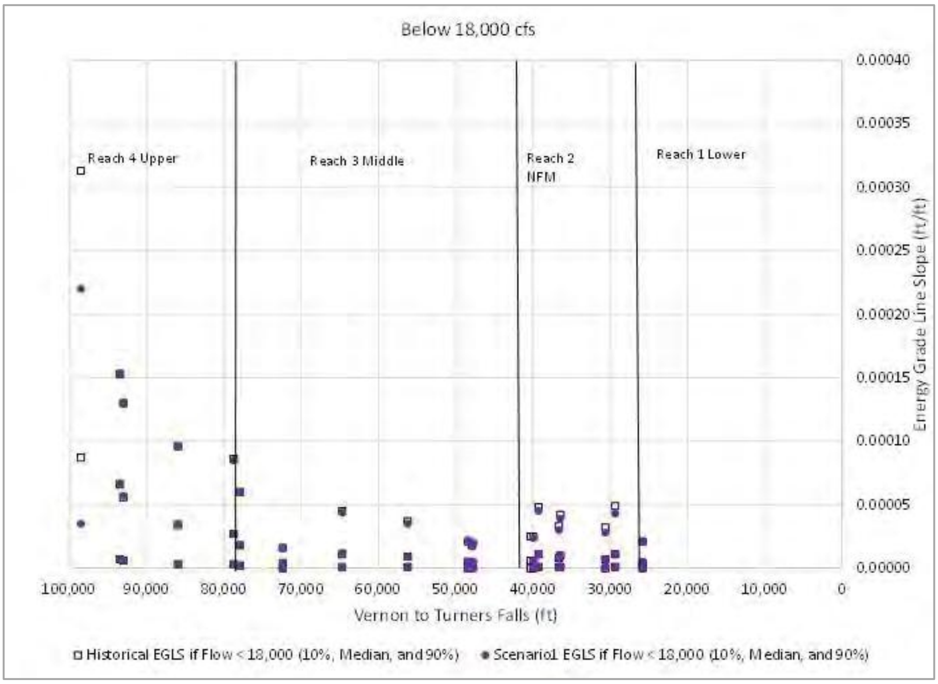


Figure 6.1.2.2-1: Energy slope trends through the Turners Falls Impoundment at flows less than 18,000 cfs

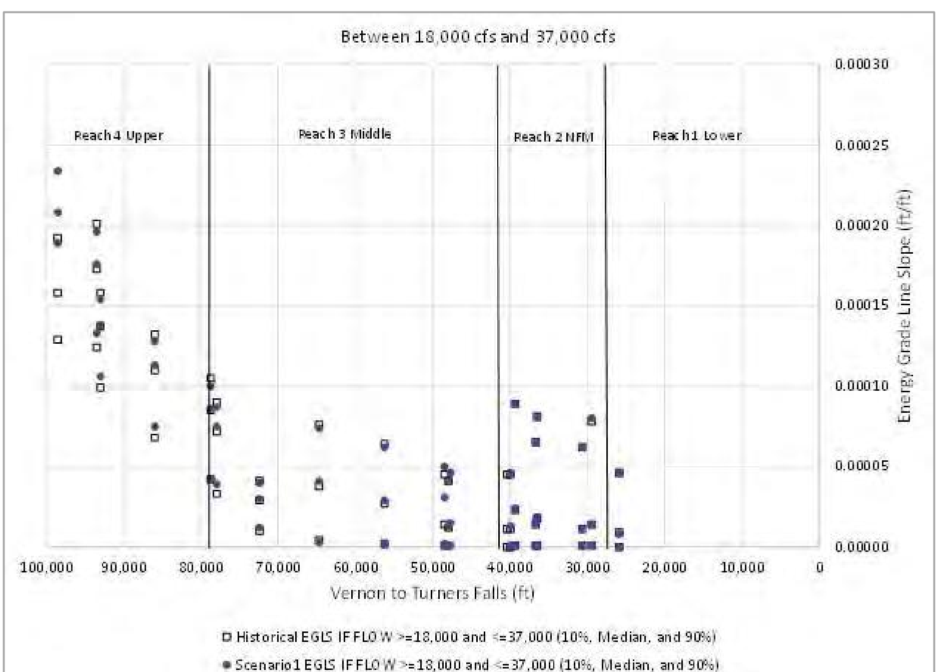


Figure 6.1.2.2-2: Energy slope trends through the Turners Falls Impoundment at flows between 18,000 and 37,000 cfs

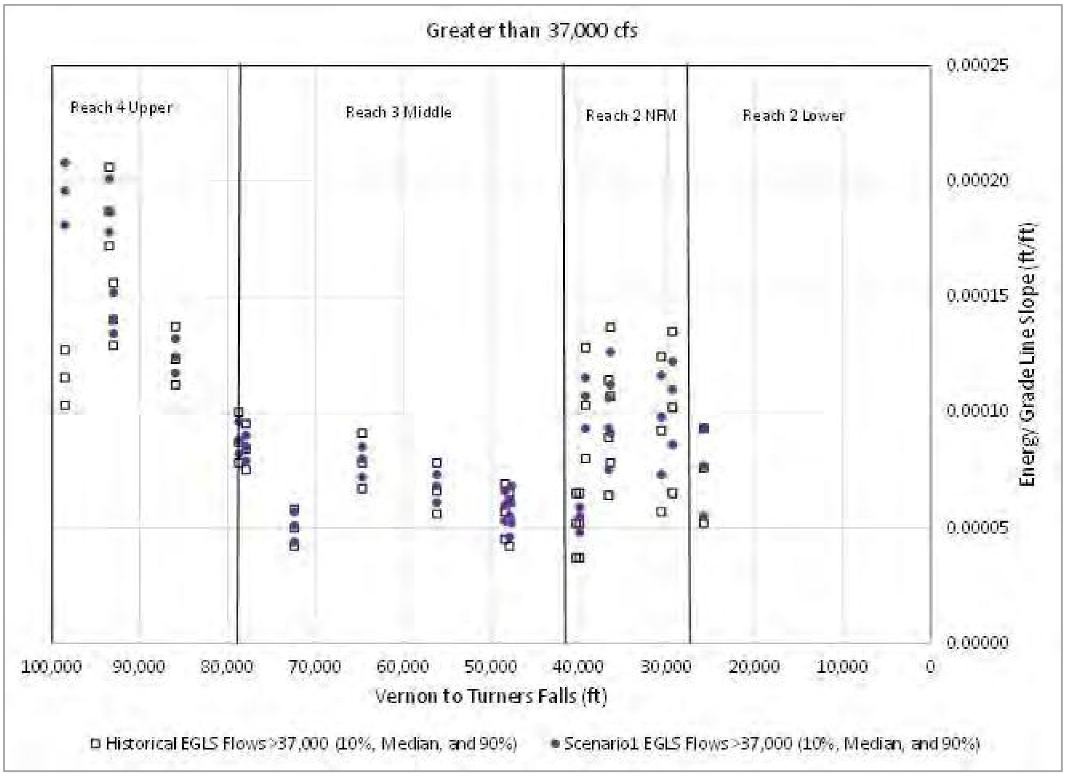
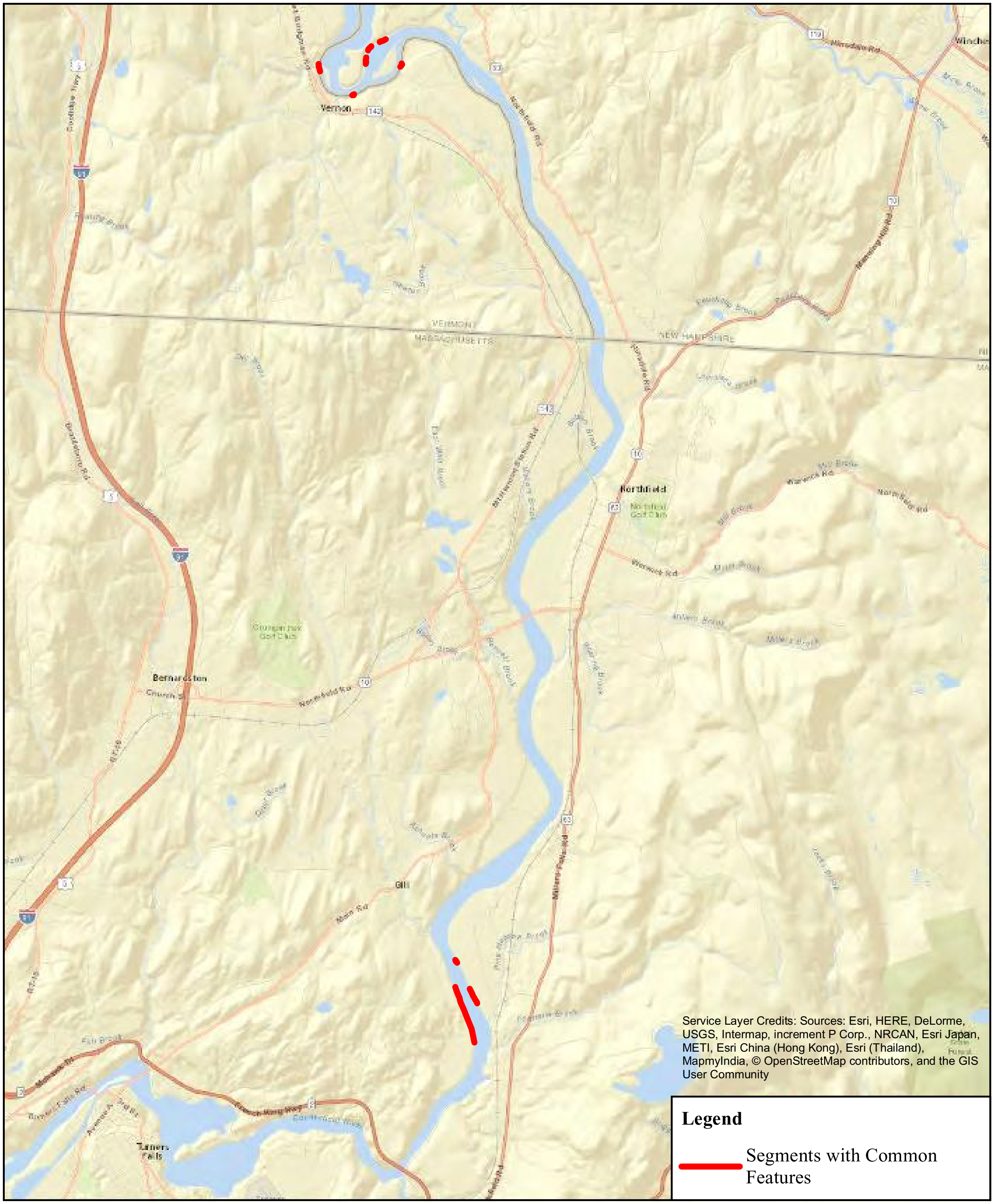


Figure 6.1.2.2-3: Energy slope trends through the Turners Falls Impoundment at flows over 37,000 cfs



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.75 1.5 3 Miles

Figure 6.1.2.2-4:
Locations of Riverbank Segments with Features and Characteristics similar to those Detailed Study Sites where Hydropower Project Operations are a Cause of Erosion

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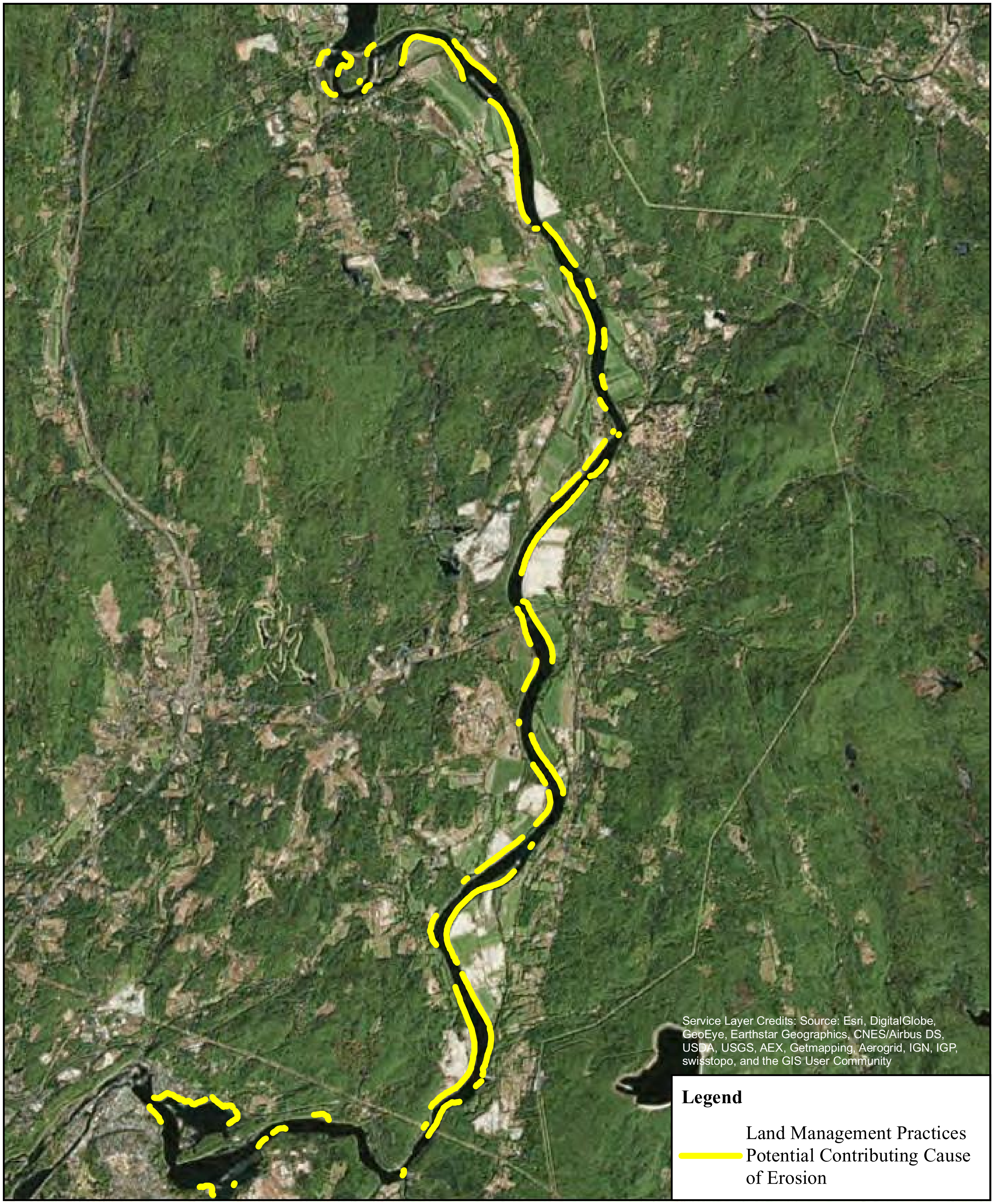

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.75 1.5 3 Miles

Figure 6.1.2.2-5: Location of Turners Falls Impoundment Riverbank Segments where Land Management Practices are a Potential Contributing Cause of Erosion

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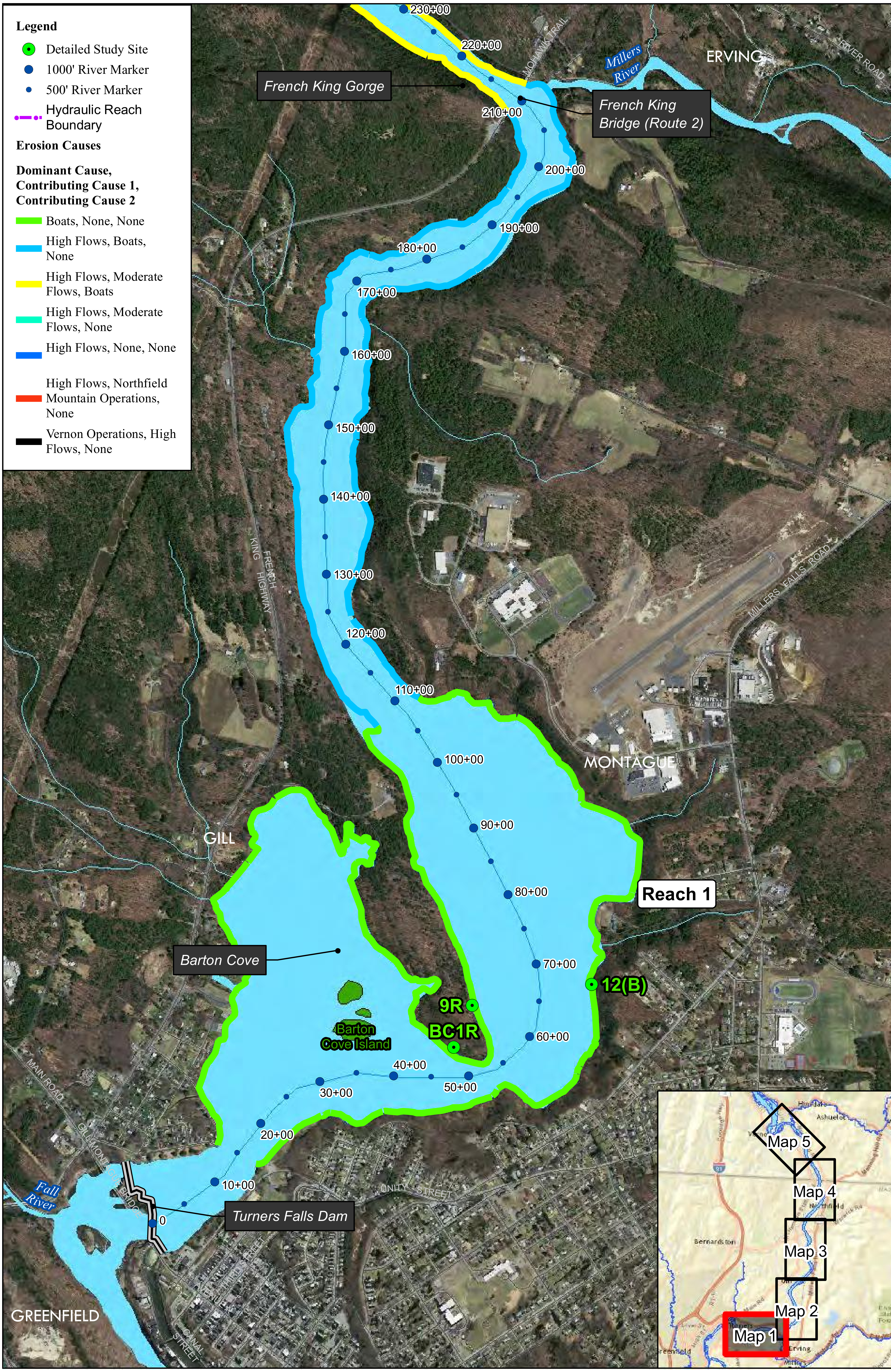

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

0 625 1,250 2,500 Feet

Figure 6.1.2.2-6:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 1

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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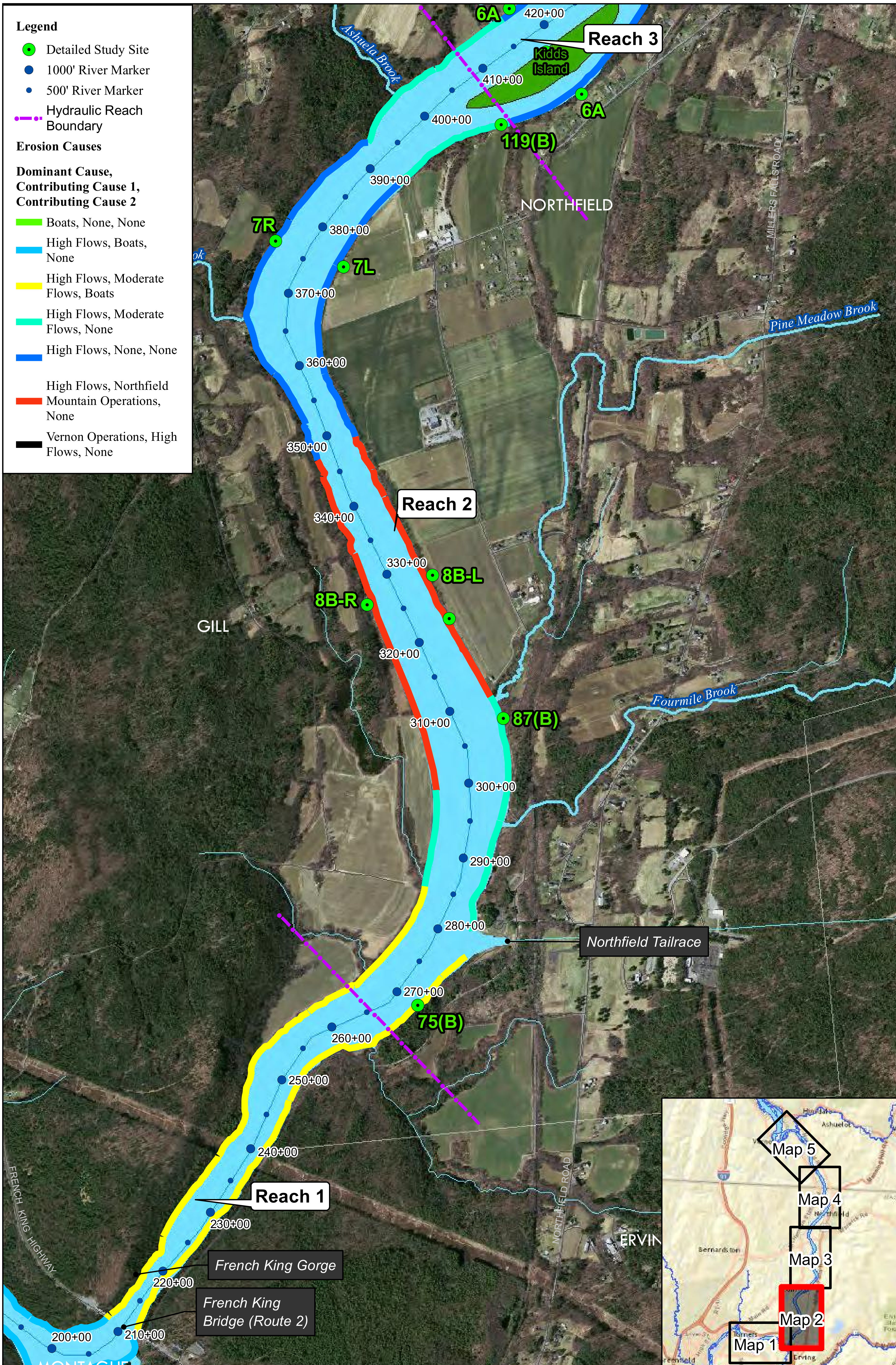

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 625 1,250 2,500 Feet

Figure 6.1.2.2-6:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 2

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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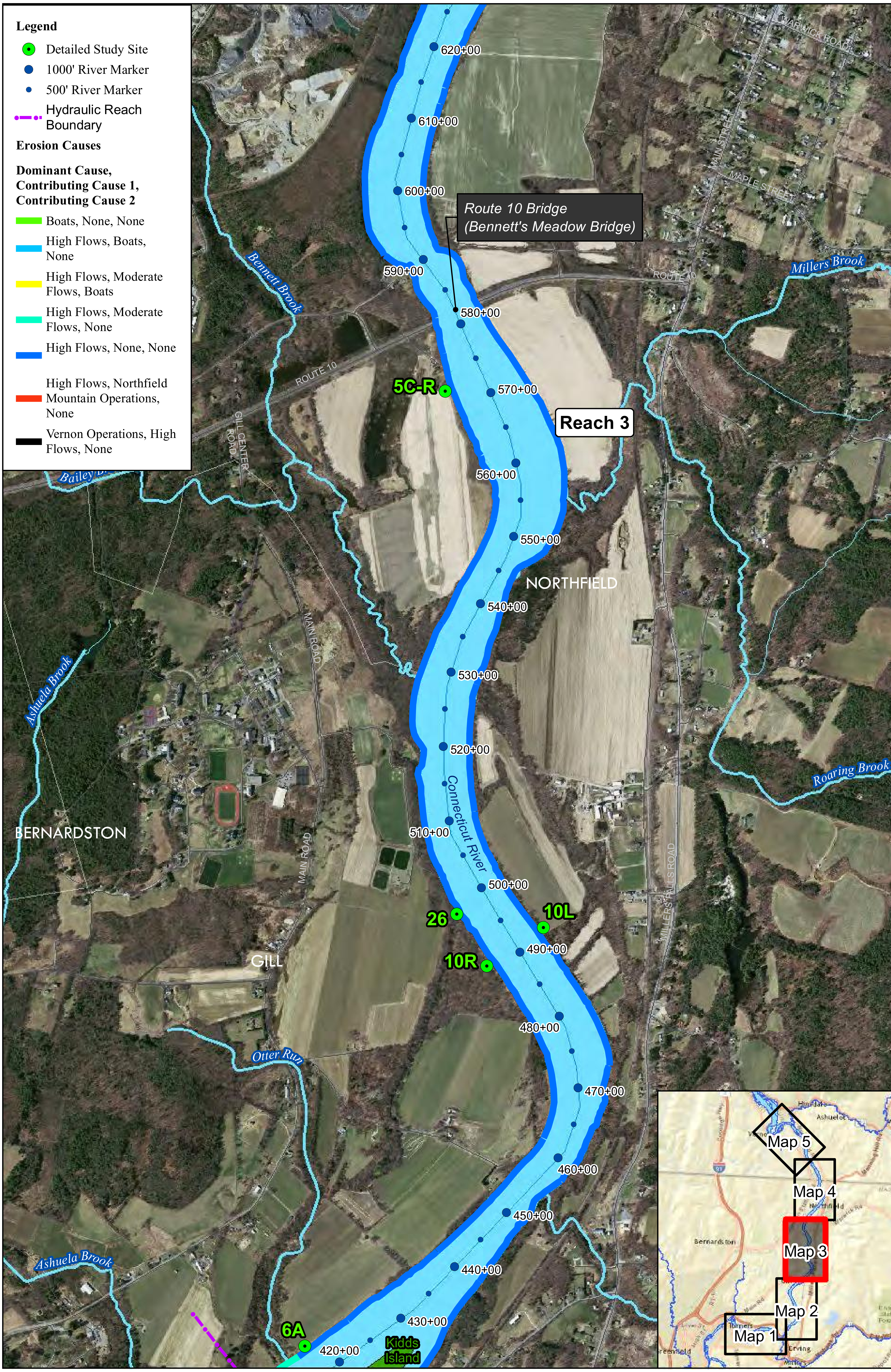

FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 625 1,250 2,500 Feet

Figure 6.1.2.2-6:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 3

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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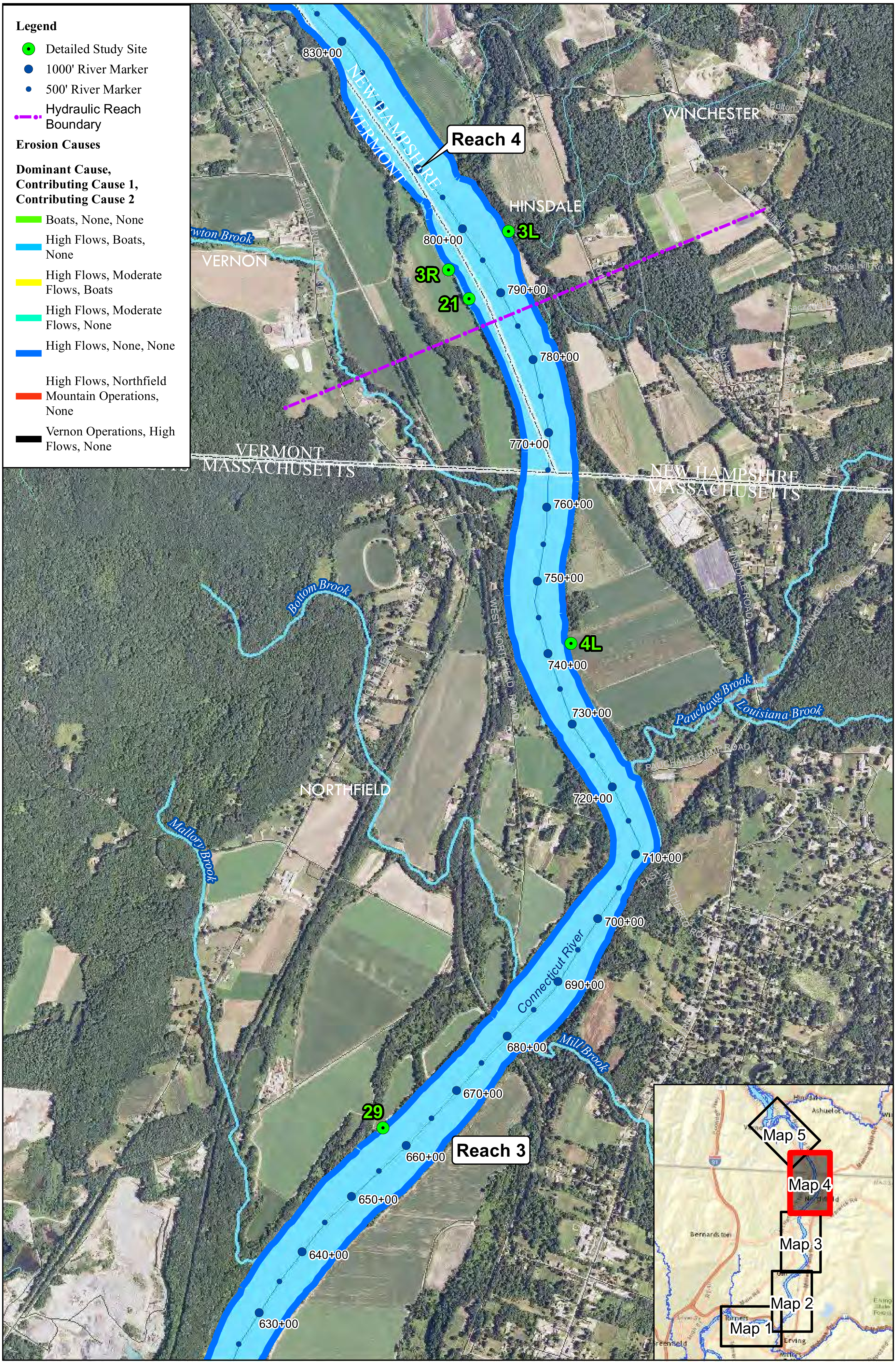

FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 625 1,250 2,500 Feet

Figure 6.1.2.2-6:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 4

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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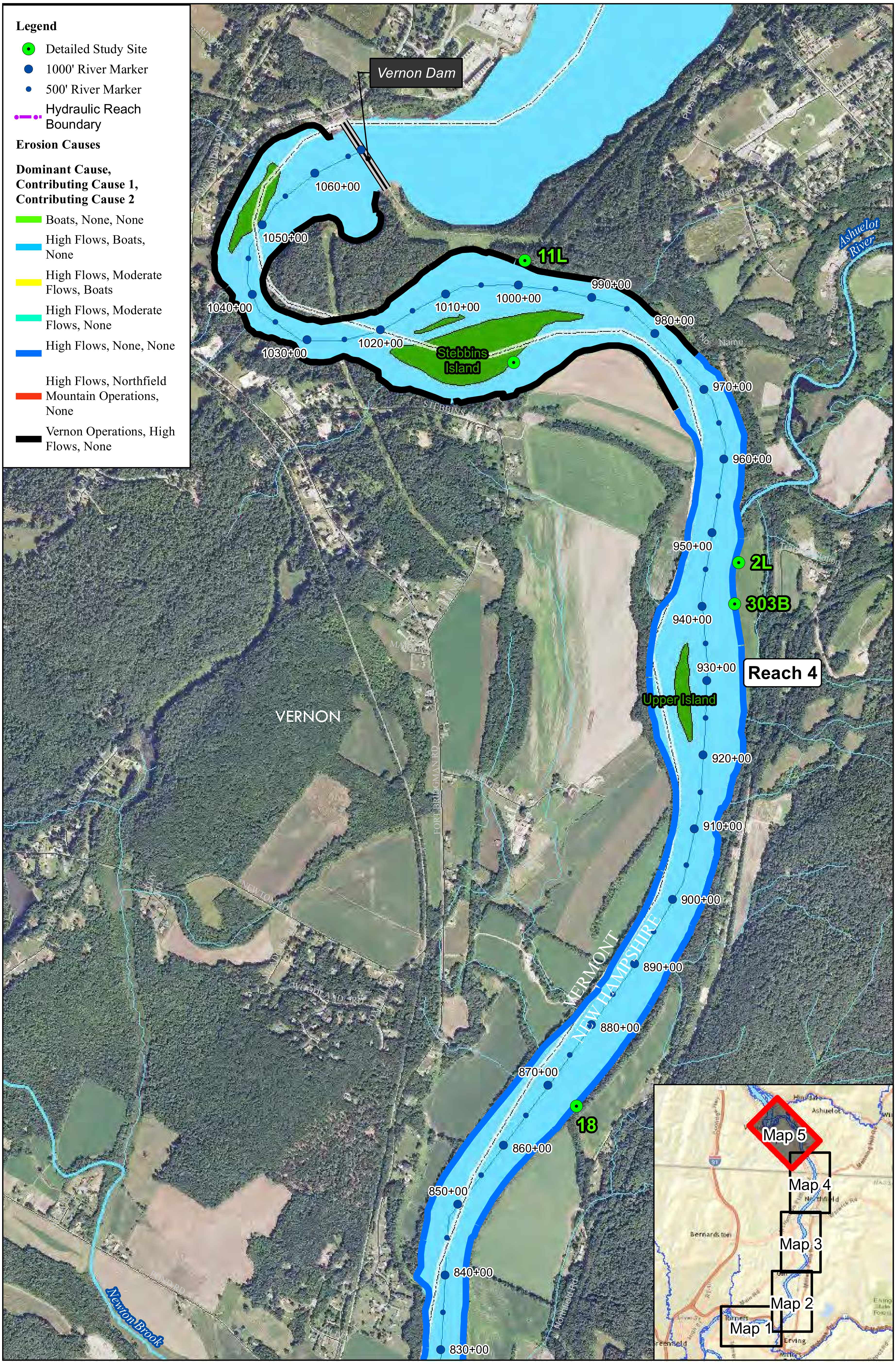

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 625 1,250 2,500 Feet

Figure 6.1.2.2-6:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 5

Service Layer Credits: Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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6.1.3 Analysis of Operational Changes - 2000-2014

The FERC SPDL issued on September 13, 2013 recommended that FirstLight conduct a longer term trend analysis to inform the understanding of erosion responses to changes in operation and to provide data for the development of license conditions. The SPDL went on to recommend that FirstLight include an analysis of operational changes through the period 1999 to 2013 to identify any correlation between operational changes and observed changes in erosion rates (FERC, 2013). In order to be consistent with the BSTEM modeling period, and the period for which digital Project operations data exists, FirstLight conducted the recommended analysis for the 2000-2014 period.

During the analysis period several significant events occurred which altered hydropower operations in the TFI, these events included:

- the hydraulic capacity of the Vernon Hydroelectric Project was increased from 9,930 cfs to 17,130 cfs in 2008 (TransCanada, 2013);
- the Northfield Mountain Project was offline due to an outage from May 1 to November 19, 2010;
- FERC deregulation of the energy market started in 1996, Independent System Operator New England (ISO-NE) was created in 1997 to operate the regional power system, implement wholesale markets, and to ensure open access to transmission lines. In 2003, ISO-NE launched market redesign with locational pricing, day-ahead and real-time markets to more accurately reflect cost of wholesale power and provide clearer economic signals for infrastructure investment (ISO, 2016); and
- Four periods when FERC issued FirstLight temporary license amendments for the Northfield Mountain Project. The temporary amendments allowed for expanded use of the Upper Reservoir which could result in increased generation if the extra capacity was utilized. FirstLight was granted temporary amendments for the periods: June 1, 2001 to April 30, 2002[53], December 2005 to March 2006, June 16 to September 30, 2006, December 2014 to March 2015, and December 2015 to March 2016.

In order to understand the impacts these operating changes may have had on erosion processes throughout the TFI the results of the BSTEM modeling efforts were reviewed and analyzed. As previously discussed, natural high flows were found to be the dominant cause of erosion at the majority of the detailed study sites and riverbank segments throughout the TFI. Furthermore, as noted in Section 6.1.2, a hydropower project can only have an impact on erosion processes within its hydraulic reach. Given this, a subset of detailed study sites in reaches 4 and 2 were selected for in-depth analysis. Detailed study sites which were selected include:

- **Reach 4 (Upper):** 11L and 2L-Post; and
- **Reach 2 (Northfield Mountain):** 119BL, 8BL, 8BR-Pre, and 75BL

In the upper reach (which includes Vernon), Site 11L was chosen as it was the only site in the TFI where Vernon operations were found to be a cause of erosion; Site 2L-Post is the next site downstream. No other sites were selected in reach 4 for this analysis given that high flows were found to be the dominant, and only, cause of erosion in the rest of the reach. In the Northfield Mountain reach Sites 119BL and 75BL

[53] The 2001-2002 temporary amendment allowed for an increase in generation for a maximum of 20 days throughout the amendment period.

were chosen as they are located at the downstream and upstream extent of the reach. Sites 8BL and 8BR-Pre were selected as these were the only existing sites which were found to have Northfield Mountain operations as a contributing cause of erosion. Table 6.1.3-1 summarizes the average annual erosion rate, 95% erosion flow threshold, and 50% erosion flow threshold for each site.

As discussed in Section 6.1.2, the dominant cause of erosion at Site 11L was Vernon operations with natural high flows as a contributing cause. At site 2L-Post the dominant cause of erosion was natural high flows with no contributing causes. Similarly, natural high flows was the dominant cause of erosion at all sites in reach 2. Contributing causes of erosion included moderate flows (119BL and 75BL), boats (75BL), and Northfield Mountain Project operations (8BL and 8BR-Pre). Review of Table 6.1.3-1 further supports these findings where it is observed that the 95% and 50% erosion flow thresholds at Site 11L are below the hydraulic capacity of Vernon (17,130 cfs). The 50% erosion flow threshold at all other sites (reach 4 or 2) is greater than the natural high flow threshold. In reach 2, the 95% erosion flow threshold is greater than the natural high flow threshold at all sites except 119BL (~25,000 cfs) and 75BL (~34,000 cfs). The results of the analysis described in this section further support the finding that hydropower operations play a very limited in erosion processes in the TFI.

Once the subset of sites was chosen, the first step was to summarize the total erosion which occurred for each year during the period 2000-2014 (Tables 6.1.3-2 and 6.1.3-3). The tables provide a summary of: (1) the total erosion for each year during the period 2000-2014; (2) the total erosion for flows below the natural high flow threshold for each year for the period 2000-2014 (17,130 cfs or 37,000 cfs depending on location); and (3) the total erosion for flows above the natural high flow threshold for each year for the period 2000-2014. For the purpose of this analysis, emphasis was placed on the total erosion which occurred each year below the natural high flow threshold at each site as this represented the amount of erosion that was likely due to hydropower operations and did not account for naturally occurring high flows.

The results of the table were then analyzed and broken out for several periods of interest, including: (1) before and after the Vernon capacity upgrade (Table 6.1.3-4); (2) during the Northfield Mountain outage and a calendar period with similar hydrology (2012) (Table 6.1.3-5); and (3) during the years when Northfield Mountain had temporary license amendments (Table 6.1.3-6). As shown in the tables, a slight increase in the amount of erosion after the Vernon upgrade at Site 11L is observed, however, given that the observed increase was only ~0.1 ft^3/ft, the increase could be the result of different flows and/or model noise. Comparison of the period when Northfield Mountain was offline with a similar hydrologic period when Northfield Mountain was operated normally found that essentially no erosion occurred at sites 8BL, 8BR-Pre, and 75BL during either period and that erosion at site 119BL was actually greater during the outage than it was when Northfield Mountain was online. Finally, differences in the erosion during the years when Northfield Mountain had a temporary license amendment and other years were very minor and did not show a correlation of increased erosion.

To analyze the changes in Northfield Mountain Project operations due to deregulation of the energy market analysis then focused on how the Project was operated in the 2000-2014 time frame. Three periods (not counting 2010) of generally similar operations were noted:

- 2000-2002;
- 2003-2009; and
- 2011-2014

Due to the high flows that occurred in 2011, a 2012-2014 period was also analyzed. Northfield Mountain Project operations data were reviewed for the 2000-2014 period to determine if the Project changed its operations in response to the deregulated market or other factors. Total megawatt hours (MWH) for pumping and generating as well as the percent of time that 1, 2, 3, or 4 units were used for pumping and generating were examined for each period (Table 6.1.3-7 and Figure 6.1.3-1). As shown in the table and figure, Northfield Mountain has actually operated less frequently and with less units since 2009.

To determine if the change in operating conditions had an impact on erosion processes in Reach 2 (i.e., did more erosion occur when the Project was operated more), the total annual amount of erosion for each year at Sites 119BL, 8BL, 8BR-Pre, and 75BL were compared (Table 6.1.3-8). As shown in the table, erosion was generally slightly lower in the post 2009 period (2010 was not used) but again not substantially and could be the result of model noise or differences in hydrology. As described in footnotes in the appropriate tables, at Site 75BL, almost 9 ft^3/ft of geotechnical erosion was modeled to have occurred in 2007 during flows <= 37,000 cfs. Although the geotechnical failure occurred at flows <=37,000 cfs it was likely largely the result of hydraulic erosion which occurred over time during high flows (>37,000 cfs).

As demonstrated throughout this report and again in the analysis presented above, hydropower operations have a very limited impact on erosion in the TFI. The analysis presented above analyzed various changes in operating conditions at both Vernon and Northfield Mountain and found that there was no discernable difference in erosion amounts associated with changes in operating conditions. The results of this analysis are consistent with the broader findings of this study; that is, natural high flows are the dominant cause of erosion in the TFI with hydropower operations having a limited localized impact, if any impact at all.

