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 0.161 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.

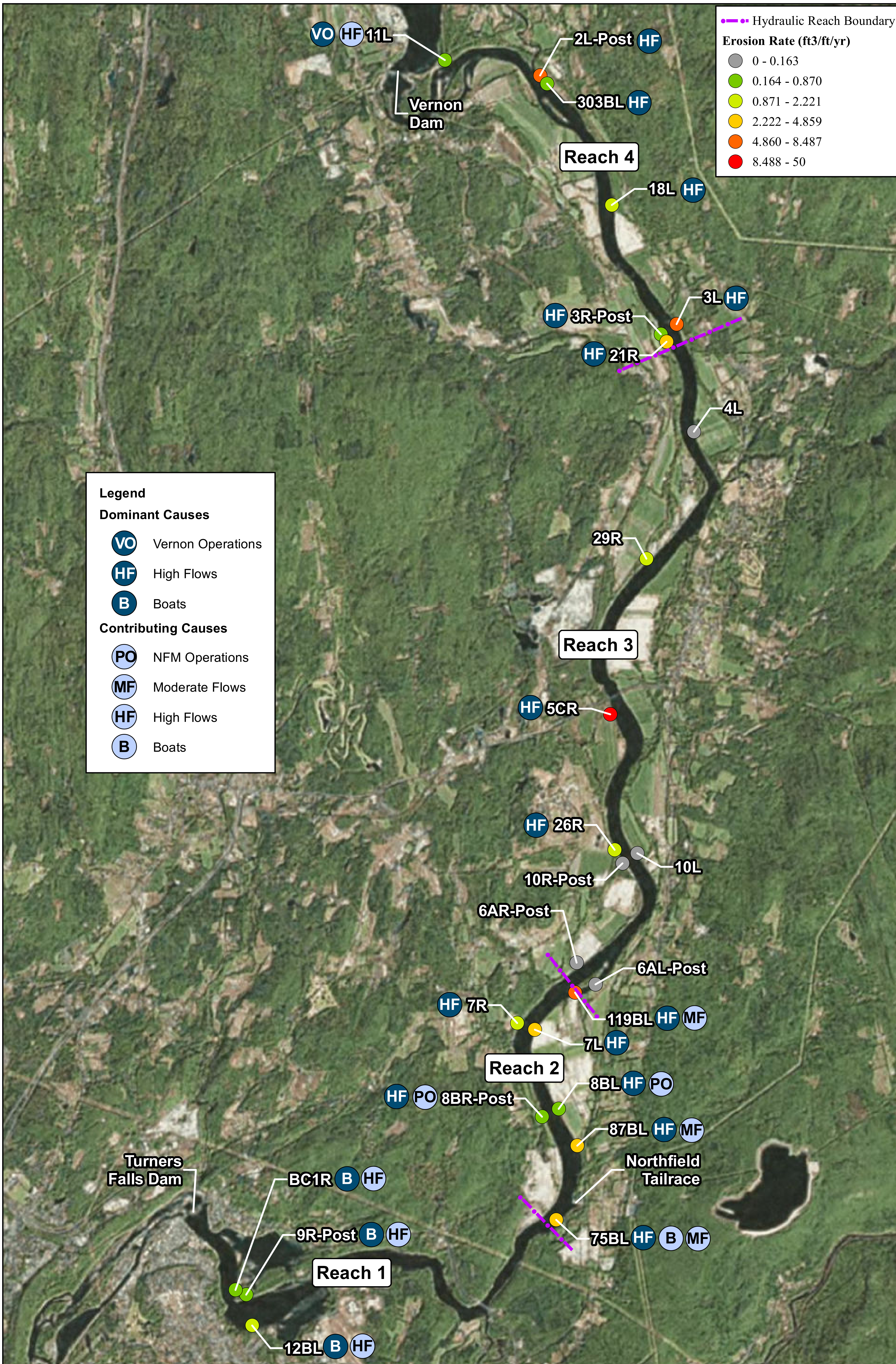
Table 6.1.1-1: Distribution of Mean Annual Erosion Rates by Site

Mean Annual Erosion Rate Classes	Corresponding Erosion Rate ($ft^3/ft/y$)	Number of Detailed Study Sites	Detailed Study Sites
0-5%	<0.161	5	4L, 10L, 10R, 6AL, 6AR
6-25%	0.162 – 0.87	8	11L, 303BL, 3R, 8BL, 8BR, 9R, BC-1R
26-50%	0.88 – 2.36	5	18L, 21R, 29R, 26R, 7R, 12BL
51-75%	2.37 – 5.65	4	2L, 7L, 87BL, 75BL
76-95%	5.66 – 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

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

STUDY 3.1.2

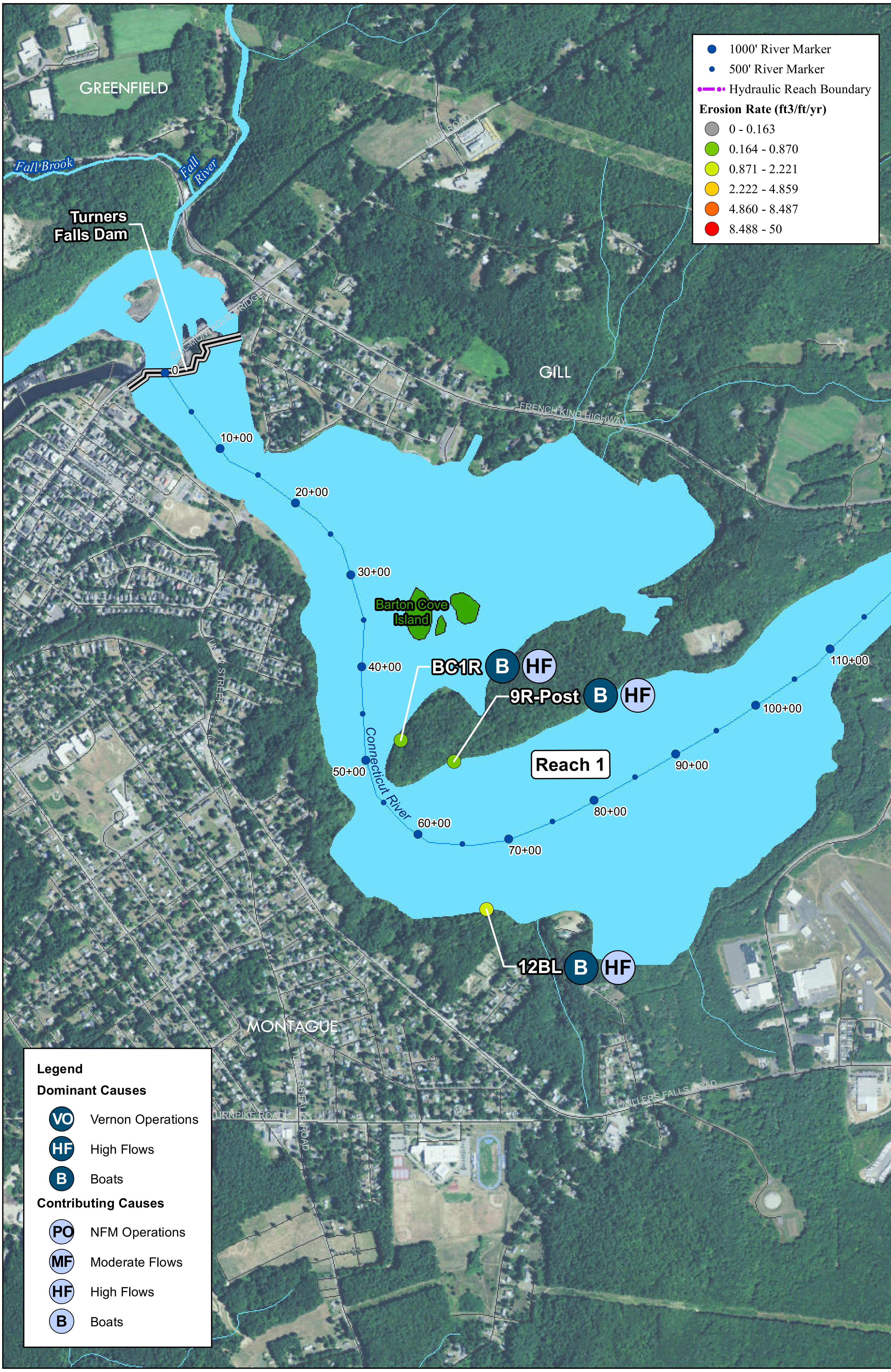
N

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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-1_index.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