Table 6.1.3-1 Erosion Flow Thresholds at Targeted Detailed Study Sites

Reach	Site	Station	Baseline Condition		
			Total Erosion ($ft^3/ft/yr.$)	95 % of erosion occurs at flows greater than (cfs)	50 % of erosion occurs at flows greater than (cfs)
4 (Vernon)	11L	100000	0.297	500	4,985
	2L-Post	94500	0.214	51,924	65,195
2 (Northfield Mtn.)	119BL	41000	5.876	24,796	53,969
	8BL	32750	0.427	77,997	84,138
	8BR-Pre	32750	0.312	66,504	69,312
	75BL	27000	3.755	33,822	48,054

Table 6.1.3-2: Total Erosion Each Year at a Subset of Detailed Study Sites (Reach 4)

Site 11L[54]															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >17,130 cfs (ft^3/ft)	NA	NA	NA	NA	NA	0.0095	0.0357	0.0160	0.0379	0.0072	0.0282	0.1298	0.0014	0.0027	0.0003
Total Erosion <=17,130 cfs (ft^3/ft)	**NA**	**NA**	**NA**	**NA**	**NA**	**0.0380**	**0.1144**	**0.4596**	**0.1214**	**0.3416**	**0.2697**	**0.4078**	**0.3193**	**0.1298**	**0.2480**
Total Erosion (ft^3/ft)	NA	NA	NA	NA	NA	0.0475	0.1501	0.4756	0.1593	0.3488	0.2979	0.5376	0.3206	0.1326	0.2483
Site 2L-Post[55]															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >17,130 cfs (ft^3/ft)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.000	0.002	0.439
Total Erosion <=17,130 cfs (ft^3/ft)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**0.005**	**0.007**	**0.006**
Total Erosion (ft^3/ft)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.005	0.009	0.444

54 First survey conducted in 2005

55 First survey conducted post-restoration was in 2012

Table 6.1.3-3: Total Erosion Each Year at a Subset of Detailed Study Sites (Reach 2)

Site 119BL															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >37,000 cfs (ft^3/ft)	2.523	3.953	1.462	4.028	0.925	6.620	4.528	4.391	10.329	3.730	4.700	15.350	0.241	0.634	7.818
Total Erosion <=37,000 cfs (ft^3/ft)	**1.038**	**0.532**	**0.838**	**1.477**	**0.743**	**1.725**	**1.663**	**0.681**	**1.362**	**0.571**	**1.177**	**1.582**	**0.300**	**0.653**	**0.544**
Total Erosion (ft^3/ft)	3.561	4.485	2.300	5.506	1.669	8.345	6.191	5.071	11.691	4.301	5.876	16.931	0.541	1.287	8.362
Site 8BL															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >37,000 cfs (ft^3/ft)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.087	0.000	0.000	0.000
Total Erosion <=37,000 cfs (ft^3/ft)	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Total Erosion (ft^3/ft)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.087	0.000	0.000	0.000

Site 8BR-Pre[56]															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >37,000 cfs (ft^3/ft)	0.335	5.723	0.160	1.252	0.074	2.700	0.879	1.769	1.386	0.172	0.186	74.912	NA	NA	NA
Total Erosion <=37,000 cfs (ft^3/ft)	**0.000**	**0.002**	**0.001**	**0.003**	**0.000**	**0.004**	**0.002**	**0.002**	**0.004**	**0.004**	**0.002**	**0.004**	NA	NA	NA
Total Erosion (ft^3/ft)	0.335	5.725	0.161	1.255	0.074	2.704	0.881	1.771	1.390	0.175	0.187	74.916	NA	NA	NA
Site 75BL															
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Total Erosion >37,000 cfs (ft^3/ft)	1.624	3.574	0.693	2.220	0.357	3.006	1.761	2.542	3.676	1.053	1.354	20.026	0.053	0.125	1.666
Total Erosion <=37,000 cfs (ft^3/ft)	**0.133**	**0.130**	**0.122**	**0.157**	**0.132**	**0.190**	**0.173**	**0.161**	**0.195**	**0.164**	**0.231**	**0.134**	**0.122**	**0.152**	**0.175**
Total Erosion (ft^3/ft)	1.757	3.703	0.815	2.377	0.488	3.196	1.934	11.638[57]	3.871	1.217	1.586	20.160	0.175	0.277	1.841

Note: for most of the study sites, the BSTEM modeling ended in August of 2014 based on the last survey of the cross section.

[56] Last survey which was conducted prior to restoration was in 2011

[57] Almost 9 ft^3/ft of geotechnical erosion was modeled to have occurred in 2007 during flows <= 37,000 cfs, however, the geotechnical failure was likely largely the result of hydraulic erosion which occurred over time during high flows (>37,000 cfs).

Table 6.1.3-4: Comparison of Total Annual Erosion at Site 11L Before and After Vernon's Capacity Increase

BEFORE VERNON CAPACITY INCREASE		AFTER VERNON CAPACITY INCREASE	
Year	**Total Erosion <17,130 cfs (ft^3/ft)**	**Year**	**Total Erosion <17,130 cfs (ft^3/ft)**
2005	0.0475	**2009**	0.3488
2006	0.1501	**2010**	0.2979
2007	0.4756	**2011**	0.5376
2008	0.1593	**2012**	0.3206
		2013	0.1326
		2014	0.2483
Average	**0.2081**	**Average**	**0.3143**

Table 6.1.3-5: Comparison of Total Erosion for the Northfield Mountain Outage (May 1 to November 19, 2010) vs. a Similar Period (May 1- November 19, 2012)

Total Erosion <37,000 cfs (ft^3/ft)		
Site	**2010**	**2012**
119BL	1.136	0.643
8BL	0.000	0.000
8BR-Pre	0.0018	0.0012
75BL	0.000	0.000

Table 6.1.3-6: Comparison of Total Annual Erosion (<37,000 cfs) for Select Years (Reach 2)

Total Erosion <37,000 cfs (ft^3/ft)						
Site	**2001**	**2002**	**2005**	**2006**	**2012**	**2014**
119BL	0.532	0.838	1.725	1.663	0.300	0.544
8BL	0.000	0.000	0.000	0.000	0.000	0.000
8BR-Pre	0.002	0.001	0.004	0.002	NA	NA
75BL	0.130	0.122	0.190	0.173	0.122	0.175

Table 6.1.3-7: Comparison of Northfield Mountain Project Operations 2000-2014

Northfield Mountain - Summary of Net Monthly and Annual Generation (MWH) for 2000 to 2014

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	157,351	131,094	125,737	129,019	144,954	139,323	190,031	205,477	184,650	167,439	139,645	155,752	1,870,472
2001	138,633	105,502	150,565	164,074	160,922	172,880	187,517	203,549	201,358	191,469	153,844	168,665	1,998,978
2002	136,523	103,437	141,198	133,679	146,994	132,568	146,600	185,188	196,329	174,822	168,801	167,005	1,833,144
2003	130,126	124,585	112,260	98,449	89,020	133,009	134,548	119,934	134,217	84355	116,700	139,201	1,416,404
2004	141,351	90,200	112,840	103,857	112,097	125,896	112,995	128,896	136,736	119,890	122,353	128,224	1,435,335
2005	110,358	61,864	87,156	74,377	86,454	125,696	138,225	126,601	98027	109,068	104,009	109,238	1,231,073
2006	109,578	82,360	98,692	107,359	118,492	110,219	133,915	139,214	120,725	113,678	125,271	139,147	1,398,650
2007	132,605	76,064	54,029	62,831	82,046	118,986	146,089	194,557	195,152	165,484	133,335	141,776	1,502,954
2008	127,655	128,575	138,742	141,327	127,381	160,269	212,444	146,638	111,357	104,468	120,801	118,252	1,637,909
2009	90,332	82,182	76,542	97,149	86,154	107,715	135,735	176,610	131,289	126,293	106,205	133,929	1,350,135
2010	126,198	99,201	109,006	71,612	83	0	0	0	0	0	32,244	89,887	528,231
2011	96,439	82,752	72,367	55,866	69,610	81,690	142,141	106,248	93,523	110,491	71,918	69,741	1,052,786
2012	57,045	38,936	65,705	93,555	99,673	77,037	132,357	140,865	86,191	74,027	99,027	77,183	1,041,601
2013	88,692	85,026	71,356	68,421	83,307	81,206	144,181	94,930	80,654	76,997	84,133	110,535	1,069,438
2014	85,727	87,745	87,358	84,204	105,758	100,985	129,180	129,100	128,599	113,603	119,270	114,094	1,285,623

Northfield Mountain - Summary of Net Monthly and Annual Consumption (MWH) in Pumping Mode for 2000 to 2014

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	157,351	131,094	125,737	129,019	144,954	139,323	190,031	205,477	184,650	167,439	139,645	155,752	1,870,472
2001	138,633	105,502	150,565	164,074	160,922	172,880	187,517	203,549	201,358	191,469	153,844	168,665	1,998,978
2002	136,523	103,437	141,198	133,679	146,994	132,568	146,600	185,188	196,329	174,822	168,801	167,005	1,833,144
2003	130,126	124,585	112,260	98,449	89,020	133,009	134,548	119,934	134,217	84355	116,700	139,201	1,416,404
2004	141,351	90,200	112,840	103,857	112,097	125,896	112,995	128,896	136,736	119,890	122,353	128,224	1,435,335
2005	110,358	61,864	87,156	74,377	86,454	125,696	138,225	126,601	98027	109,068	104,009	109,238	1,231,073
2006	109,578	82,360	98,692	107,359	118,492	110,219	133,915	139,214	120,725	113,678	125,271	139,147	1,398,650
2007	132,605	76,064	54,029	62,831	82,046	118,986	146,089	194,557	195,152	165,484	133,335	141,776	1,502,954
2008	127,655	128,575	138,742	141,327	127,381	160,269	212,444	146,638	111,357	104,468	120,801	118,252	1,637,909
2009	90,332	82,182	76,542	97,149	86,154	107,715	135,735	176,610	131,289	126,293	106,205	133,929	1,350,135
2010	126,198	99,201	109,006	71,612	83	0	0	0	0	0	32,244	89,887	528,231
2011	96,439	82,752	72,367	55,866	69,610	81,690	142,141	106,248	93,523	110,491	71,918	69,741	1,052,786
2012	57,045	38,936	65,705	93,555	99,673	77,037	132,357	140,865	86,191	74,027	99,027	77,183	1,041,601
2013	88,692	85,026	71,356	68,421	83,307	81,206	144,181	94,930	80,654	76,997	84,133	110,535	1,069,438
2014	85,727	87,745	87,358	84,204	105,758	100,985	129,180	129,100	128,599	113,603	119,270	114,094	1,285,623

Table 6.1.3-8: Comparison of Total Average Annual Erosion in different time periods (Reach 2)

Total Average Erosion <37,000 cfs ($ft^3/ft/y$)				
Site	**2000-2002**	**2003-2009**	**2011-2014**	**2012-2014**
119BL	0.803	1.175	0.770	0.499
8BL	0.000	0.000	0.000	0.000
8BR-Pre	0.001	0.003	0.004	NA
75BL	0.128	0.167[58]	0.146	0.150

Note: due to high flows *in 2011, a 2012-2014 time period was also added*

[58] Almost 9 ft^3/ft of geotechnical erosion was modeled to have occurred in 2007 during flows <= 37,000 cfs, however, the geotechnical failure was likely largely the result of hydraulic erosion which occurred over time during high flows (>37,000 cfs).

Figure 6.1.3-1: Comparison of Northfield Mountain Project Generation 2000-2014

6.1.4 Comparison of Findings - USACE 1979 Study

As previously noted, in 1979 the USACE conducted a study examining the causes of erosion in the TFI and the Connecticut River. The 1979 study, entitled *"Connecticut River Streambank Erosion Study Massachusetts, New Hampshire, and Vermont,"* analyzed erosion along the Connecticut River over a study reach of 141 miles extending from the Turners Falls Dam, upstream through the TFI, Vernon Impoundment, Bellows Falls Development, and the Wilder Impoundment. The results of the 1979 study were compared against the results of Study No. 3.1.2 to determine what similarities or differences may exist between the studies. Any differences between the two studies were investigated to determine the cause(s) of the differences. This section presents background information of the 1979 USACE study as well as a comparison of results.

6.1.4.1 Background

As previously discussed, the 1979 USACE study reach encompassed 141 miles spanning from Turners Falls Dam upstream through the Wilder Impoundment. The study reach included five hydropower projects, including Turners Falls, Northfield Mountain, Vernon, Bellows Falls, and Wilder, as well as some un-impounded reaches of river (Figure 6.1.4.1-1). The study utilized data on slope, cross-sections, water level fluctuations, sediment size distributions and other available data in the analysis and applied accepted theoretical relationships to analyze and evaluate the various causes of erosion.

The USACE study utilized *"the tractive force method of evaluating bank stability,"* which is a method that *"is widely accepted nationally and internationally. However, this method as applied does not account for all of the factors known to contribute to the erosion process."* As a result, the tractive force method was extended to include other causes of erosion beyond the tractive force or shear stress exerted on the bed and banks of a river by flowing water. Additional causes of erosion which were analyzed and evaluated included (USACE, 1979):

- Shear stress or velocity;
- Flood Variation;
- Stage Variation;
- Pool Fluctuations;
- Wind waves;
- Boat waves;
- Freeze-thaw;
- Ice;
- Seepage Forces; and
- Gravitational Forces

According to the 1979 report, the relative magnitude and the relative duration of the forces causing bank erosion for non-cohesive and stratified bank materials were assessed *qualitatively* and rated from 1 to 9 in ascending order of estimated effect. The qualitative assessment was accomplished through examination of available data, review of current theory (as of 1979), personal experience, and professional judgement (USACE, 1979).

The theoretical analysis and evaluation described above was coupled with an evaluation of erosion sites along the Connecticut River. The 1979 study evaluated all erosion sites in the study reach to classify the erosional type and assist in the classification of the erosional forces present to that particular type. From this evaluation, 103 erosion sites were selected as representative of all erosional patterns within the river. The erosion sites identified as part of this effort represented the most severe bank erosion cases along the river. Each study area was then evaluated and classified into six different groups from which characteristics were delineated and subgroups established (USACE, 1979).

The groups are essentially the same as the riverbank features and characteristics that have been utilized in the various FRR surveys conducted by FirstLight. These groups, or features and characteristics include:

- Bank height (low banks <15 ft, high banks >15 ft)
- Erosion type (mass wasting, head cutting, sloughing, shallow washing, undercutting)
- Erosion site location (upper pool, middle pool, lower pool, natural reach)
- Bank location (outer bend, inner bend, straight reach)
- Soil type (cohesive, non-cohesive, straight reach)
- Vegetation (vegetated, barren)

From the 103 erosion sites initially identified, six index sites were established for detailed study. Of the six index sites selected, only one (Site 255) was located in the TFI. Site 255 is located in Gill, MA on the right bank of the river (looking downstream) adjacent to Kidds Island (Figure 6.1.4.1-2). This site is located in an agricultural area located upstream of a tributary (Otter Run Brook). Figure 6.1.4.1-3 show the study site using 1960's and 1990's aerial photography. As observed in the figure, a very narrow riparian vegetation zone is present in the 1960's photograph with riparian vegetation being absent in the 1990's imagery. Another factor to consider in evaluating Site 255 is that this area of the TFI was heavily utilized for recreation by people who would camp on and boat in the vicinity of the island (Figure 6.1.4.1-4). Boat traffic and riverbank erosion caused by boat waves was studied in the 1990s ("Connecticut River Riverbank Management Master Plan (DRAFT)," June 1991, Northrop, Devine & Tarbell). Regarding boat traffic, the report states, *"riverbank use was most intense at the Otter Run Brook area where 36 boats passed in one thirty-minute period while 13 boats were beached on the shore and 50 people were counted along the riverbank/beach area."* They noted erosion associated with boat waves in this part of the river,

"Lower bank movement was photographed and measured in order to assess the impacts of boat waves on the shoreline areas. Especially significant were long expansive lower bank cutting episodes near the Otter Run Brook area and 14-16" cuts in the lower bank northeast of the Route 10 Bridge area."

Conditions due to camping on Kidds Island by boaters became problematic and overnight camping on the island was prohibited in August, 2011 and effective for the 2012 season to the present.

Examples of some of the information collected at the index sites as part of the 1979 study included partial cross-section surveys (Figure 6.1.4.1-5) and limited velocity information, particularly near the Northfield Mountain tailrace. The 1979 report observed that during Northfield Mountain pumping operations negative velocities were computed from the Northfield Mountain tailrace to the Turners Falls Dam, the maximum being -0.25 feet per second (fps) near the tailrace with velocities becoming much less nearer to Turners Falls Dam. Average velocities upstream from the tailrace were increased during pumping but only reached a maximum of 0.46 fps. The report noted that average velocities of this magnitude are not associated with significant erosion. During generation at Northfield Mountain, flows downstream of the tailrace were nearly double those upstream. The maximum velocity, however, was 2.81 fps which is considered quite small (USACE, 1979).

The 1979 study did not, however, include as Study No. 3.1.2 has, a specific analysis of bank-stability processes, linking the hydraulic action of flow and waves with the gravitational forces that result in bank failures. The technology for much of this work had not been developed as bank-stability modeling was still in its infancy.

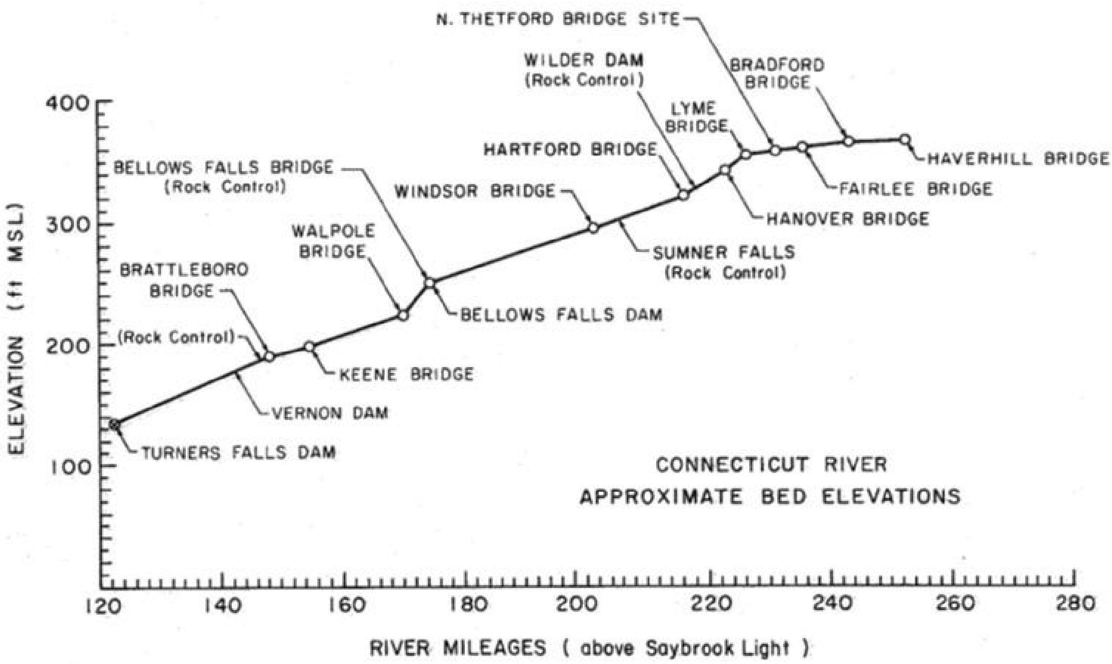


Figure 6.1.4.1-1 1979 USACE Study Reach – Connecticut River (USACE, 1979)

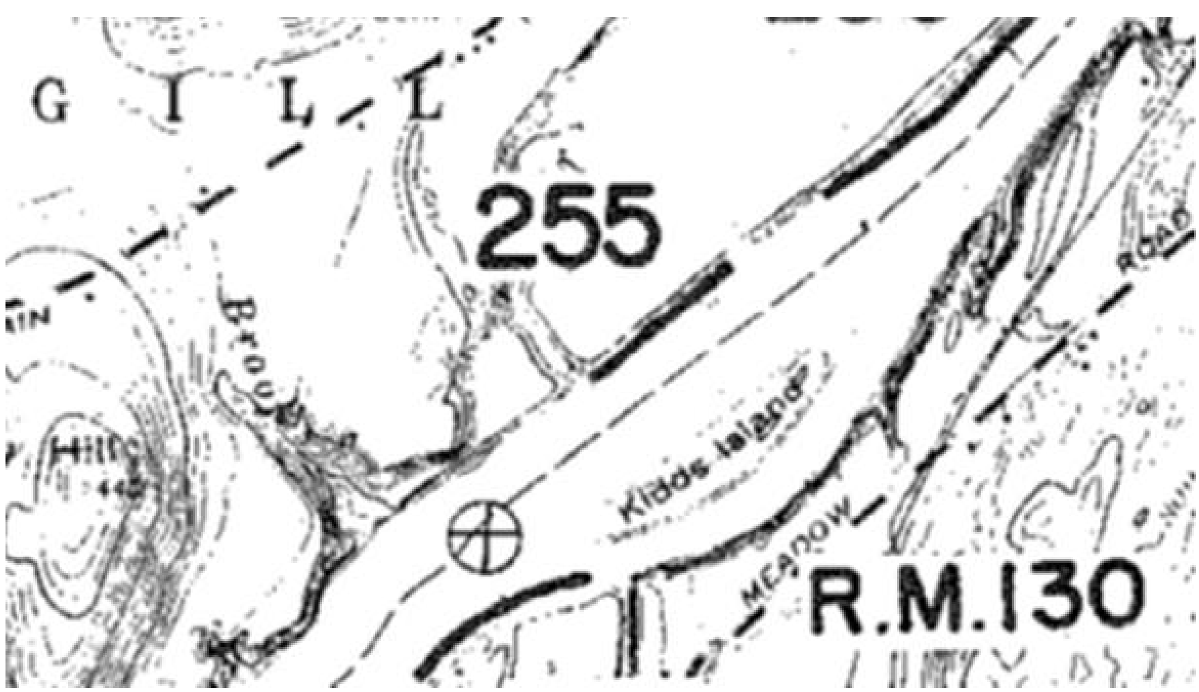
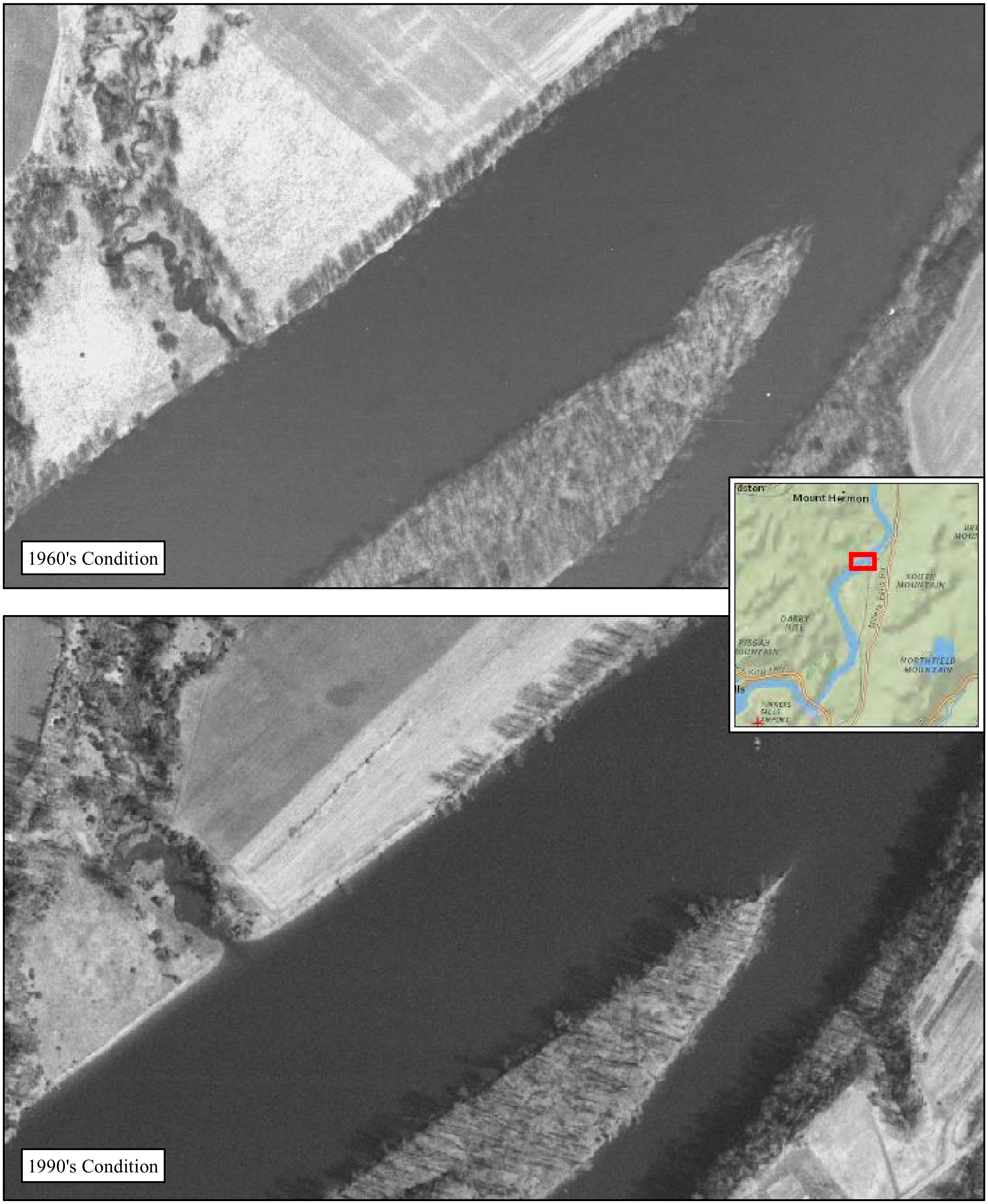


Figure 6.1.4.1-2 TFI USACE Index Site 255 (USACE, 1979)



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 200 400 800 Feet

Figure 6.1.4.1-3:
TFI USACE Index Site 255
1960's and 1990's Condition

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_4_1-3.mxd

Power boating, including water skiing, is a growing recreational activity along the river - July 4, 1990.

The long, exposed beach west of Kidds Island is a popular summer recreational spot for boaters - July 4, 1990.

Figure 6.1.4.1-4: Example of Past Boat Activity in the Vicinity of USACE Site 255 (July 4, 1990) (Top)
Figure 6.1.4.1-5: Index Site Cross-section Survey Examples (USACE, 1979) (Bottom)

6.1.4.2 Comparison of the 1979 USACE Study and Study No. 3.1.2

The results of the 1979 USACE study and Study No. 3.1.2 were compared to identify similarities and differences. Prior to conducting any direct comparison of results it is important to first understand any differences in methodology to provide context for comparison of the results.

When comparing the methodologies of the 1979 USACE study and Study No. 3.1.2 a number of significant differences are observed which can limit the ability to directly compare the results of the two studies. First, the USACE study focused on a much longer and broader reach of the Connecticut River with only one detailed study site (or index site) within the TFI. The TFI index site used in the USACE study was not representative of all riverbank features, characteristics, or erosion conditions found throughout the TFI. By contrast, Study No. 3.1.2 focused exclusively on the TFI and included 25 detailed study sites that were representative of the riverbank features, characteristics, and erosion conditions found throughout the TFI. The study sites examined as part of Study No. 3.1.2 allowed for a comprehensive examination of the entire TFI which took into account the varying geotechnical, geomorphic, and hydraulic conditions present throughout the TFI as opposed to a snap shot of one specific type of riverbank which was examined during the USACE study.

Secondly, the 1979 USACE study was based on a very limited dataset whereas Study No. 3.1.2 was based on robust data which had been collected over the course of a 15-year period or longer. The USACE study was based largely on field observations, photographs, and limited cross-section survey data collected over an 18-month period. By contrast, Study No. 3.1.2 was based on extensive geomorphic, geotechnical, hydrologic, and hydraulic data collected at various locations throughout the TFI dating back to 1999 or earlier. As part of the efforts associated with Study No. 3.1.2, and as discussed previously in this report, each of the 25 detailed study sites were examined extensively to determine the hydraulic and geotechnical resistance of the banks, and their various material properties. Annual cross-section surveys were analyzed to determine riverbank changes over time, full river reconnaissance surveys were conducted every 3-5 years to document erosion conditions, and hydrologic and hydraulic data were collected and/or modeled throughout the geographic extent of the TFI. The dataset which was available for Study No. 3.1.2 allowed for a more comprehensive and in-depth examination of erosion processes and the forces associated with them.

Lastly, the 1979 USACE study was limited by the technology of its time especially when compared against the tools at FirstLight's disposal for Study No. 3.1.2. The USACE study was based on a mix of qualitative observations, theoretical analysis, and limited hydraulic data and did not benefit from application of a physically based model focusing on the specific controls and processes responsible for bank erosion (BSTEM) as Study No. 3.1.2 did. BSTEM was calibrated using 15-years of surveyed cross-section data and was utilized to determine changes in riverbank conditions over time and the causes of those changes. In addition, Study No. 3.1.2 benefited from multiple, fully calibrated hydraulic models (HEC-RAS and River2D) to fully examine the hydrology and hydraulics of the TFI and how the forces associated with flowing and fluctuating water may impact erosion processes. These tools were not available to the USACE when they conducted their study in 1979. Table 6.1.4.2-1 provides a side-by-side comparison of the two study efforts.

Although the methodologies between the two studies had some fundamental differences, the main conclusion of each study is consistent; that is, high flows and the shear stress associated with those flows are the primary cause of erosion in the study area. While the main conclusion of each study was consistent, the contributing causes of erosion identified in the studies varied. This is to be expected given the significant differences in methodology previously discussed. Study No. 3.1.2 found that high flows were such a dominant cause of erosion that the vast majority of TFI riverbanks (68%) did not have a contributing cause of erosion. Boats were the next highest contributing cause accounting for 16% of the total length of TFI riverbanks, followed by natural moderate flows (10%), High Flows (9%), and lastly Northfield Mountain operations (4%). Note that the total percentages of the contributing causes do not equal 100% as moderate flows and boats were found to be contributing causes at a number of the same riverbank segments.

By contrast, the USACE study findings are frequently interpreted as ranking water level fluctuations due to hydropower operations as "causing" 15 to 18% of erosion to riverbanks for the entire study area (not just the TFI). The following quotes from the 1979 USACE report put this interpretation into perspective:

- "Erosional forces acting on the banks due to pool fluctuations are on the order of 15-18 percent of the shear stresses caused by the flowing water…"
- "Complete elimination of hydro-pool fluctuations would increase bank stability in the pools on the order of 15-18 percent."

This determination was based on a ranking of the "relative" magnitudes and durations of the forces. No actual link between forces and erosion was made in the USACE study as was made in Study No. 3.1.2. As discussed earlier in this section, the USACE study was largely qualitative and based on limited available data. The USACE study made few actual measurements or computations of velocity or shear stress and no determination of resistance to erosion, geotechnical soil strength properties, or measurements of root density or strength as were conducted in Study No. 3.1.2. In addition, the USACE study did not conduct in-depth hydrologic and hydraulic analyses related to hydropower operations or in-depth examination of boat waves as Study No. 3.1.2 did. While the 1979 USACE study provides some useful information and historical context, for the reasons discussed throughout this section it is reasonable to conclude that the findings of Study No. 3.1.2 provide a more accurate and complete representation of the erosion processes, and forces associated with them, throughout the TFI than the USACE study does.

Table 6.1.4.2-1: Comparison of 1979 USACE Study and Study No. 3.1.2

Comparison Category	1979 USACE Study	2016 Erosion Causation Study
Study reach	Turners Falls Dam to upstream reaches of Wilder Impoundment – 141 miles of river	Turners Falls Dam to Vernon Dam – 20 miles of river
Detailed study sites	6 index sites over 141 miles of river (0.0425 sites per mile). One of the six sites was located in the TFI.	25 detailed study sites over 20 miles of river (1.25 sites per mile), all located in the TFI.
Representativeness of index/detailed study sites	Focused on *"most severe bank erosion cases along the river"*	25 detailed study sites were selected to ensure that the fullest range of riverbank and erosion conditions were included as documented in (*"Selection of Detailed Study Sites,"* 2014)
Cross-section survey time period	November 1975 – June 1976 (No significant peak flows occurred during this time period)	1999-2014 (A greater range of flows occurred during this time period, including Tropical Storm Irene. Flows during this time period were found to be representative of the longer post-flood control period – see OHWM discussion)
Photographs	Photos taken at index sites semi-annually over an 18 month period	Entire TFI photographed and videoed using geo-referencing GPS technology starting in 1998 and again in 2001, 2004, 2008, and 2013
Riverbank features and characteristics classification	At 103 sites over 141 miles, using 6 riverbank features and 2 to 5 characteristics per feature	Continuously along the entire TFI at 596 riverbank segments (not including islands) in the 20 miles of the TFI, using 11 riverbank features and 3 to 7 characteristics per feature
Analysis approach	Geomorphic and engineering analyses, with limited data spread over a very long reach of river and very short time frame, heavily oriented towards theoretical approach	Three-level approach utilizing geomorphic analysis, engineering analysis, and computer modeling utilizing state of the art, physically-based computer model with site-specific data at 25 detailed study sites (bank geometry, sediment size distribution, erosion rate, geotechnical soil strength properties, soil moisture, vegetation and root structure), calibrated using 15 years of cross-section survey data driven by 15 years of calibrated hydraulic modeling using an hourly time step. Geomorphic and engineering analyses utilized data collected over decades, observations, historic aerial photographs

7 CONCLUSIONS

The causes of erosion in the TFI were analyzed via state-of-the-science modeling at 25 detailed study sites located throughout the study area and geomorphic and engineering analyses. The detailed study sites spanned the longitudinal extent of the TFI and were representative of the riverbank features, characteristics, and erosion conditions found throughout the study area. The results from the 25 detailed study sites were then extrapolated throughout the TFI such that each riverbank segment identified during the 2013 FRR had a dominant and, in some cases, contributing cause(s) of erosion assigned to it. The complex hydrologic and hydraulic characteristics of the TFI were also examined in-depth and accounted for during this process and were found to be just as important to erosion processes as riverbank features and characteristics were.

Geomorphic and engineering analyses, based on field observations during high flow events, hydraulic analyses, and suspended sediment data analysis, show that moderate and high flows are the primary cause of erosion in the TFI. Hydraulic modeling shows that the French King Gorge is the hydraulic control for the reach of the TFI upstream of the gorge at moderate to high flows which means that hydraulic conditions (water surface elevations and velocities) during these periods are controlled by natural hydraulics imposed by the gorge and not Turners Falls Dam. Since most erosion occurs at moderate to high flows and hydraulic conditions during moderate to high flows are controlled by the French King Gorge, project-related influences on erosion are minimal. Observations of erosion during boat wave events show this to be a significant factor in causing erosion. Analysis of historic aerial photographs show significant areas of erosion prior to the construction and operation of Northfield Mountain, consistent with the fact that all alluvial rivers, even those in a state of dynamic equilibrium without hydropower operations or other external influences, experience erosion. Geomorphic and engineering analyses are consistent with the findings of the computer modeling analysis conducted at the 25 detailed study sites in the three-level analysis approach.

In summary, Study No. 3.1.2 found the following:

- Naturally occurring moderate and high flows have the greatest impact on erosion in the TFI. Natural high flows are the dominant cause of erosion at 78% of all riverbank segments in the TFI and a contributing cause of erosion at 9% of all segments. Moderate flows are a contributing cause of erosion at 10% of all riverbank segments;

- Hydropower operations have a very limited localized impact, to no impact at all, on bank erosion in the TFI:

    - Northfield Mountain Project operations are not a dominant cause of erosion at any riverbank segment in the TFI. They are a contributing cause of erosion at 4% of the total riverbank segments (8,600 ft.);

    - Turners Falls Project operations are not a dominant or contributing cause of erosion at any riverbank segment in the TFI; and

    - Vernon Project operations are a dominant cause of erosion at 9% of all riverbank segments in the TFI (20,200 ft.). They are not a contributing cause of erosion at any riverbank segment

- Boats are a dominant cause of erosion at 13% of all riverbank segments in the TFI (30,800 ft.), all of which are located in the lower reach (reach 1). They are a contributing cause of erosion at 16% of all riverbank segments (36,000 ft.);

- The dominant causes of erosion generally followed a clear spatial pattern with Vernon project operations being the dominant cause from Vernon Dam to downstream of detailed study site 11L, natural high flows from downstream of detailed study site 11L to upstream of the entrance to Barton Cove, and boat waves from upstream of the entrance to Barton Cove to Turners Falls Dam;

- High flows were found to be such a dominant cause of erosion that the vast majority of the TFI riverbank segments (68%) did not have a contributing cause of erosion assigned to them. Riverbank segments which exhibited contributing causes were limited to hydraulic reaches 4 - Vernon (high flows), 2 – Northfield Mountain (moderate flows, Northfield Mountain operations, and boats), and 1 - Lower (moderate flows and boats);

- Land management practices and anthropogenic influences are a potential contributing primary cause of erosion at 44% of all riverbank segments in the TFI (101,000 ft.);

- Based on analysis of historic information from the Connecticut River, as well as other river systems, ice has the potential to be a naturally occurring dominant cause of erosion in the TFI in the future given the right climatic and hydrologic conditions. Due to the hydrologic and hydraulic characteristics of the TFI, it is anticipated that hydropower operations will have limited to no impact on ice as related to bank erosion; and

- Potential secondary causes of erosion such as wind waves, animals, seepage and piping, and freeze-thaw were found to be insignificant in causing erosion in the TFI beyond the limited, localized areas where they may exist.

Study No. 3.1.2 was conducted in accordance with the RSP using a robust dataset which spanned a 15-year period, proven analysis methods, and state-of-the-science modeling platforms. The team of professionals assembled for this effort, including the developer of BSTEM, were approved by MADEP at the onset of the study and have decades of experience around the world. The results of this study were based on the analysis of a wide variety of datasets including hydrologic, hydraulic, geotechnical, and geomorphic data, analysis of both empirical and modeled data (including both 1-D and 2-D hydraulic models and BSTEM), and review of a wealth of historic information. The findings of this study represent the most thorough understanding of erosion dynamics in the TFI to date.

8 LITERATURE CITED

Abernethy, B., and Rutherfurd, I. (2001). The distribution and strength of riparian tree roots in relation to river bank reinforcement, Hydrological Processes, 15, 63-79

Al-Madhhachi, A. T., Hanson, G. J., Fox, G. A., Tyagi, A. K., and Bulut, R. (2013). Measuring soil erodibility using laboratory "mini" JETs. T. ASABE.

American Society for Testing and Materials (ASTM). (1995). Annual Book of ASTM Standards: Construction, v. 04-09. American Society for Testing and Materials, West Conshohocken, PA. Section 4.

Bain, G.W. (Ed.), no date, Geology of Northern Part – Connecticut Valley: Guidebook for the 49th Meeting of the New England Geological Conference, Edwards Brothers, Inc.: Ann Arbor, MI, 56.

Burns, R. M., and Honkala, B. H., (Eds.). (1990). Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol. 2, 877 p.

Ettema, R. (2002). Review of Alluvial-channel Responses to River Ice. Journal of Cold Regions Engineering. Vol. 16, 4. American Society of Civil Engineers.

Federal Energy Regulatory Commission (FERC). (2013). Study Plan Determination Letter for the Turners Falls Hydroelectric Project and the Northfield Mountain Pumped Storage Project." Letter to FirstLight. 13 Sept. 2013.

Ferrick, M.G., Lemieux, G.E., Weyrick, P.B. & Demont, W. (1988a). Dynamic Ice Breakup Control for the Connecticut River near Windsor, Vermont.

Ferrick, M.G., Lemieux, G.E., Weyrick, P.B. & Demont, W. (1988b). Options for Management of Dynamic Ice Breakup on the Connecticut River near Windsor, Vermont. CRREL Report 88-1.

Field Geology Services. (2004). Fluvial Geomorphology Assessment of the Northern Connecticut River, Vermont and New Hampshire. Farmington, ME: Connecticut River Joint Commissions.

Field Geology Services. (2007). Fluvial geomorphology study of the Turners Falls Pool on the Connecticut River between Turners Falls, MA and Vernon, VT. Prepared for Northfield Mountain Pumped Storage Project. Farmington, ME: Field Geology Services.

FirstLight. (2013). Revised Study Plan for the Turners Falls Hydroelectric Project (No. 1889) and Northfield Mountain Pumped Storage Project (No. 2485). Northfield, MA: Author.

FirstLight. (2014a). Relicensing Study No. 3.1.1 2013 Reconnaissance Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889). Prepared by Kit Choi, PE, Cardno Entrix, New England Environmental, Simons & Associates and Gomez and Sullivan Engineers. Northfield, MA: Author.

FirstLight (2014b). Relicensing Study No. 3.1.2 Northfield Mountain/Turners Falls Operations Impact on Existing Erosion and Potential Bank Instability, Selection of Detailed Study Sites. Prepared by

Simons & Associates, New England Environmental, Cardno ENTRIX, Kit Choi. Northfield, MA: Author.

FirstLight. (2015a) Relicensing Study 3.1.3 Sediment Management Plan 2014 Summary of Annual Monitoring. Prepared Gomez and Sullivan Engineers. Filed with FERC in December 2015. Northfield, MA: Author.

FirstLight. (2015b). Relicensing Study No. 3.2.2 Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Addendum. Prepared by Gomez and Sullivan Engineers. Northfield, MA: Author.

Fredlund, D.G., Morgenstern, N.R., & Widger, R.A. (1978). The shear strength of unsaturated soils. Canadian Geotechnical Journal. 15, 313-321.

Gray, D.H., Sotir, R. B. (1996). Biotechnical and soil bioengineering: a practical guide for erosion control. John Wiley & Sons, New York.

Grover, N.C. (1937). The Floods of March 1936 Part 1. New England Rivers. U.S. Government Printing Office. Washington, D.C.: U.S. Department of Interior.

Hales, T.C., Ford, C.R. Ford, Hwang, T., Vose, J. M., & Band, L. E. (2009), Topographic and ecologic controls on root reinforcement, J. Geophys. Res., 114, F03013, doi:10.1029/2008JF001168.

Hanson, G. J. (1990). "Surface erodibility of earthen channels at high stress, Part II - Developing an in situ testing device", Transactions ASAE, 33(1), 132-137.

Hanson, G. J., & Cook, K. R. (1997). "Development of excess shear stress parameters for circular jet testing", American Society of Agricultural Engineers Paper No. 97-2227. American Society of Agricultural Engineers, St. Joseph, MO.

Hanson G.J., and Simon, A. (2001). Erodibility of cohesive streambeds in the loess area of the Midwestern USA. Hydrological Processes, 15: 23-28.

Hemenway, A.M. (1891). A Local History of All the Towns in the State Civil, Educational, Biographical, Religious and Military Volume V: The Towns of Windham County. Vermont Historical Gazetteer. Carrie E.H. Page: Brandon, VT. 271-336. (Available on-line at http://www.rootsweb.com/~vtwindha/vhg5/vernon.htm).

Hoek, E. and Bray J. (1977). Rock Slope Engineering. Institute of Mining and Metallurgy, 402 p.

ISO New England, Inc. (ISO) (2016). Our History. http://www.iso-ne.com/about/what-we-do/history. (April, 2016)

Kinnison, H.B., Conover, L.F., and Bigwood, B.L. (1938). Stages and flood discharges of the Connecticut River at Hartford, Connecticut: U.S. Geological Survey Water-Supply Paper 836-A.

Leopold, L., Wolman, G. & Miller, J. (1964). Fluvial Processes in Geomorphology. New York, NY: Dover Publications, Inc.

Little, R. (2016). Earth View, LLC Geological History of the Connecticut River Valley. http://earthview.rocks/ctriver.html.

Little, W. C., Thorne, C. R. & Murphy, J. B. (1982). Mass Bank Failure Analysis of Selected Yazoo Basin Streams. Transcripts of the American Society of Agricultural Engineering. Volume 25, 1321-1328.

Lohnes, R. A. & Handy, R. L. (1968). Slope Angles in Friable Loess. Journal of Geology. Volume 76(3), 247-258.

Longuet-Higgins, M. S. (1952). On the statistical distributions of the heights sea waves. Journal of Marine Research, 11(3), 245-265.

Lutenegger, J. A. & Hallberg, B. R. (1981). Borehole Shear Test in Geotechnical Investigations. ASTM Special Publications 740, 566-578.

Micheli, E.R., & Kirchner, W. (2002). Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics. Earth Surface Processes and Landforms, 27: 687-697.

Morgenstern, N. R. & Price, V. E. (1965). The analysis of the stability of general slip surfaces. Ge´otechnique 15, No. 1, 79–93.

Nanson, G.C., Von Krusenstierna, A., Bryant, E.A. & Renilson, M.R. (1993). Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon river, Tasmania.

Natural Resources Conservation Service (NRCS) (2016) http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074846 (April, 2016)

New England Environmental. (2001). Erosion Control Plan for the Turners Falls Pool of the Connecticut River. Amherst, MA: Northeast Utilities Service Company.

New England Environmental, Inc. (2005). Erosion Control Plan for the Turner Falls Pool of the Connecticut - 2004 Full River Reconnaissance Report. Amherst, MA. Northeast Utilities Service Company.

Northrop, Devine & Tarbell, Inc. (1991). Connecticut River Riverbank Management Master Plan (Draft). Amherst, MA. Northeast Utilities Service Company

Pollen-Bankhead, N. & Simon, A. (2009). Enhanced application of root-reinforcement algorithms for bank-stability modeling. Earth Surface Processes and Landforms 34(4): 471-480. DOI: 10.1002/esp.1690.

Pollen-Bankhead N., Thomas, R.E., and Simon, A. (2013). The reinforcement of soil by roots: Recent advances and directions for future research. Treatise on Geomorphology 12(3), 103-127.

Pollen, N. (2007). Temporal and spatial variability in root reinforcement of streambanks: Accounting for soil shear strength and moisture. Catena, 69(3), 197-205.

Pollen, N., & Simon, A. (2005). Estimating the mechanical effects of riparian vegetation on streambank stability using a fiber bundle model. Water Resources. Res. 41, W07025, doi:10.1029/2004WR003801

Pressey, E.P., (1910). Montague (3rd ed). The Montague Historical Society, Inc. Hadley Printing Company, Inc. Holyoke, MA: 264.

Reid, J.B. (1990). Riverbank Erosion on the Connecticut River at Gill, Massachusetts: its Causes and its Timing. Hampshire College, Unpublished report.

Rittenour, T.M. & Brigham-Grette, J., (2000). A Drainage History for Glacial Lake Hitchcock: Varves, Landforms, and Stratigraphy: In, J. Brigham-Grette Ed., North Eastern Friends of the Pleistocene Field Guidebook, Dept. of Geosciences Contribution No. 7, University of Massachusetts, Amherst.

Schumm, S.A. (1977). The Fluvial System. New York: John Wiley and Sons. 338 p.

Scott, K.J. (2005). Montague: Labor and Leisure. Images of America Series. Portsmouth, NH: Arcadia Publishing. 128 p.

Simon, A. (1989). A model of channel response in disturbed alluvial channels. Earth Surface Processes and Landforms. 14(1): 11-26.

Simon, A. & Collison, A.J.C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on stream-bank stability, Earth Surface Processes and Landforms 27(5): 527-546.

Simon, A., & Curini, A. (1998). Pore pressure and bank stability: The influence of matric suction. In Water Resources Engineering '98, ed. Abt S.R., 358-363. New York: American Society of Civil Engineers.

Simon, A., Curini, A., Darby, S., & Langendoen, E. (1999). Stream-bank mechanics and the role of bank and near-bank processes in incised channels. In: S. Darby and A. Simon, eds. Incised River Channels. 123-152. New York: John Wiley and Sons.

Simon A, Curini A, Darby, S.E, & Langendoen E.J. (2000). Bank and near-bank processes in an incised channel, Geomorphology 35: 183-217.

Simon, A. and Klimetz, P. D. (2012). Analysis of Long-Term Sediment Loadings from the Upper North Fork Toutle River System, Mount St Helens, Washington. USDA-ARS National Sedimentation Laboratory Technical Report No. 77, Oxford, Mississippi, 109 p.

Simon, A., Thomas, R.E. and Klimetz, L., 2010. Comparison and experiences with field techniques to measure critical shear stress and erodibility of cohesive deposits. In Proc., 4th Federal Interagency Hydrologic Modeling Conference and the 9th Federal Interagency Sedimentation Conference, Las Vegas, NV, June 27 – July 1, 2010, 13 p. (CD-ROM ISBN 978-0-9779007-3-2).

Simon, A., Pollen-Bankhead, N. & Thomas, R.E. (2011). Development and Application of a Deterministic Bank Stability and Toe Erosion Model for Stream Restoration. In: Simon, A., S.J. Bennett, J. Castro and C.R. Thorne (eds.), Stream Restoration in Dynamic Systems: Scientific Approaches, Analyses, and Tools. American Geophysical Union: Washington.

Simon, Andrew F. Douglas Shields, Robert Ettema, Carlos Alonso, Marie Marshall-Garsjo, Andrea Curini and Lyle Steffen. (1999). Channel Erosion on the Missouri River, Montana between Fort Peck Dam and the North Dakota boarder. Coordinated Resource Management Group-Lower Missouri River (CRM). Culbertson, Montana: CRM.

Simons & Associates (S&A). (1990a) *Analysis of Ice Formation on the Platte River.* Prepared for Central Nebraska Public Power & Irrigation District and Nebraska Public Power District as part of the deficiency response to the Federal Energy Regulatory Commission. Ft. Collins, CO: Author.

Simons & Associates (S&A). (1990b). Physical Process Computer Model of Channel Width and Woodland Changes on the North Platte, South Platte and Platte Rivers. Prepared for Central Nebraska Public Power & Irrigation District and Nebraska Public Power District as part of the deficiency response to the Federal Energy Regulatory Commission. Ft. Collins, CO: Author.

Simons & Associates (S&A). (1992). Analysis of Bank Erosion at the Skitchwaug Site in the Bellows Falls Pool of the Connecticut River.

Simons & Associates (S&A). (1998a). Erosion control plan for the Turners Falls Pool of the Connecticut River. Prepared for Northeast Utilities. Ft. Collins, CO: Author.

Simons & Associates (S&A). (1998b). Long Term Riverbank Plan for the Turners Falls Pool of the Connecticut River. Prepared for Western Massachusetts Electric (The Northeast Utilities System). Ft. Collins, CO: Author.

Simons & Associates (S&A). (1999). Erosion Control Plan for the Turners Falls Pool of the Connecticut River. Prepared for Northeast Utilities. Ft. Collins, CO: Author.

Simons & Associates (S&A). (2000). Physical History of the Platte River in Nebraska: Focusing upon Flow, Sediment Transport, Geomorphology, and Vegetation. Prepared for US Department of the Interior. Ft. Collins, CO: Author.

Simons & Associates (S&A). (2002). Calibration of SEDVEG Model Based on Specific Events from Demography Data. Prepared for US Department of the Interior. Ft. Collins, CO: Author.

Simons & Associates (S&A). (2009). Full River Reconnaissance - 2008: Turners Falls Pool, Connecticut River. Prepared for FirstLight Power Resources. Midway, UT: Author.

Simons & Associates (S&A). (2012a). Analysis of Erosion in Vicinity of Route 10 Bridge Spanning the Connecticut River. Prepared for FirstLight Power Resources. Midway, UT: Author.

Simons & Associates (S&A). (2012b). Riverbank Erosion Comparison along the Connecticut River. Prepared for FirstLight Power Resources, Midway, UT: Author.

Simons & Associates (S&A). (2013). Quality Assurance Project Plan – 2013 Full River Reconnaissance Survey. Prepared for FirstLight Power Resources. Midway, UT: Author.

Thomas, R.E., and Pollen-Bankhead, N. (2010). Modeling root-reinforcement with a fiber-bundle model and Monte Carlo simulation. Ecological Engineering, 36(1), 47-61.

Thorne, C.R & Tovey, N.K. (1981). Stability of composite river banks. Earth Surface Processes and Landforms 6: 469- 484

Thorne, C. R., Murphey, J. B. & Little, W. C. (1981). Stream Channel Stability, Appendix D, Bank Stability and Bank Material Properties in the Bluffline Streams of Northwest Mississippi. U.S. Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory. Oxford, MS. 227

Thorne, C.R. (1990). Effects of vegetation on streambank erosion and stability, in Vegetation and Erosion, edited by J.B. Thornes, Wiley, Chichester. 123-144.

TransCanada Hydro Northeast Inc. (2012). Vernon Hydroelectric Project, FERC Project No. 1904 Pre-Application Document. This Document Contains Critical Energy Infrastructure Information (CEII). Public Version –CEII Material Redacted.

US Army Corps of Engineers (USACE). (1979). Connecticut River Streambank Erosion Study: Massachusetts, New Hampshire, and Vermont. Prepared by Simons, D.B., Andrew, J.W., Li, R.M., & Alawady, M.A. Waltham, MA: Author.

Regulatory Guidance Letter, No. 05-05, December 7, 2005 (USACE)

Waldron L.J. & Dakessian, S. (1981). Soil reinforcement by roots: calculation of increased soil shear resistance from root properties. Soil Science 132(6): 427-435.

Relicensing Study 3.1.2

Northfield Mountain / Turners Falls Operations Impact on Existing Erosion and Potential Bank Instability Study Report

Volume III – Appendices

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Prepared for:

FirstLight Power Resources

Prepared by:

Simons & associates

Cardno Shaping the Future

Gomez and Sullivan Engineers

Kit Choi, PhD, PE

OCTOBER 2016

LIST OF APPENDICES

APPENDIX A – BIOS FOR KEY TEAM MEMBERS

ROBERT SIMONS, PhD, PE

Dr. R.K. Simons principal fields of interest and expertise are hydrology, hydraulics, river mechanics, erosion and sedimentation, sediment transport, geomorphology, hydraulic structures, mathematical modeling, riverine habitat modeling, riparian vegetation modeling, wetlands analysis, and analysis related to various aspects of fisheries. Dr. Simons has extensive experience on hundreds of projects covering various aspects of civil engineering focusing on the interaction and effect of projects on watersheds, rivers, and estuaries related to changing hydrology, hydraulics, fluvial geomorphology, sediment transport, erosion and sedimentation, flooding, and channel stabilization. He has analyzed the effect of hydropower operation on flooding, geomorphic response, riverbank erosion, sediment exclusion and ejection from intake head works as well as effects on riparian vegetation and habitat for various species both aquatic and terrestrial. Dr. Simons developed design methodologies for river bank protection based on hydraulic principles, risk analysis, and probability of motion. He has developed and applied a number of computer models predicting sediment transport, erosion, sedimentation, riparian vegetation dynamics, and flow/habitat relationships. He has conducted channel restoration, channel maintenance, and habitat improvement analyses.

ANDREW SIMON, PhD, PE

Dr. Andrew Simon is an internationally recognized geomorphologist at Cardno in Oxford, Mississippi. He has 35 years of research experience, 16 years with the US Geological Survey and 16 years at the USDA-Agricultural Research Service, National Sedimentation Laboratory. His process-based research has been in channel response of unstable channels, cohesive-soil erosion, streambank processes and modelling, and quantifying the role of vegetation on fluvial processes. This approach has championed the use of robust field instruments to collect data on the resistance of the channel boundary, a critical metric for analysis of channel erosion but one that is rarely used by others. He is the author of more than 100 technical publications, has edited several books and journals and is the senior developer of the Bank-Stability and Toe-Erosion Model (BSTEM). He conducts short courses all over the world in *Geomorphic Analysis of Fluvial Systems* and in the *Application of* BSTEM. His field research has taken him to Australia, New Zealand, Europe, Asia and across North America. Dr. Simon is an adjunct Professor at the University of Mississippi and Special Professor in the School of Geography, University of Nottingham, UK. He brings to the project a veteran team of engineers and field technicians to support field-data collection activities, analysis and modelling.

YAVUZ OZEREN, PhD, PE

Dr. Yavuz Ozeren is a Research Scientist at the National Center for Computational Hydroscience and Engineering (NCCHE) of the University of Mississippi. Dr. Ozeren received his Ph.D. (2009) in Civil Engineering from the University of Mississippi and, M.S. (2002) and B.S. (1999) in Civil Engineering from the Middle East Technical University, Ankara, Turkey. Dr. Ozeren has been affiliated with the University of Mississippi since 2008. He has been collaborating with the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) National Sedimentation Laboratory in several research projects involving laboratory and field experiments since 2004. His research interests lie in fluvial hydraulics, environmental fluid mechanics, and hydraulic and coastal engineering, and his has experience in field and laboratory studies as well as numerical modeling. Dr. Ozeren has numerous publications on journals and conferences. He is an active member of ASCE Environmental Water Resources Institute. He is the current chair of the Hydraulic measurements and Experimental Methods Technical Committee, and actively involved in the organization and planning of 2017 Hydraulic Measurements and Experimentation Conference. He is also a member of the International Association of Hydro-Environment Engineering and Research (IAHR), and AGU (American Geophysical Union).

KIT CHOI, PhD, PE

Dr. Choi is a licensed civil engineer specializing in geotechnical engineering and civil design, soil mechanics and foundation engineering, dams, and geotechnical applications to water resources projects. He has two years of university teaching experience and over 31 years of experience in consulting engineering practice. He has worked on a wide range of geotechnical engineering projects, including foundation investigations for commercial and industrial buildings, dams, outlet works and spillway structures; analysis and design of braced excavation support systems; static and seismic slope stability analysis and deformation analysis; two-dimensional and three-dimensional liquefaction analysis; seepage and design of filters and drains; analysis and design of post-tensioned anchors; and rock slope stability analysis. Dr. Choi is experienced in the field investigations and design of levees, stream bank protection, stream stabilization, drainage improvements, coastal seawalls and boat docks, including subsurface investigations, field reconnaissance, geotechnical assessment, and preparation of construction drawings, and technical specifications. He has designed stream bank stabilization repairs using bio-engineering techniques such as bank barbs, anchored root wads, willows, and erosion control mats to enhance fisheries.

JENNIFER HAMMOND

Jennifer Hammond has over 20 years of experience in the field of instream flow studies. Ms. Hammond has applied 1- and 2- dimensional hydraulic and habitat modelling for river habitat analysis and instream flow recommendations on rivers throughout the United States. With many years of experience in the collection of channel topography and hydraulic calibration information, and 1D/2D modelling Ms. Hammond brings valuable experience to an instream flow team. Experience includes the use of total stations (robotic and traditional), survey grade RTK GPS units, velocity meters (ADCP), laser levels, and hydro-acoustic equipment. Her hydraulic modelling experience includes HEC-RAS, PHABSIM based models and 2-dimensional finite element and finite volume models (e.g., River 2D, FESWMS, SRH-2D). Her other areas of expertise include HEC-RAS modelling for incremental dam failure and hazard analysis, salmonid bio-energetic data collection and modelling, fish passage data collection and analysis, and collection and analysis of split beam hydro-acoustic data for fish movement. In addition to Jennifer's extensive experience with hydraulic models and instream flow studies she has developed an expertise with the Bank-Stability and Toe-Erosion Model (BSTEM) with application on streams around the world.

NICK DANIS, PE

Nick Danis has nine years of design experience on public and private projects. He prides himself on being technical and creative, with a proven track record of completing complex engineering tasks. Nick's resume includes stream restoration, wetland rehabilitation, storm water management, drainage systems, storm and sanitary sewer rehabilitation, roadway design, and residential and commercial development. In addition to Nick's extensive experience with engineering design and instream geomorphic studies, he has developed an expertise with the Bank-Stability and Toe-Erosion Model (BSTEM) with application on streams around the world. Nick's experience on rivers and streams includes the Pacific Northwest, East Coast, Mississippi River, Australia, and New Zealand. Nick often uses the output from various BSTEM models to influence the engineering design going forward, creating a seamless design balancing the need for bank stability with client goals and budgets. Nick's design software experience includes: AutoCAD Civil3D, Autodesk 3ds Max Design, ArcMap, BSTEM, xpswmm, HEC-RAS, and GeoHECRAS.

TIMOTHY SULLIVAN, GISP

Mr. Sullivan's background focuses on the FERC regulatory environment, physical and environmental sciences, hydrology and hydraulics, technical writing, and Geographic Information Systems (GIS). Mr. Sullivan has served as a Project Manager, Deputy Project Manager, and/or Technical Lead for a number of FERC relicensing and compliance assignments related to both traditional and pumped storage hydroelectric projects throughout the Northeast and Mid-Atlantic. In addition, Mr. Sullivan has experience in the fields of geomorphology – including sediment transport and erosion dynamics, hydraulic modeling (HEC-RAS), and field data collection using various technologies. Mr. Sullivan is a licensed GIS Professional (GISP) with extensive experience in developing enterprise GIS solutions and conducting various geospatial analyses. Mr. Sullivan has overseen a variety of geology and soils related studies including those related to erosion causation, sediment management, sediment monitoring, and the water quality impacts of sedimentation.

JOHN HART

Mr. Hart has over 25 years of water resource experience, including the last 15 years in FERC licensing as a water resources engineer / hydrologist and project manager on over 50 hydropower projects throughout the Northeast and the country. Mr. Hart has conducted and supervised numerous flood plain analyses, detailed watershed studies, headwater benefit studies, dam break analyses and dam redesigns; culvert analyses and designs; as well as specialized hydraulic studies including sediment transport and erosion. Mr. Hart has substantial hydropower related experience with most of these projects involving hydraulic and hydrologic modeling and developing FERC license related documents including PADs, study reports, or assisting FERC in preparation of their NEPA documents and license orders. Mr. Hart is well-versed in the computer modeling of surface and ground waters, including the use of HEC-1, HEC-2, HEC-5, HEC-RAS, HEC-ResSim, River2D, TR-55, TR-20, DAMBRK, FLDWAV, MODFLOW, MT3D, GMS, HMS, MODPATH, HWBEG, UNET, and similar models.

THOMAS SULLIVAN, PE

Mr. Sullivan is a founding Principal of Gomez and Sullivan and a water resources engineer with 35 years of experience in river hydraulics as well as hydrologic and environmental assessments. He has B.S. and M.S. degrees in Environmental Engineering from the Pennsylvania State University, as well as a variety of continuing education courses in applied hydraulics and stream restoration techniques. Mr. Sullivan's areas of technical expertise include hydrologic and hydraulic analysis, instream flow analyses, and operations modeling. Over the course of his career, Mr. Sullivan has led field crews in the collection of hydraulic, habitat, and water quality data, as well as developed and calibrated hydraulic models that predict stream response to different scenarios. He has served as the Principal-in-Charge for projects to evaluate riverine hydraulics, shoreline erosion, and hydroelectric project operations.

MARK WAMSER, PE

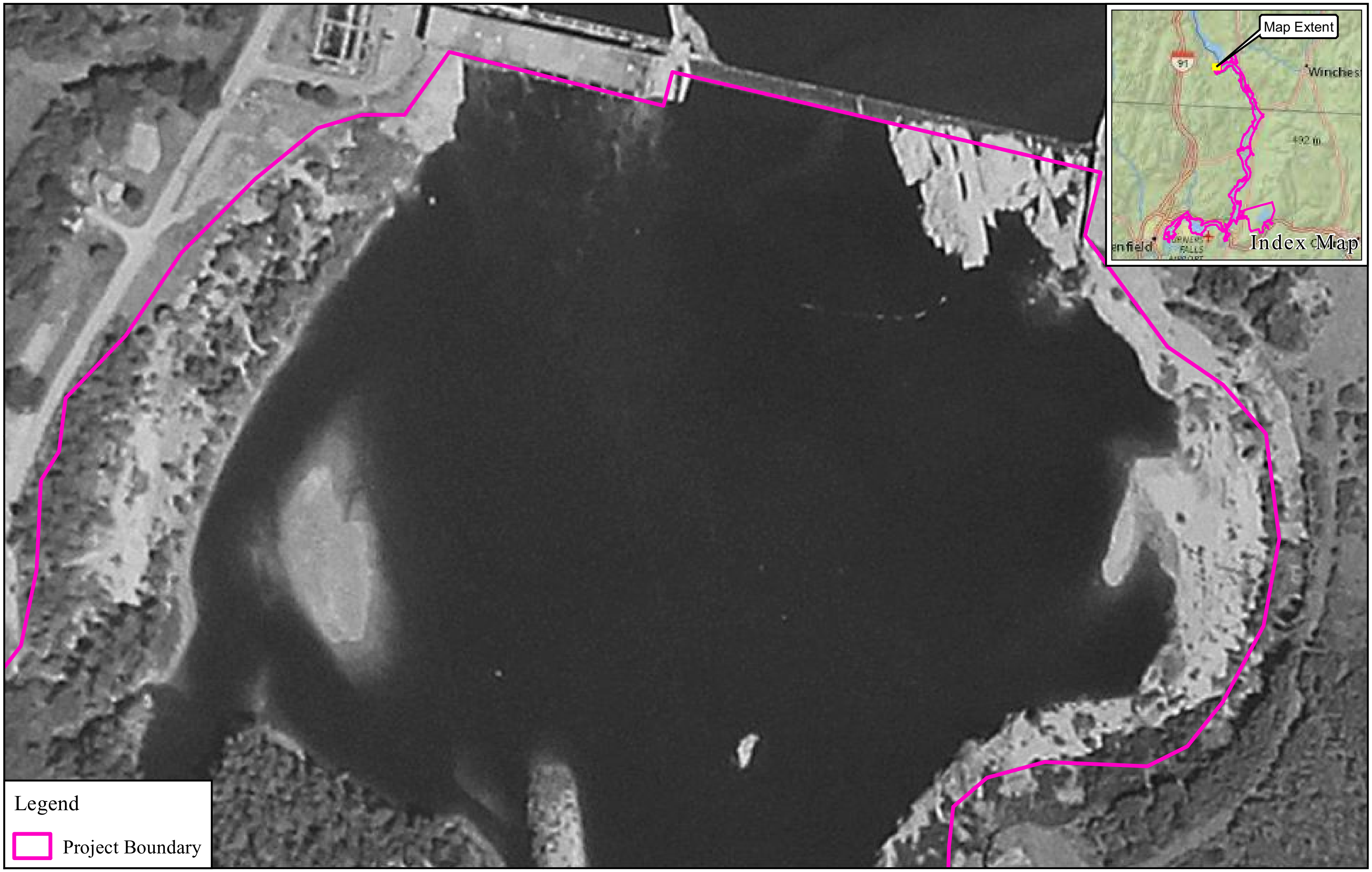
Mr. Wamser has 28 years of experience in FERC licensing and environmental and engineering studies. He has served as Project Manager for numerous FERC hydroelectric relicensing projects, as well as dam removal, water budgeting, watershed planning, water quality, and basin-wide modeling projects. In addition to his management experience, Mr. Wamser has considerable hands-on experience with operations modeling, energy analyses, instream flow studies (IFIM), water quality monitoring, fish passage analyses, impoundment level management studies, aesthetic studies, facilitation of settlement negotiations, and preparation of license applications for hydroelectric projects. Mr. Wamser's technical background includes the development of simulation models of basin-wide river/reservoir systems, development of HEC-RAS hydraulic models for dam removal and flood inundation studies, watershed assessments and action plans, and general hydrologic investigations. Mr. Wamser has had formal training in risk management, PHABSIM, HEC-RAS, sediment transport, and USFWS field techniques for IFIM studies.

APPENDIX B – HISTORIC AERIAL PHOTOS OF THE 20 SITES IDENTIFIED IN THE ECP

1 VERNON DAM

The most significant erosion feature in the Turners Falls Impoundment is located immediately downstream of Vernon Dam on the left bank (looking downstream). As discussed in S&A 2012, erosion occurs in this location due to the large eddy that forms from flow releases through Vernon Dam gates on the left side of the structure.

The 1952 photograph shows that the top of left bank is near the project boundary line (indicated in fuchsia). Recent photographs show that erosion has progressed beyond the line such that the bottom of the upper bank is beyond the line. The 2008-2010 and the Online Imagery were taken at relatively high flow conditions and show the turbulence and eddying associated with the release of flow through the left gates of Vernon Dam as well as the general turbulence in this reach of the river at these levels of flow.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Vernon Dam
1952 Imagery
(Source: North by Northeast Survey Company)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Vernon Dam
2008-2010 Imagery
(Source: NH GRANIT)

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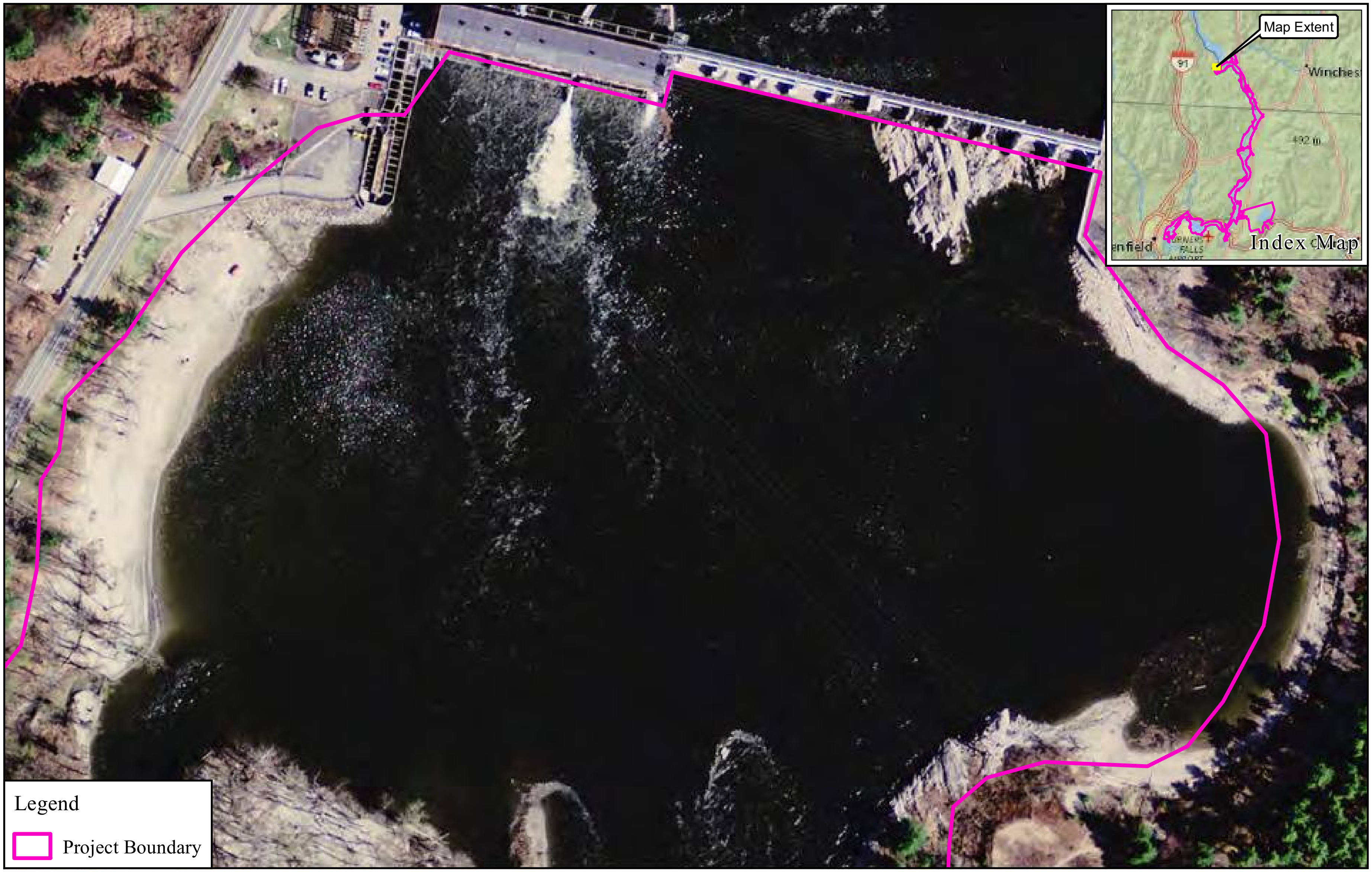

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Vernon Dam
2014 Imagery
(Source: NAIP)

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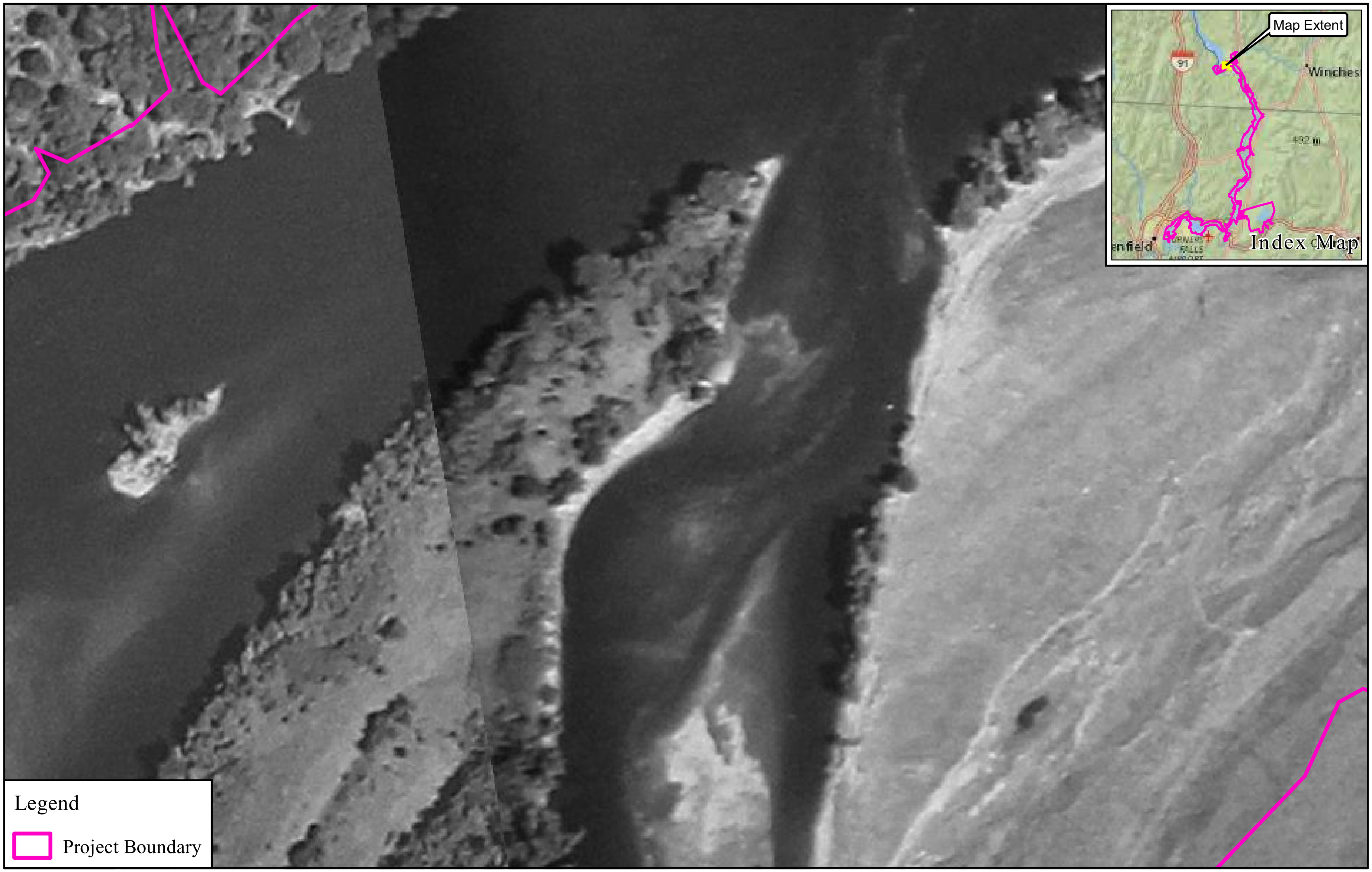
2 STEBBINS ISLAND

The 1952 photograph shows that there is little vegetation along the right bank of the river, bars and small vegetated islands to the left of the main island, and shallow flow conditions on both sides of the island. By the 2008-2010 set of photos, the downstream tip of the island had narrowed but the potentially eroded right bank which in 1952 had little to no vegetation on the bank had some establishment of vegetation on the bank. The 2014 and Online Imagery are similar to the 2008-2010 photograph.



FirstLight
Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07
Miles

Stebbins Island
1952 Imagery
(Source: North by Northeast Survey Company)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Stebbins Island
2008-2010 Imagery
(Source: NH GRANIT)

0 0.0175 0.035 0.07 Miles

FirstLight Power Resources

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Stebbins Island
2014 Imagery
(Source: NAIP)

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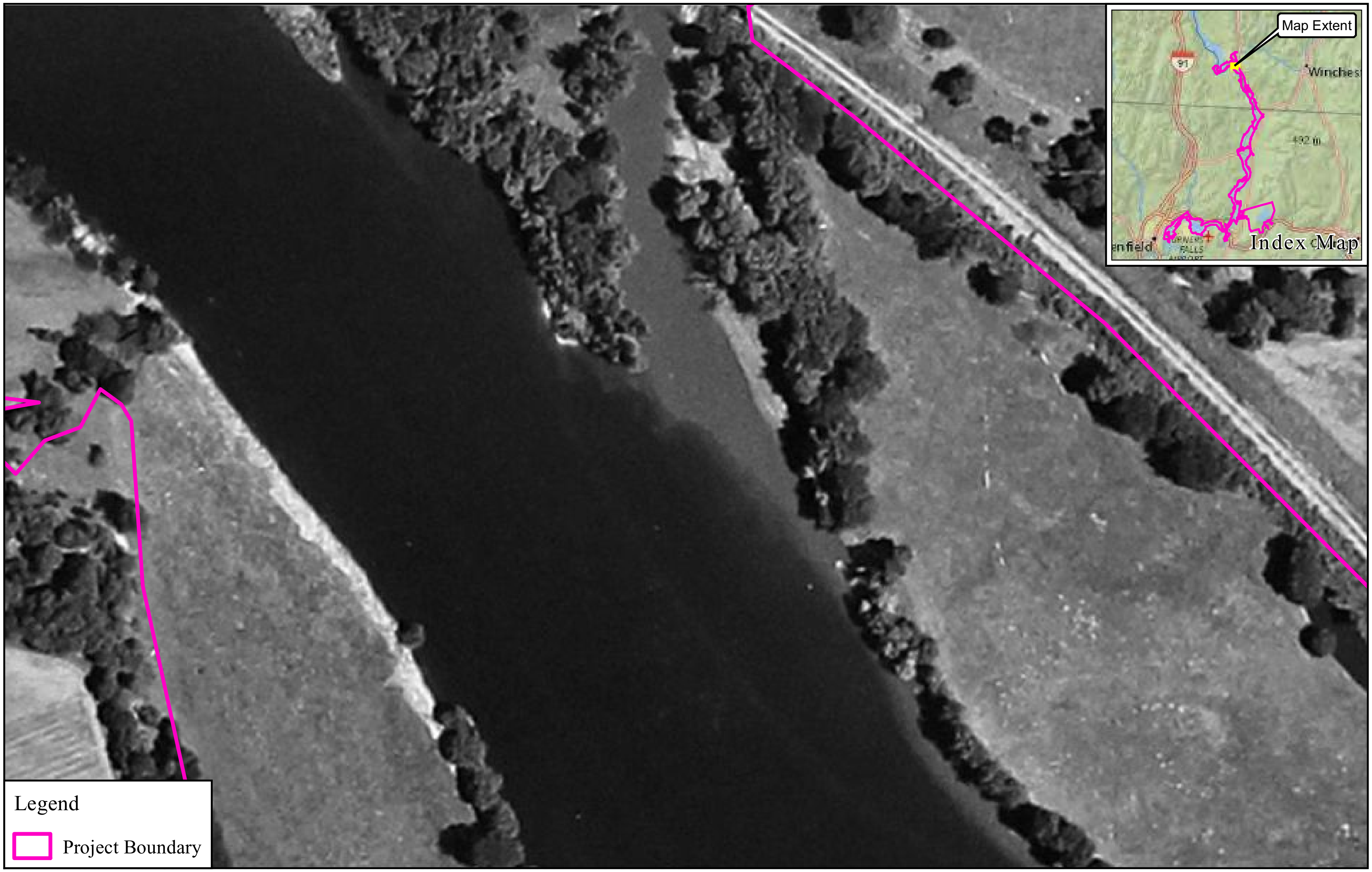
3 ASHUELOT RIVER CONFLUENCE

The 1952 photograph shows that the right bank of the river, opposite the confluence with the Ashuelot River, is eroded with no upper riverbank vegetation between the agricultural field and the river. The 2008-2010 and other recent photographs show an increase in riverbank vegetation along this same section of riverbank. On the Ashuelot side, upstream of the confluence the tip of land appears to have narrowed over time since 1952 and there is some decrease in the narrow riparian zone of upper riverbank vegetation downstream of the confluence.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Ashuelot River Confluence
1952 Imagery
(Source: North by Northeast Survey Company)

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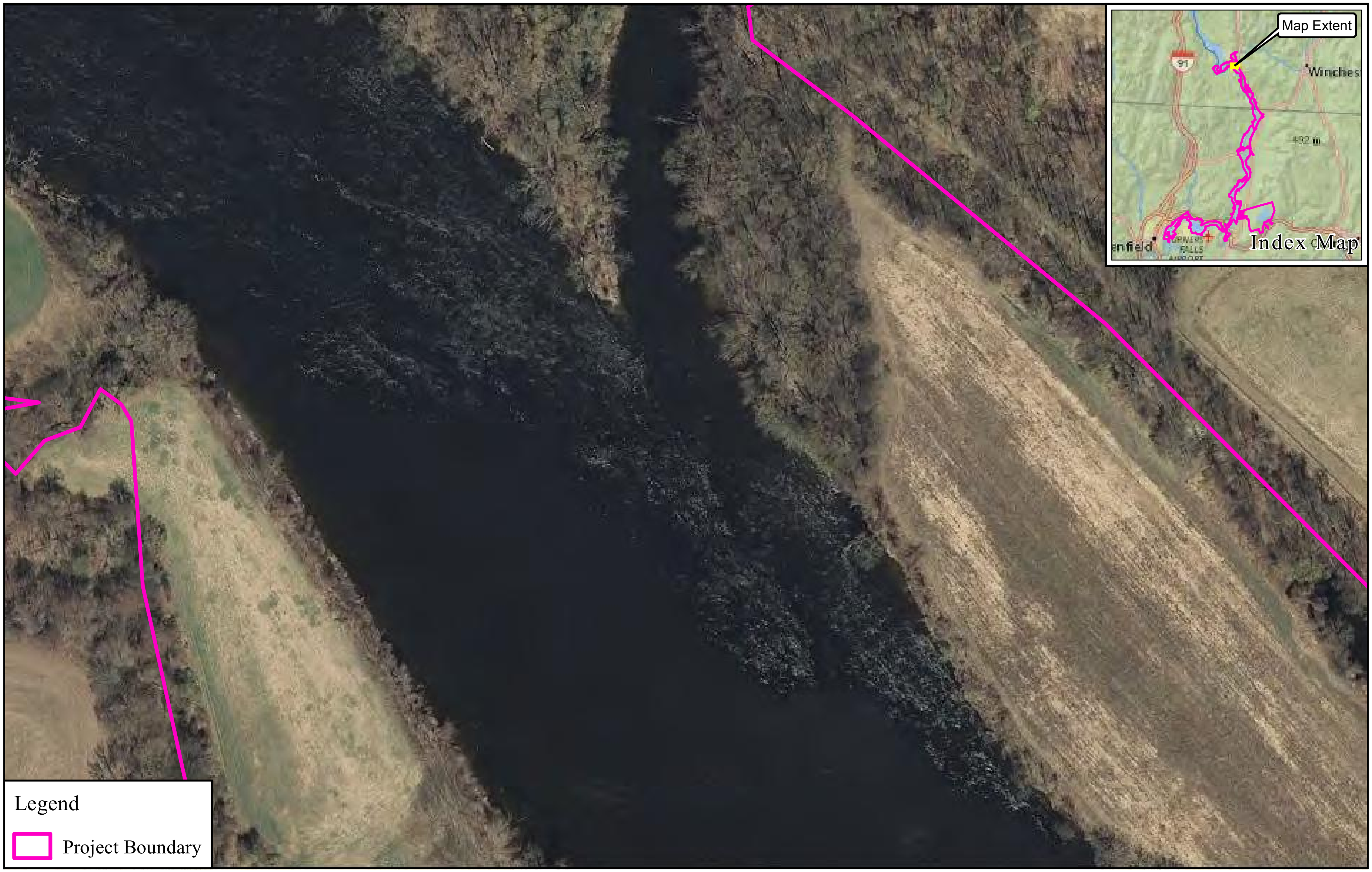

FirstLight Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Ashuelot River Confluence
2008-2010 Imagery
(Source: NH GRANIT)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Ashuelot River Confluence
2014 Imagery
(Source: NAIP)