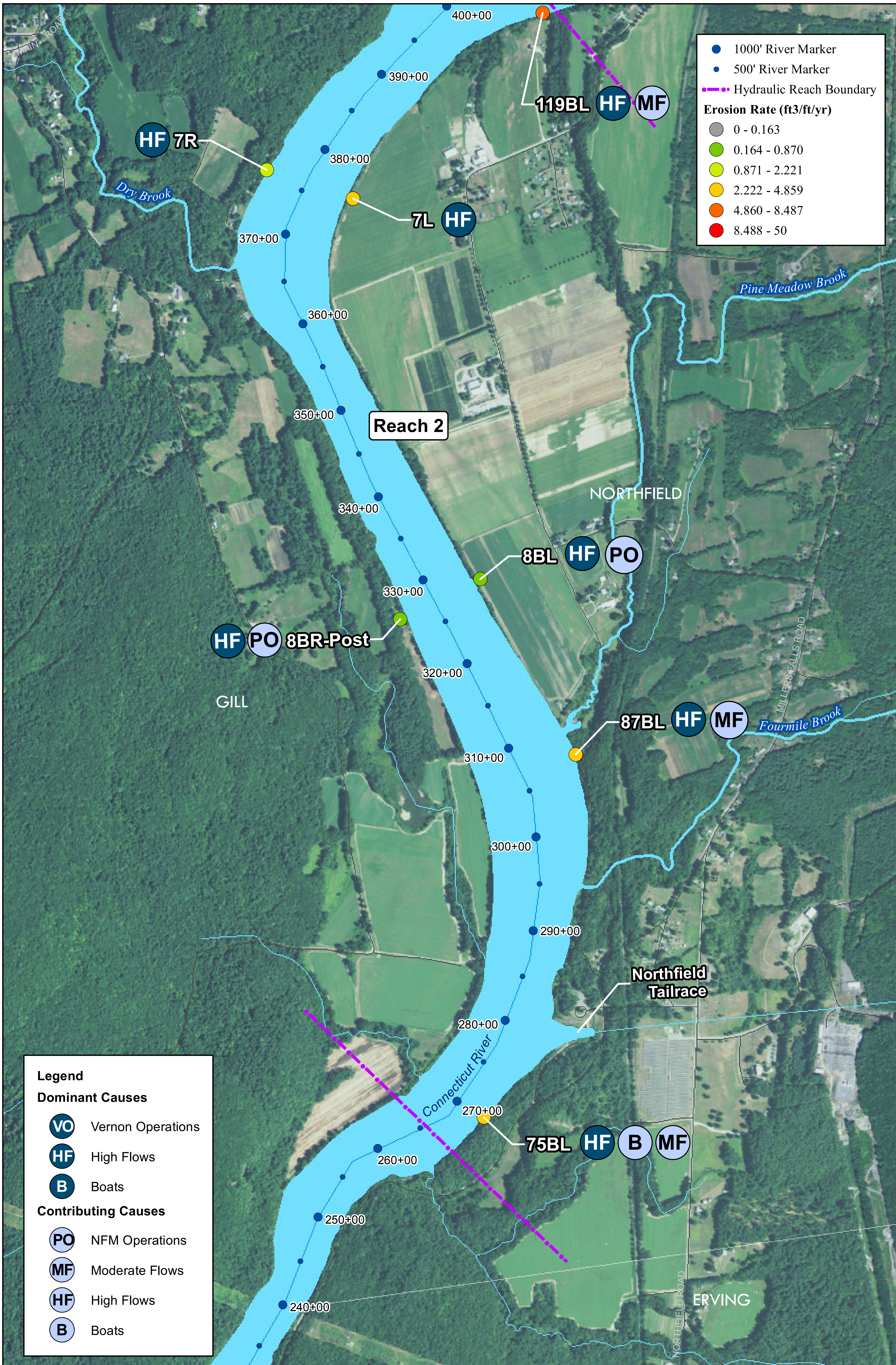
N

0 500 1,000 2,000 Feet

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

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-1_reach_2.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

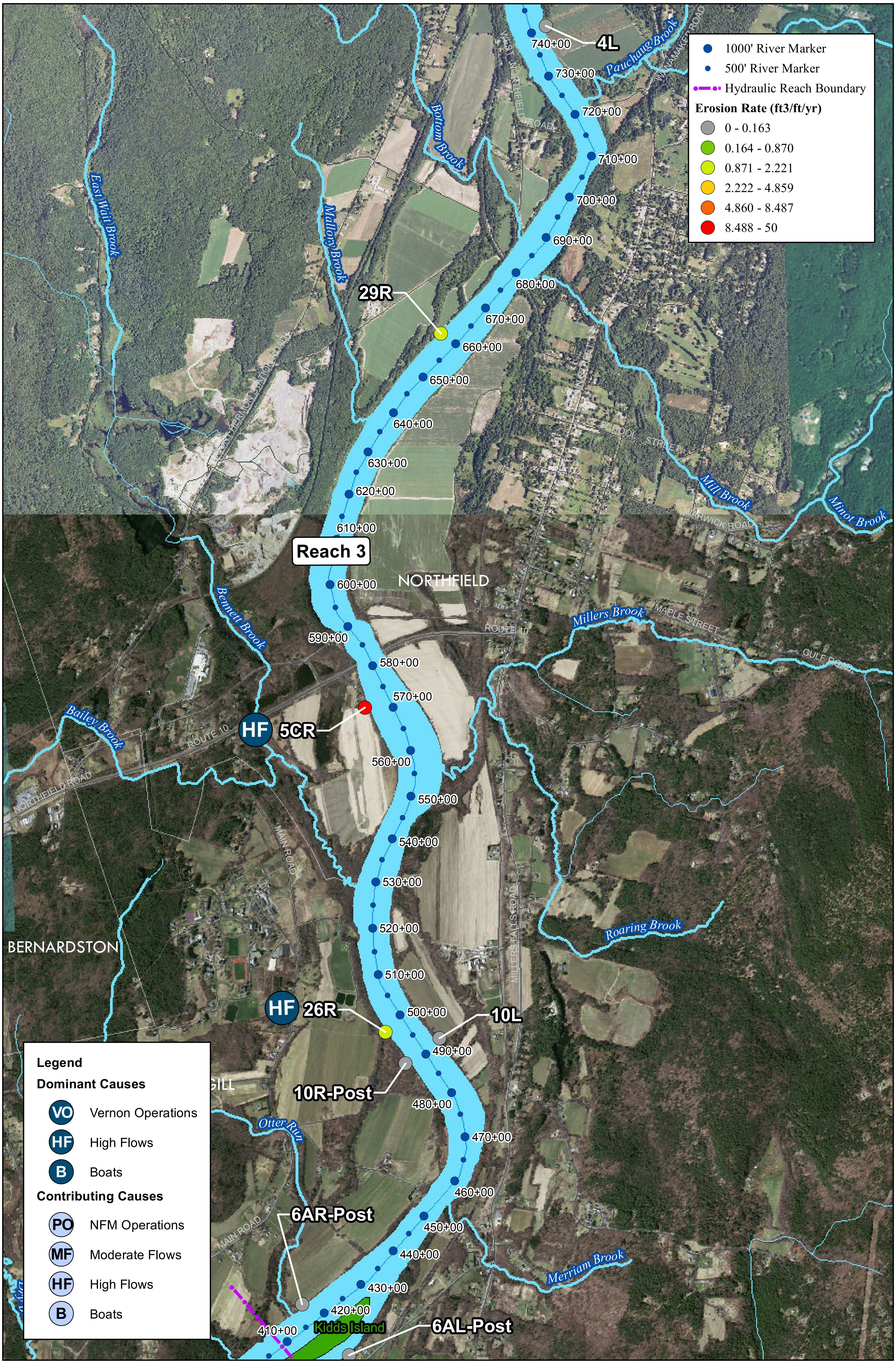
N

0 500 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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-1_reach_2.mxd



FirstLight Power Resources

N

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

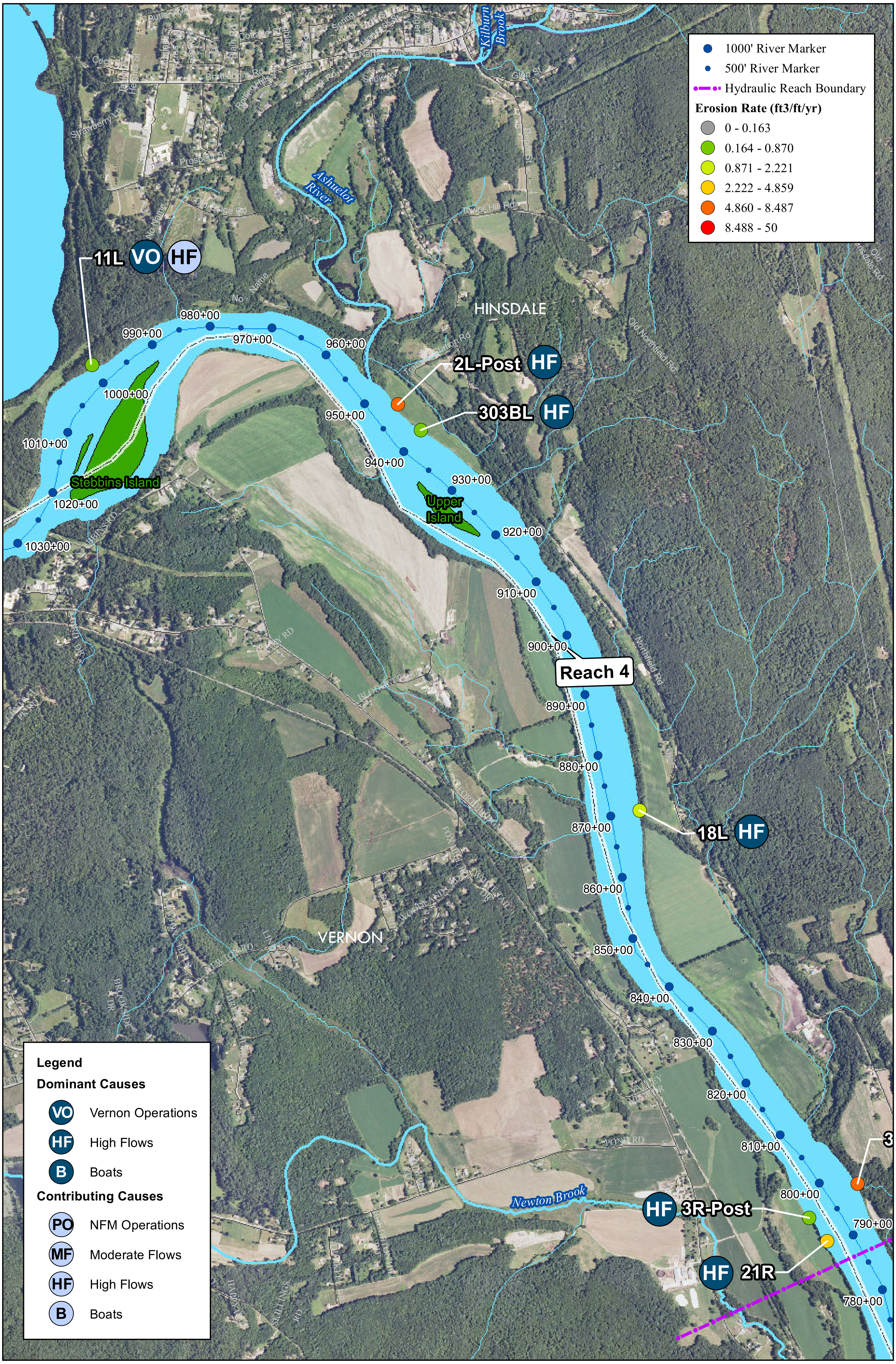
STUDY 3.1.2

0 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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-1_reach_3.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