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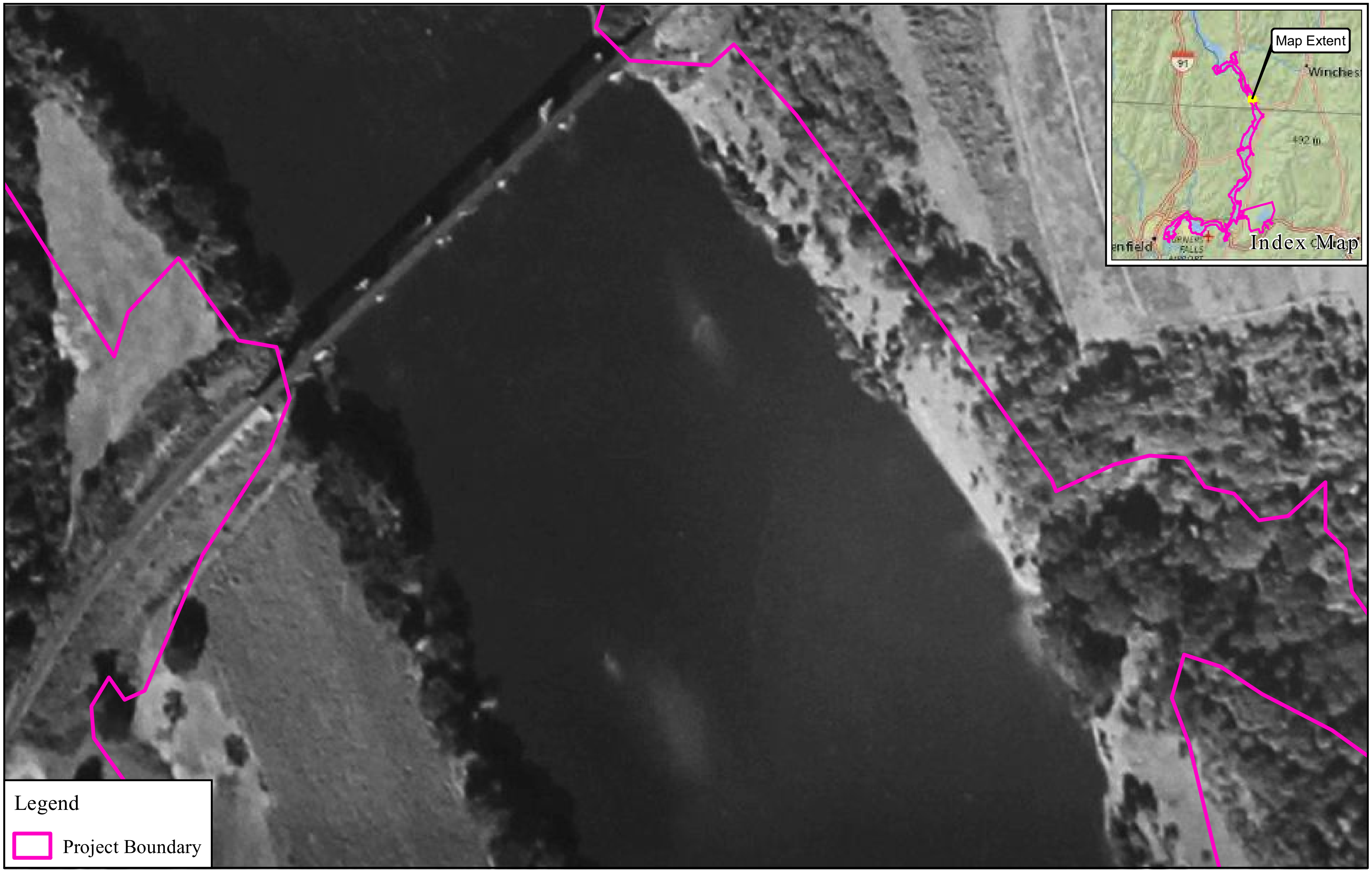
4 KENDALL

In the vicinity of the railroad bridge which has been subsequently abandoned and partially removed, in 1952 the right bank downstream of the bridge supports a band of riparian vegetation while the left bank is sparsely vegetated. In 1962, in the same location on the right bank erosion is evident with the bank shifting landward and no riparian vegetation remaining. On the left bank, a small erosion scallop has formed just downstream of the bridge with segments of reduced riparian vegetation. The bridge super-structure had been removed by the 1990s photograph, with all piers left standing in the river. By the 2008-2010 set of photographs, one of the piers had fallen into the river, probably due to scour around its base and no supporting structure to provide stability from above. The right bank is the Kendall site which was stabilized in 2008 through implementation of the ECP. Subsequent photos show the stabilized right bank and increased riparian vegetation along the left bank.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Kendall
1952 Imagery
(Source: North by Northeast Survey Company)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Kendall
1960's Imagery
(Source: USGS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Kendall
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Kendall
2008-2010 Imagery
(Source: NH GRANIT)

N

0 0.0175 0.035 0.07 Miles

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
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STUDY 3.1.2

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Kendall
2014 Imagery
(Source: NAIP)

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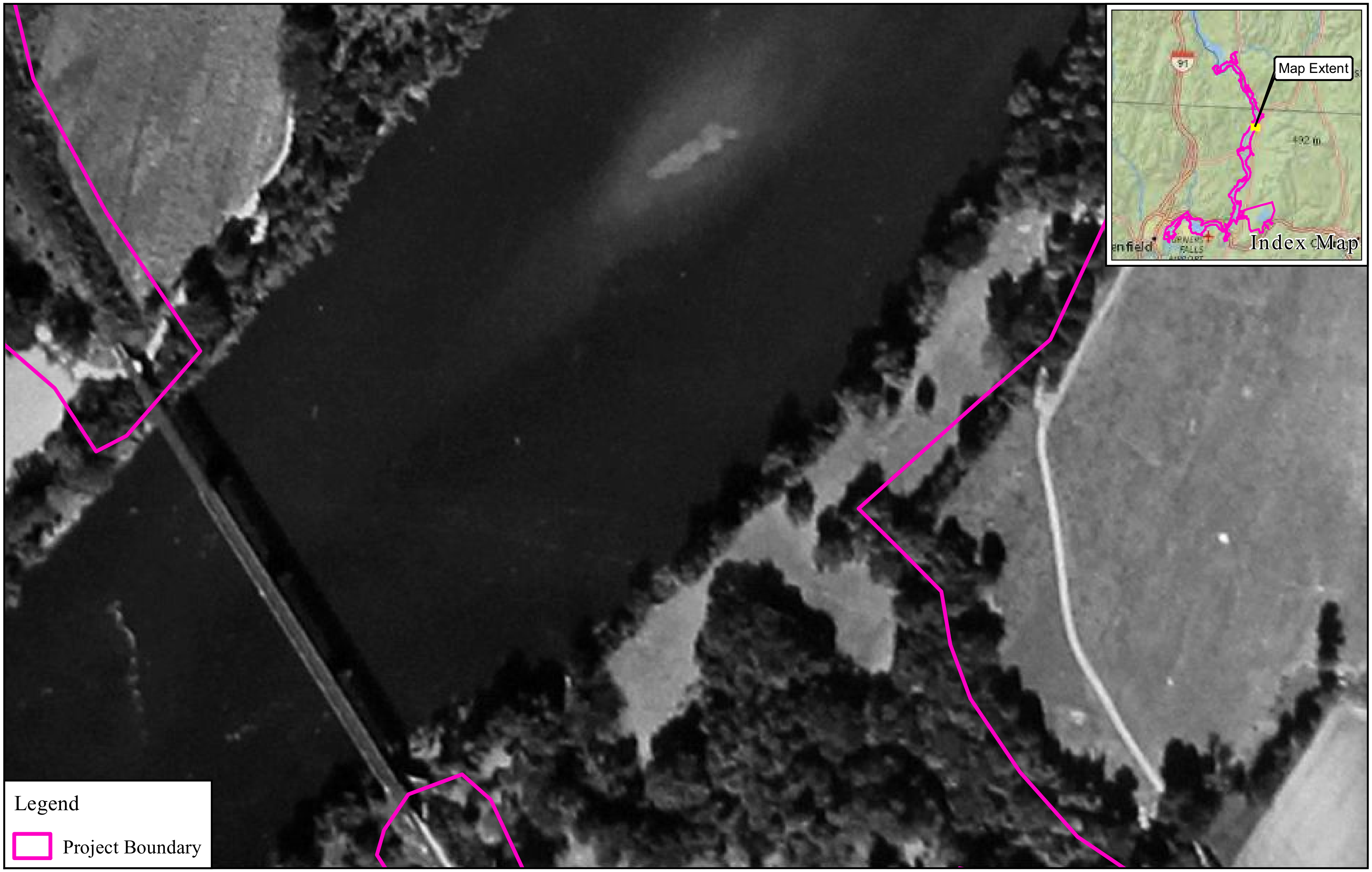
5 SCHELL BRIDGE (COUNTRY ROAD)

In the 1952 photograph, a band of riparian vegetation is found along both banks of the river upstream of the Schell Bridge. The extent of vegetation appears to be relatively consistent along the right bank through the series of photographs. On the left bank; however, the 1960s photograph shows erosion and a significant reduction in riparian vegetation. This area was called the Country Road Site, which was stabilized in 2006 through the ECP as shown in the 2008-2010 and more recent photographs.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Schell Bridge (Country Road)
1952 Imagery
(Source: North by Northeast Survey Company)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Schell Bridge (Country Road)
1960's Imagery
(Source: USGS)

0 0.0175 0.035 0.07 Miles

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
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STUDY 3.1.2

Schell Bridge (Country Road)
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Schell Bridge (Country Road)
2008-2010 Imagery
(Source: VCGI)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Schell Bridge (Country Road)
2014 Imagery
(Source: NAIP)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

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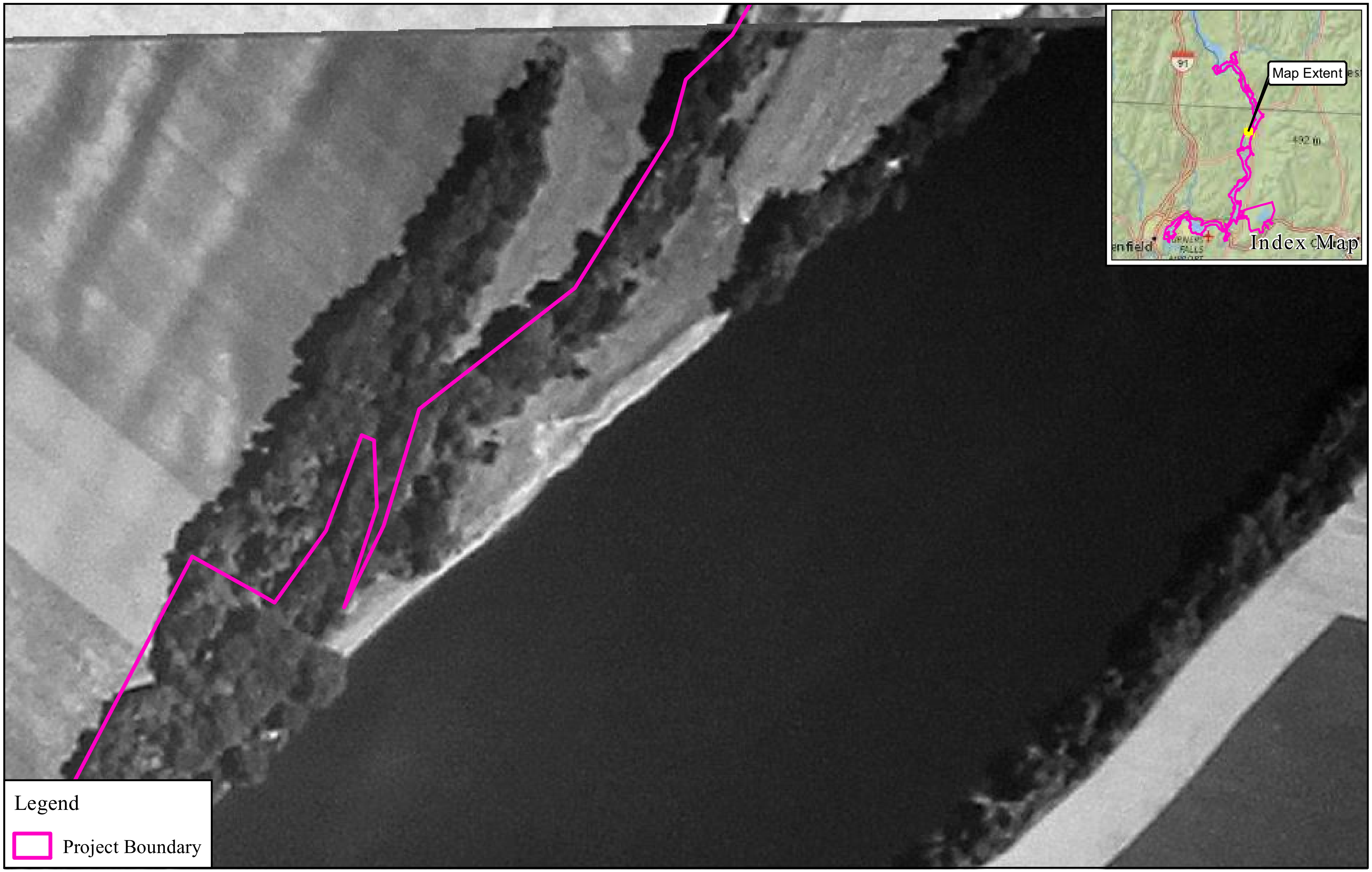
6 WICKEY

In the 1952 and 1960s photographs, there is an eroded section of riverbank with no significant riparian vegetation. During the 1990s, this site was selected for erosion repair, known as the Wickey site (constructed in 1996).



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Wickey
1952 Imagery
(Source: North by Northeast Survey Company)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Wickey
1960's Imagery
(Source: USGS)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Wickey
1990's Imagery
(Source: MassGIS)

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Wickey
2008-2010 Imagery
(Source: VCGI)

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
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STUDY 3.1.2

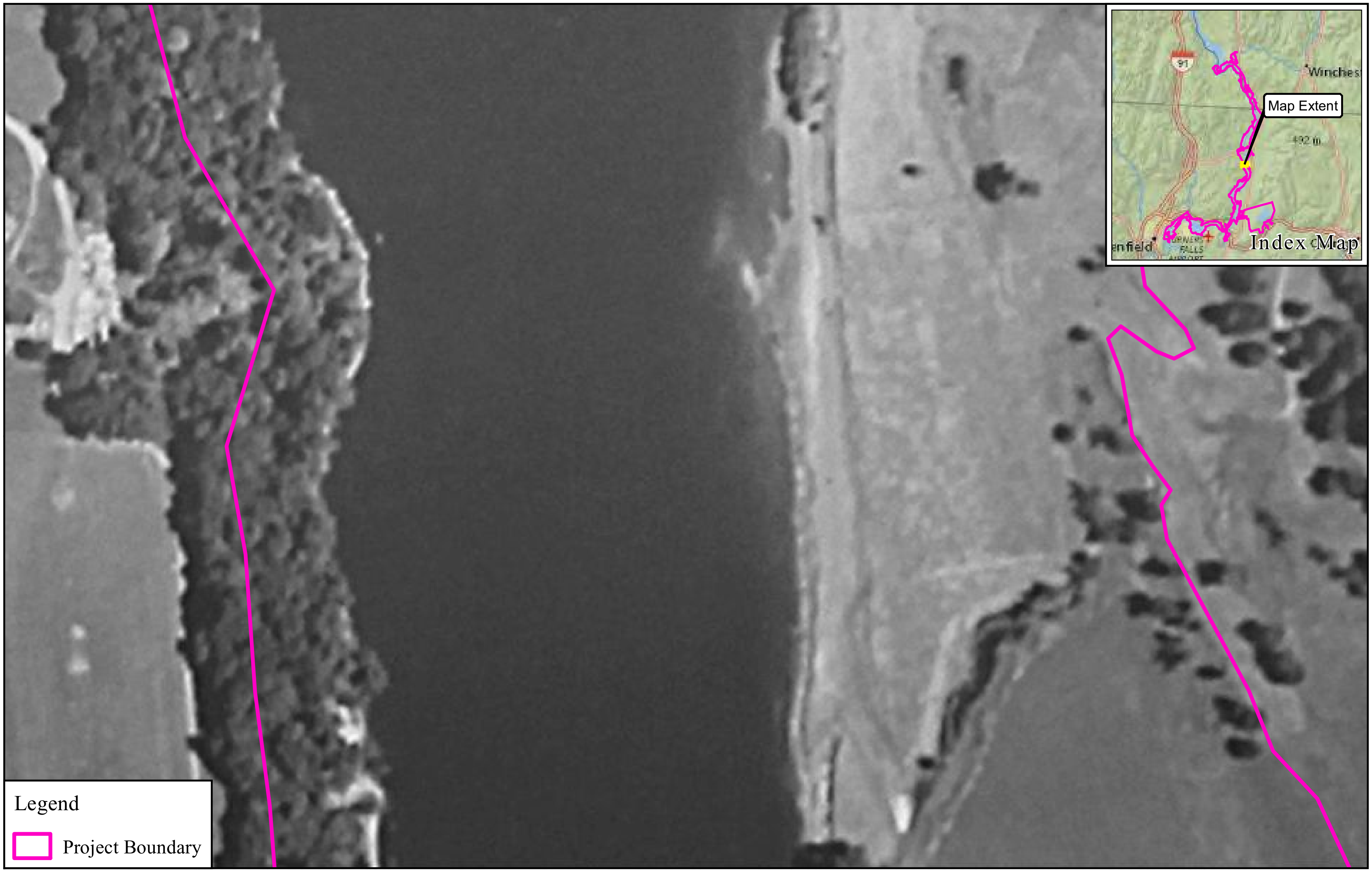
0 0.0175 0.035 0.07 Miles

Wickey
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

7 MT. HERMON

The left riverbank across the river from the Mt. Hermon School was eroded and absent riparian vegetation on the 1952 and 1960s photographs. A strip of riparian vegetation has become established along this riverbank as can be seen in the 1990s and subsequent photographs.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Mt. Hermon
1952 Imagery
(Source: North by Northeast Survey Company)

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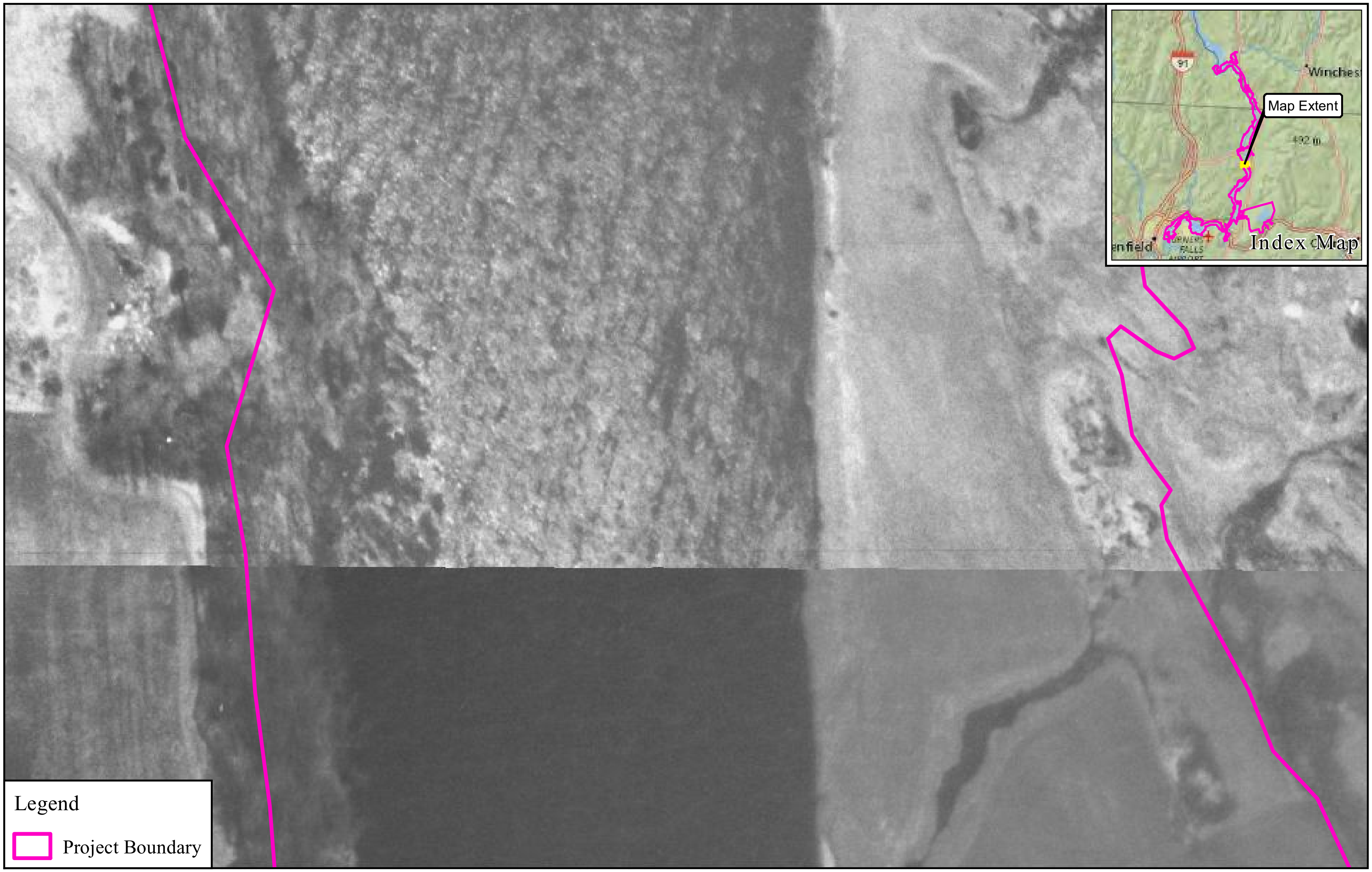


FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

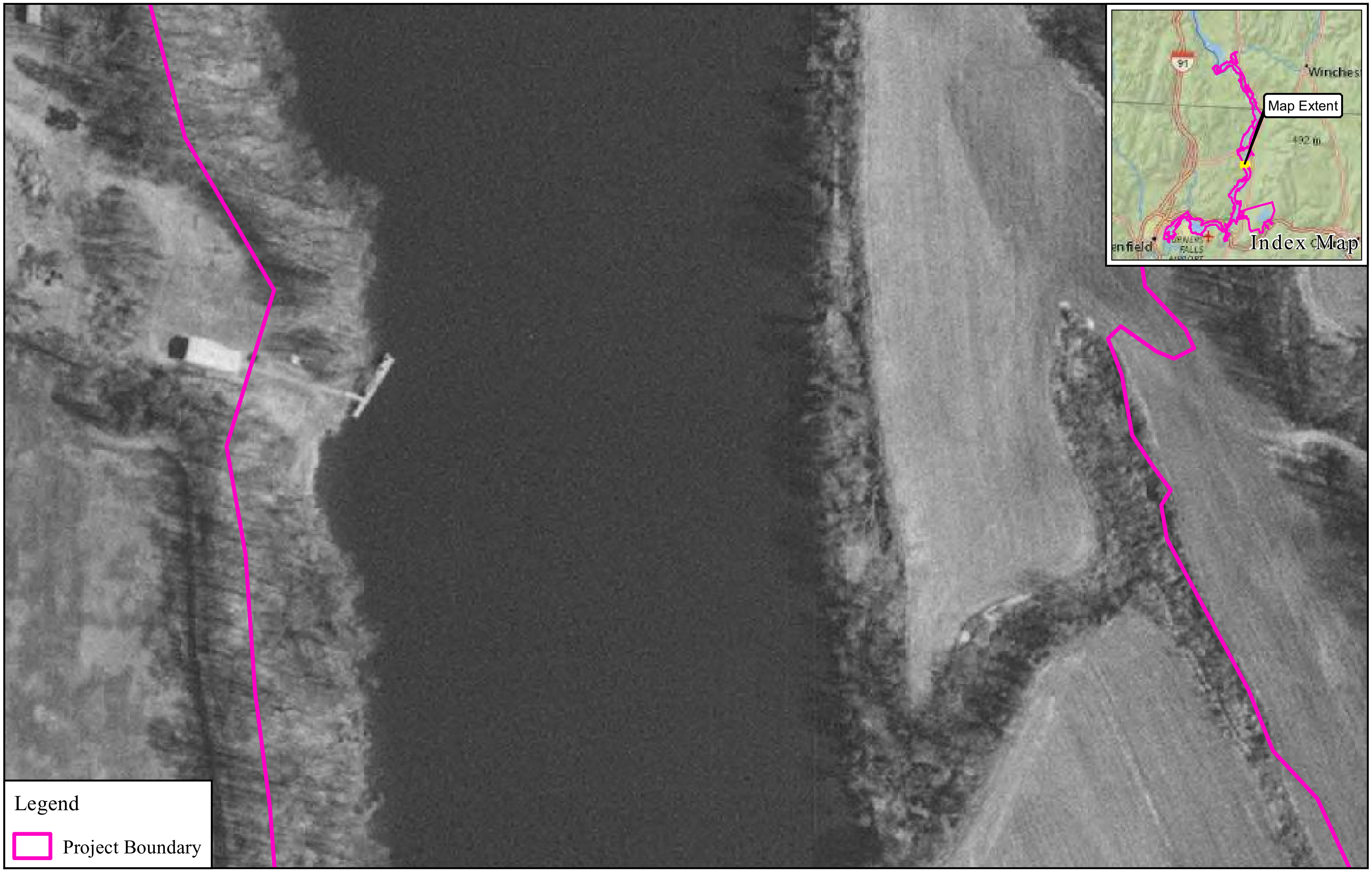
FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Mt. Hermon
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Mt. Hermon
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Mt. Hermon
2008-2010 Imagery
(Source: MassGIS)

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Mt. Hermon
2014 Imagery
(Source: NAIP)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

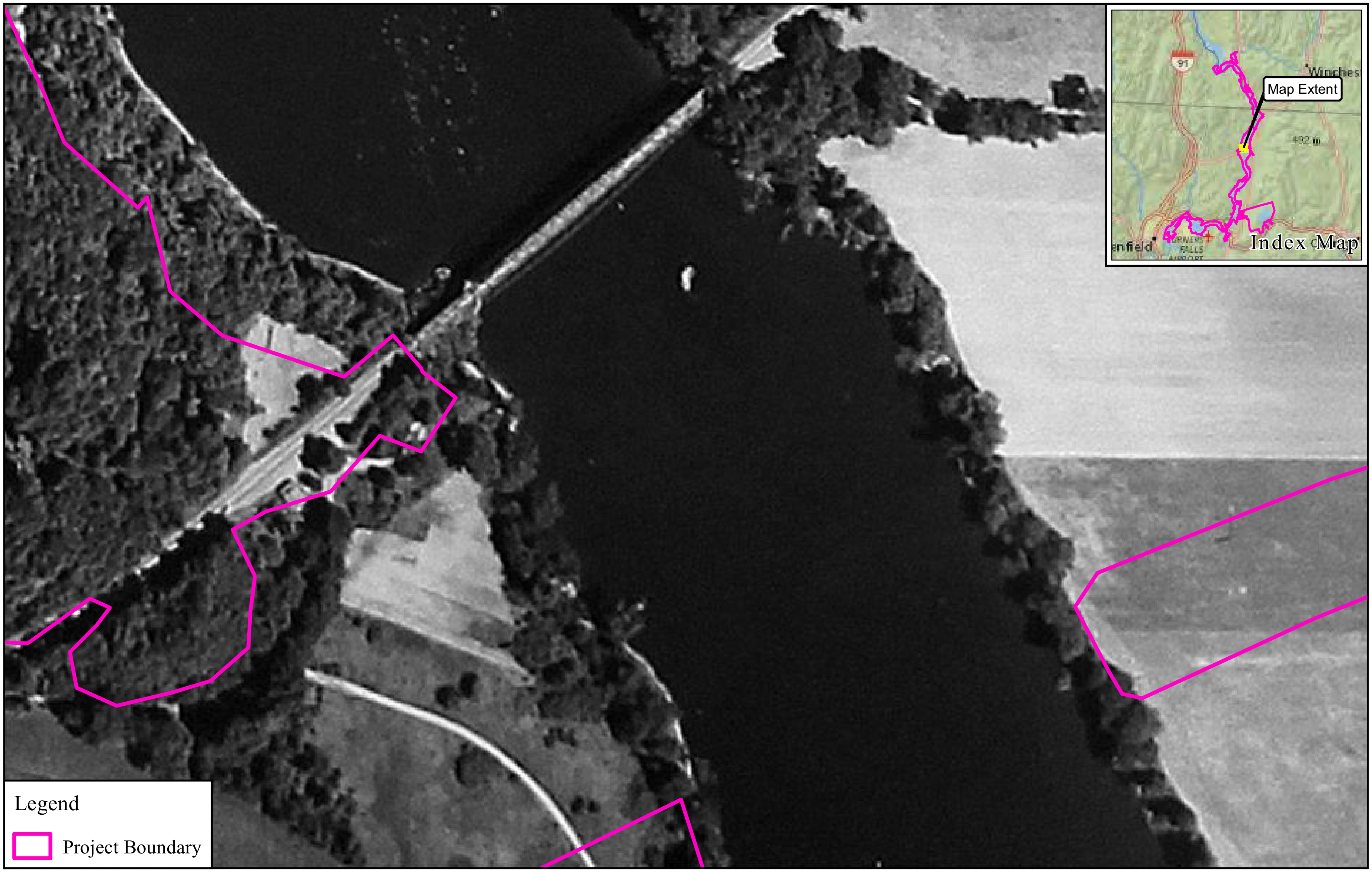
Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

8 ROUTE 10 BRIDGE

The 1952 photo shows some riparian vegetation along both banks but curvature of both banks suggests erosion has been occurring. In "Analysis of Erosion in the Vicinity of the Route 10 Bridge Spanning the Connecticut River," Simons & Associates 2012 even earlier photos were included in the analysis:

> *The series of aerial photographs show that erosion was occurring progressively during the entire period from 1929 to 1990 on both riverbanks focused primarily in the area downstream of the old Bennett Meadow Bridge. Erosion is evident during the entire sequence of aerial photographs from 1929 through 1990 and erosion was progressing prior to raising the Turners Falls Dam in 1972 and before the construction and operation of the Northfield Mountain Pumped Storage Project.*

The right bank upstream of the bridge was stabilized in 1997 (Crooker) and no additional stabilization was conducted because of the unique and extreme hydraulics associated with the river in this reach where the bridge is located.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.0175 0.035 0.07 Miles

Rt. 10 Bridge
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Rt. 10 Bridge
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Rt. 10 Bridge
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FirstLight Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Rt. 10 Bridge
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

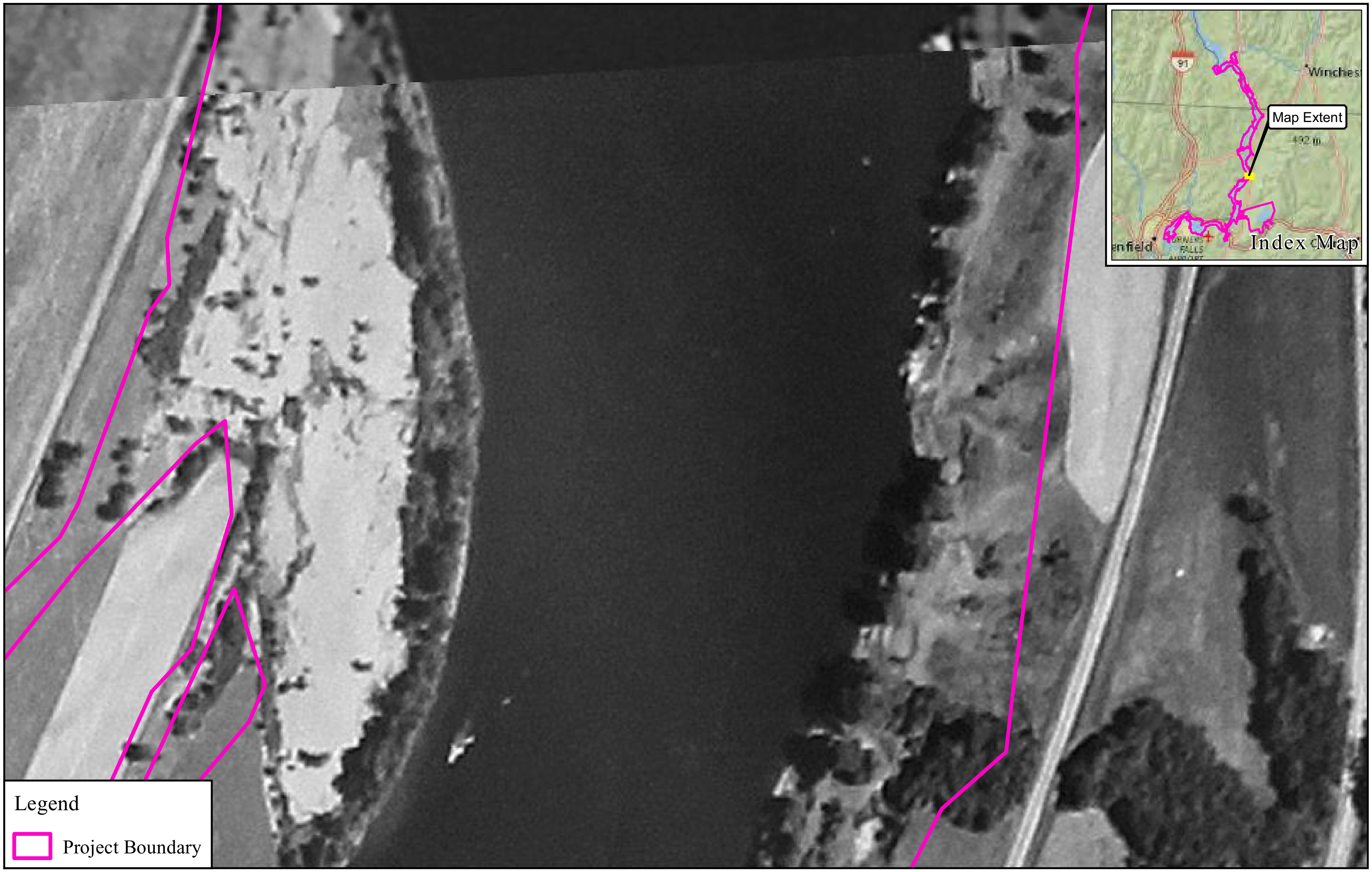
0 0.0175 0.035 0.07 Miles

Rt. 10 Bridge
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

9 URGIEL

At a bend in the river upstream of Kidds Island the 1952 photograph shows a reach with some riparian vegetation. The 1960s photograph shows erosion and associated decrease in riparian vegetation. The right bank is the Urgiel downstream site which was stabilized in 2005 as shown in the 2008-2010 and subsequent photographs. The riparian vegetation has become denser over the years on the right bank.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

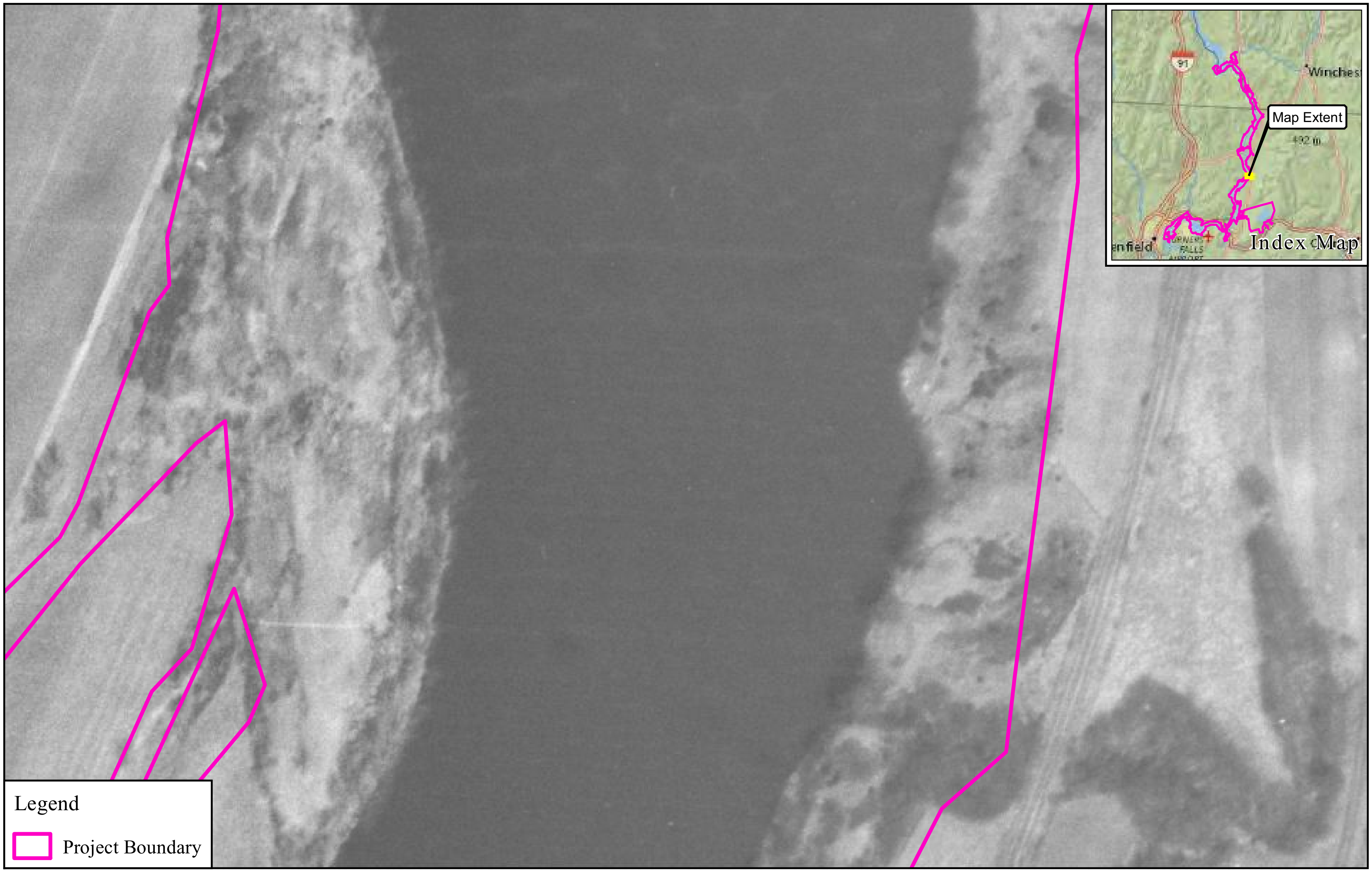
Urgiel
1952 Imagery
(Source: North by Northeast Survey Company)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Urgiel
1960's Imagery
(Source: USGS)

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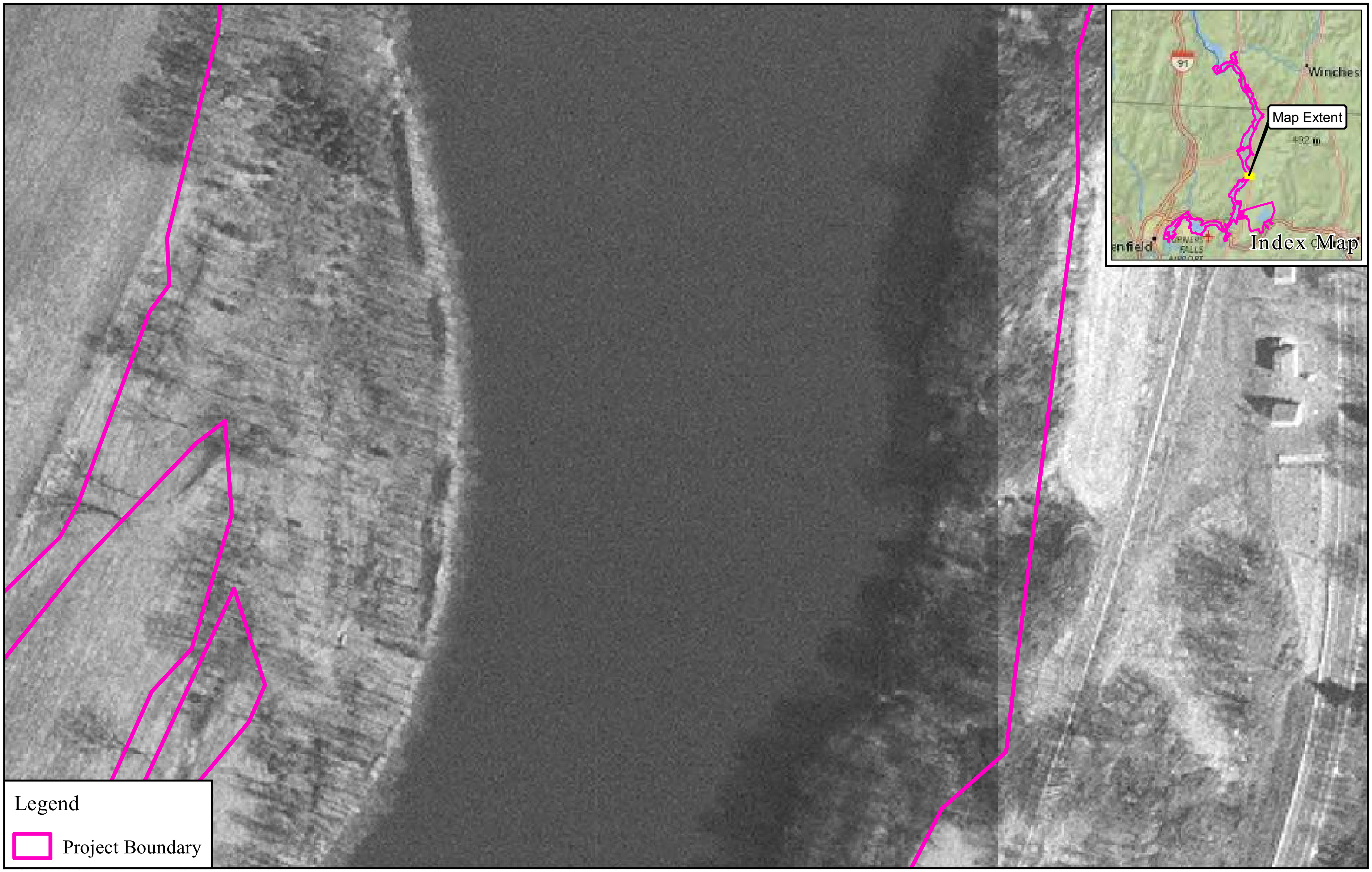


FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Urgiel
1990's Imagery
(Source: MassGIS)

0 0.0175 0.035 0.07 Miles

FirstLight Power Resources

N

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107   Filed Date: 10/14/2016

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Urgiel
2008-2010 Imagery
(Source: MassGIS)

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

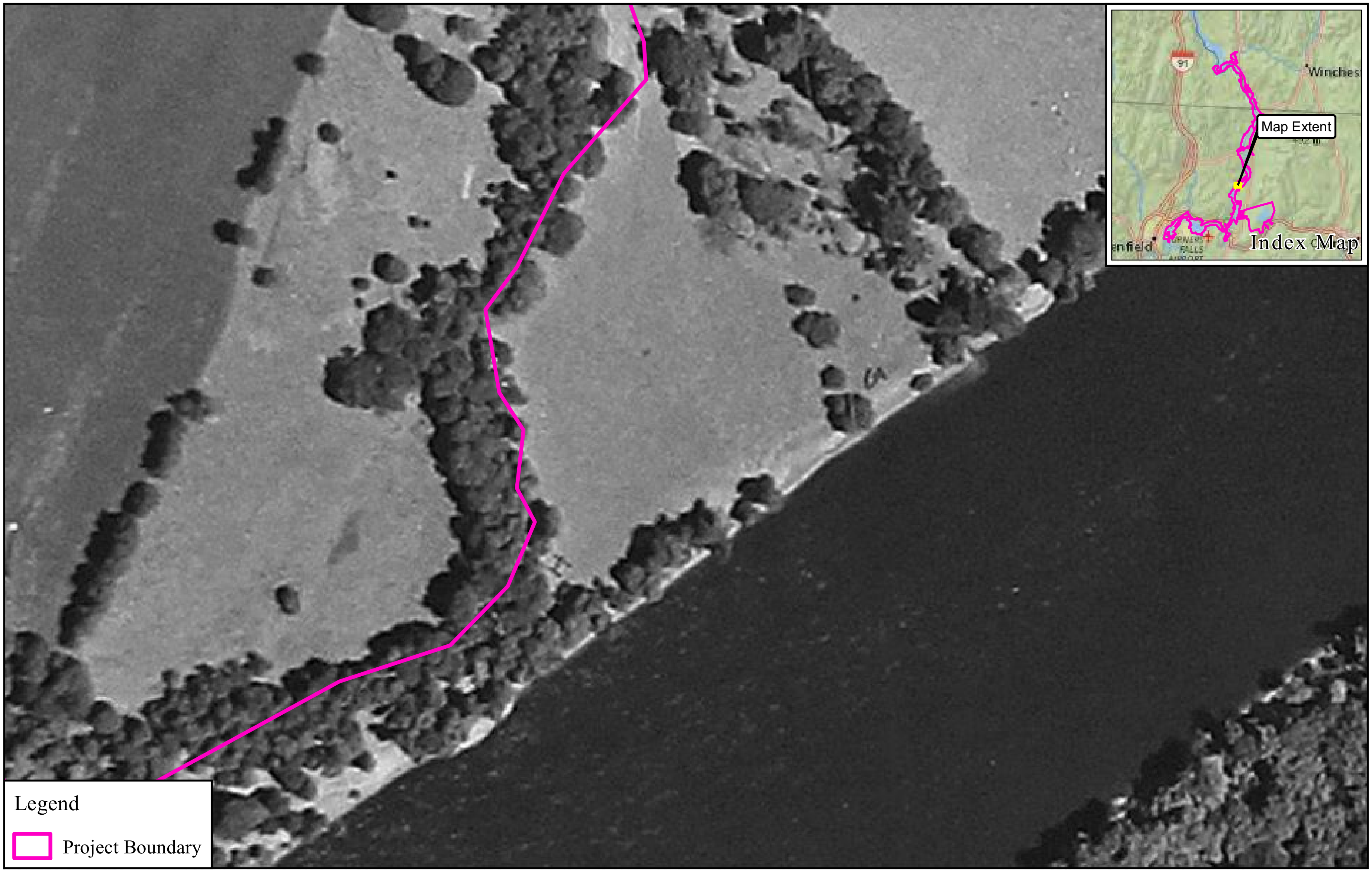
0 0.0175 0.035 0.07 Miles

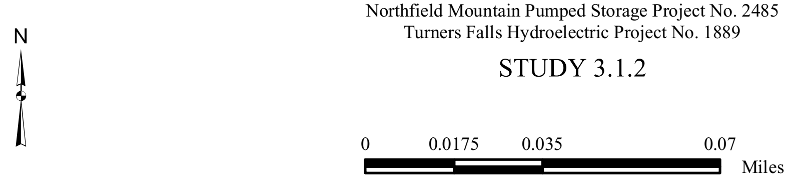
Urgiel
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

10 FLAGG - DOWNSTREAM OF OTTER RUN

The right bank downstream of Otter Run was sparsely vegetated in 1952. By the 1990s photograph no riparian vegetation can be seen on the bank. This reach of the river is in the vicinity of Kidds Island where camping and significant boating activity occurred until recent years. This eroded area was identified in the ECP and is known as the Flagg site. The portion of the Flagg site downstream of Otter Run was restored in 2000 but has been affected by cattle which, while there has been an increase in vegetation and stability, the vegetation is limited by the effect of cattle.