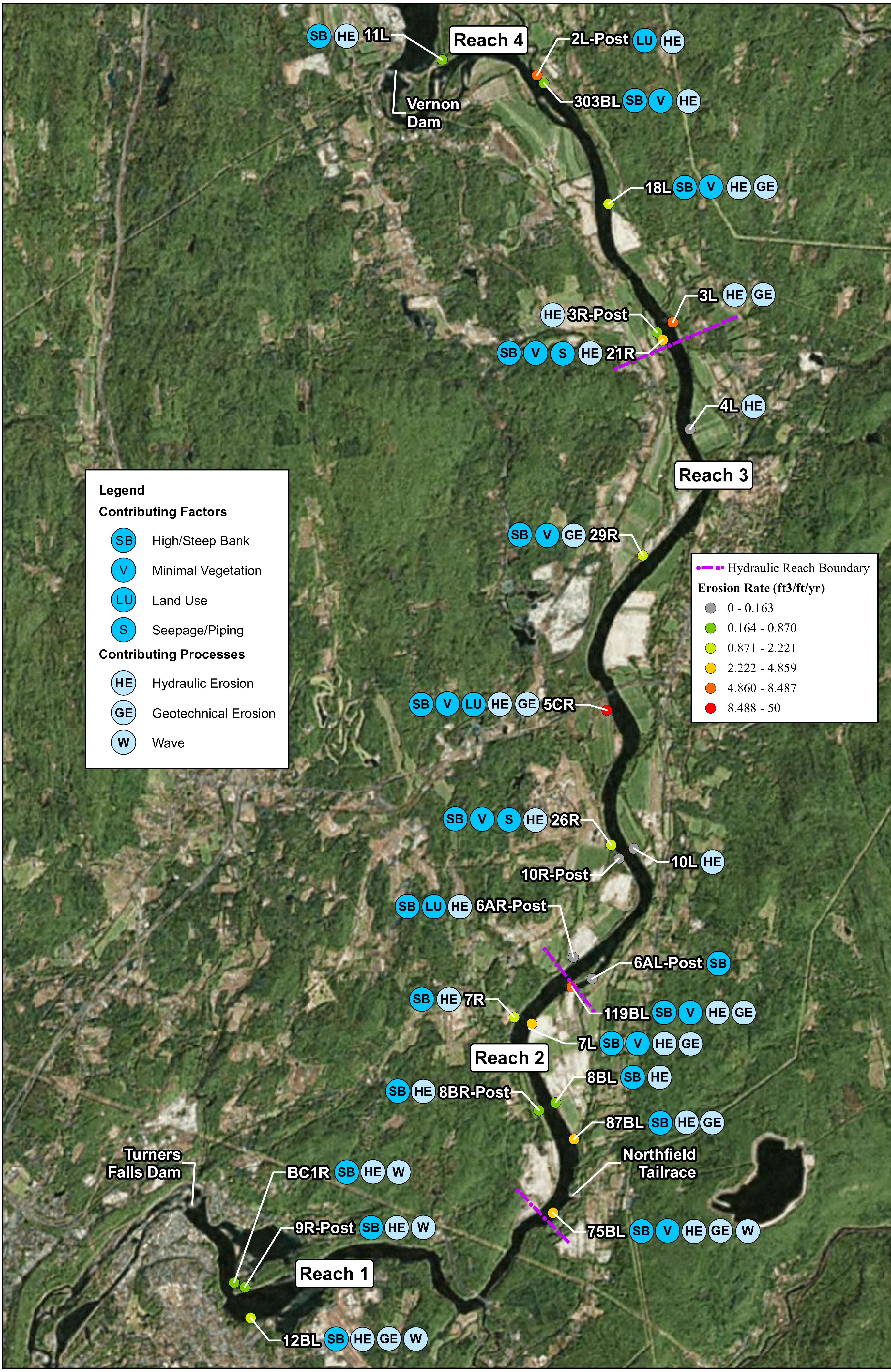
N

0 750 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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-1_reach_4.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

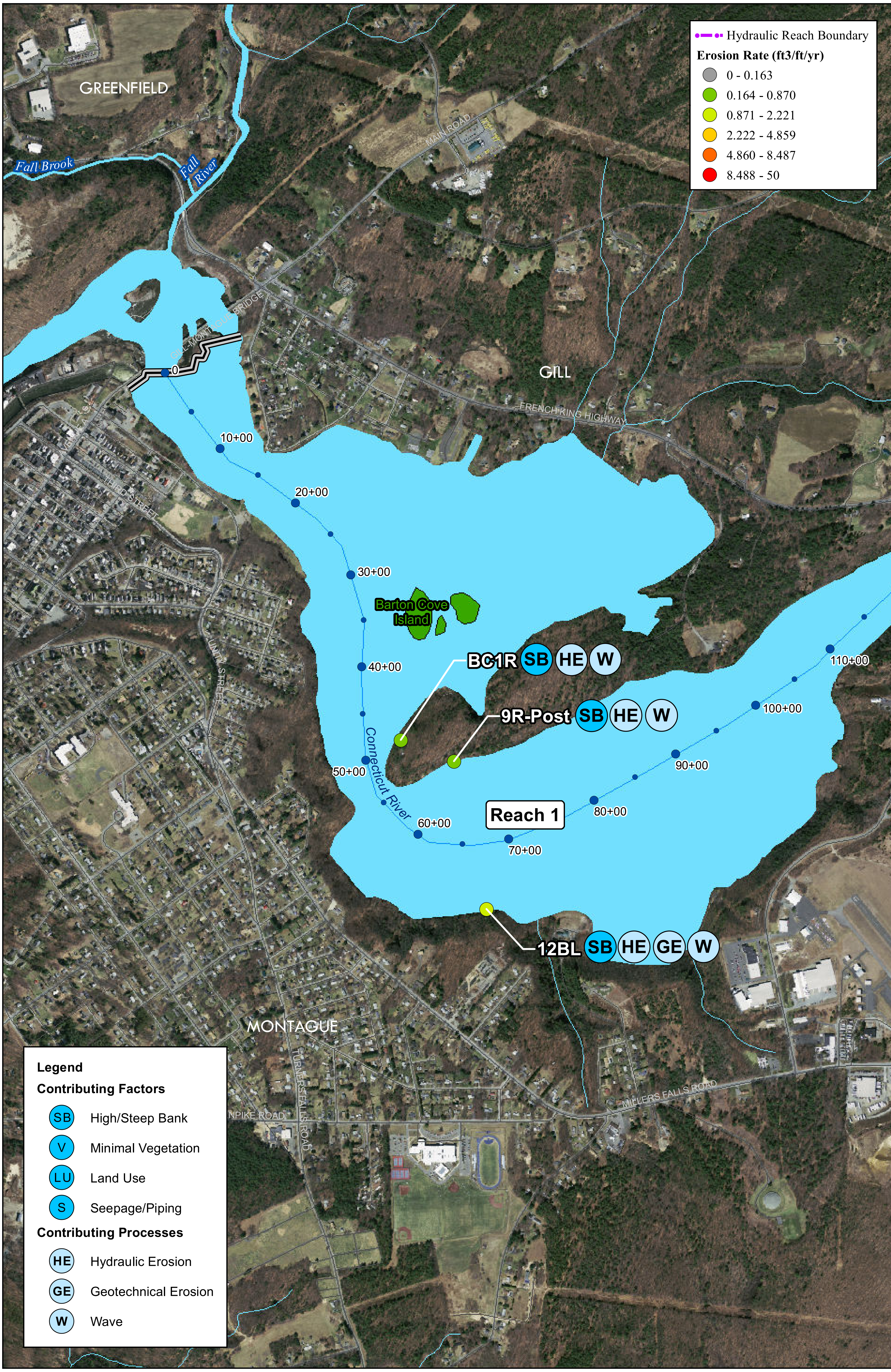
N

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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-2_index.mxd