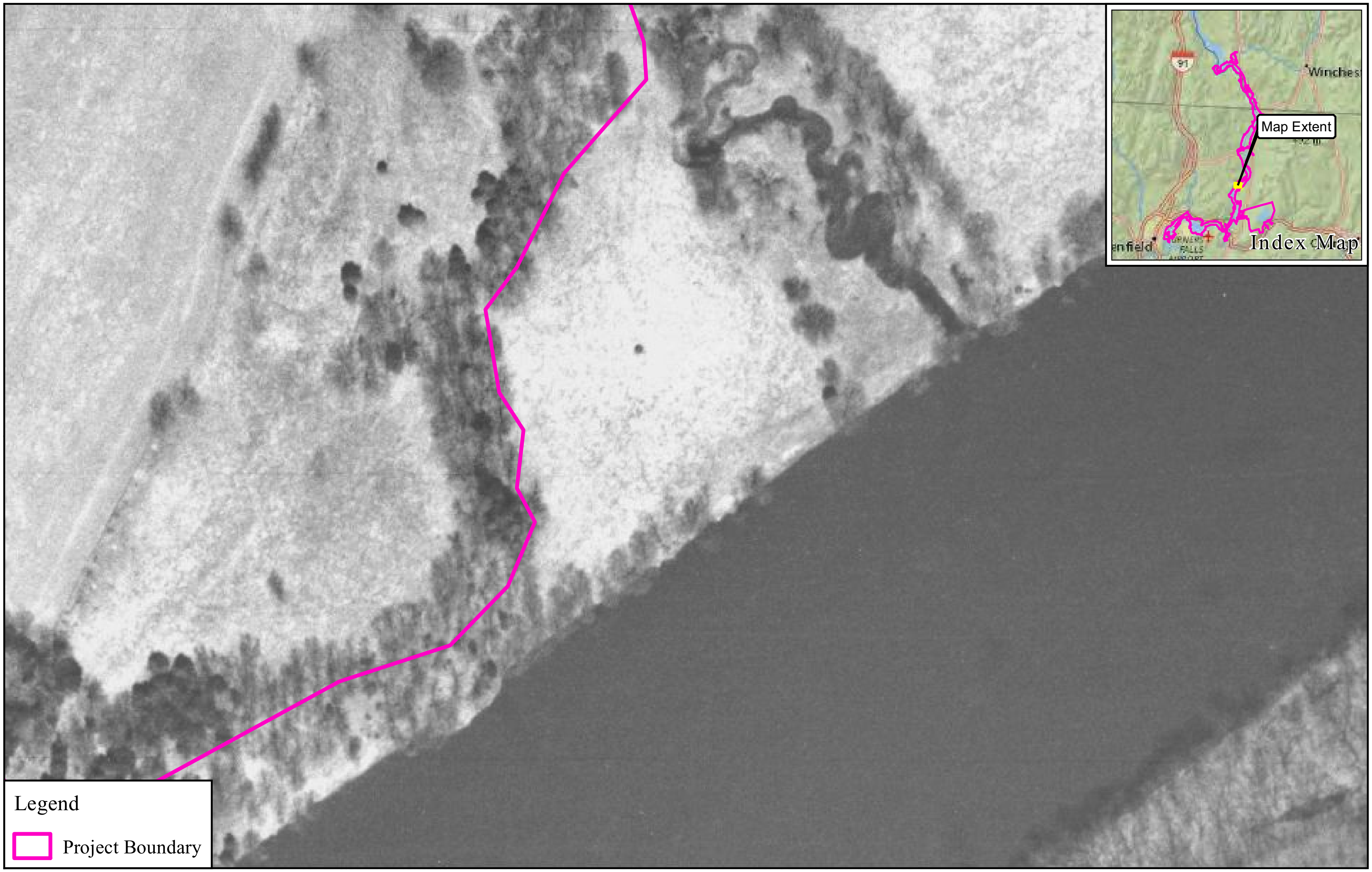


FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Flagg (downstream of Otter Run)
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FirstLight Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Flagg (downstream of Otter Run)
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Flagg (downstream of Otter Run)
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Flagg (downstream of Otter Run)
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Flagg (downstream of Otter Run)
2014 Imagery
(Source: NAIP)

N

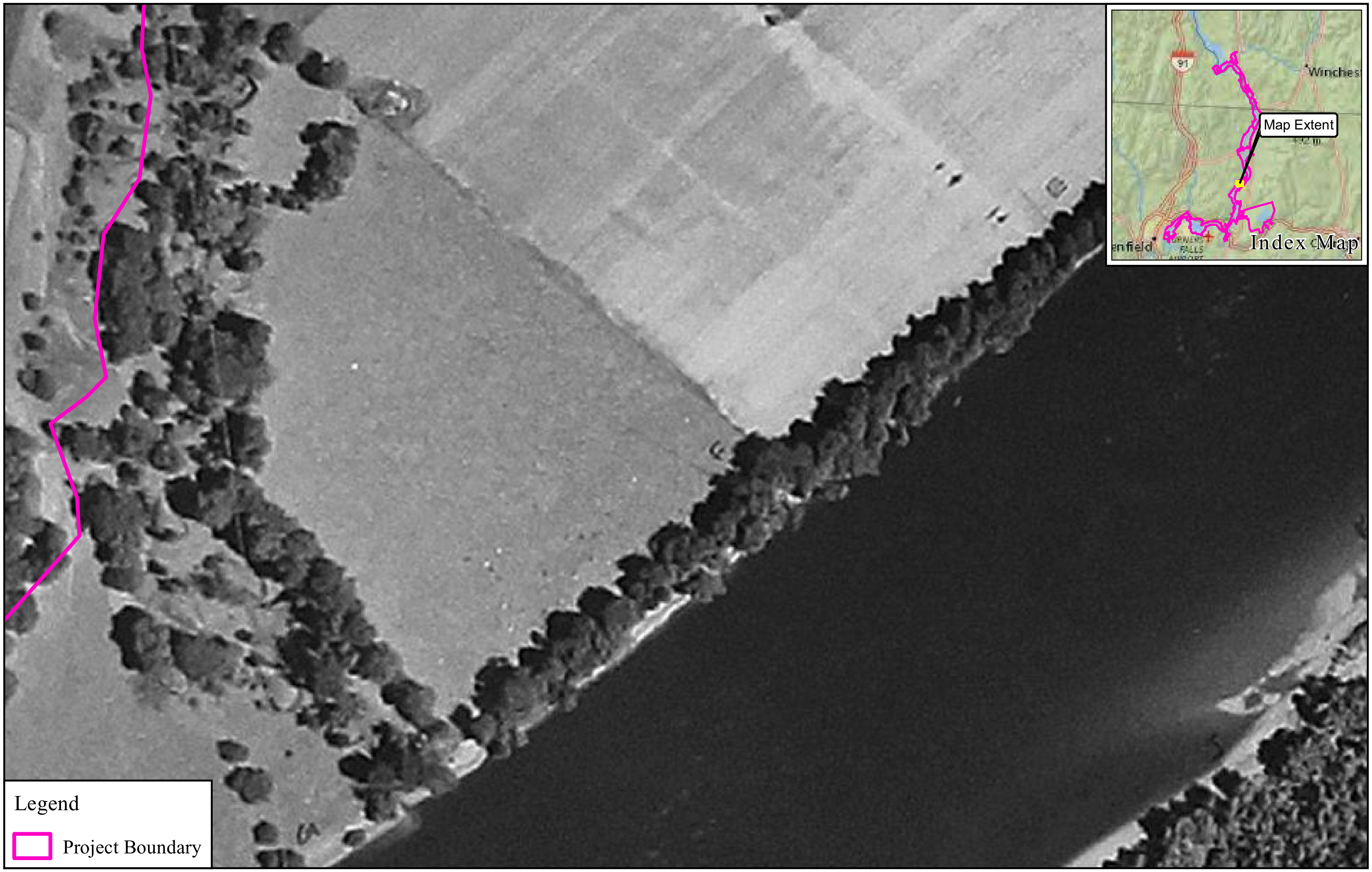
0 0.0175 0.035 0.07 Miles

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

11 FLAGG - UPSTREAM OF OTTER RUN

The right bank upstream of Otter Run follows the same pattern as the segment downstream from 1952 through the 1990s photographs with sparse riverbank vegetation in the 1950s and 1960s and virtually no riparian vegetation and erosion evident in the 1990s. This upstream site was stabilized in 2000 as part of the Flagg site through the ECP. This segment of the site was fenced off without access to cattle and is now densely vegetated and has a rock toe with aquatic vegetation growing on the lower riverbank. The riparian vegetation can be seen in the recent photographs.



FirstLight Power Resources

N

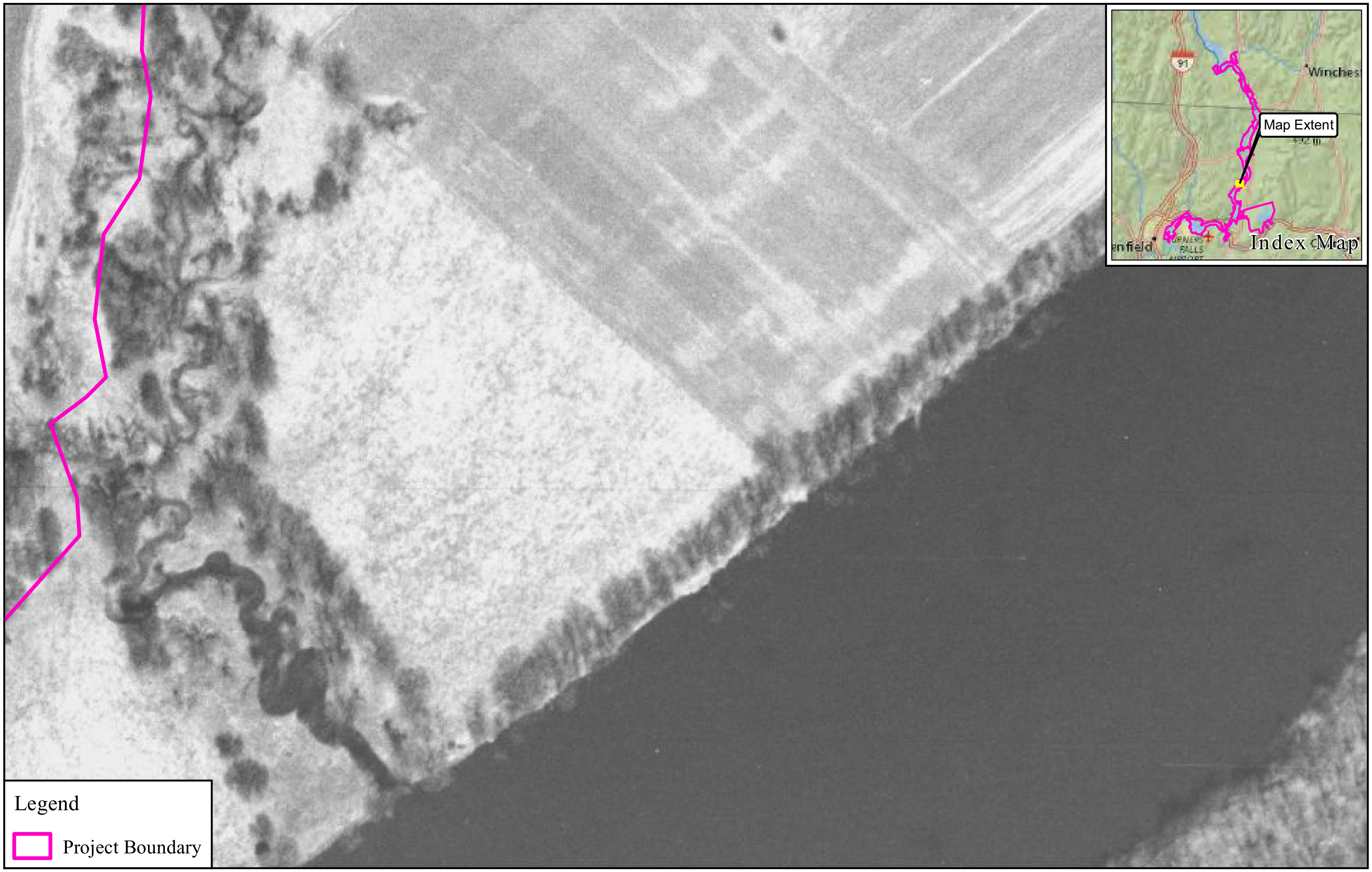
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Flagg (upstream of Otter Run)
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Flagg (upstream of Otter Run)
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.0175 0.035 0.07 Miles

Flagg (upstream of Otter Run)
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Flagg (upstream of Otter Run)
2008-2010 Imagery
(Source: MassGIS)

FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Flagg (upstream of Otter Run)
2014 Imagery
(Source: NAIP)

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

12 SKALSKI

The left bank of the river in the vicinity of Kidds Island has a band of riparian vegetation in the 1952, 1960s and 1990s photographs. While not apparent in the photographs, erosion had been occurring along this bank and was identified in the ECP and stabilized in 2004 as the Skalski site as can be seen in the more recent photographs with a rock toe and vegetated upper bank.

Document Accession #: 20161014-5107 Filed Date: 10/14/2016

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Skalski
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0   0.0175   0.035   0.07 Miles

Skalski
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FirstLight Power Resources

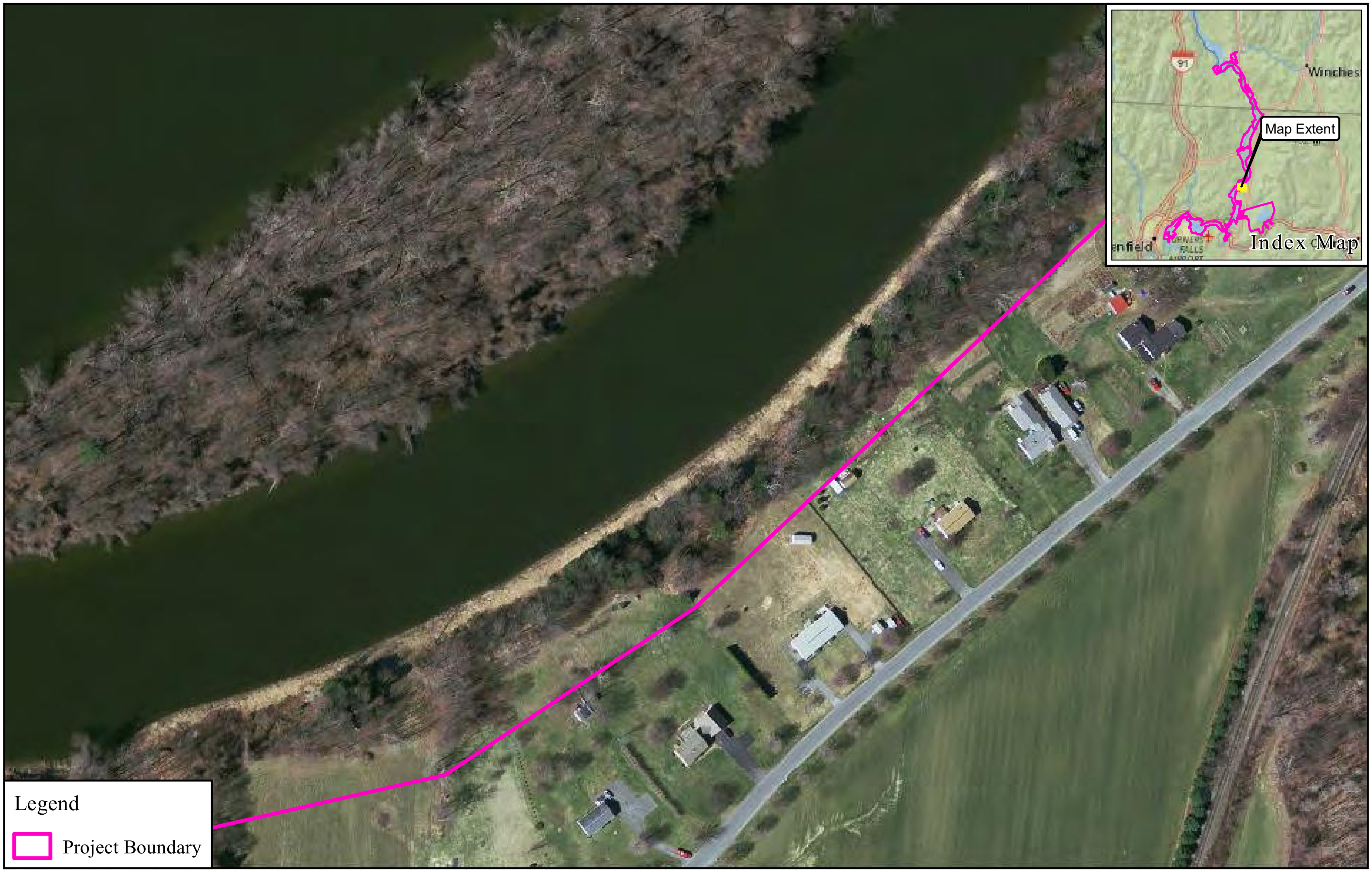
N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Skalski
1990's Imagery
(Source: MassGIS)



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

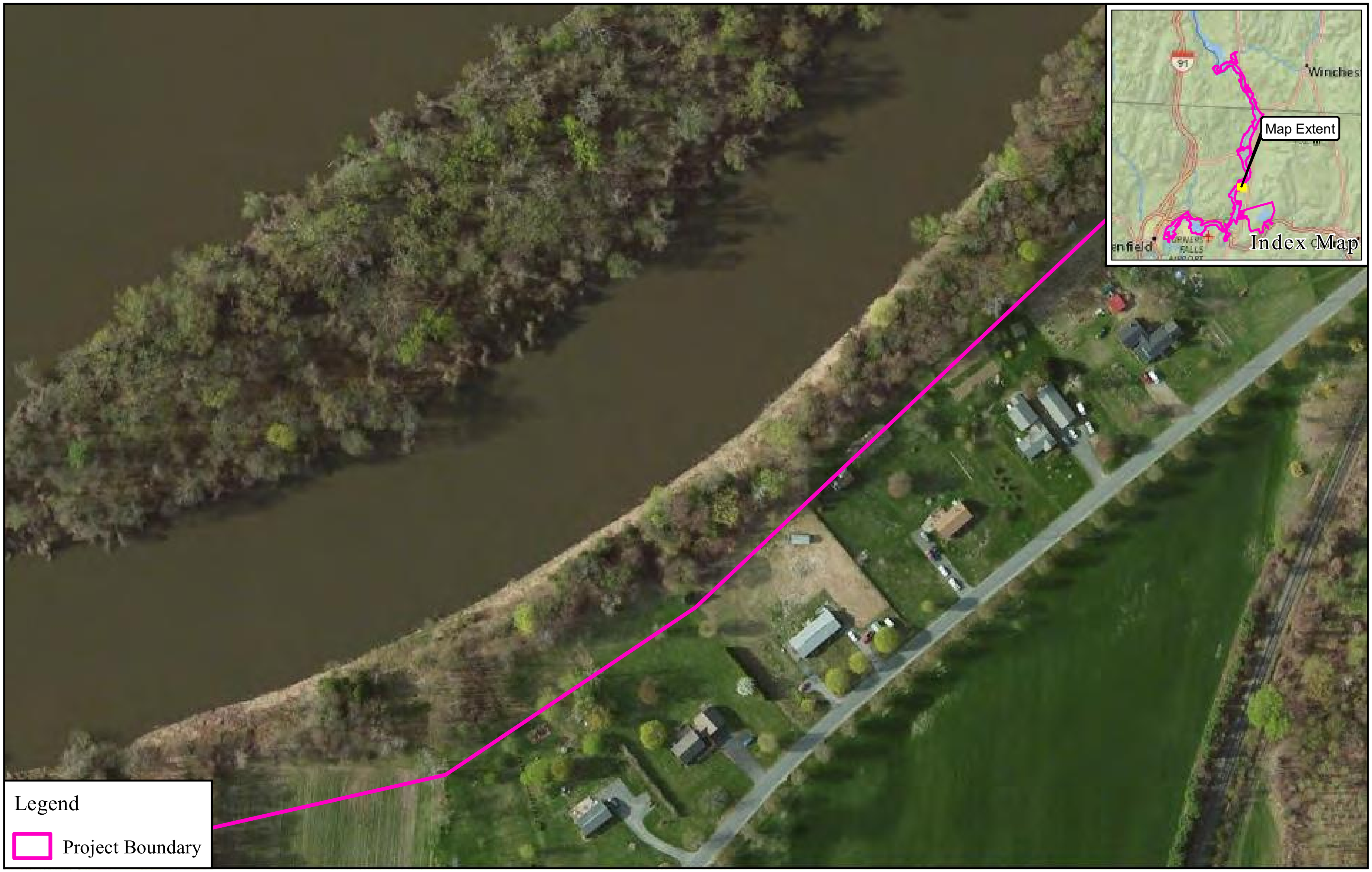
0 0.0175 0.035 0.07 Miles

Skalski
2008-2010 Imagery
(Source: MassGIS)

FirstLight Power Resources

N

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

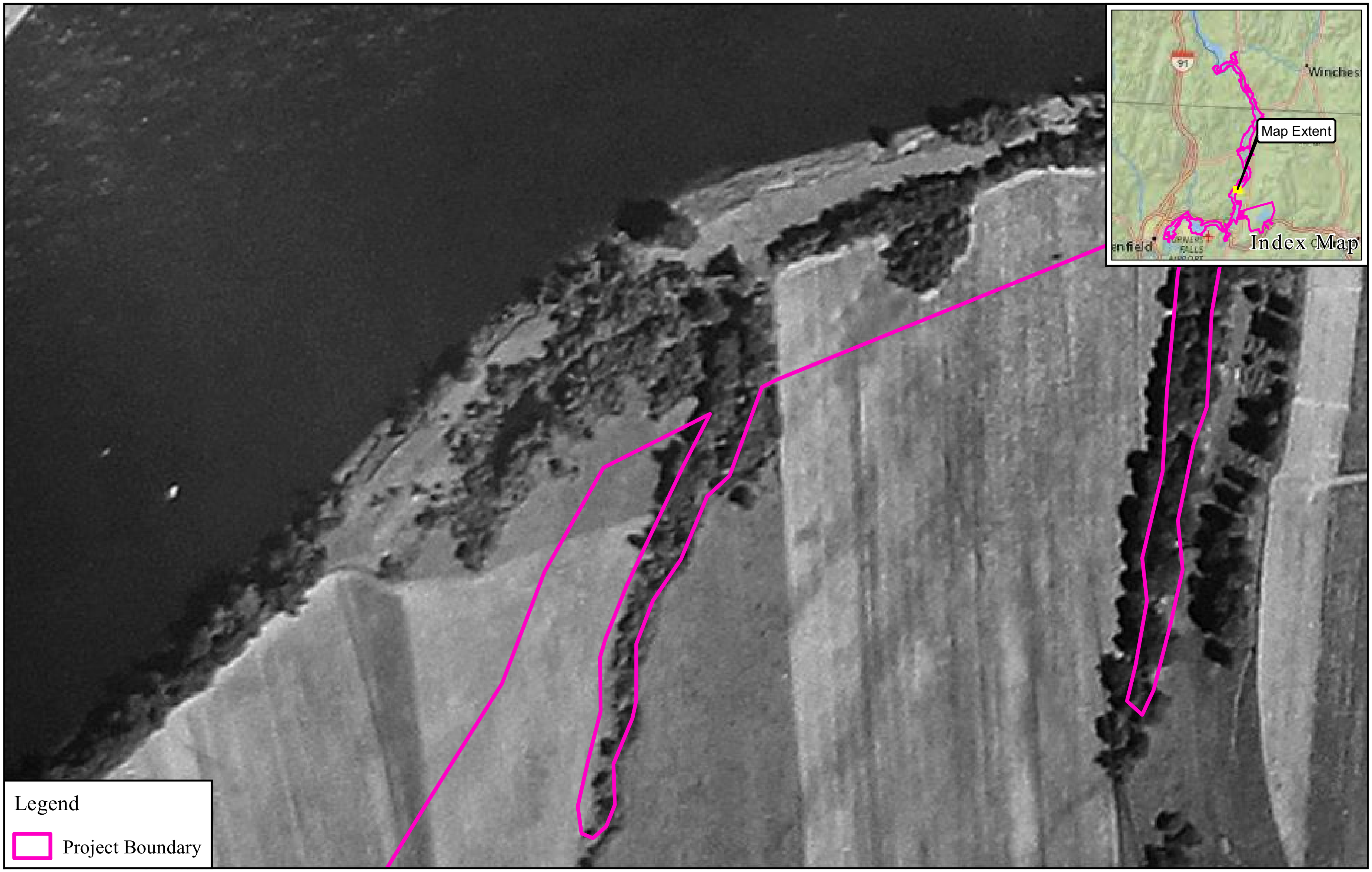
Skalski
2014 Imagery
(Source: NAIP)

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

13 LEFT BANK DOWNSTREAM OF KIDDS ISLAND

On the left bank downstream of Kidds Island the 1952 and 1960s photographs show eroded conditions with little riparian vegetation. By the 1990s, the narrow remnants of a field appear to have been eroded away and into another band of riparian vegetation.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

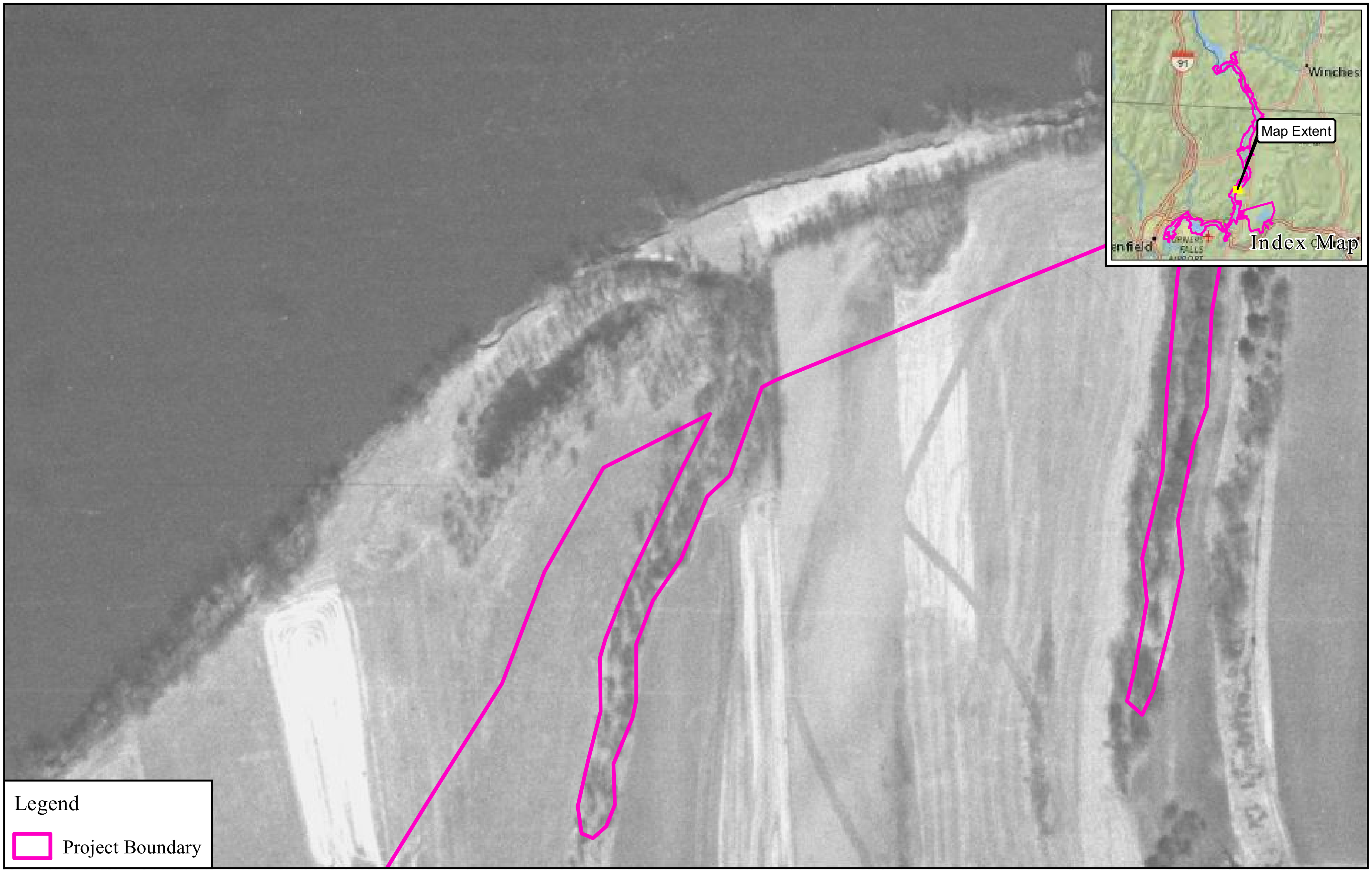
STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Left Bank Downstream of Kidds Island
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Left Bank Downstream of Kidds Island
1960's Imagery
(Source: USGS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

Left Bank Downstream of Kidds Island
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Left Bank Downstream of Kidds Island
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

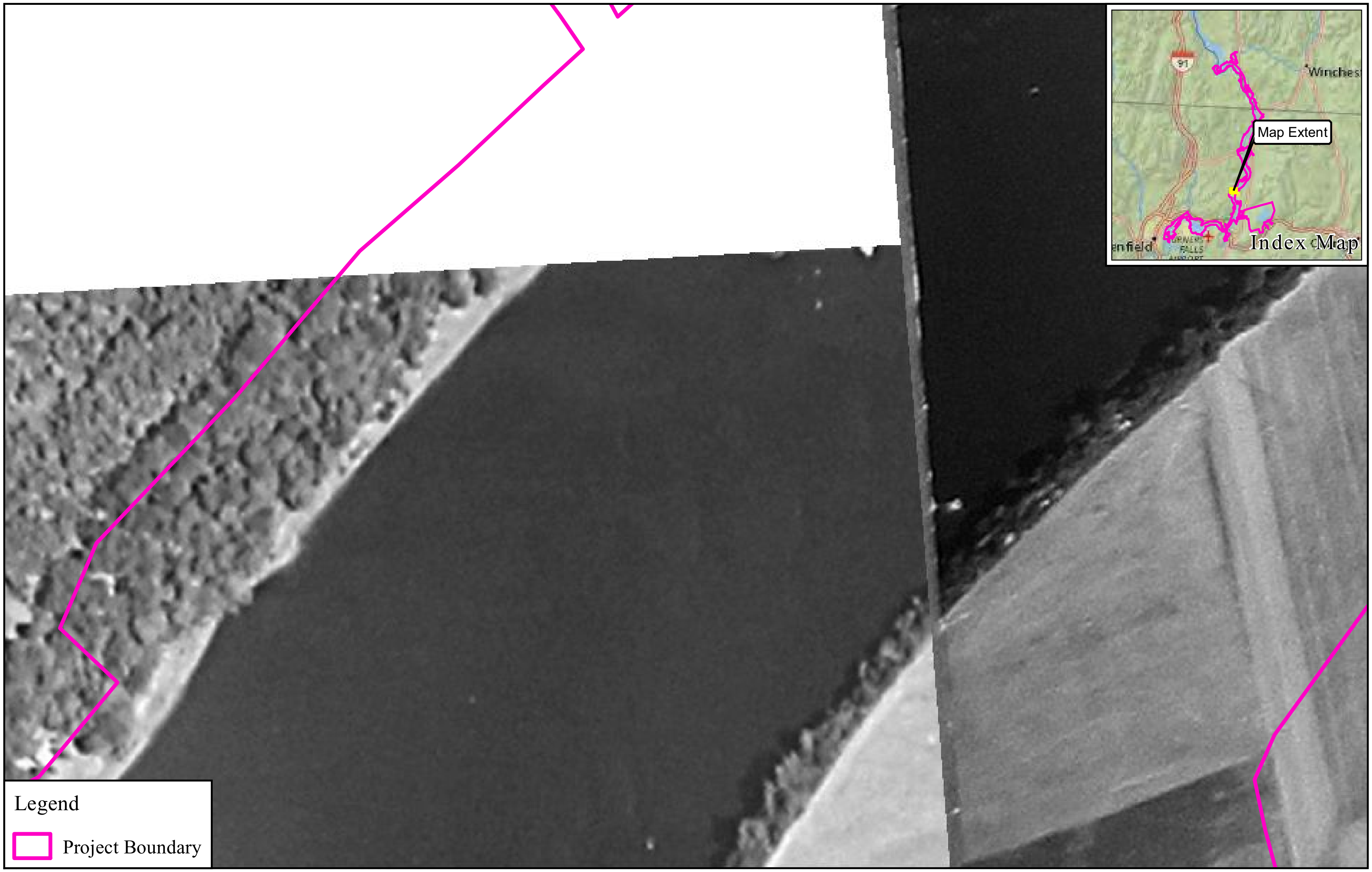
FirstLight Power Resources

Left Bank Downstream of Kidds Island
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

14 L'ETOILE

Another few thousand feet downstream of Kidds Island on the left bank is another area adjacent to an agricultural field with a very narrow band of riparian vegetation which appears to have narrowed over time from 1952 to the 1990s. In 1998 stabilization occurred at what was called the L'Etoile site which can be seen in subsequent photographs.



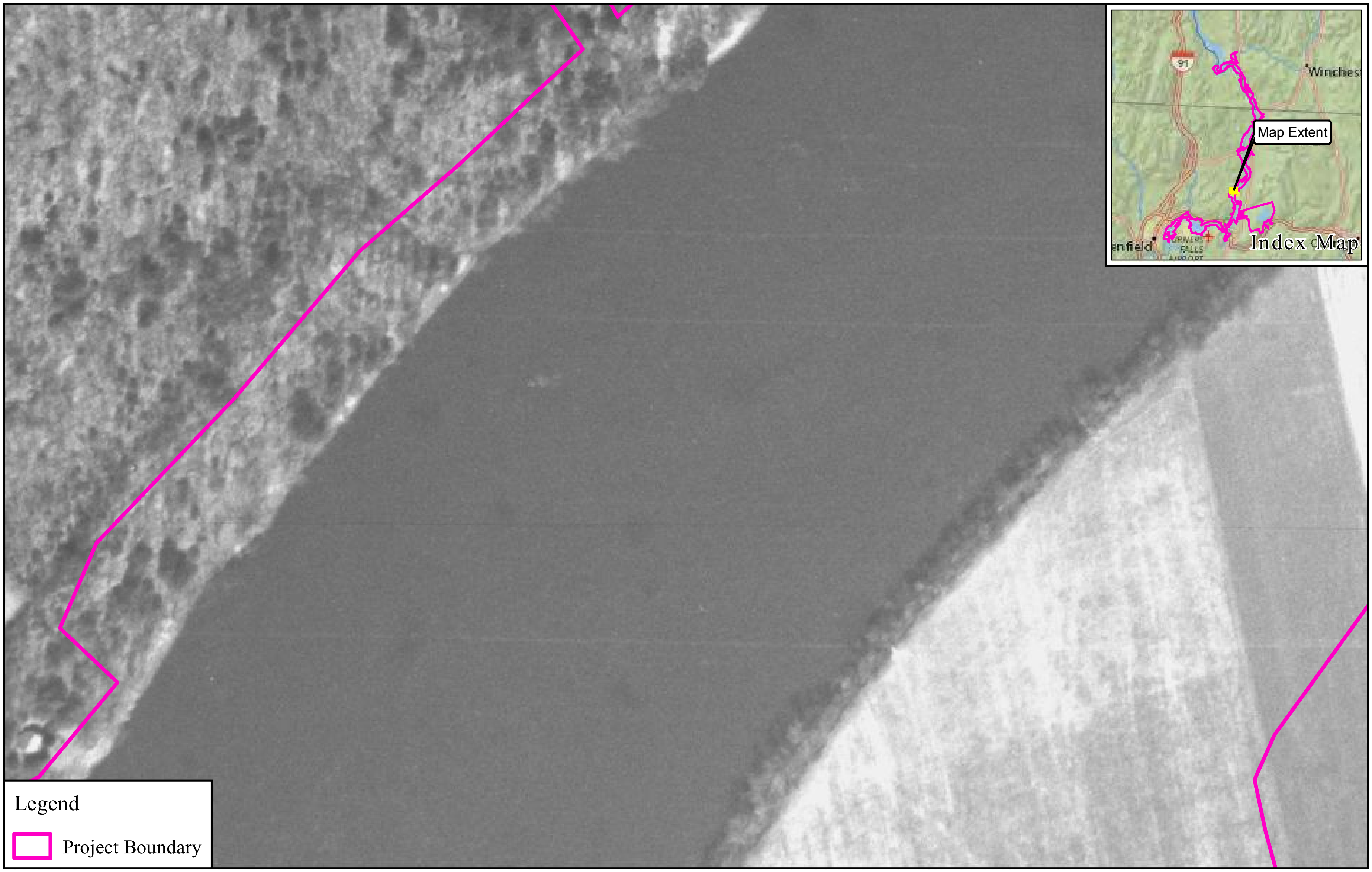
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

L'Etoile
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



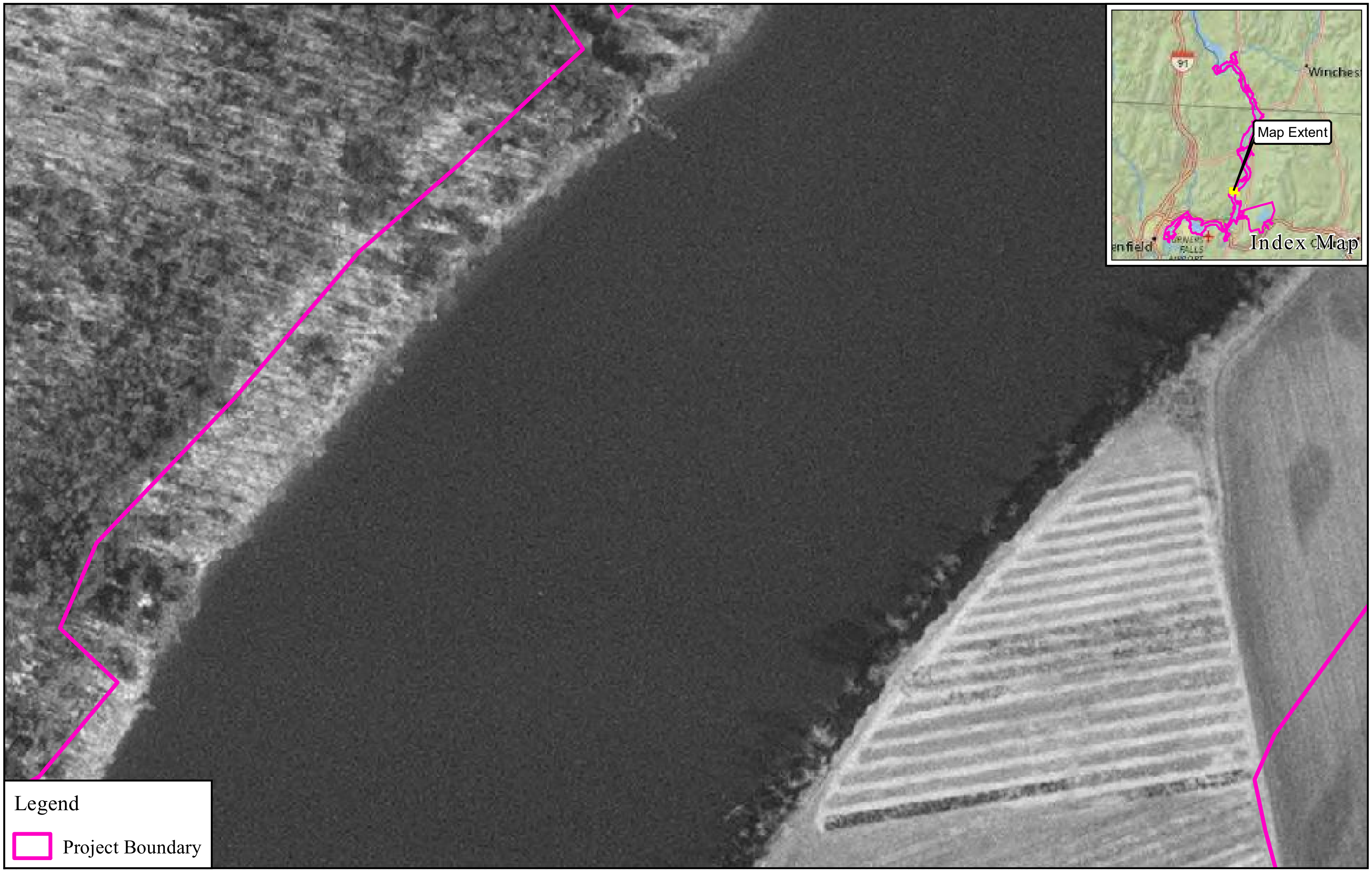
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

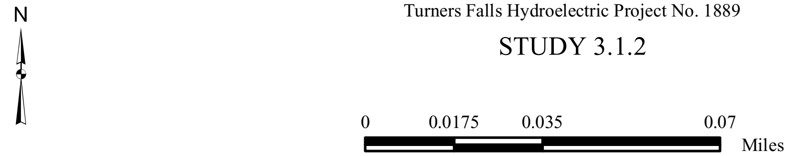
STUDY 3.1.2

L'Etoile
1960's Imagery
(Source: USGS)

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd





FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

L'Etoile
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

L'Etoile
2008-2010 Imagery
(Source: MassGIS)

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

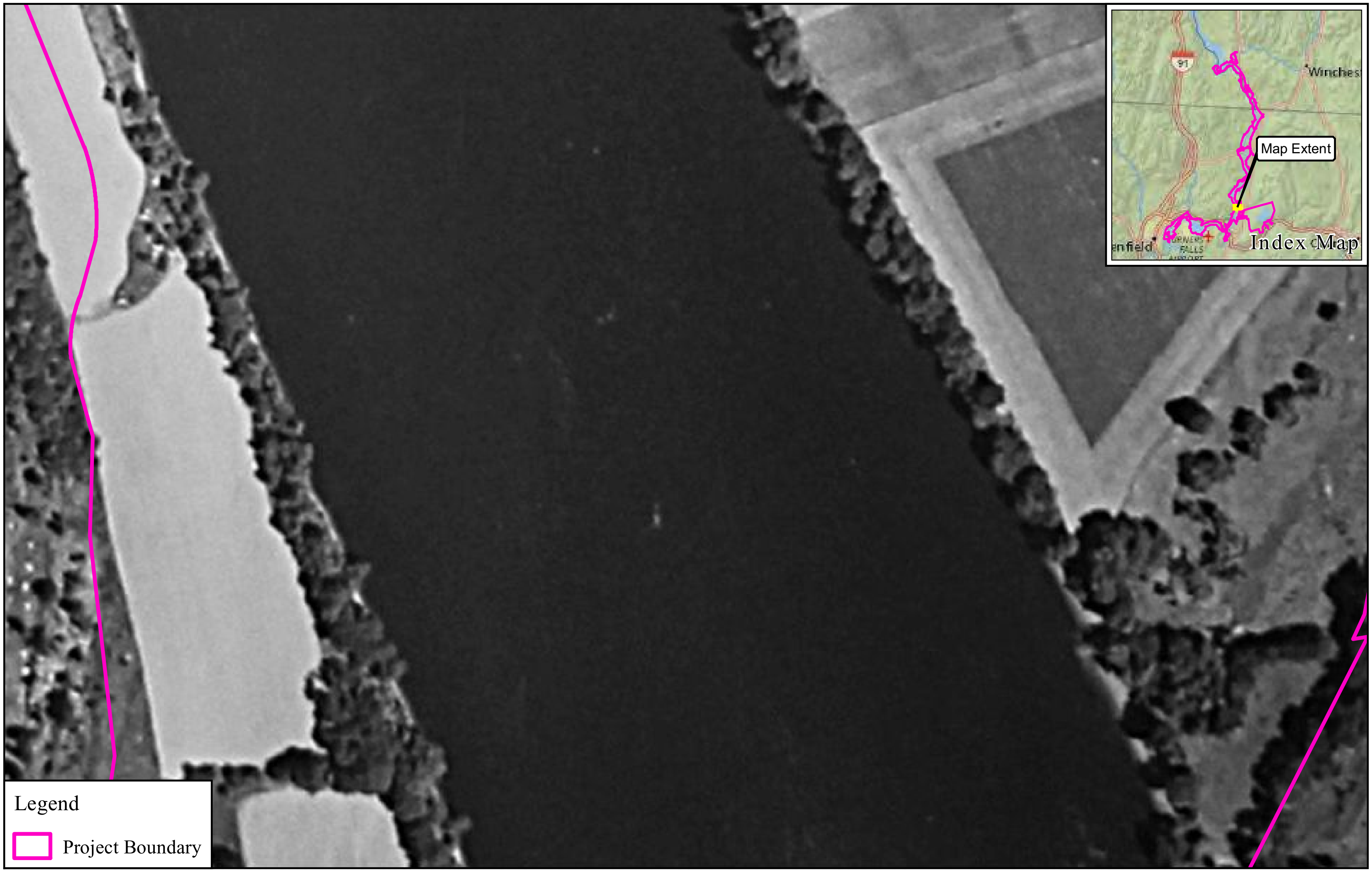
N

L'Etoile
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

15 SHEARER/BATHORY-GALLAGHER

Upstream of the tailrace along both banks there was a band of riparian vegetation in the 1952 photograph. By the 1960s photograph the riparian zone appear to have decreased and erosion is evident. The left bank was stabilized in 1996 (Shearer site) and the right bank was stabilized through the ECP as the Bathory/Gallagher site in 2012 as can be seen on recent photographs.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

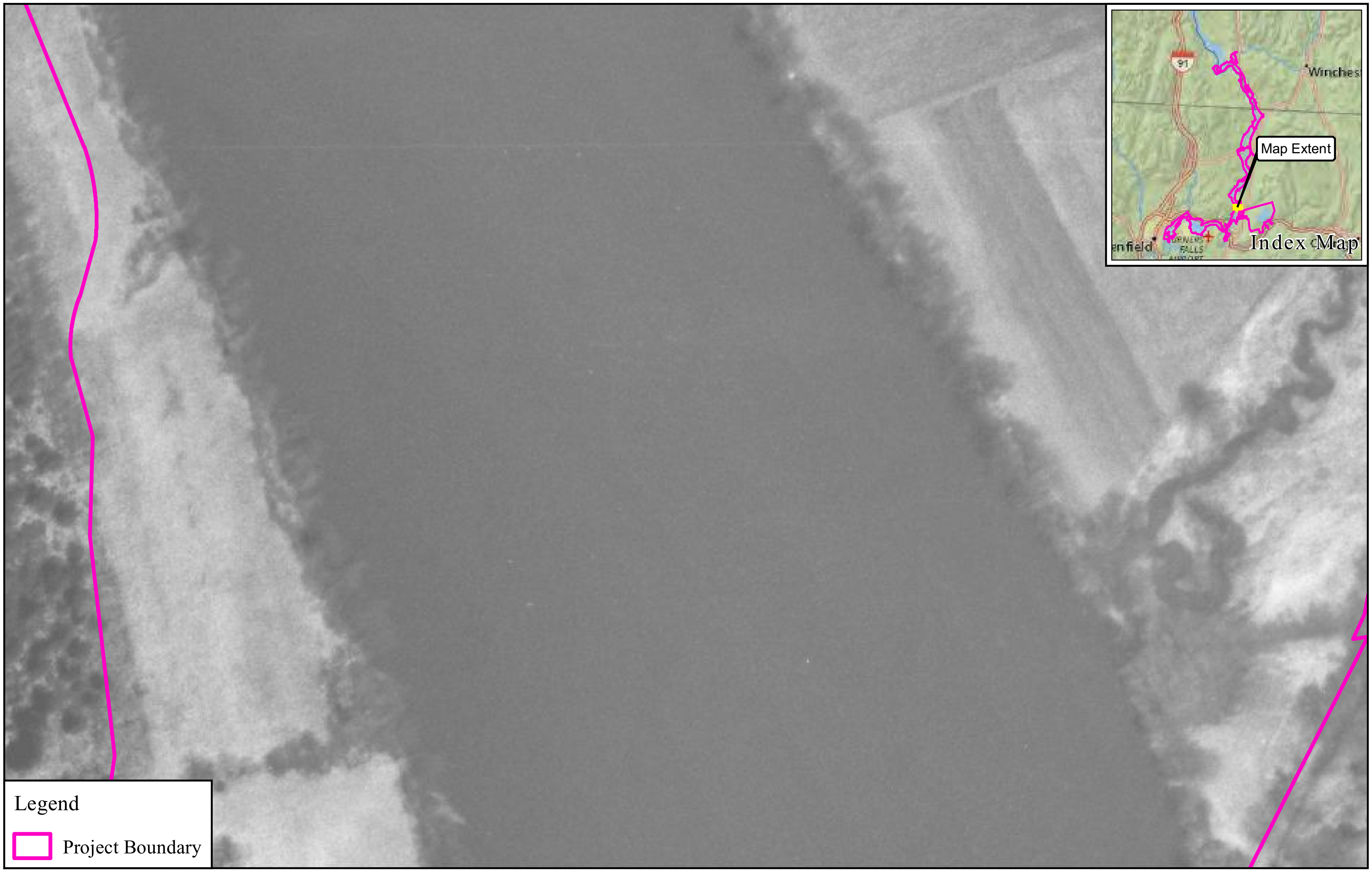
Shearer/Bathory-Gallagher
1952 Imagery
(Source: North by Northeast Survey Company)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Shearer/Bathory-Gallagher
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Legend

Project Boundary

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.0175 0.035 0.07 Miles

Shearer/Bathory-Gallagher
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

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FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Shearer/Bathory-Gallagher
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

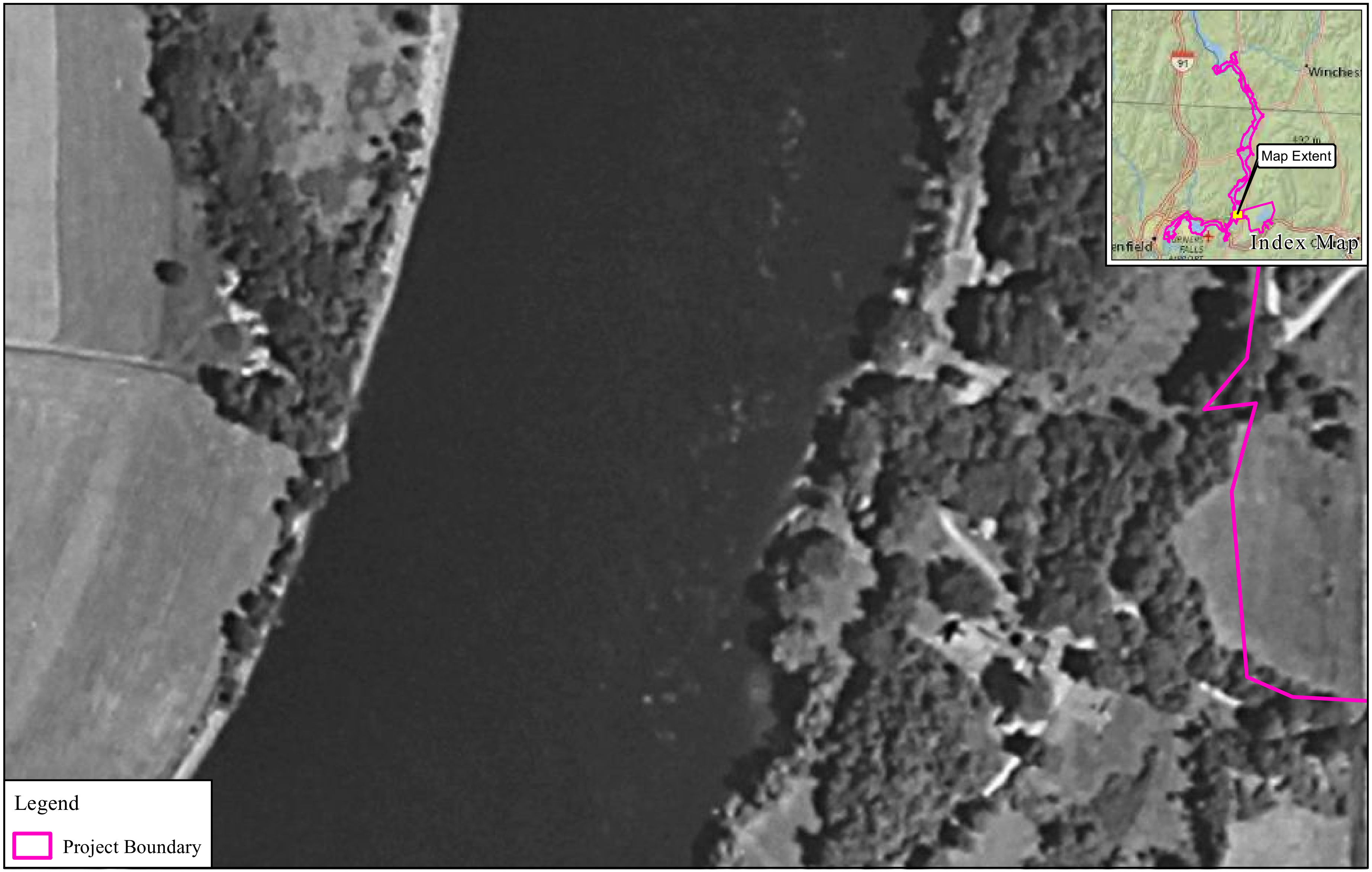
0 0.0175 0.035 0.07 Miles

Shearer/Bathory-Gallagher
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

16 UPPER SPLIT RIVER

The right bank of the river in this location is eroded and has little riparian vegetation in the 1952 and 1960s photographs. The lower part of the photograph of the right bank was stabilized using rock (see discussion of tailrace in next segment) while the upper part of the photograph of the right bank was selected as the Upper Split River site and was stabilized in 2010 using a gravel beach and large woody debris as can be seen on the 2014 photograph.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 0.0175 0.035 0.07 Miles

Upper Split River
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Upper Split River
1960's Imagery
(Source: USGS)

0 0.0175 0.035 0.07 Miles

N

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107   Filed Date: 10/14/2016

FirstLight Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Upper Split River
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Upper Split River
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Upper Split River
2014 Imagery
(Source: NAIP)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

17 NORTHFIELD MOUNTAIN TAILRACE

The right bank across the river from the future tailrace for Northfield Mountain appears to be eroded and devoid of riparian vegetation in the 1952 and 1960s photographs, before the construction of the project. Rock from project construction was used to stabilize this eroded bank during the construction process. The rock has stabilized the toe of the bank and riparian vegetation has become established above the rock.

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

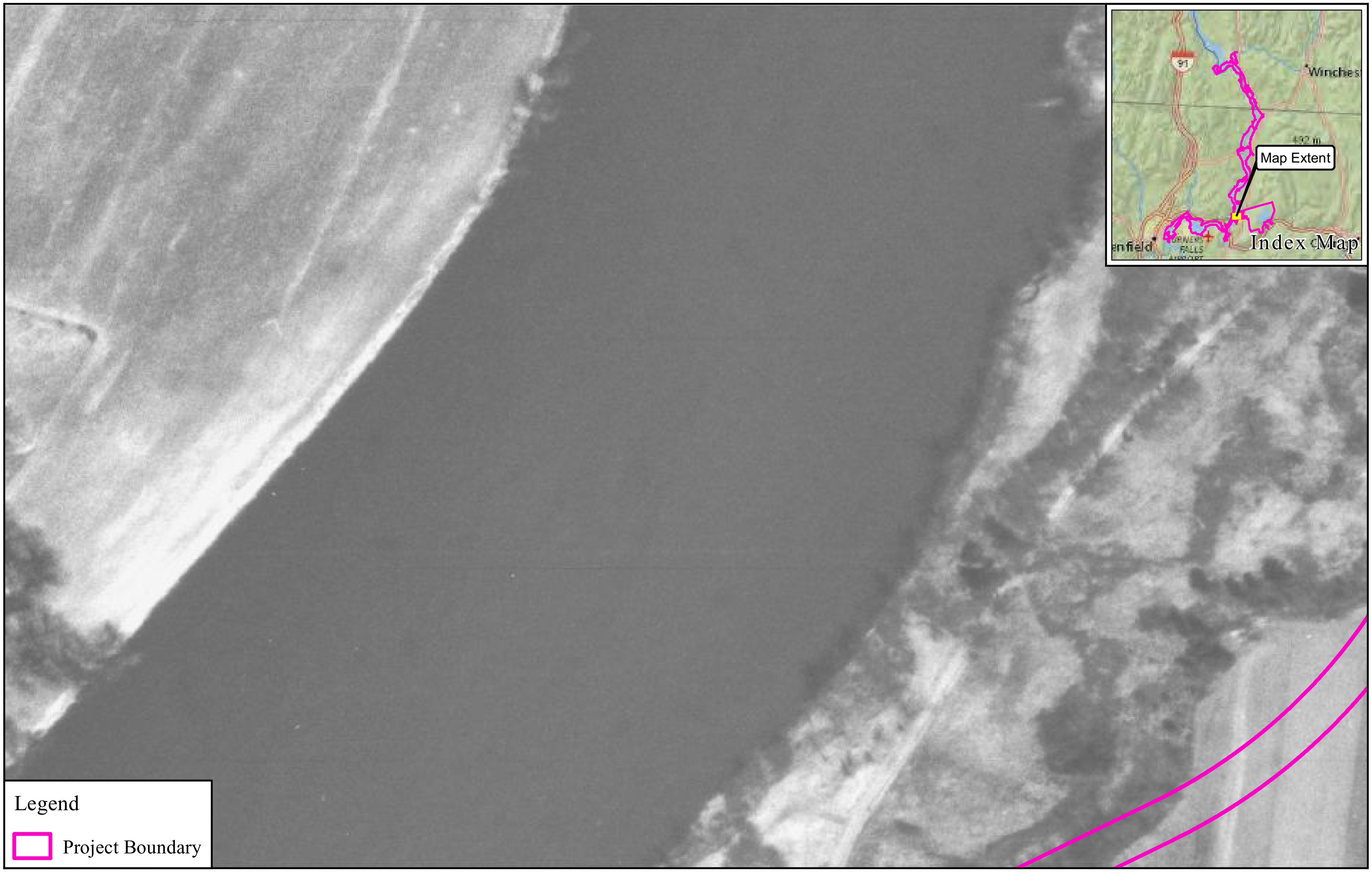
N

0 0.0175 0.035 0.07 Miles

Northfield Mountain Tailrace
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107   Filed Date: 10/14/2016



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

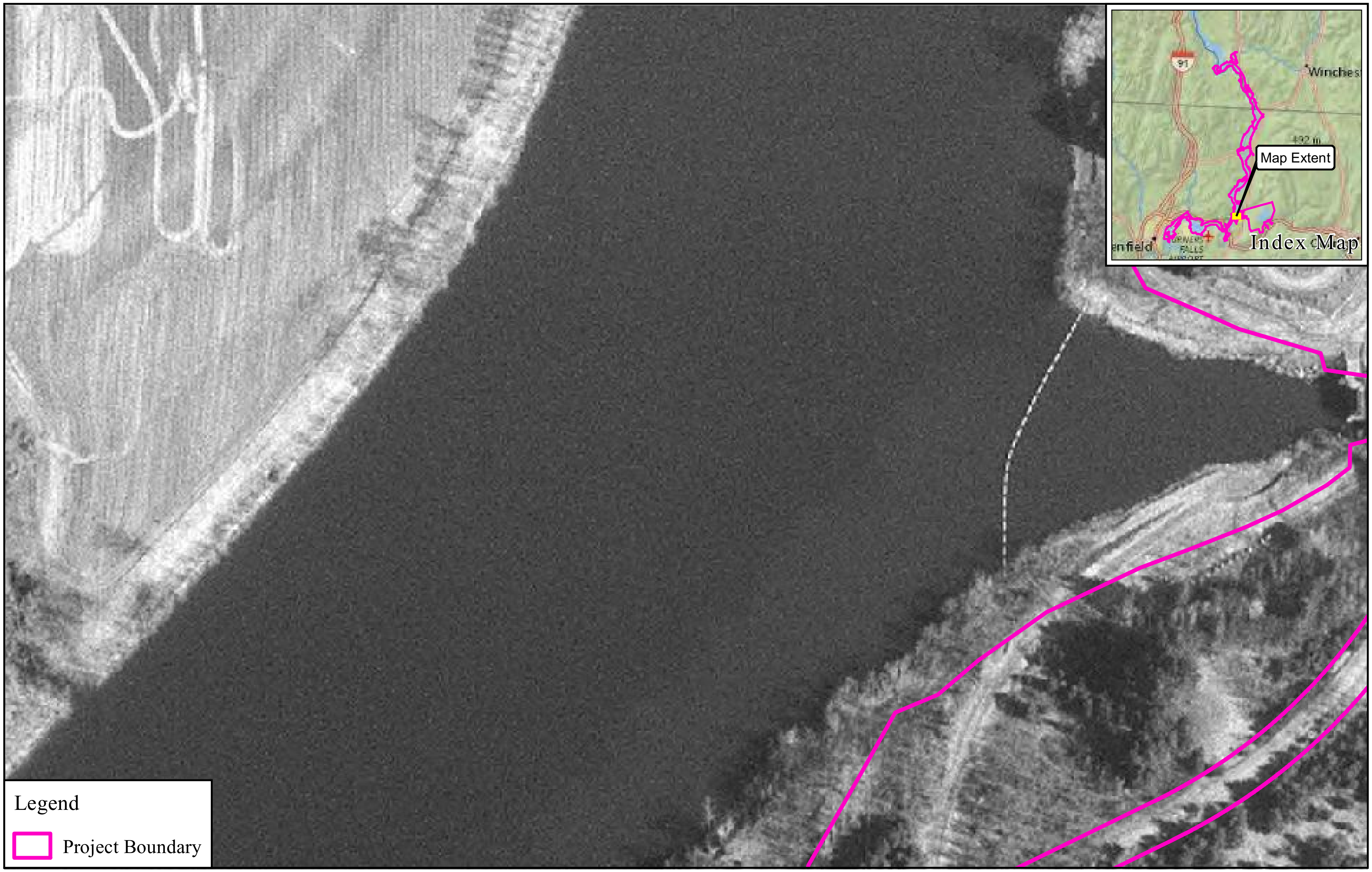
0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Northfield Mountain Tailrace
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Northfield Mountain Tailrace
1990's Imagery
(Source: MassGIS)

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

FirstLight Power Resources

Northfield Mountain Tailrace
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107   Filed Date: 10/14/2016

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

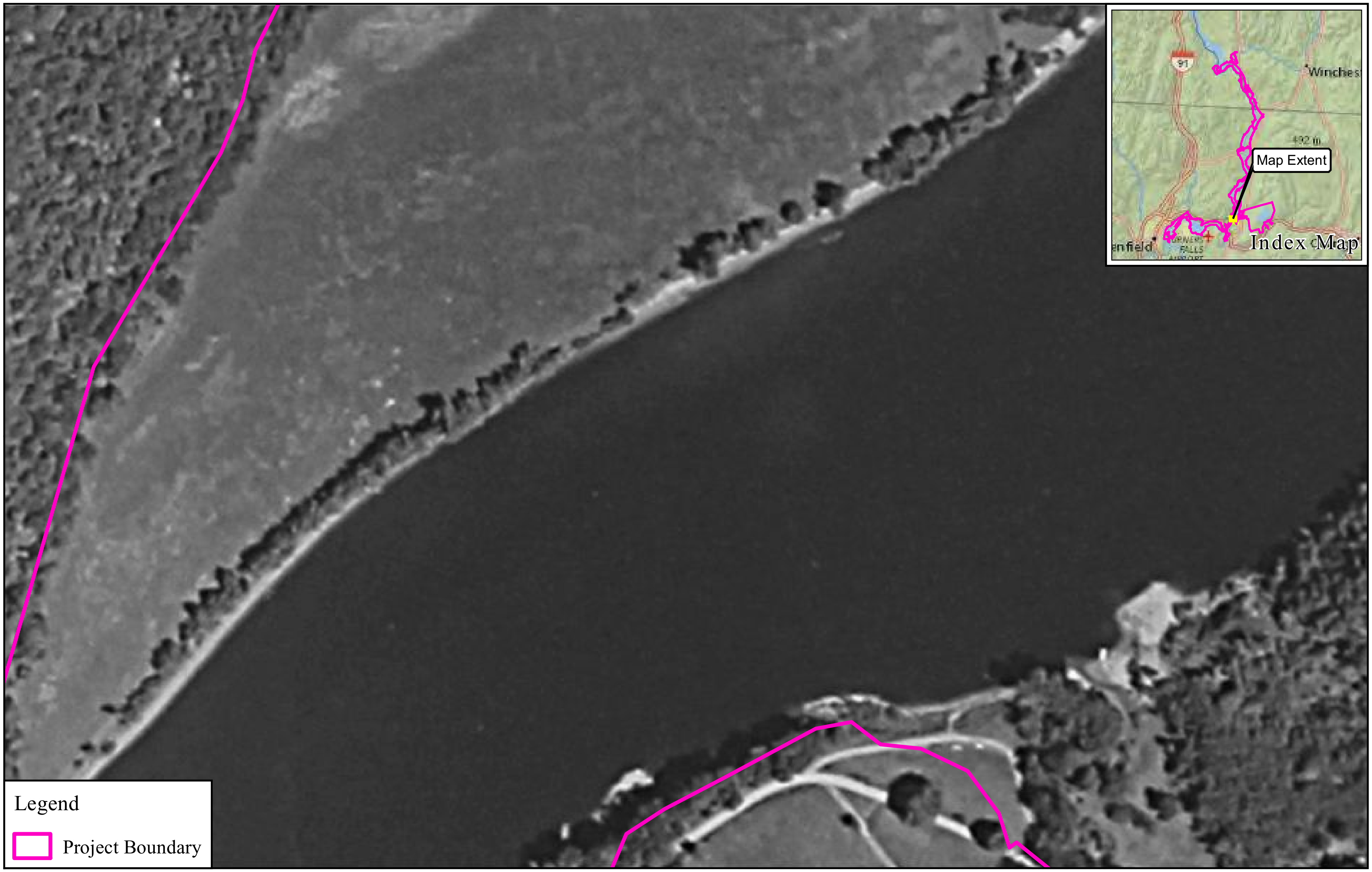
0   0.0175   0.035   0.07
Miles

Northfield Mountain Tailrace
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

18 LOWER SPLIT RIVER/DURKEE POINT

The right bank in the 1952 photograph is sparsely vegetated with apparent erosion as is a segment of the left bank. By the 1960s photographs erosion of the left bank segment is apparent while the right bank remains sparsely vegetated with some erosion. The right bank sight is called the Lower Split River site which was stabilized in 2009 and the left bank segment is called Durkee Point and was stabilized in 2003, both through implementation of the ECP.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

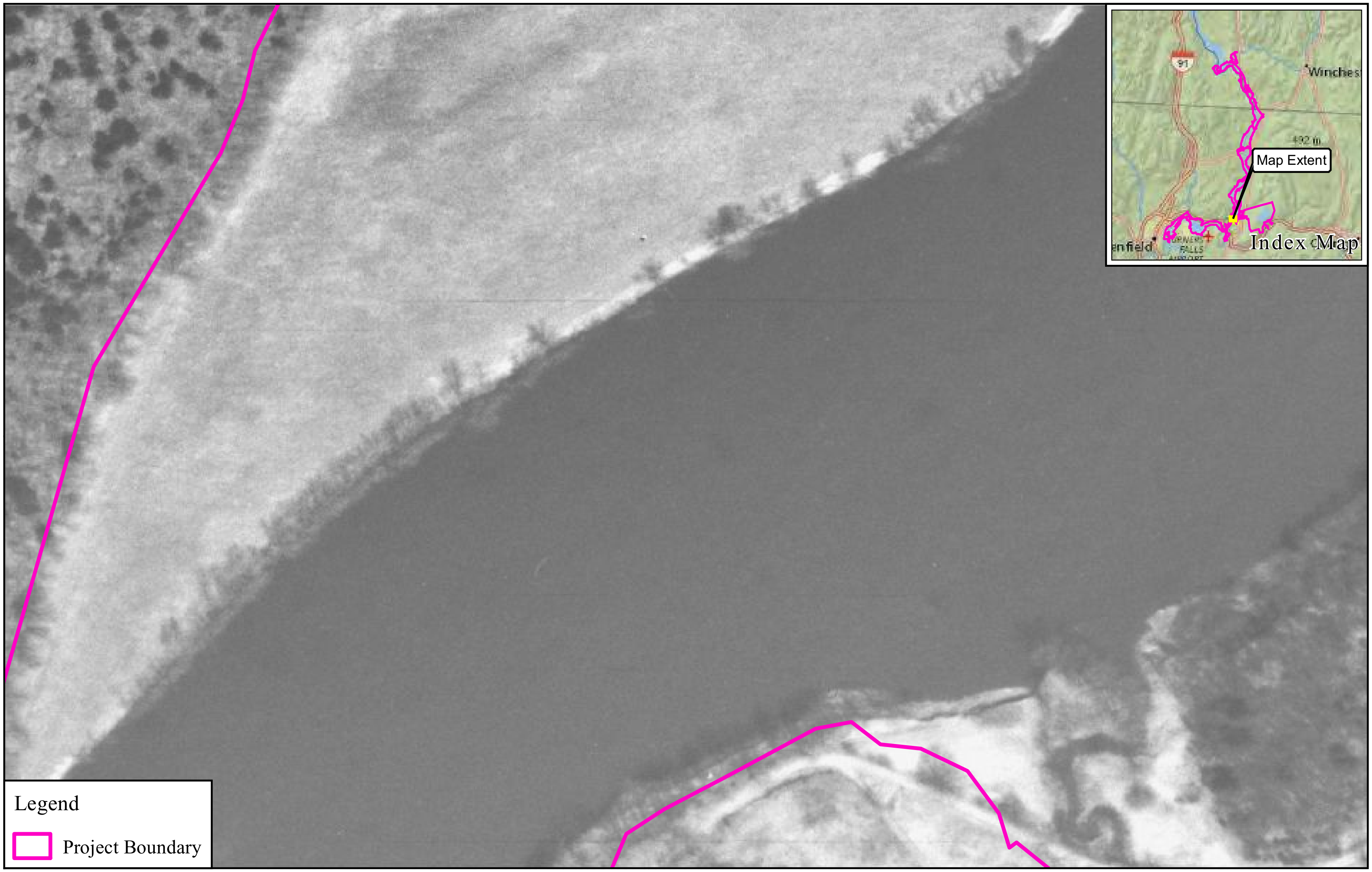
Lower Split River
1952 Imagery
(Source: North by Northeast Survey Company)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Lower Split River
1960's Imagery
(Source: USGS)

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Lower Split River
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

Lower Split River
2008-2010 Imagery
(Source: MassGIS)

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107 Filed Date: 10/14/2016

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

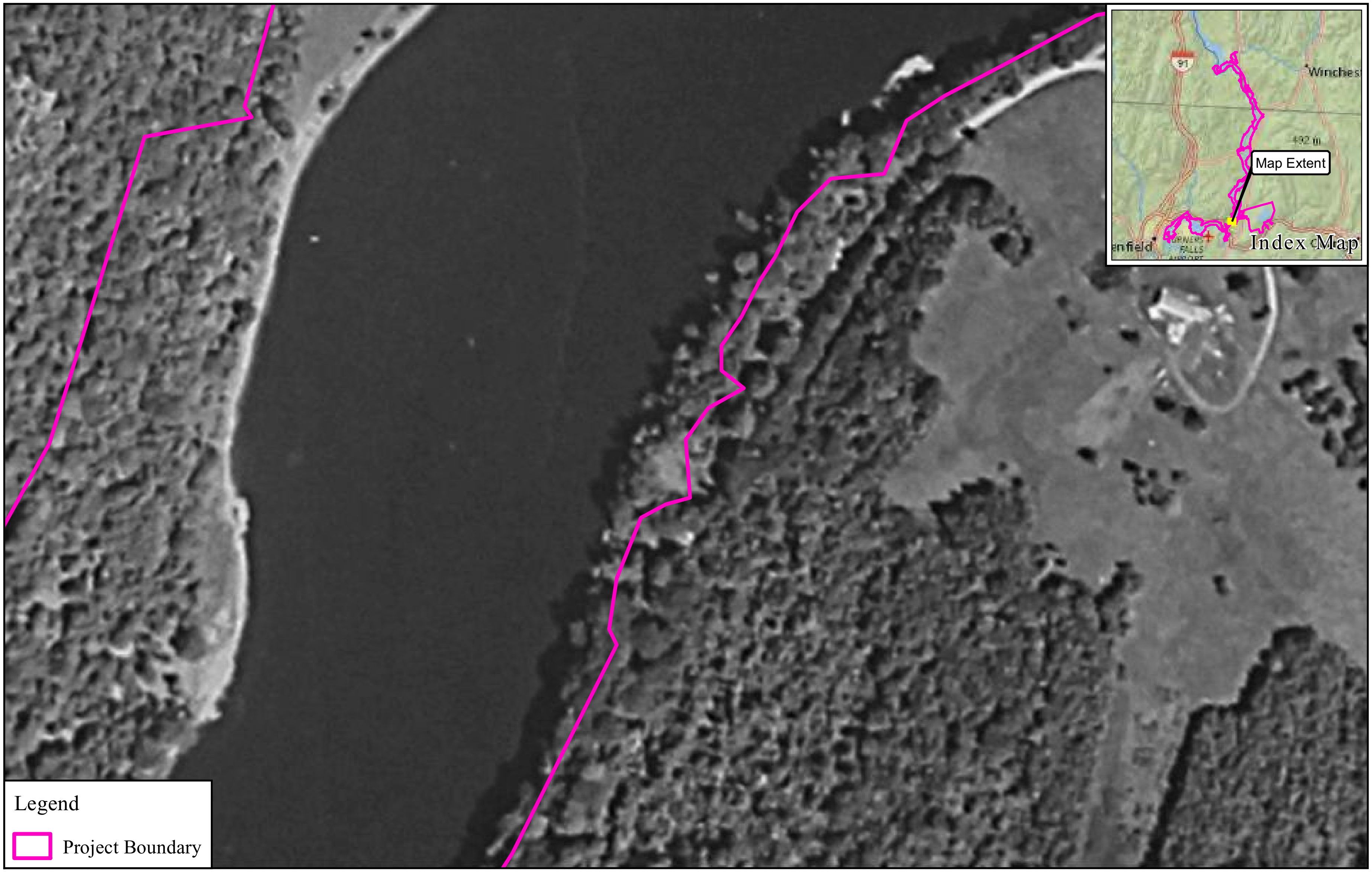
0 0.0175 0.035 0.07 Miles

Lower Split River
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

19 RIVER ROAD

On the inside of the bend along the left bank erosion has occurred over time with the bank moving landward compared to the project boundary line as noted in changes in the bank from the 1952 to 1960s and subsequent photographs. This area was stabilized in 2003 through the ECP and is called the River Road Site.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

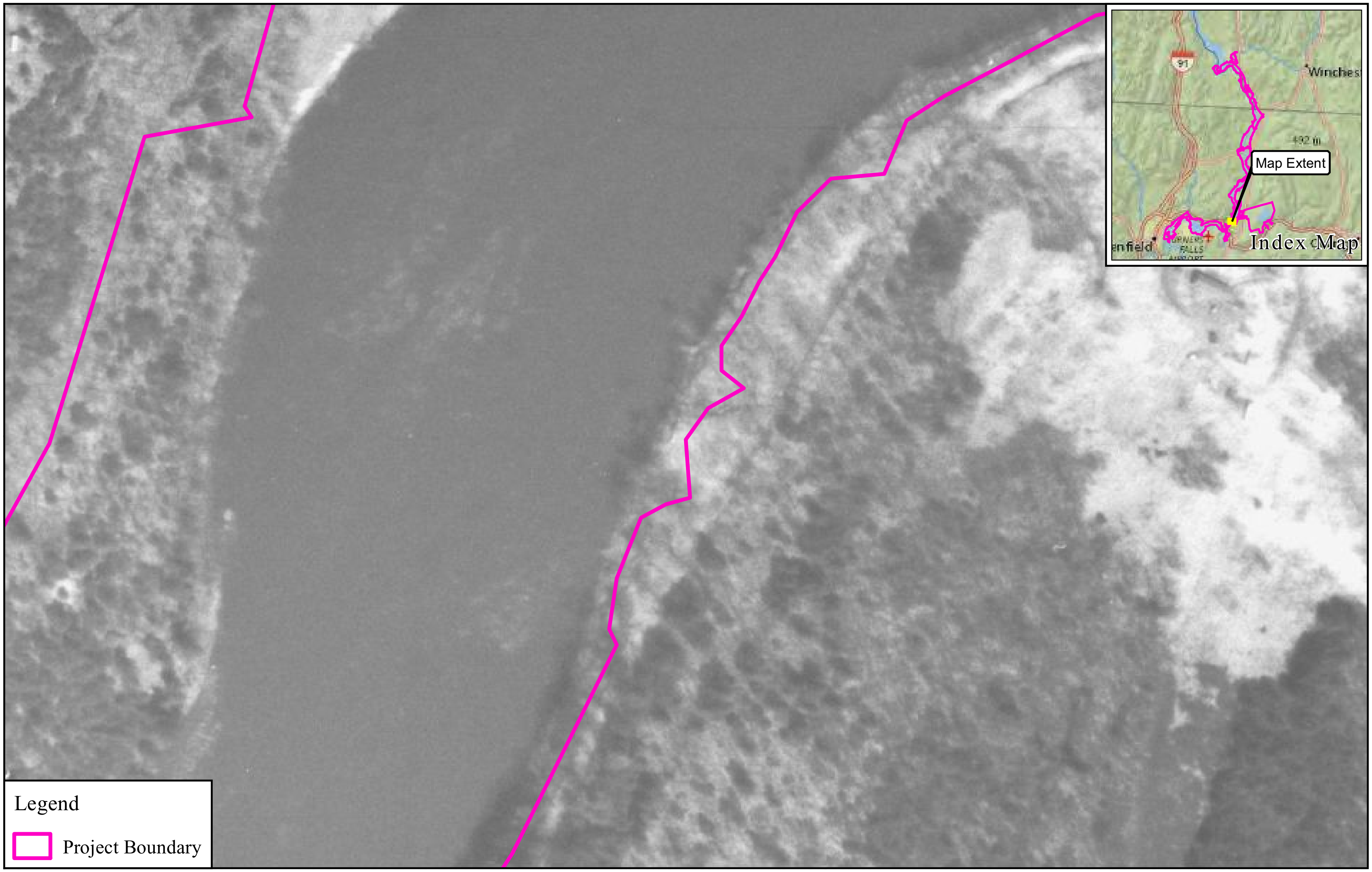
N

0 0.0175 0.035 0.07 Miles

River Road
1952 Imagery
(Source: North by Northeast Survey Company)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107 Filed Date: 10/14/2016