FirstLight Power Resources

N

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

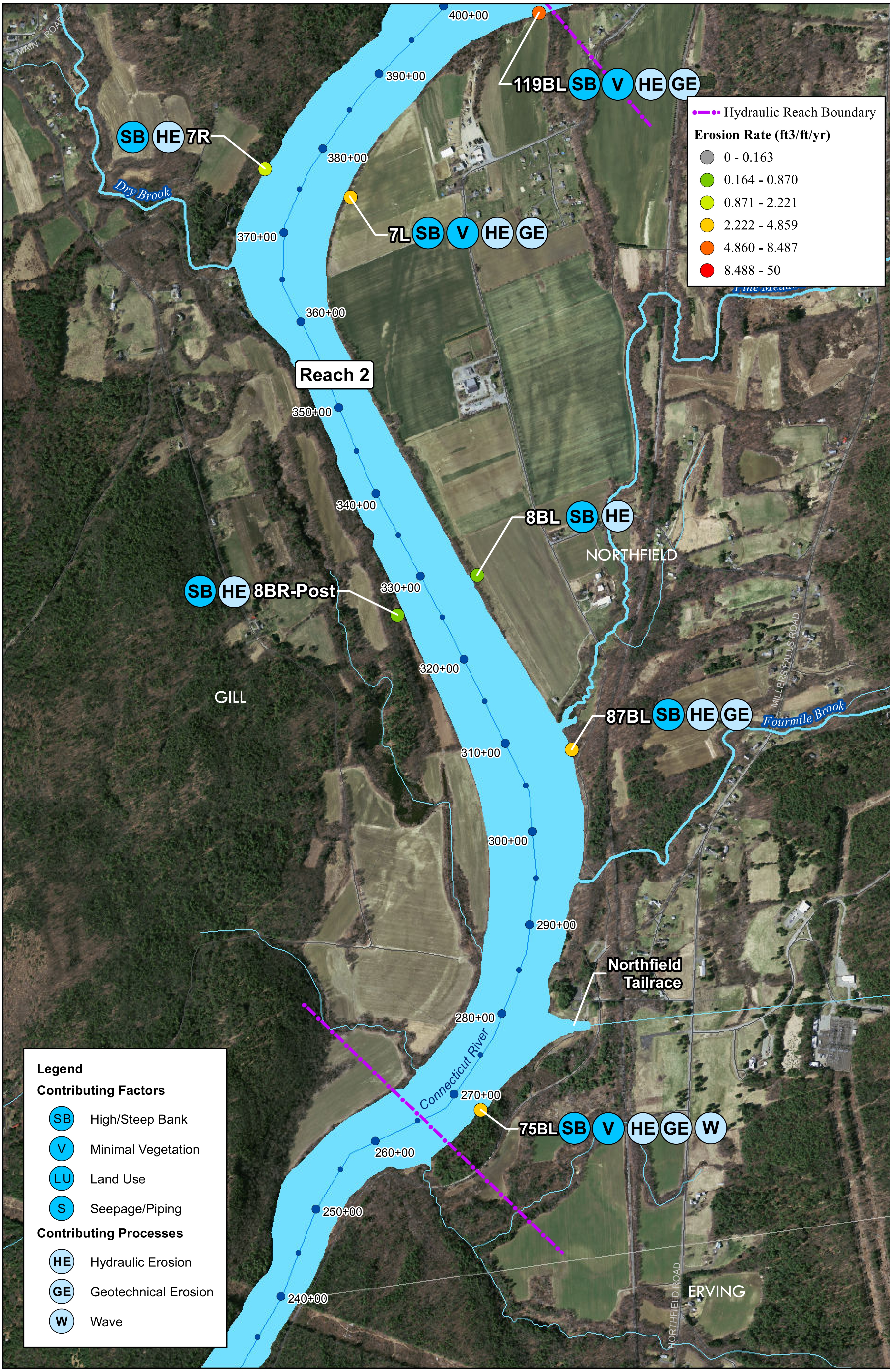
STUDY 3.1.2

0 500 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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-2_reach_1.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

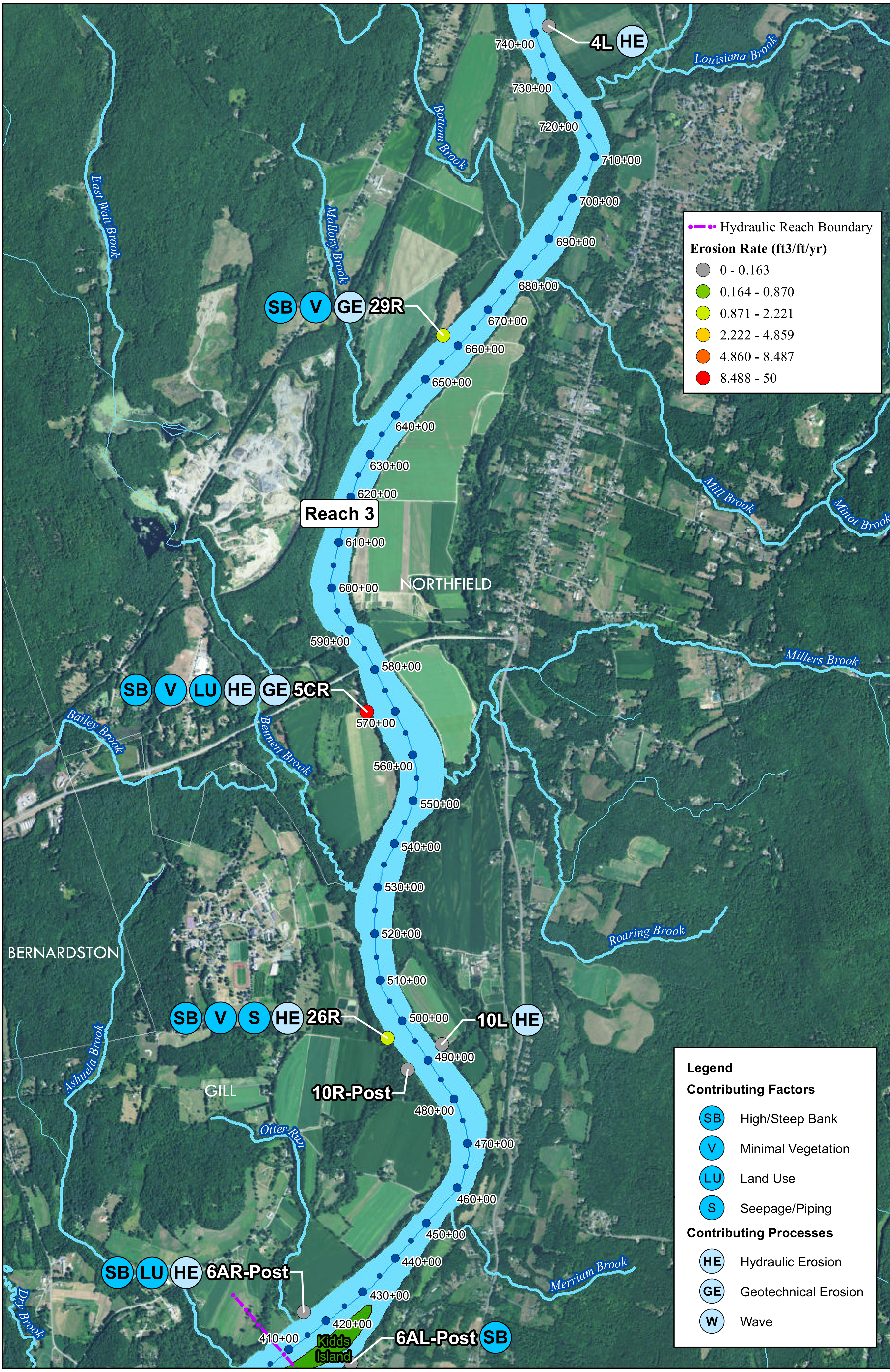
N

0 500 1,000 2,000 Feet

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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-2_reach_2.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