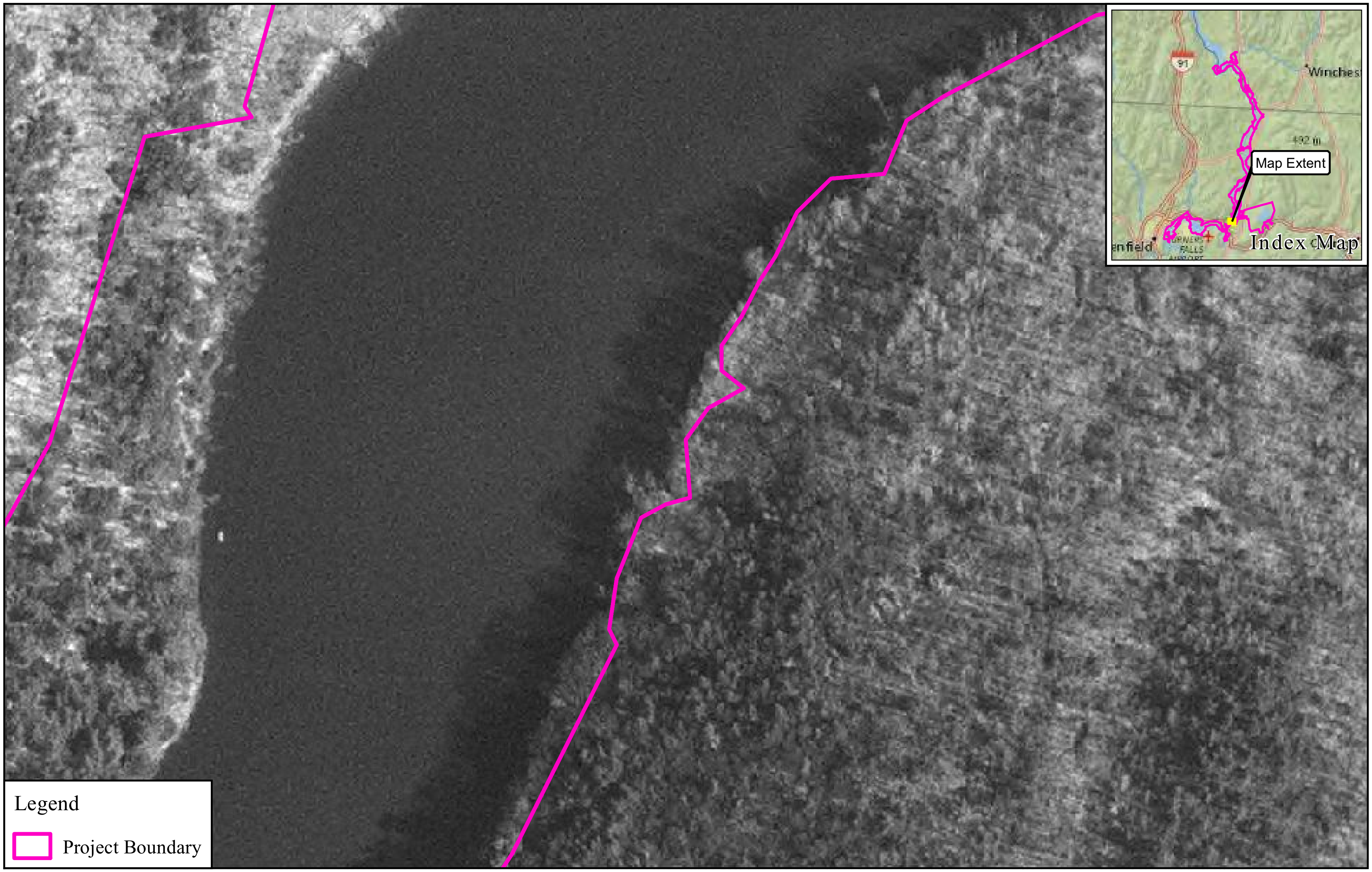
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

River Road
1960's Imagery
(Source: USGS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

River Road
1990's Imagery
(Source: MassGIS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

N

River Road
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

Document Accession #: 20161014-5107 Filed Date: 10/14/2016

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

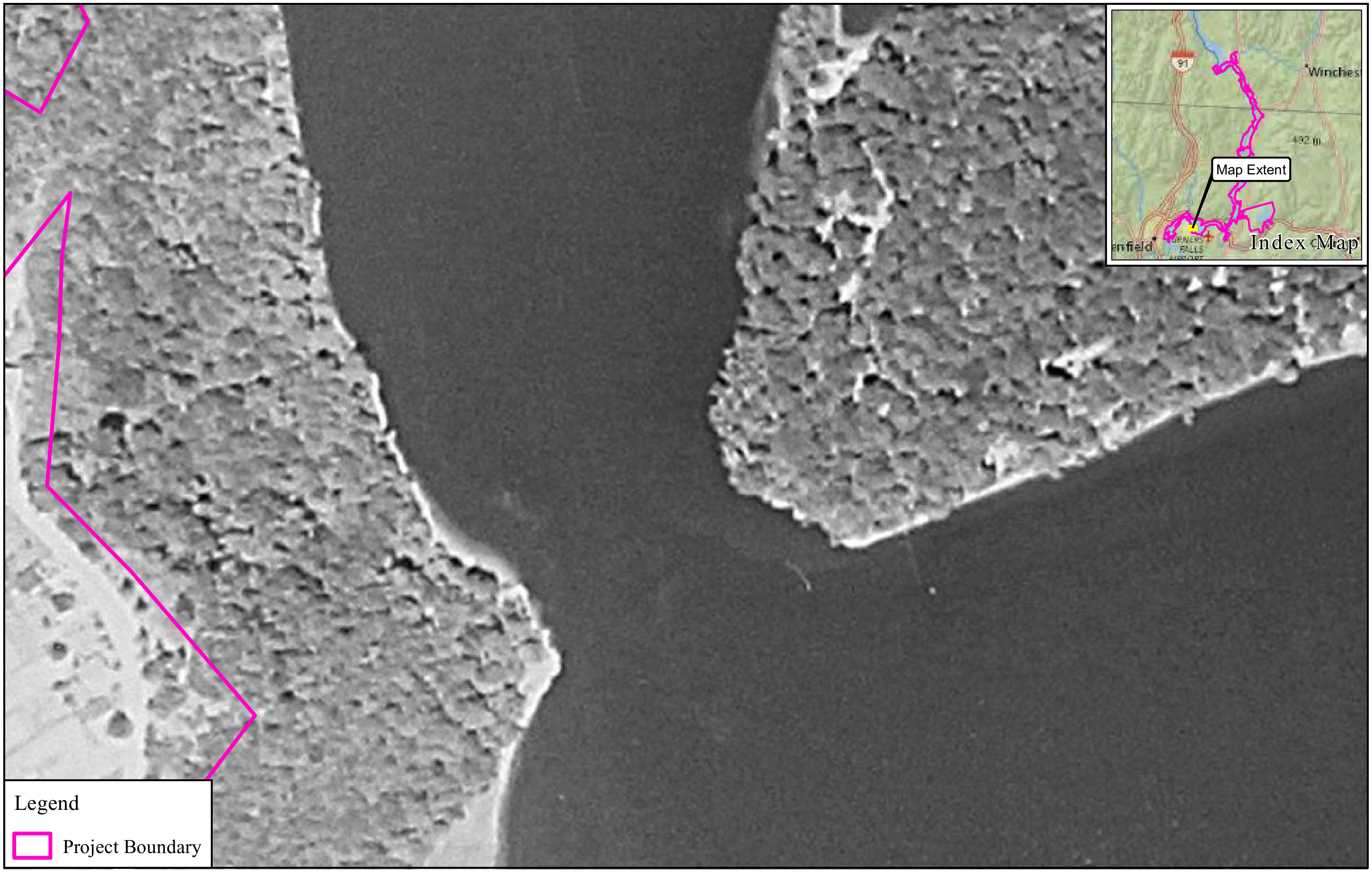
N

River Road
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

20 CAMPGROUND POINT

Campground Point is the peninsula that separates Barton Cove from the reach of river leading upstream to French King Gorge. Some erosion is evident in the earlier photographs such as 1952 continuing through the 2008 photograph, when it was stabilized as part of the ECP in 2008 as the Campground Point Site. The 2014 photograph shows an increase in vegetation on the stabilized site.



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

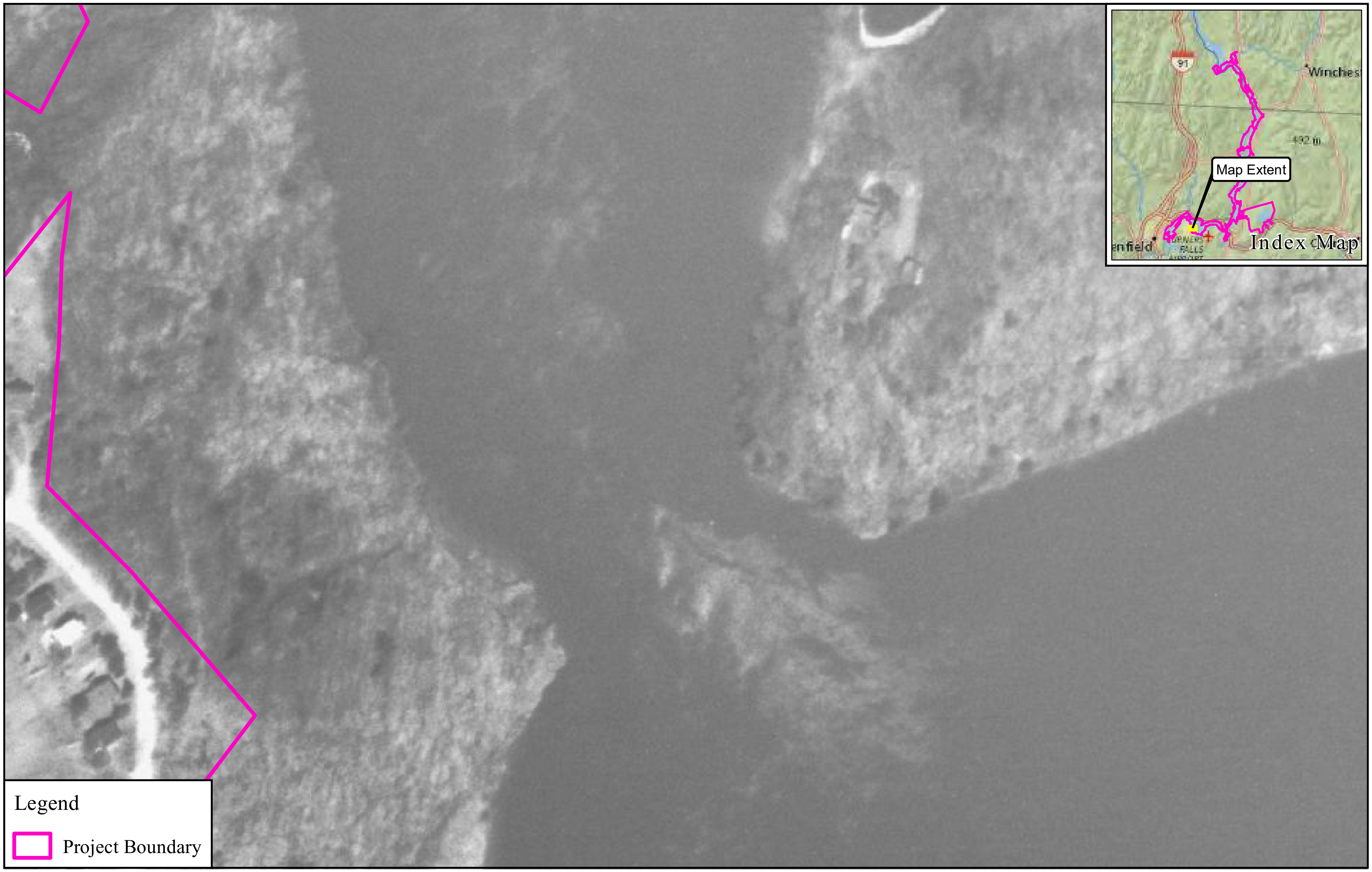
0 0.0175 0.035 0.07 Miles

N

Campground Point
1952 Imagery
(Source: North by Northeast Survey Company)

FirstLight Power Resources

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

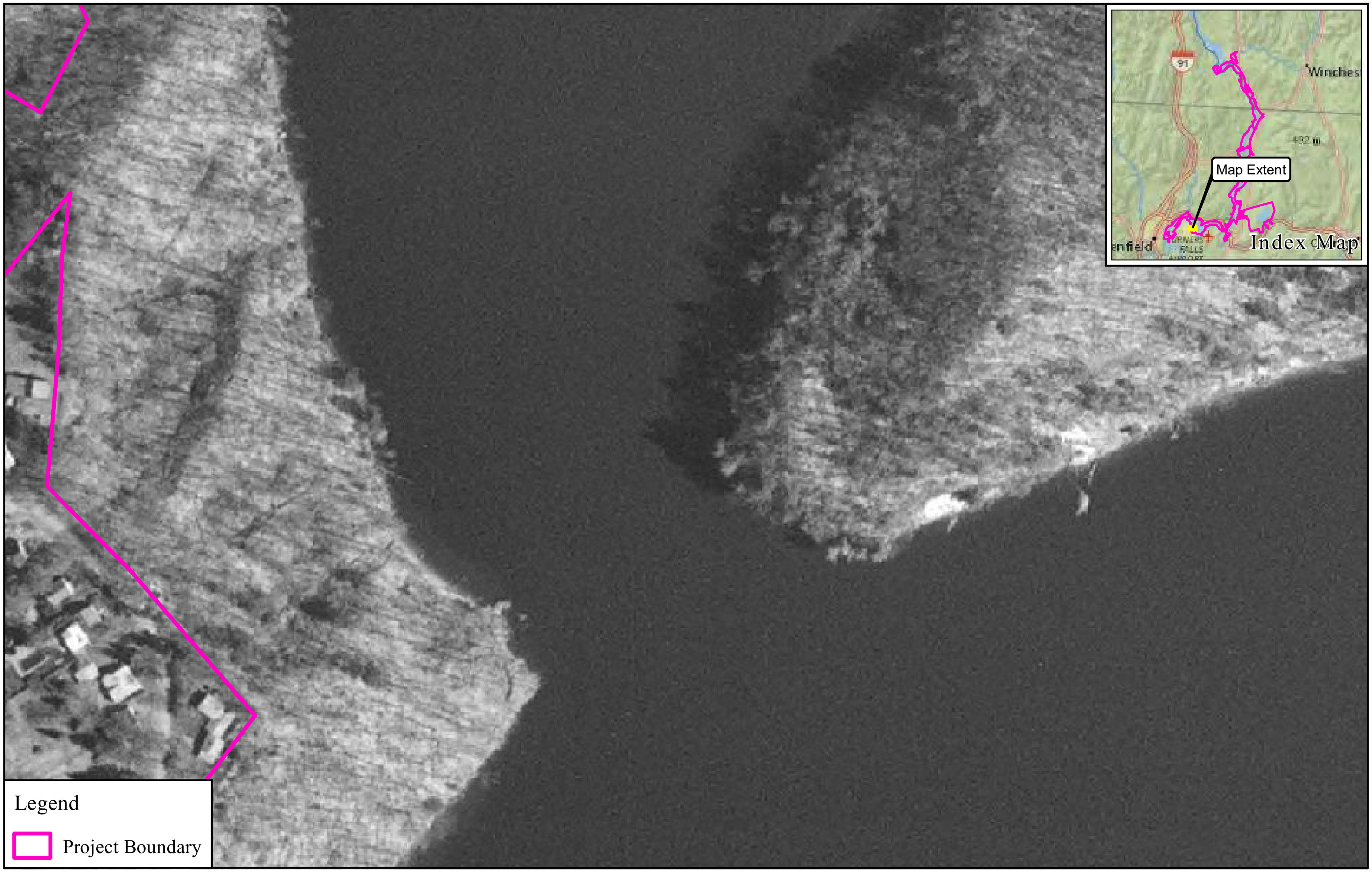
Campground Point
1960's Imagery
(Source: USGS)

FirstLight Power Resources

N

0 0.0175 0.035 0.07 Miles

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Campground Point
1990's Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Campground Point
2008-2010 Imagery
(Source: MassGIS)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

FirstLight Power Resources

N

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

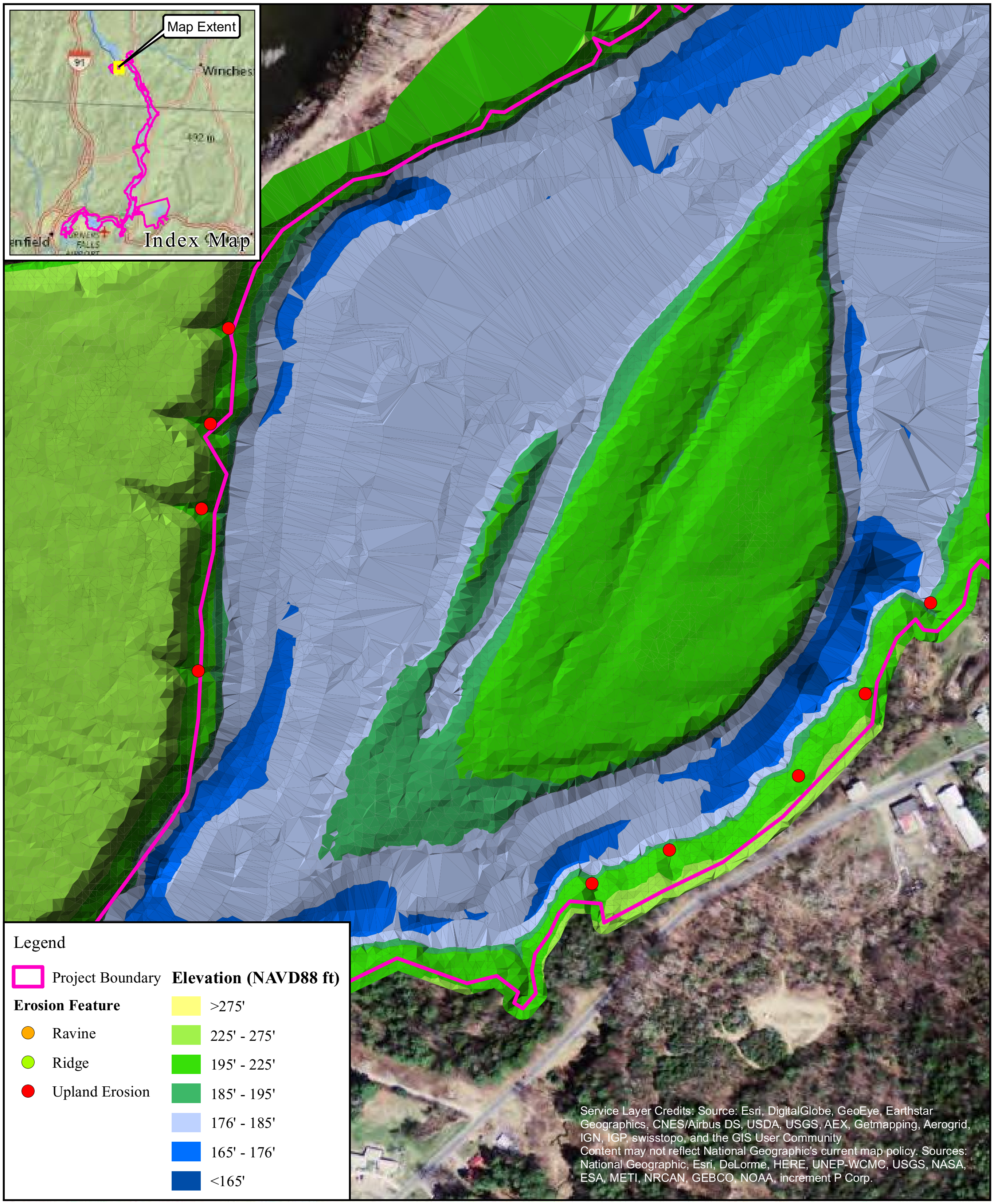
STUDY 3.1.2

0 0.0175 0.035 0.07 Miles

Campground Point
2014 Imagery
(Source: NAIP)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_b.mxd

APPENDIX C – UPLAND EROSION FEATURES



FirstLight Power Resources

N

0 200 400 800 Feet

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

C-1 Upland Erosion near Stebbins Island

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd

Figure C-2 Right bank upstream-most upland erosion feature (Stream)

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

C-3 Ravine Erosional Feature

N

0 200 400 800 Feet

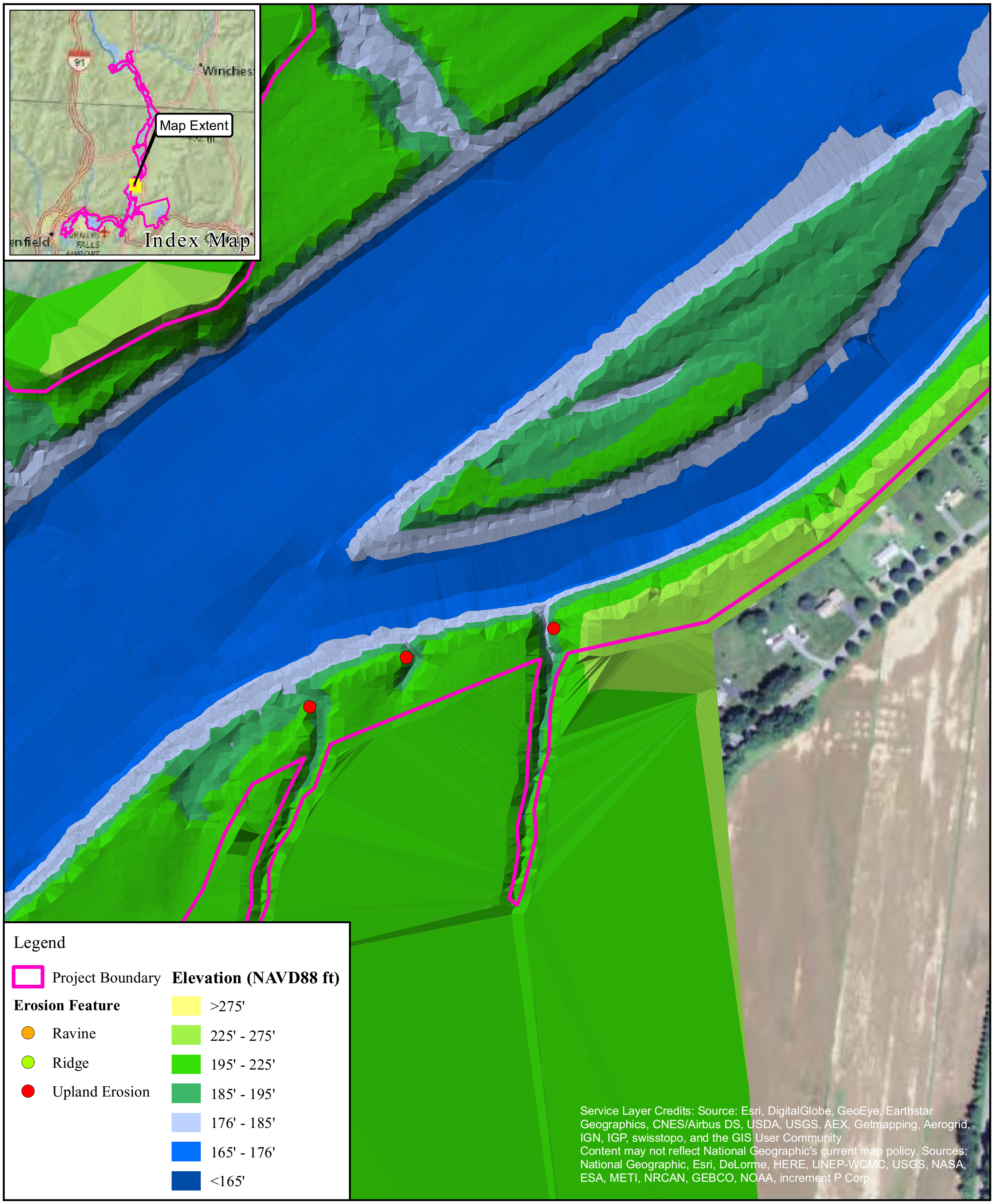
Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd

Figure C-4. Looking downhill into ravine (Photo 272, 9/29/2015)

Figure C-5. From ravine looking uphill (Photo 288, 9/29/2015)

Figure C-6 From second ravine looking uphill (Photo 316, 9/29/2015)

Figure C-7 Divide between two ravines (Photo 325, 9/29/2015)



FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

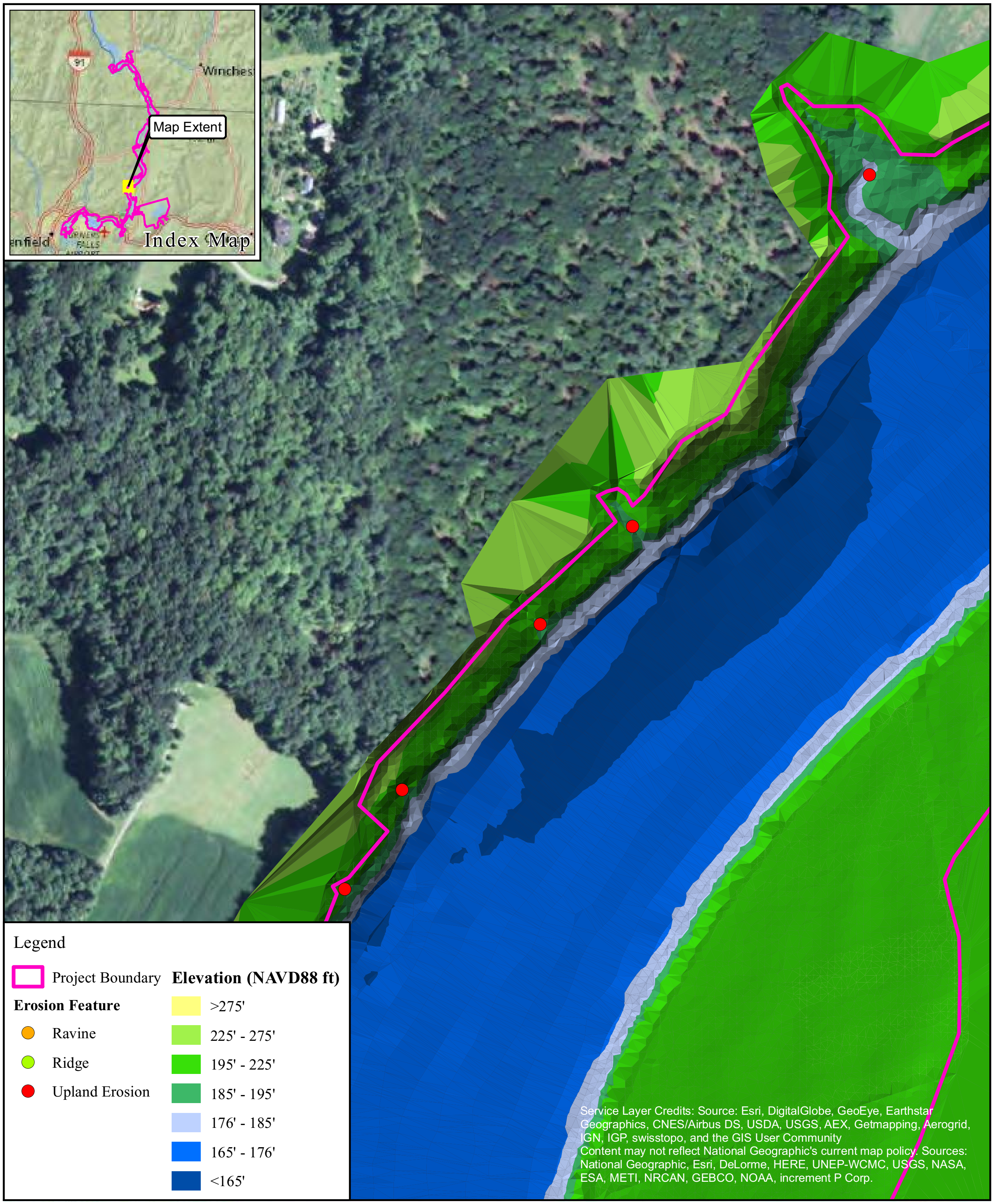
STUDY 3.1.2

N

0 200 400 800 Feet

C-8 Upland Erosion Near Kidds Island (Left Bank)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd



FirstLight Power Resources

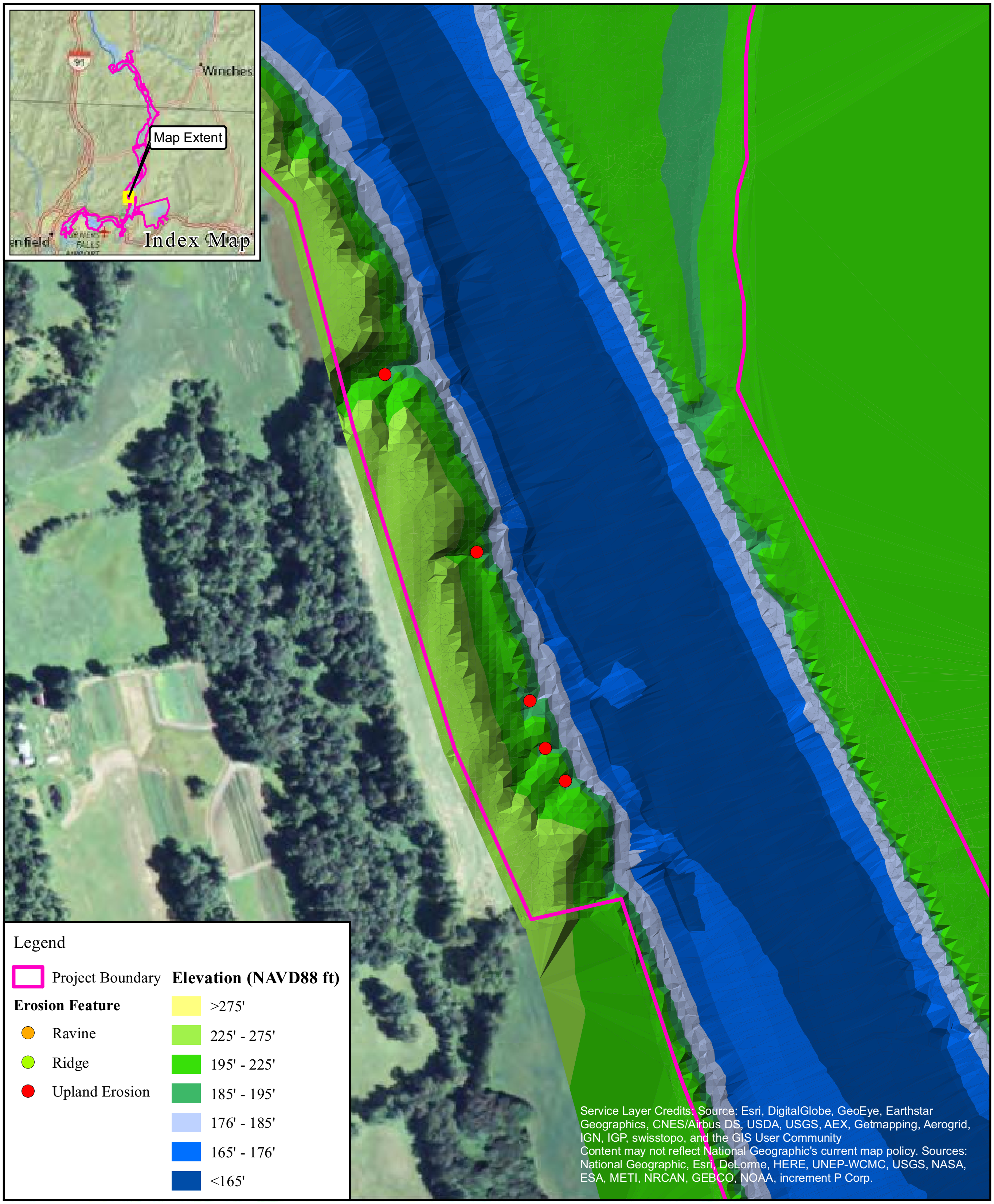
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

C-9 Upland Erosion Downstream of Kidds Island (Right Bank)

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd

Document Accession #: 20161014-5107   Filed Date: 10/14/2016



FirstLight Power Resources

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

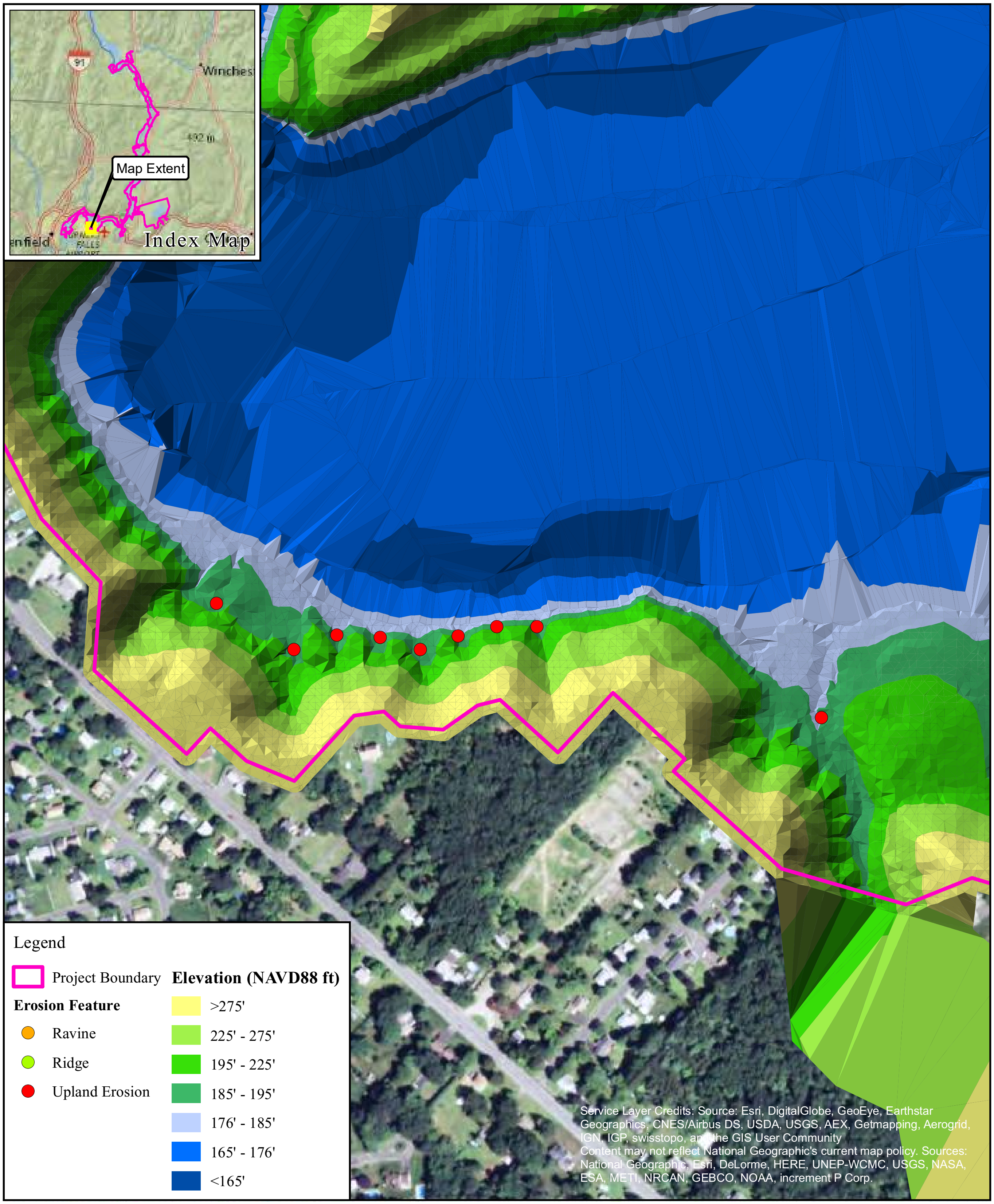
STUDY 3.1.2

C-10 Upland Erosion

N

0 200 400 800 Feet

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

C-11 Upland Erosion near Montague Rod and Gun Club

Path: W:\gis\studies\3_1_2\maps\final_report\appendix_c.mxd

Figure C-12 Upland erosion feature (Photo 9517)

APPENDIX D – DETAILED STUDY SITE ASSESSMENTS

Synopsis of Land-Based Surveys
2014 Connecticut River Detailed Site Assessments

Location ID	Date	Station (Note 1)	Coordinates		Left or Right Bank (Note 2)	Previously Stabilized?	Photo Reference No.
			Latitude	Longitude			
11L	9/23/14	10,000+00	42.77306	-72.50294	Left	No	802 - 807
2L	Not Surveyed (Note 3)	945+00	42.77062	-72.48576	Left	Yes (Bonnette Farm)	Not Surveyed (Note 3)
3L	9/23/14	795+00	42.73602	-72.45993	Left	No	808 - 814
3R	9/23/14	795+00	42.73457	-72.46257	Right	Yes (Kendall)	815 - 820
4L	9/23/14	737+00	42.71964	-72.45590	Left	No	821-824
4AL	9/23/14	738+00	42.71993	-72.45606	Left	No	825 - 830
5CR	9/23/14	572+50	42.68102	-72.47197	Right	No	831 - 835
10L	9/24/14	490+00	42.66099	-72.46698	Left	No	855 - 858
10R	9/24/14	490+00	42.65999	-72.46927	Right	Yes (Urgiel Upstream)	850 - 854
6AL	9/24/14	417+50	42.64249	-72.47578	Left	Yes (Skalaski)	859 - 864
6AR	Not Surveyed (Note 4)	417+50	42.64470	-72.48036	Right	Yes (Flagg)	Not Surveyed (Note 4)
7L	9/25/14	375+00	42.63684	-72.48664	Left	No	871 - 877
7R	9/25/14	375+00	42.63824	-72.49010	Right	No	879 - 884
8BL	9/25/14	327+50	42.62466	-72.48204	Left	No	885 - 891
8BR	Not Surveyed (Note 5)	327+50	42.62256	-72.48390	Right	No	Not Surveyed (Note 5)
9R	Not Surveyed (Note 6)	65+00	42.59856	-72.54261	Right	Yes (Campground Point)	Not Surveyed (Note 6)
BC-1R	9/24/14	47+50	42.59935	-72.54431	Right	No	836 - 843
303L	9/22/14	940+00	42.76950	-72.48410	Left	No	795 - 799
119BL	9/24/14	407+00	42.64167	-72.47889	Left	No	866, 867, 869, 870
87BL	9/25/14	307+50	42.61982	-72.47829	Left	No	892 - 897
75L	9/25/14	270+00	42.60946	-72.48226	Left	No	898 - 904
12BL	Not Surveyed (Note 7)	67+50	42.59425	-72.54115	Left	Yes (Montague)	Not Surveyed (Note 7)
18L	Not Surveyed (Note 8)	870+00	42.75252	-72.47180	Left	No	Not Surveyed (Note 8)
21R		792+50	42.73313	-72.46147	Right	No	
29R		660+00	42.70262	-72.46536	Right	No	
26R		500+00	42.66106	-72.47071	Right	No	

Notes: (1) Station is measured in feet, with Station 0+00 at Turners Fall Dam, increasing upstream.
(2) Left and right bank is referenced facing downstream.
(3) Transect 2L was surveyed as land-based observation point #19 (Sta. 947+50) in November 2013.
(4) Transect 6AR was surveyed as land-based observation point #25 (Sta. 410+00) in November 2013.
(5) Transect 8BR was surveyed as land-based observation point #23 (Sta. 321+00) in November 2013.
(6) Transect 9R was surveyed as land-based observation point #27 (Sta. 62+00) in November 2013.
(7) Boat-based point 12BL was surveyed as land-based observation point #28 (Sta. 65+00) in November 2013.
(8) Land-based points #18L, 21R, 29R, and 26R were surveyed in November 2013.

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *11L*

Personnel: *YKC, CM, RKS*

Date: *September 23, 2014*

Time: *10:40 AM*

Photo Reference Numbers: *802 - 807*

Station Number: *1000+00*

Latitude: *42.77306*

Longitude: *-72.50294*

Left or Right Bank (Looking Downstream): *Left*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

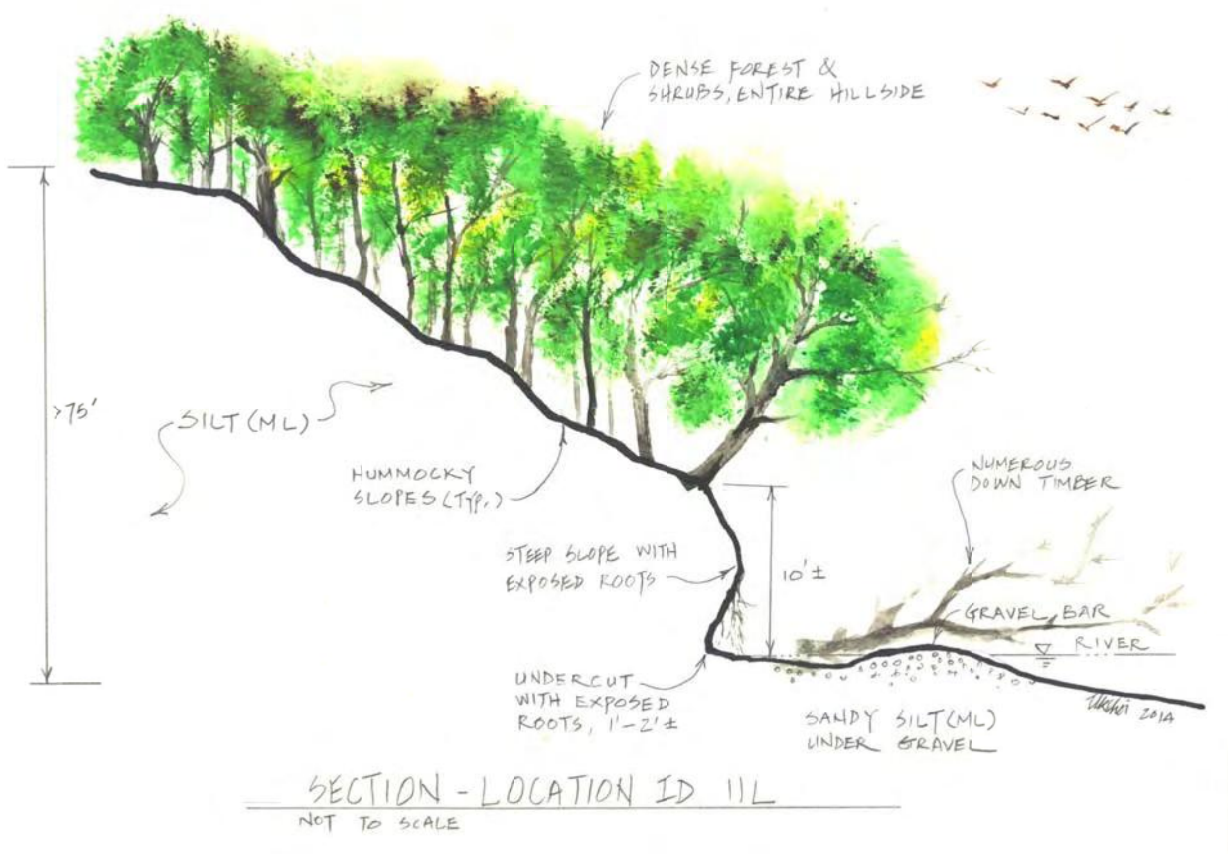
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, light brown.
Lower Bank below Gravel Bar: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, gray.