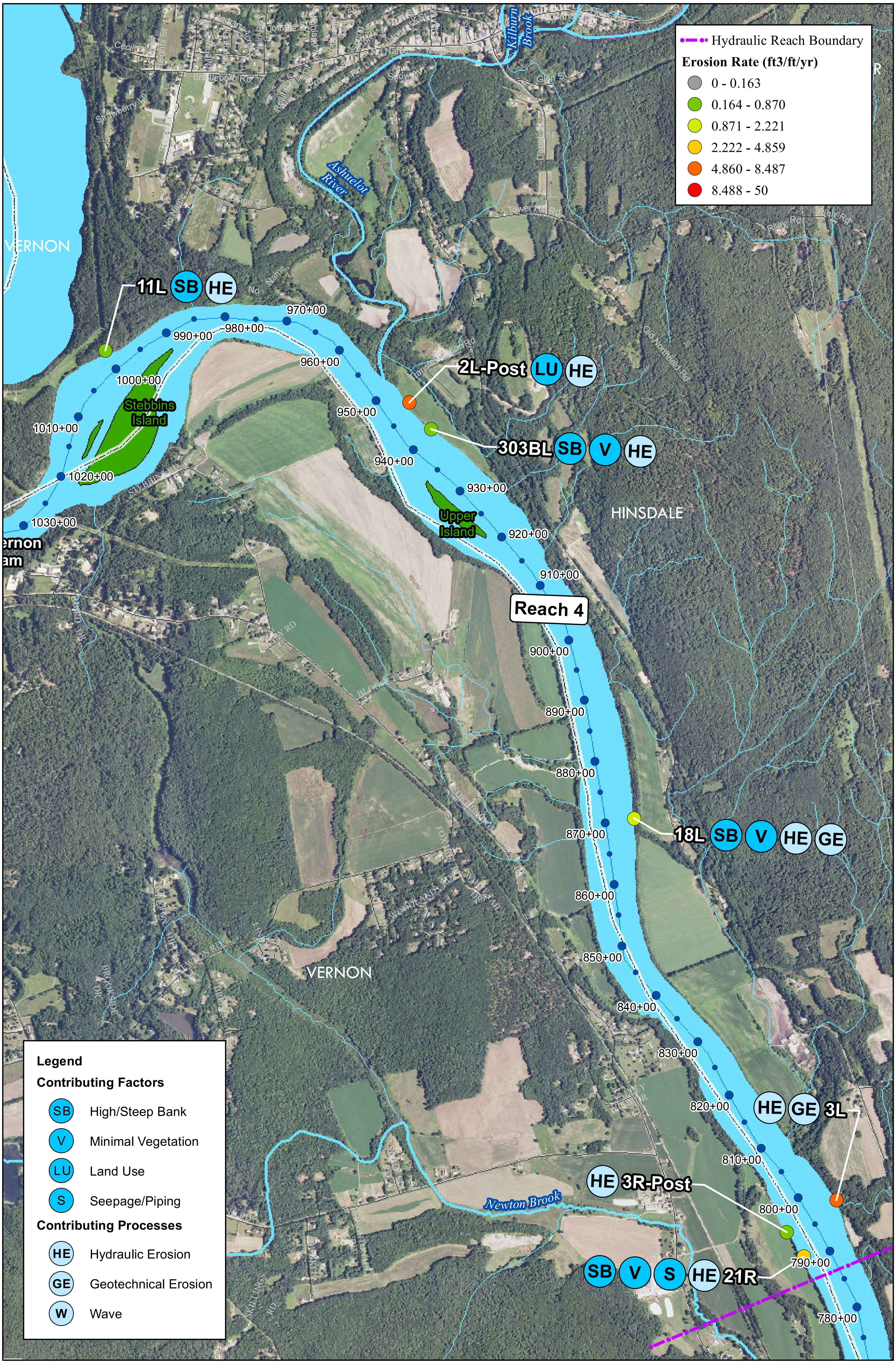
N

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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-2_reach_3.mxd



FIRSTLIGHT HYDRO GENERATING COMPANY
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 6.1.1-2:
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, AeroGRID, IGN, and the GIS User Community

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_1-2_reach_4.mxd

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.

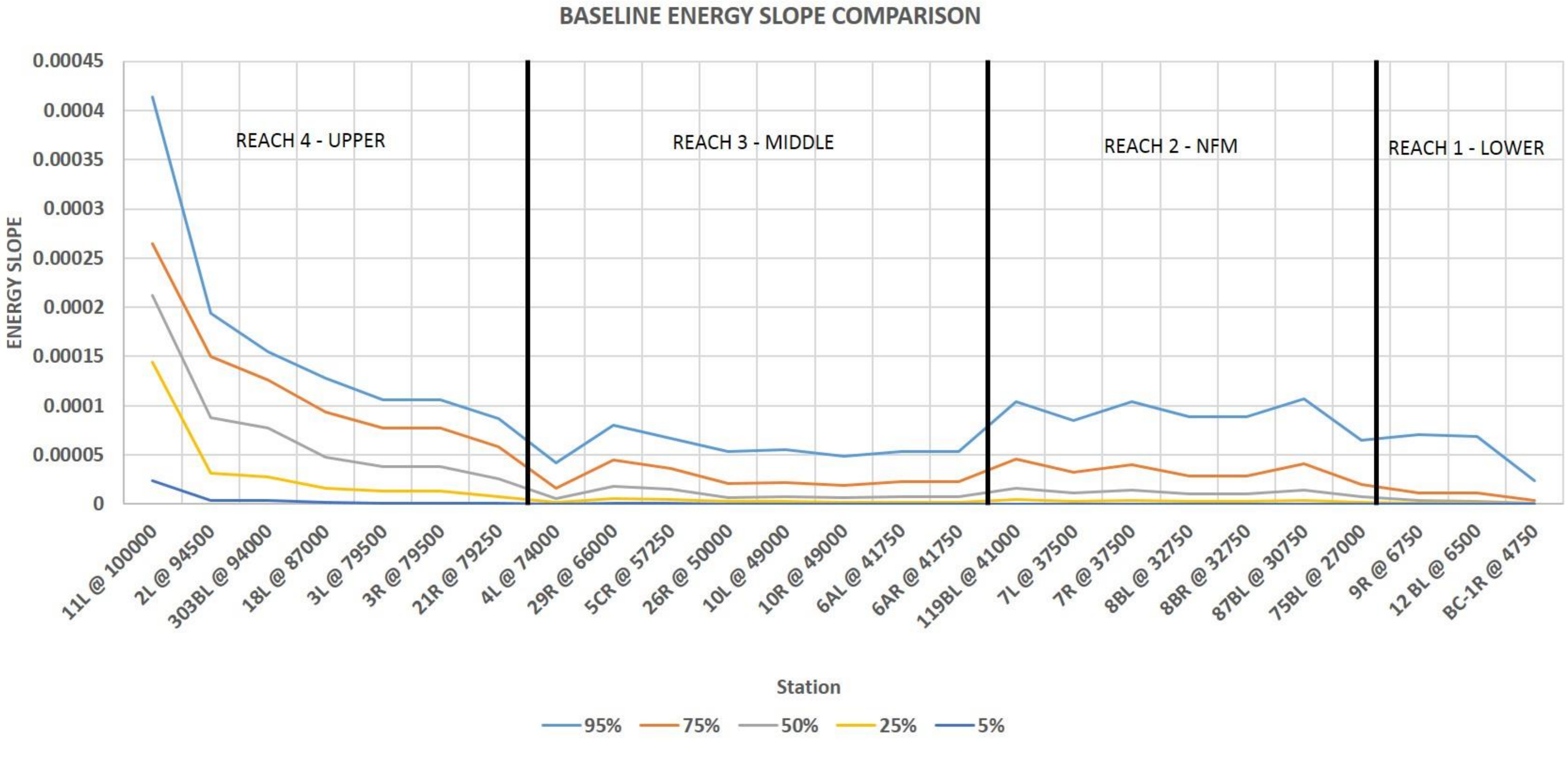


Figure 6.1.2.1-1: Energy slope trends through the Turners Falls Impoundment

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		56,081					
2L - Post		94500		X		19,537					
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

					Upper Riverbank				Lower Riverbank			Erosion Conditions			
Detailed Study Site	**Hydraulic Reach**	**Dominant Cause of Erosion**	**Contributing Cause of Erosion**	**FRR Segment**	**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.

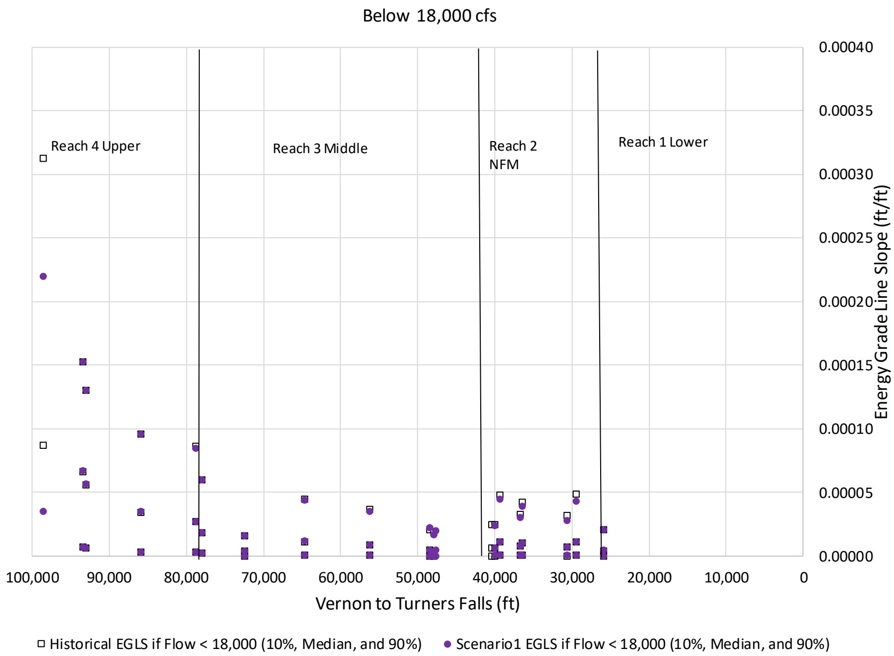


Figure 6.1.2.2-1: Energy slope trends through the Turners Falls Impoundment at flows less than 18,000 cfs