Observed Erosion Features:

- *Steep slope at river level (lower 10 feet of Upper Bank)*
- *Mass wasting with hummocky terrain in upland*
- *Undercuts with exposed roots*
- *Some leaning trees*
- *Numerous down timber*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 11L   **Date:** *September 23, 2014*

Station Number: *1000+00*

Bank Vegetation:

Top: Heavy (90%) cover – Broad leaved deciduous tree
Tree (90%): red oak, eastern white pine, red maple, silver maple, black birch, yellow birch*
Shrub (80%): staghorn sumac, willow, birch, dead snags (>3), multiflora rose
Vine: bittersweet, Virginia creeper, grape*

Face: Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (25%): red maple, black birch, eastern white pine, red oak, basswood*
Shrub (70%): sumac, red maple sapling, multiflora rose, Japanese barberry*
Vine: oriental bittersweet, grape, Virginia creeper*
Herbaceous (45%): river rye, woolgrass, boneset, beggartick (*Bidens spp.*), mixed goldenrods* (Solidago spp.), *cattails, Iris, mixed asters, purple loosestrife*

Toe: Sparse (<5%) – mixed emergent (broad-leaved & narrow leaved, persistent & non-persistent)
Herbaceous: rushes (inc. Juncus, Eleocharis), Sagittaria spp., Phalaris, *Iris, mixed grasses*

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Forested further back from restoration site, & Agricultural (row crop – cow corn)

Sensitive Receptor:
No

Notes:
Bank is densely vegetated and very steep

Eroding bank with overhanging roots

Bald eagle nest nearby (upstream)

Transect continues through Stebbins Island an on to Right bank across River

Invasive vegetation including multiflora rose, creeper, bittersweet & loosestrife

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 802

Photo No. 803

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 804

Photo No. 805

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 806

Photo No. 807

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *3L* **Personnel:** *YKC, CM, RKS*

Date: *September 23, 2014* **Time:** *12:05 PM* **Photo Reference Numbers:** *808 - 814*

Station Number: *795 + 00* **Latitude:** *42.73602* **Longitude:** *-72.45993*

Left or Right Bank (Looking Downstream): *Left*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

Stratigraphy:

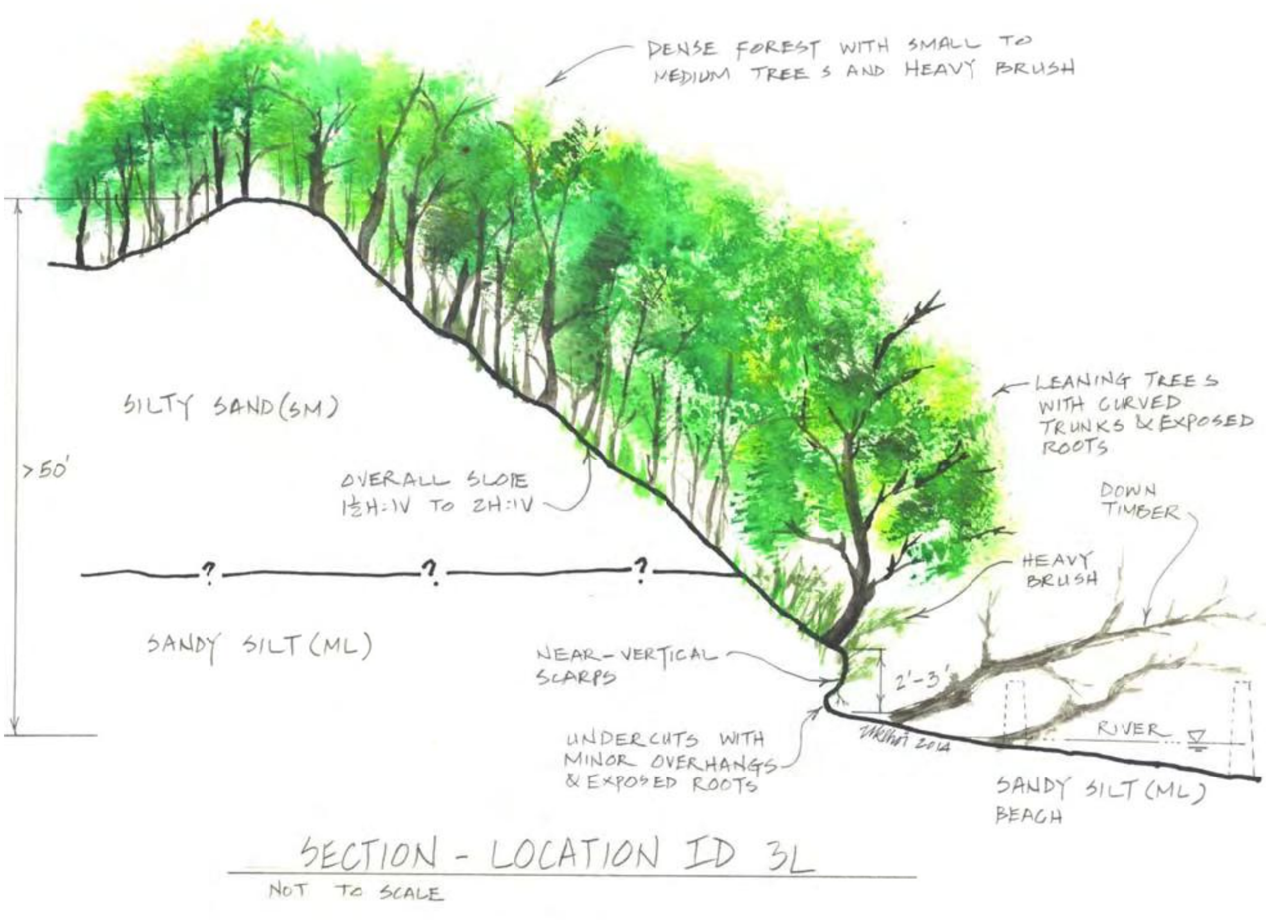
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank Upper Layer: SILTY SAND (SM) – Fine to coarse sand, approx. 10% - 20% gravel, approx. 10% - 20% low-plasticity fines, brown.
Upper Bank Lower Layer: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% very fine sand, gray.
Lower Bank: SANDY SILT (ML) – same as Lower Layer of Upper Bank.

Observed Erosion Features:

- *Near vertical scarps with undercuts and exposed roots at river level*
- *Minor overhangs*
- *Leaning trees with curved trunks*
- *Some mass-wasting near river level*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: *3L* **Date:** *September 23, 2014*

Station Number: *795+00*

Bank Vegetation:

Top: *Heavy (>50%) cover – Broad leaved deciduous tree*
Tree (90%): red oak, silver maple, green ash, sycamore, elm, basswood, black birch, eastern white pine*
Shrub (85%): barberry, multiflora rose, black birch saplings, eastern white pine saplings, red maple saplings*
*Vine (45%): oriental bittersweet**
Herbaceous (30%): cinnamon fern, sensitive fern, lady fern, mixed asters, mixed goldenrods (Solidago spp.)

Face: *Heavy (>50%) cover – Broad leaved deciduous tree*
Tree (80%): red oak, elm, black birch, ash, sycamore, basswood*
Shrub/sapling (90%): basswood, black birch, elm, ash, autumn olive, Japanese barberry, willow, white oak, staghorn sumac, multiflora rose*
*Herbaceous (80%): Mixed grasses (*Phalaris arundinacea*, Calamagrostis canadensis), *mixed goldenrods* (Solidago spp.)*, mixed asters, cutgrass (*Leersia oryzoides), *beggartick* (Bidens spp.), *purple loosestrife, panic grass, clover*

Toe: *None*

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Forested & Agricultural

Sensitive Receptor:
No

Notes:
Near vertical erosion scarps with undercuts.

Leaning/downed trees at river level.

Narrow riparian forest with Japanese barberry dominating the understory, with agricultural fields (potato) at the top of the hill.

Invasive species present (bittersweet & barberry common, some loosestrife & autumn olive present)

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 808

Photo No. 809

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 810

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 811

Photo No. 812

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 813

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 814

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *3R*

Personnel: *YKC, CM, RKS*

Date: *September 23, 2014*

Time: *12:40 PM*

Photo Reference Numbers: *815 - 820*

Station Number: *795 + 00*

Latitude: *42.73457*

Longitude: *-72.46257*

Left or Right Bank (Looking Downstream): *Right*

Previously Stabilized? *Yes (Kandall Site, 2008)*

Geologic / Geotechnical Observations:

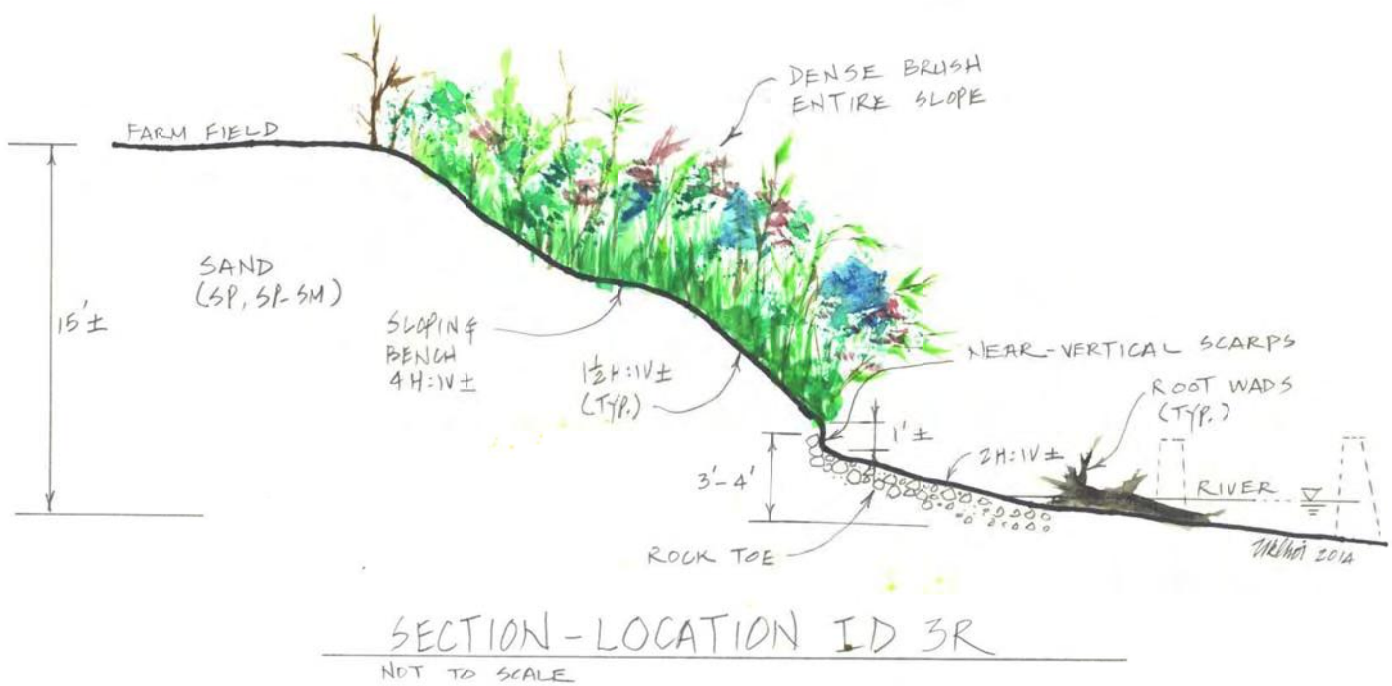
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

SAND (SP, SP-SM) – Fine sand, approx. 5% - 10% low-plasticity fines, brown.
ROCK TOE – 1" – 4" riprap rock, angular, hard, minor deterioration.

Observed Erosion Features:

- *Little erosion of stabilized slope.*
- *Minor near-vertical scarps near the top of rock toe*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: *3R* **Date:** *September 23, 2014*

Station Number: *795+00*

Bank Vegetation:

Top: Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (1%): pin oak (fringe)
Shrub (80%): staghorn sumac, willows, dogwoods, loosestrife, ash, red maple,* Ilex glabra
Herbaceous: Aster, mixed grasses*

Face: Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (0%)
Shrub/sapling (60%): willow, sumac, loosestrife, dogwood, quaking aspen,* Ilex glabra
*Herbaceous (100%): mixed grasses (*Phalaris arundinacea*, panic grass,* Leersia spp.*), mixed asters, beggartick (*Bidens spp.*), cinnamon fern,* Polygonum spp.*, mixed goldenrods (*Solidago spp.*), lupine, jewelweed, clover*

Toe: None
rock toe

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Restored & Agricultural

Sensitive Receptor:
No

Notes:
Previously restored site (Kendall), with angular rip-rap stone exposed at toe.

Large patch of rooted submerged aquatic veg in LUW in front of study site

Very steep bank

Agricultural field (row crop – cow corn) at top of bank

Diverse vegetative community from restoration (includes I. glabra *and lupine)*

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 815 - 820
Location ID 3R – September 23, 2014

Photo No. 815

Photo 816

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 815 - 820
Location ID 3R – September 23, 2014

Photo No. 817

Photo No. 818

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 815 - 820
Location ID 3R – September 23, 2014

Photo No. 819

Photo No. 820

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *4L*

Personnel: *YKC, CM, RKS*

Date: *September 23, 2014* **Time:** *2:45 PM* **Photo Reference Numbers:** *821 - 824*

Station Number: *737 + 00* **Latitude:** *42.71964* **Longitude:** *-72.45590*

Left or Right Bank (Looking Downstream): *Left*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

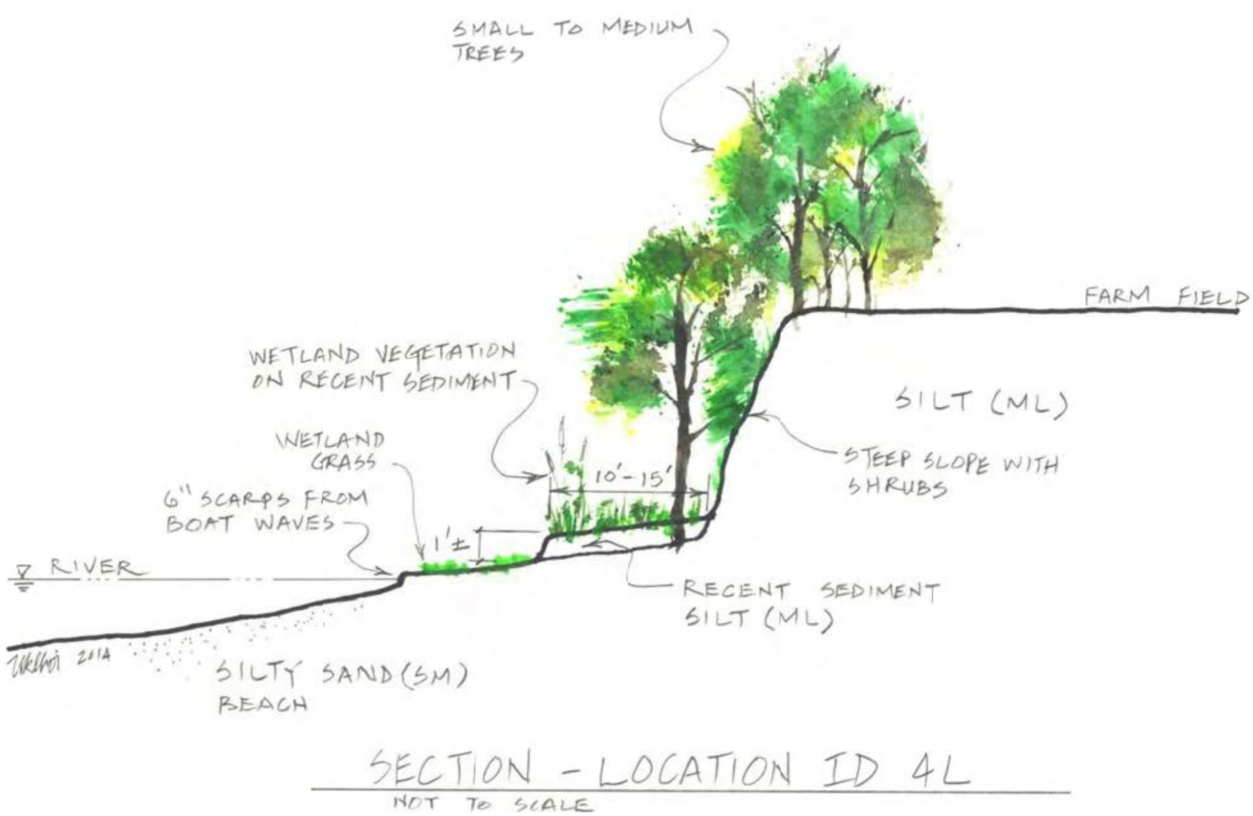
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, brown.
Lower Bank: SILTY SAND (SM) – Mostly fine sand, approx. 10% - 15% low-plasticity fines, gray.
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, mottled brown and orange, organic.

Observed Erosion Features:

- *Steep slope, entire Upper Bank.*
- *Minor erosion of recent sediment where there was no wetland vegetation.*
- *6-inch deep erosion scarp at river level from boat waves.*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: *4L*   **Date:** *September 23, 2014*

Station Number: *737+00*

Bank Vegetation:

Top: Heavy (>50%) cover – Broad leaved deciduous tree
Tree (60%): silver maple, red maple, elm, ash, black locust, cottonwood, basswood*
Shrub (60%): elm, multiflora rose, ash saplings, autumn olive, black birch, glossy buckthorn*
Vine (65%): bittersweet
Herb (60%): mixed grasses, poison ivy, jewelweed, nightshade, mixed asters & Solidago spp.

Face: Moderate (>50%) cover – Broad leaved deciduous shrub/vine
Tree (15%): silver maple, elm, red maple, cottonwood*
Shrub (40%): elm, silver maple sampling, red maple sapling, cottonwood sapling, multiflora rose*
Vine (65%): bittersweet, some Virginia creeper
*Herbaceous (75%): mixed grasses (*Phalaris arundinacea*, Leersia spp.)*, poison ivy, woolgrass,* boneset, Polygonum spp., *sedges* (inc. Carex spp.), *rushes* (inc. Eleocharis spp., Juncus effuses,) *beggartick* (Bidens spp.)*, purple loosestrife*

Toe: Heavy (>50%) cover – Narrow leaved persistent emergent
Tree (5%): silver maple, red maple, elm*
Shrub/vine (10%): loosestrife, cottonwood seedlings, red maple seedlings
Herbaceous (85%): *woolgrass*, umbrella sedge*, Eleocharis spp.*, cattails,* Scirpus pungens, Phalaris arundinacea, Juncus spp., Leersia spp.*, loosestrife,* Penthorum sedoides

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Very thin riparian buffer with Agricultural (row crop: corn & sunflower) at top of the bank

Sensitive Receptor:
No

Notes:
Very open & sunny

Persistent & Non-persistent Emergent vegetation growing on recently deposited sediment (silt)

Largest patch of Eleocharis *we've documented*

Invasives inc. bittersweet, buckthorn, autumn olive, loosestrife, and multiflora rose

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 821 - 824
Location ID 4L – September 23, 2014

Photo No. 821

Photo 822

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 821 - 824
Location ID 4L – September 23, 2014

Photo No. 823

Photo 824

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *4AL* **Personnel:** *YKC, CM, RKS*

Date: *September 23, 2014* **Time:** *3:10 PM* **Photo Reference Numbers:** *825 - 830*

Station Number: *738 + 00* **Latitude:** *42.71993* **Longitude:** *-72.45606*

Left or Right Bank (Looking Downstream): *Left*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

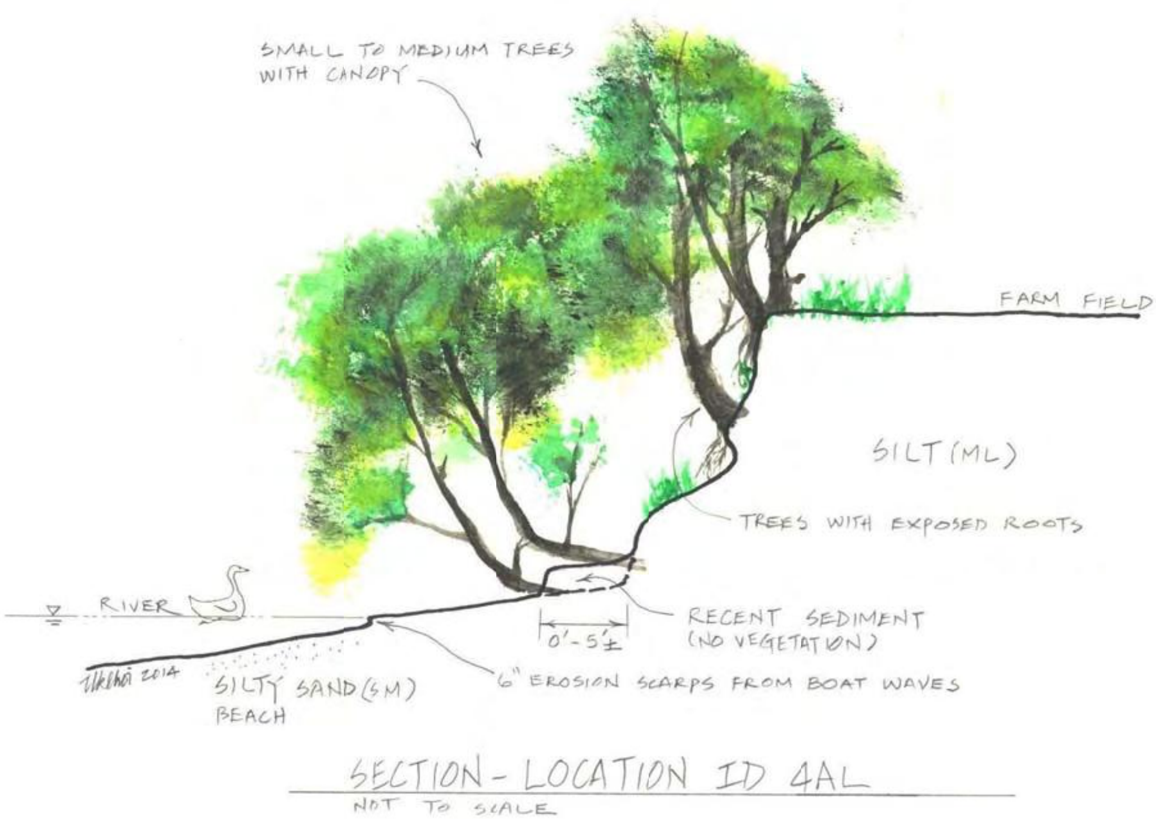
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, brown.
Lower Bank: SILTY SAND (SM) – Mostly fine sand, approx. 10% - 15% low-plasticity fines, gray.
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, mottled brown and orange, organic.

Observed Erosion Features:

- *Steep slope, entire Upper Bank.*
- *Leaning trees and undercuts at toe of Upper Bank, some with exposed roots*
- *Overhangs with exposed roots near top of Upper Bank*
- *Significantly less recent sediment compared with Site 4L which is just 100 feet away. Little to no wetland vegetation on recent sediment.*
- *6-inch deep erosion scarp at river level from boat waves*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: *4L* **Date:** *September 23, 2014*

Station Number: *738+00*

Bank Vegetation:

Top: Heavy (>50%) cover – Broad leaved deciduous tree
Tree (90%): silver maple, elm, green ash*
Shrub (60%): silver maple, elm, sumac*
Vine (70%): bittersweet
Herb (60%): mixed grasses, poison ivy

Face: Heavy (>50%) cover – Broad leaved deciduous tree
Tree (65%): silver maple, elm, green ash*
Shrub: silver maple, elm, ash*
Vine (65%): bittersweet, some Virginia creeper
Herbaceous (5%): mixed grasses, poison ivy

Toe: none
bare ground

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Very thin riparian buffer with Agricultural (row crop: corn & sunflower) at top of the bank

Sensitive Receptor:
No

Notes:
Heavily shaded site (with large mature silver maples), located approx. 100' upstream & 100' downstream from more open site, each with a non-persistent/persistent emergent shelf (one of these, the area ~100' downstream, is Site 4L)

Significant bittersweet invasion here

Exposed roots on bank face

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 825 - 830
Location ID 4AL – September 23, 2014

Photo No. 825

Photo 826

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 825 - 830
Location ID 4AL – September 23, 2014

Photo No. 827

Photo 828

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 825 - 830
Location ID 4AL – September 23, 2014

Photo 829

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 825 - 830
Location ID 4AL – September 23, 2014

Photo 830

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *5CR*

Personnel: *YKC, CM, RKS*

Date: *September 23, 2014*

Time: *4:10 PM*

Photo Reference Numbers: *831 - 835*

Station Number: *572+50*

Latitude: *42.68102*

Longitude: *-72.47197*

Left or Right Bank (Looking Downstream): *Right*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

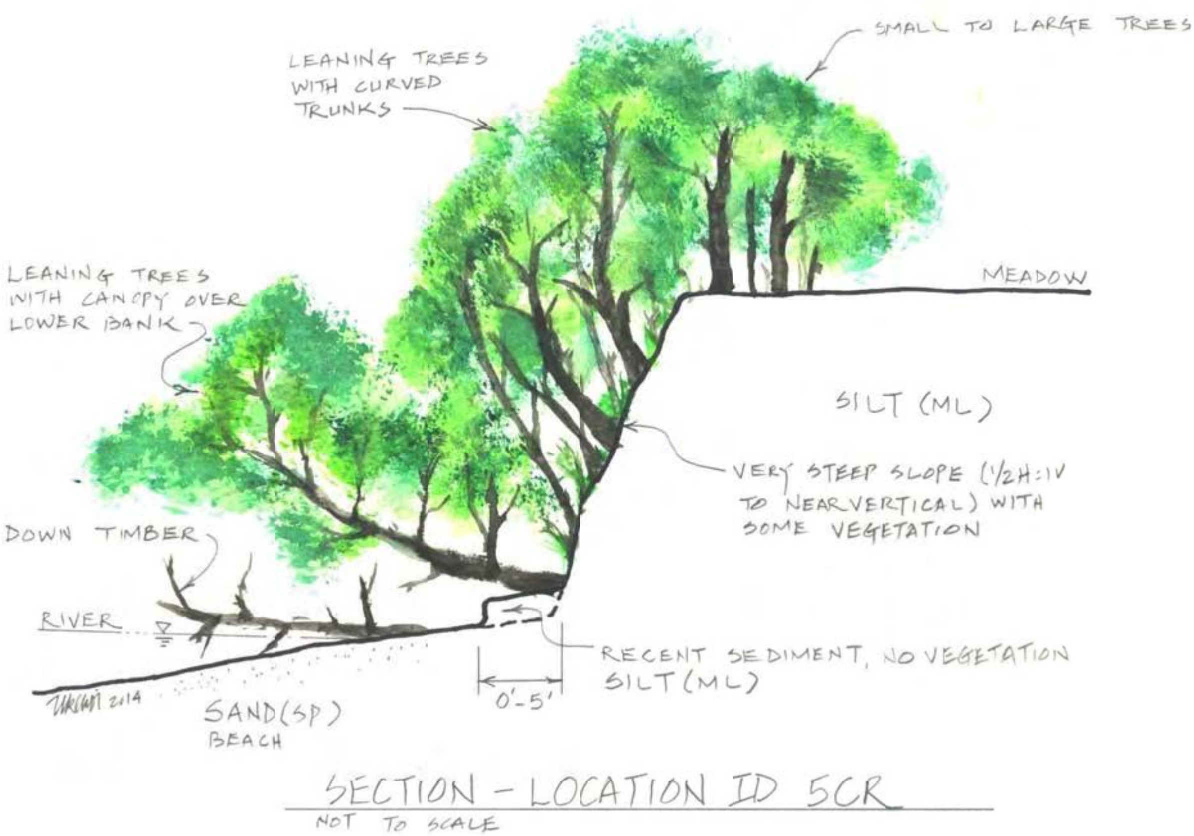
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, approx. 10% - 20% fine sand, gray.
Lower Bank: SAND (SP) – Fine to medium sand, <5% low-plasticity fines, brown.
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, brown.

Observed Erosion Features:

- *Leaning trees, some with curved trunks, with exposed roots.*
- *Very steep slope, entire Upper Bank.*
- *Minor undercuts*
- *Recent sediment with no vegetation*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 5CR **Date:** *September 23, 2014*

Station Number: *572+50*

Bank Vegetation:

Top: *Heavy (>50%) cover – Broad leaved deciduous tree*
Tree (60%): silver maple, elm, ash, black locust, basswood, cottonwood, red maple, sugar maple*
Shrub: elm, alder, multiflora rose, ash saplings*
Vine (50%): bittersweet, some grape
Herb (5%): mixed grasses, poison ivy

Face: *Moderate (>50%) cover – Broad leaved deciduous tree*
Tree (50%): black locust, ash, basswood*
Shrub: black locust, alder, ash, basswood, elm, blueberry, sugar maple saplings*
Vine: bittersweet, grape
*Herbaceous (15%): mixed grasses (*Calamagrostis canadensis*), *NY fern, rushes* (inc. Juncus effusus), *sedges* (inc. Carex spp.), *beggartick* (Bidens spp.)*, meadow rue, mixed goldenrods* (Solidago spp.)

Toe: *Sparse (1%) cover – Narrow-leaved persistent emergent*
Tree: cottonwood seedlings
*Herbaceous: mixed grasses (*Calamagrostis canadensis*, Phalaris arundinacea, Leersia spp.)

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Very thin riparian buffer with Agricultural at top of the bank

Sensitive Receptor:
No

Notes:
Very steep, near vertical, bank with overhangs & exposed roots

Adjacent to Bennett Meadows agricultural & recreational area

Invasive species, particularly bittersweet

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 831 - 835
Location ID 5CR – September 23, 2014

Photo No. 831

Photo 832

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 831 - 835
Location ID 5CR – September 23, 2014

Photo No. 833

Photo 834

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 831 - 835
Location ID 5CR – September 23, 2014

Photo 835

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *10L*

Personnel: *YKC, CM, RKS*

Date: *September 24, 2014*

Time: *12:15 PM*

Photo Reference Numbers: *855 - 858*

Station Number: *490+00*

Latitude: *42.66099*

Longitude: *-72.46698*

Left or Right Bank (Looking Downstream): *Left*

Previously Stabilized? *No*

Geologic / Geotechnical Observations:

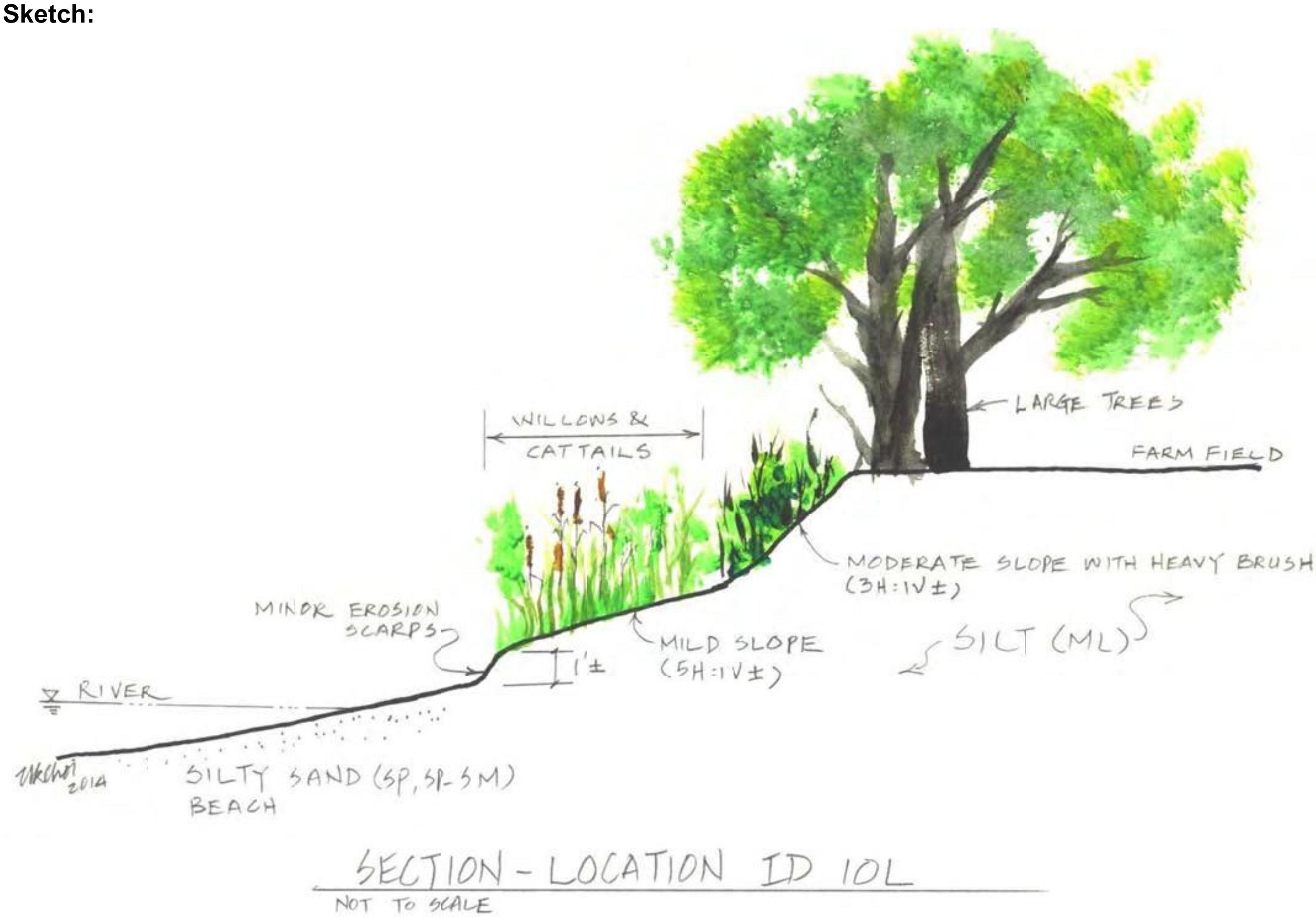
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, gray.
Lower Bank: SAND (SP, SP-SM) – Fine sand, approx. 5% - 10% low-plasticity fines, gray.

Observed Erosion Features:

- *Little to no erosion.*
- *Minor erosion scarps at the toe of Upper Bank where there was no wetland vegetation.*

Site Sketch:



Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 10L **Date:** *September 24, 2014*

Station Number: *490+00*

Bank Vegetation:

Top: Moderate (25-50%) cover – Broad leaved deciduous tree
Tree (45%): silver maple, ash, weeping willow, red maple*
Shrub (70%): red maple sapling, alder, elm*
Vine: bittersweet
Herbaceous (15%): Jerusalem artichoke, jewelweed, poison ivy, mint, mixed upland grasses

Face: Moderate (25-50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (15%): red maple, silver maple, weeping willow*
Shrub (35%): willow, purple loosestrife, red maple sapling, elm*
Herbaceous (15%): cattail, umbrella sedge, 3-way sedge,* Phalaris arundinacea*, woolgrass, jewelweed,* Eleocharis spp.*,* Bidens*, mixed unidentified grasses, mixed* Solidago spp.

Toe: sparse (<10%) cover – robust persistent emergent
Tree (0%):
Shrub (<1%): purple loosestrife, willow*
Herbaceous (<10%): cattail, sedges and rushes (inc. umbrella sedge, 3-way sedge*, Carex spp., Juncus effusus, Juncus canadensis, *woolgrass*, Eleocharis spp.)

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Agricultural (row crop – corn) with very thin riparian buffer ~1 tree width

Sensitive Receptor:
No

Notes:
There is a willow bench with some loosestrife mixed in

Very thin riparian buffer (~1 tree width) along row crop (corn) field edge

Invasive species present including purple loosestrife, multiflora rose, bittersweet, and garden escapees

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 855 - 858
Location ID 10L – September 24, 2014

Photo No. 855

Photo 856

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 855 - 858
Location ID 10L – September 24, 2014

Photo No. 857

Photo 858

Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 10R **Date:** *September 24, 2014*

Station Number: *490+00*

Bank Vegetation:

Top: Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (5%): pin oak, cottonwood, red oak, hickory, silver maple, red maple*
Shrub (80%): staghorn sumac, winged euonymus, black locust sapling, quaking aspen, white oak sapling, raspberry, honeysuckle
Vine: creeper, bittersweet*
Herbaceous (45%): mixed upland grasses, mixed Solidago spp.*, mixed asters*

Face: Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
Tree (1%): pin oak, cottonwood*
Shrub (70%): sumac, alder, honeysuckle, multiflora rose, dogwoods, raspberry, red maple saplings, willow*
Herbaceous (15%): mixed grasses (inc. Calamagrostis*, Phalaris arundinacea), *mixed asters, mixed goldenrods* (Solidago spp.)

Toe: none
Bare rock

** Dominant species in each vegetative strata is marked with an **

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Forested further back from restoration site, & Agricultural (row crop – cow corn)

Sensitive Receptor:
No

Notes:
Restoration Site (Urgiel Upstream), with 2-6” angular riprap rock at toe and no erosion at toe

Some slumping above rock toe, mid-slope and near the top of the slop of the upper bank

The “Fuzzy Tree” site – there is a single stand-out tree at the top of the bank engulfed in Virginia creeper, which makes this site distinguishable to many. The creeper is red in the fall.

Site is mostly vegetated with sumac at the top of the bank

Lots of invasives here, inc: bittersweet, creeper, honeysuckle, winged euonymus, and multiflora rose

Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: *10R* **Personnel:** *YKC, CM, RKS*

Date: *September 24, 2014* **Time:** *11:30 AM* **Photo Reference Numbers:** *850 - 854*

Station Number: *490+00* **Latitude:** *42.65999* **Longitude:** *-72.46927*

Left or Right Bank (Looking Downstream): *Right*

Previously Stabilized? *Yes (Urgiel Upstream, 2001)*

Geologic / Geotechnical Observations:

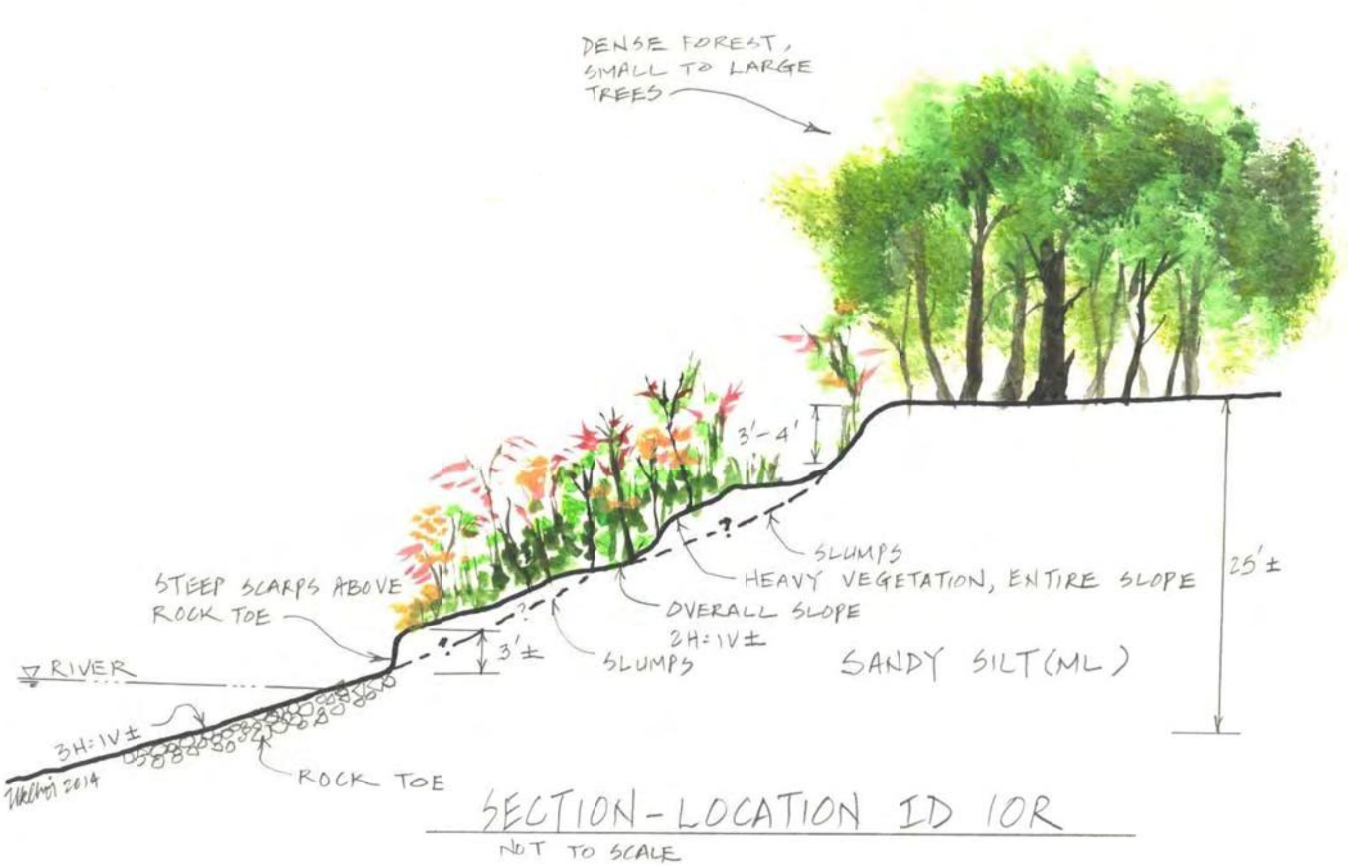
Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

SANDY SILT (ML) – Low plasticity, approx. 30% - 40% fine sand, brown.
Rock Toe – 2" to 6" riprap rock, angular, hard, little deterioration.

Observed Erosion Features:

- *Little erosion at rock toe, with no depressions or movements observed.*
- *Some slumping above rock toe, mid-slope, and near the top of slope of Upper Bank.*

Site Sketch:



2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 850 - 854
Location ID 10R – September 24, 2014

Photo No. 850

Photo No. 851

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 850 - 854
Location ID 10R – September 24, 2014

Photo No. 852

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 850 - 854
Location ID 10R – September 24, 2014

Photo No. 853