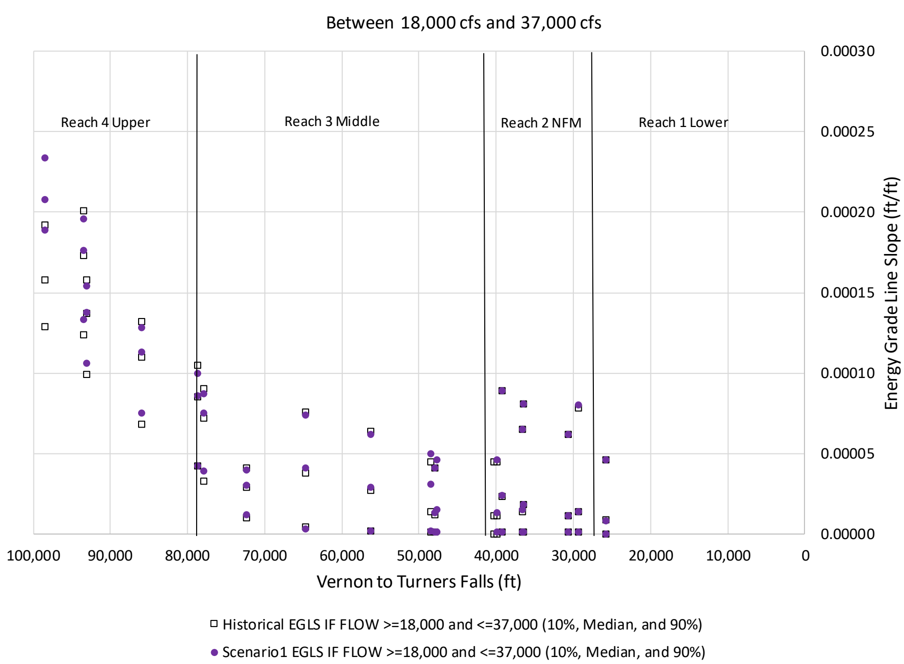


Figure 6.1.2.2-2: Energy slope trends through the Turners Falls Impoundment at flows between 18,000 and 37,000 cfs

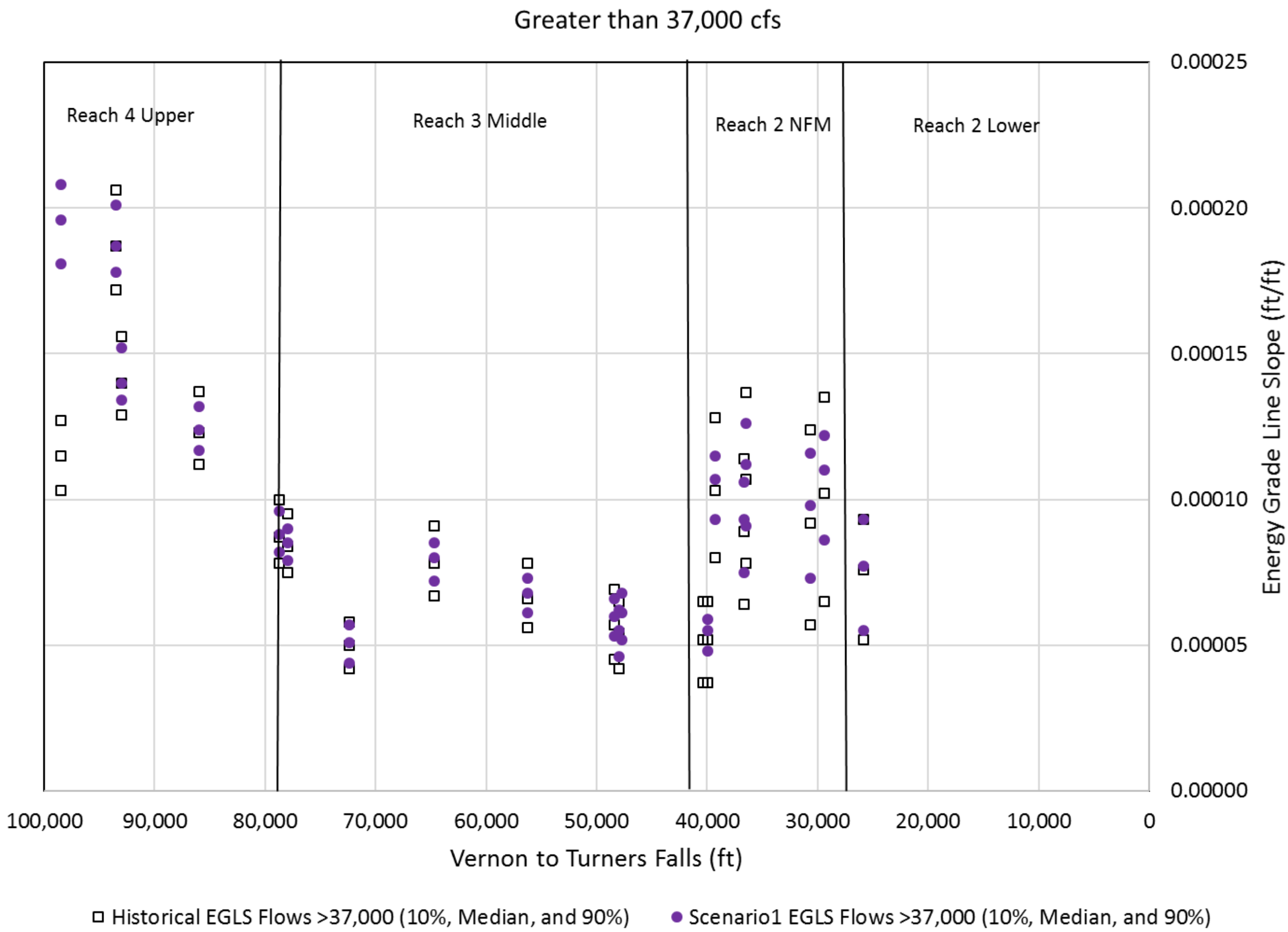
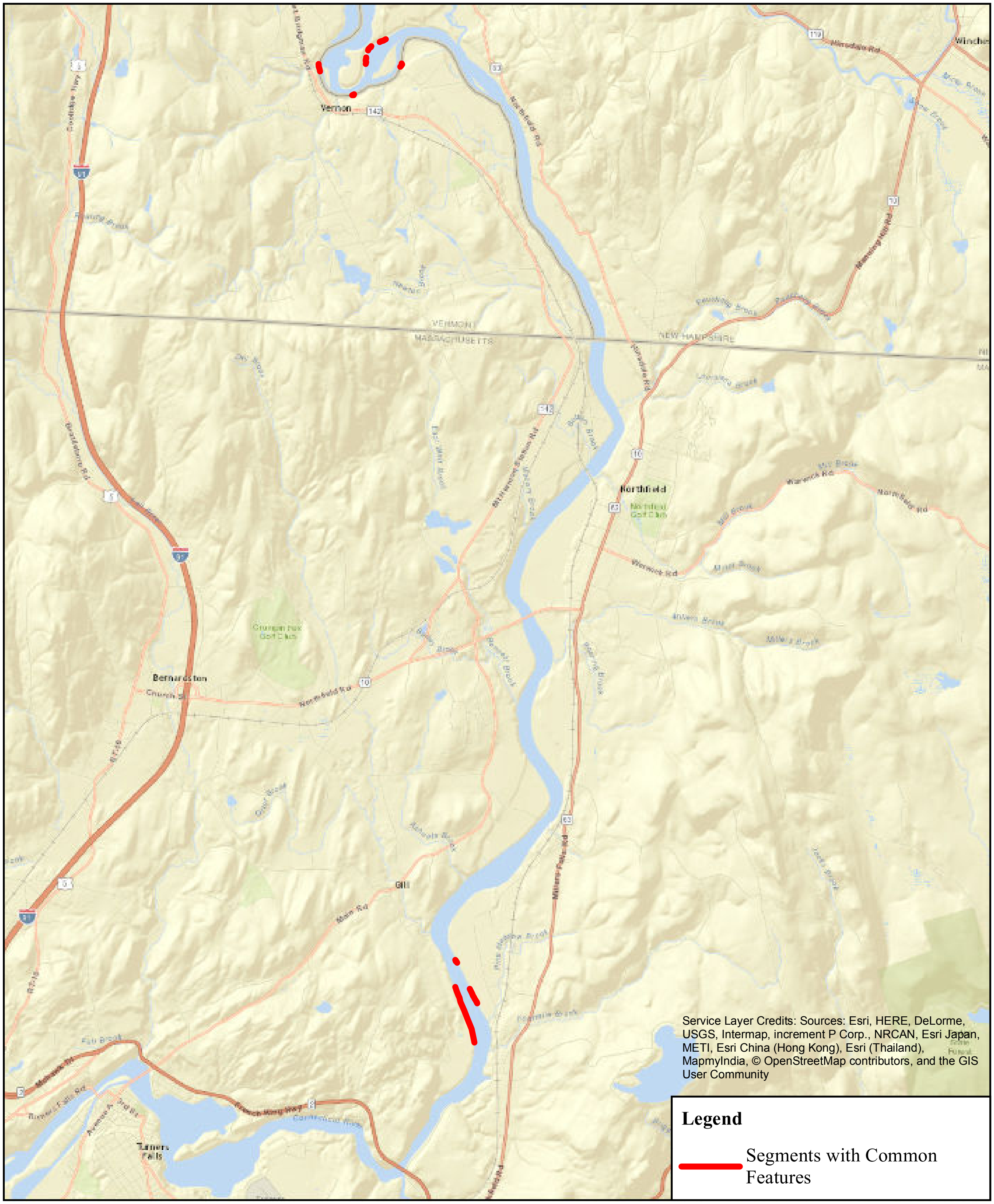


Figure 6.1.2.2-3: Energy slope trends through the Turners Falls Impoundment at flows over 37,000 cfs



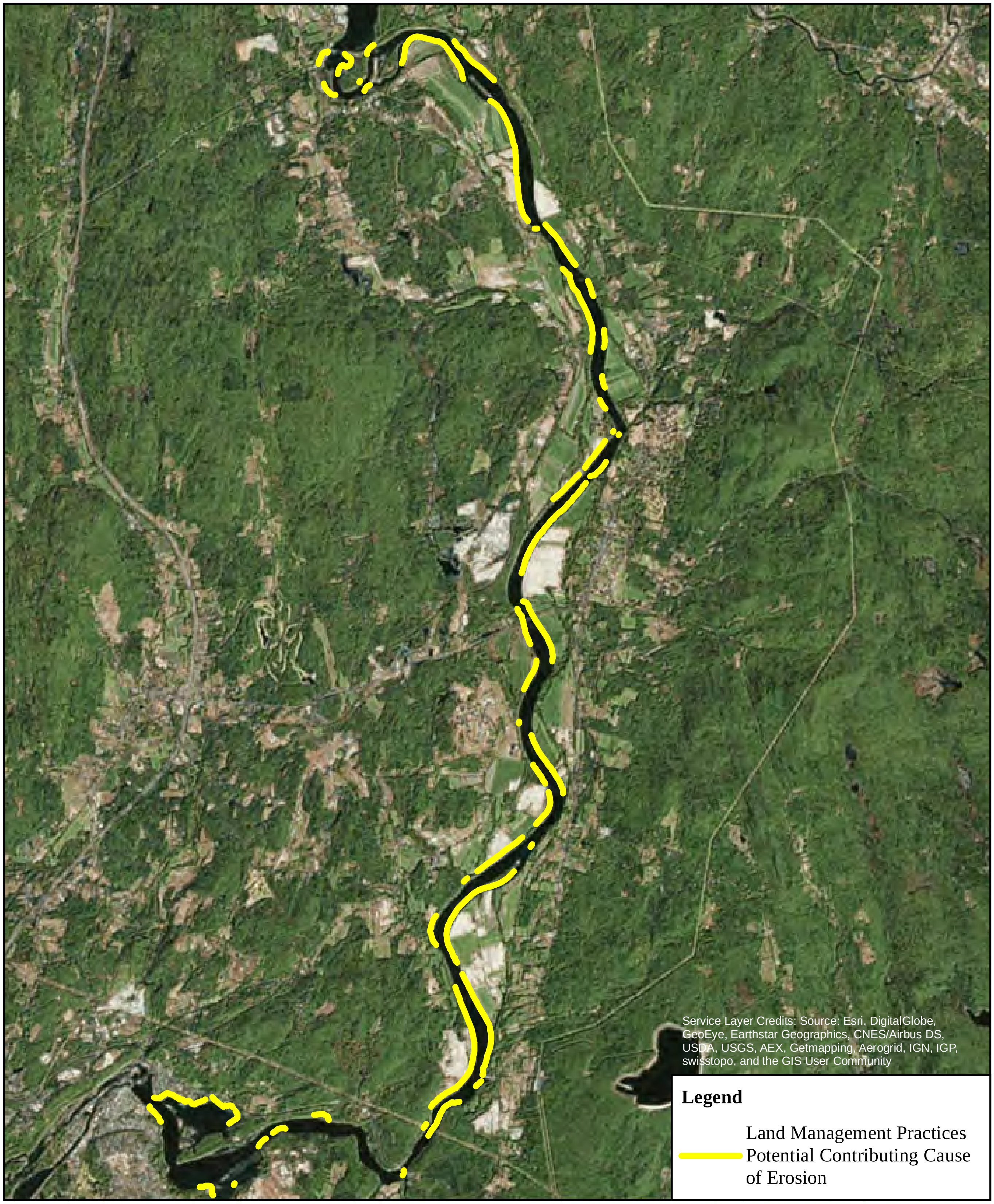
FirstLight Power Resources

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

STUDY 3.1.2

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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-4.mxd



FirstLight Power Resources

N

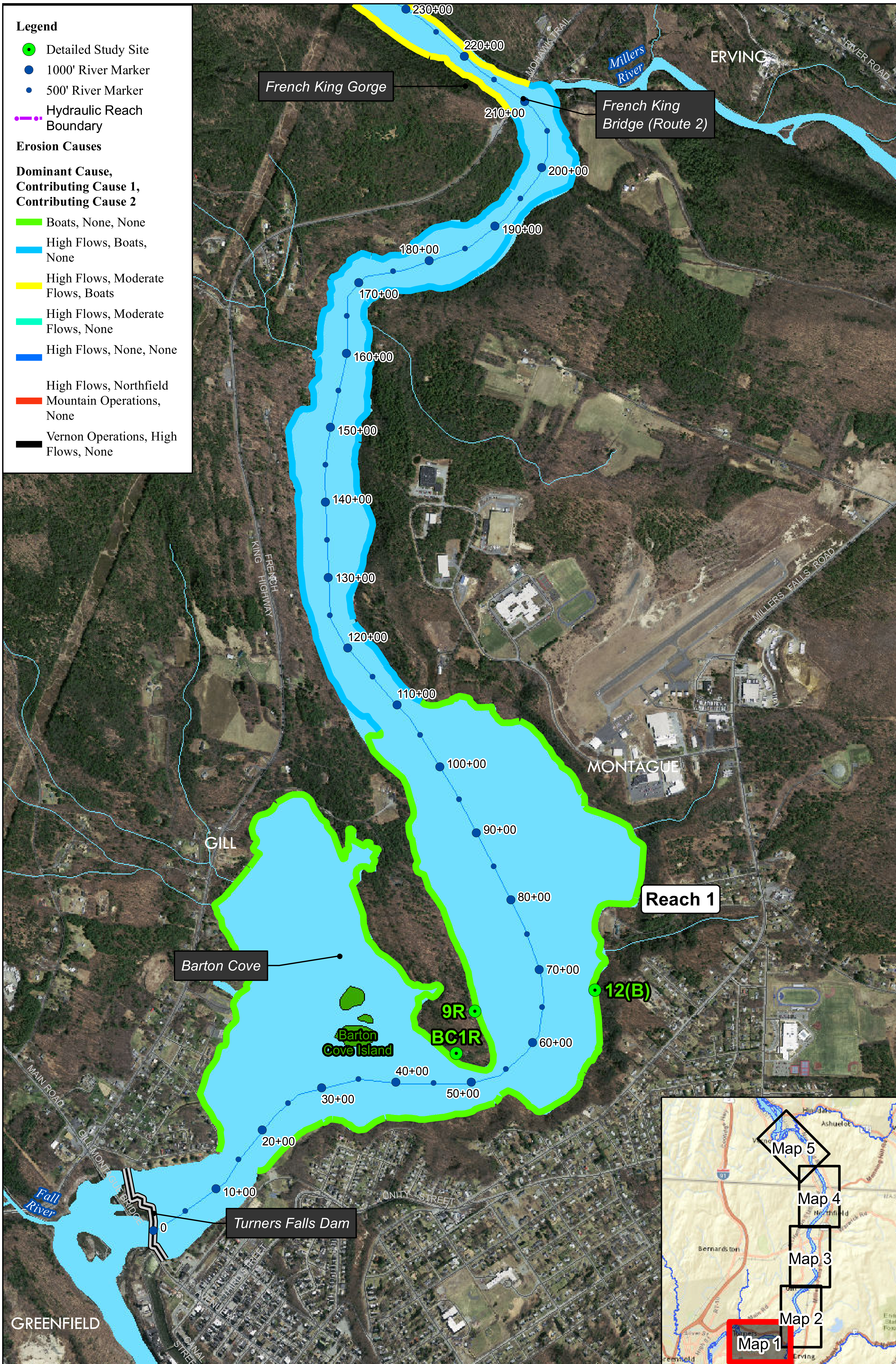
FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

0 0.75 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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-5.mxd



FirstLight Power Resources

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

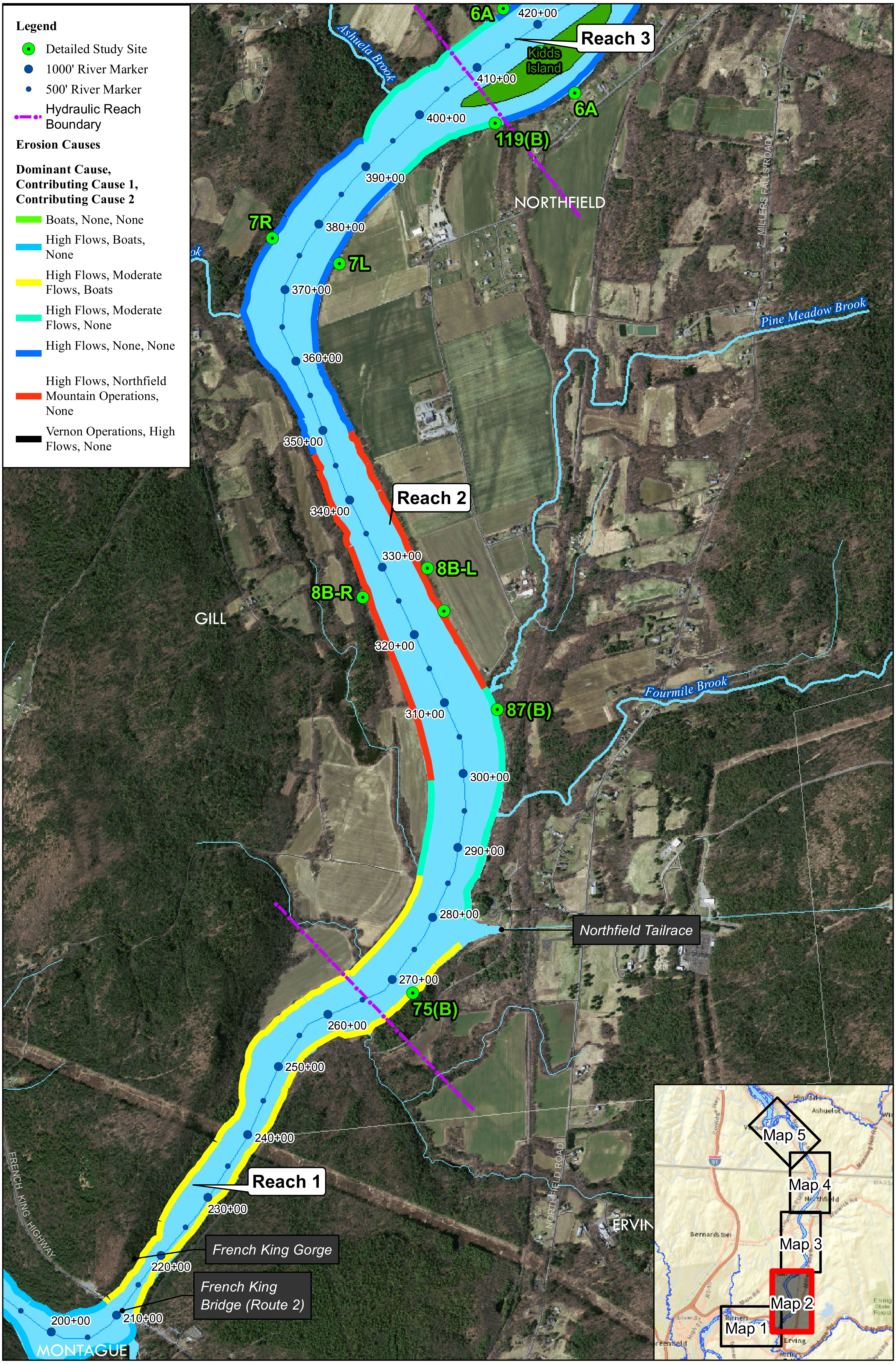
STUDY 3.1.2

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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-6.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

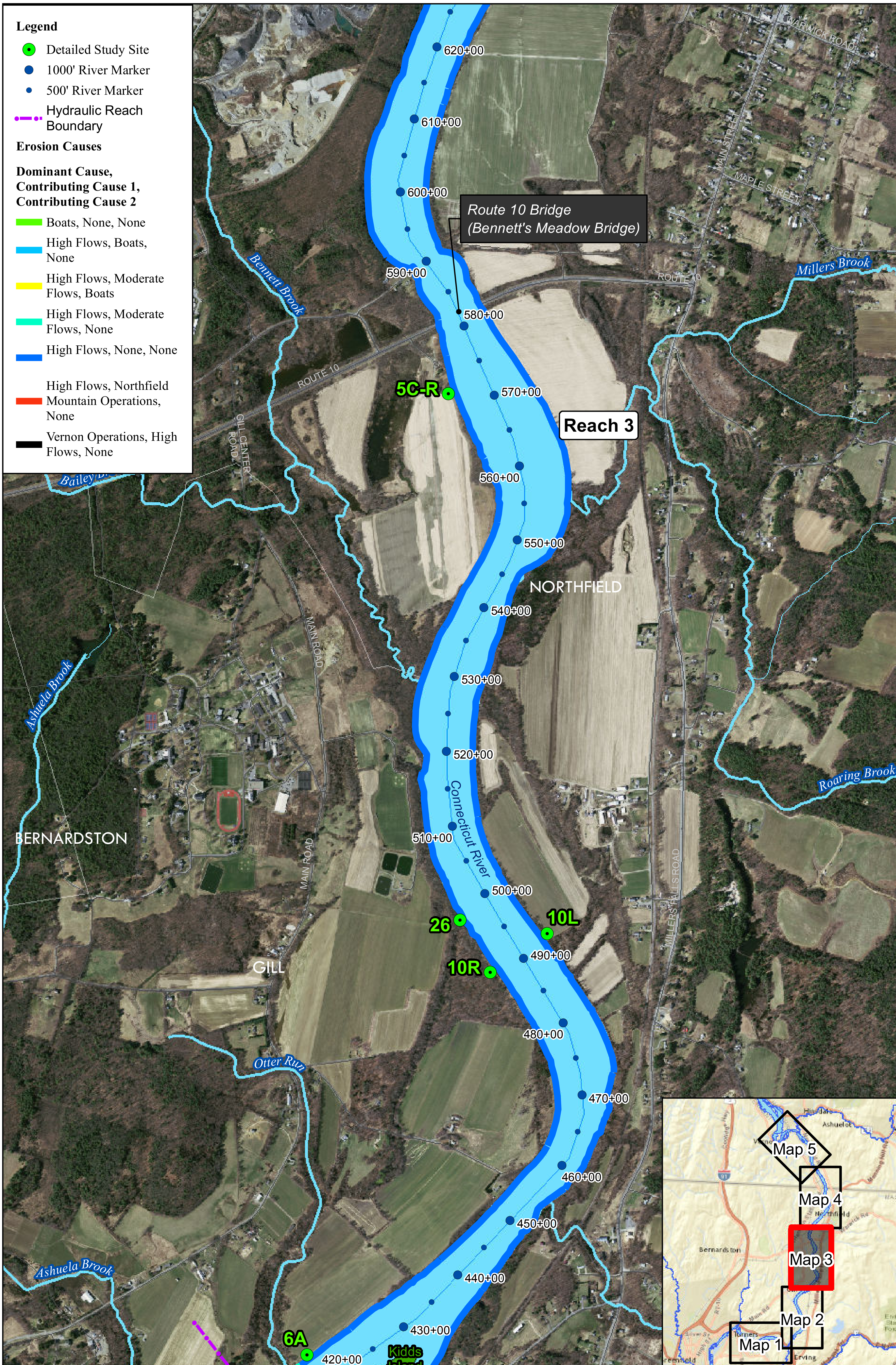
N

0 625 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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-6.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

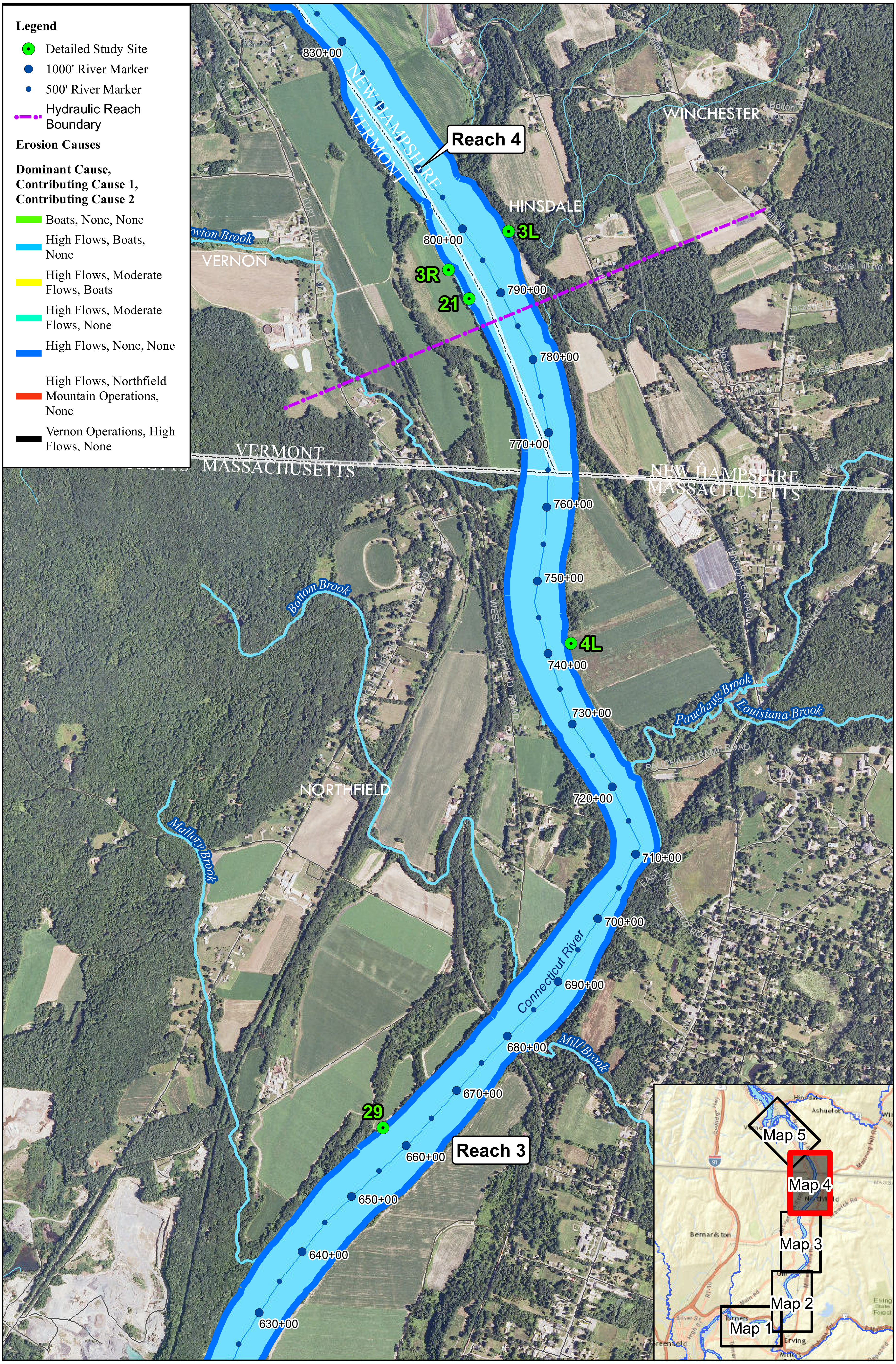
N

0 625 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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-6.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

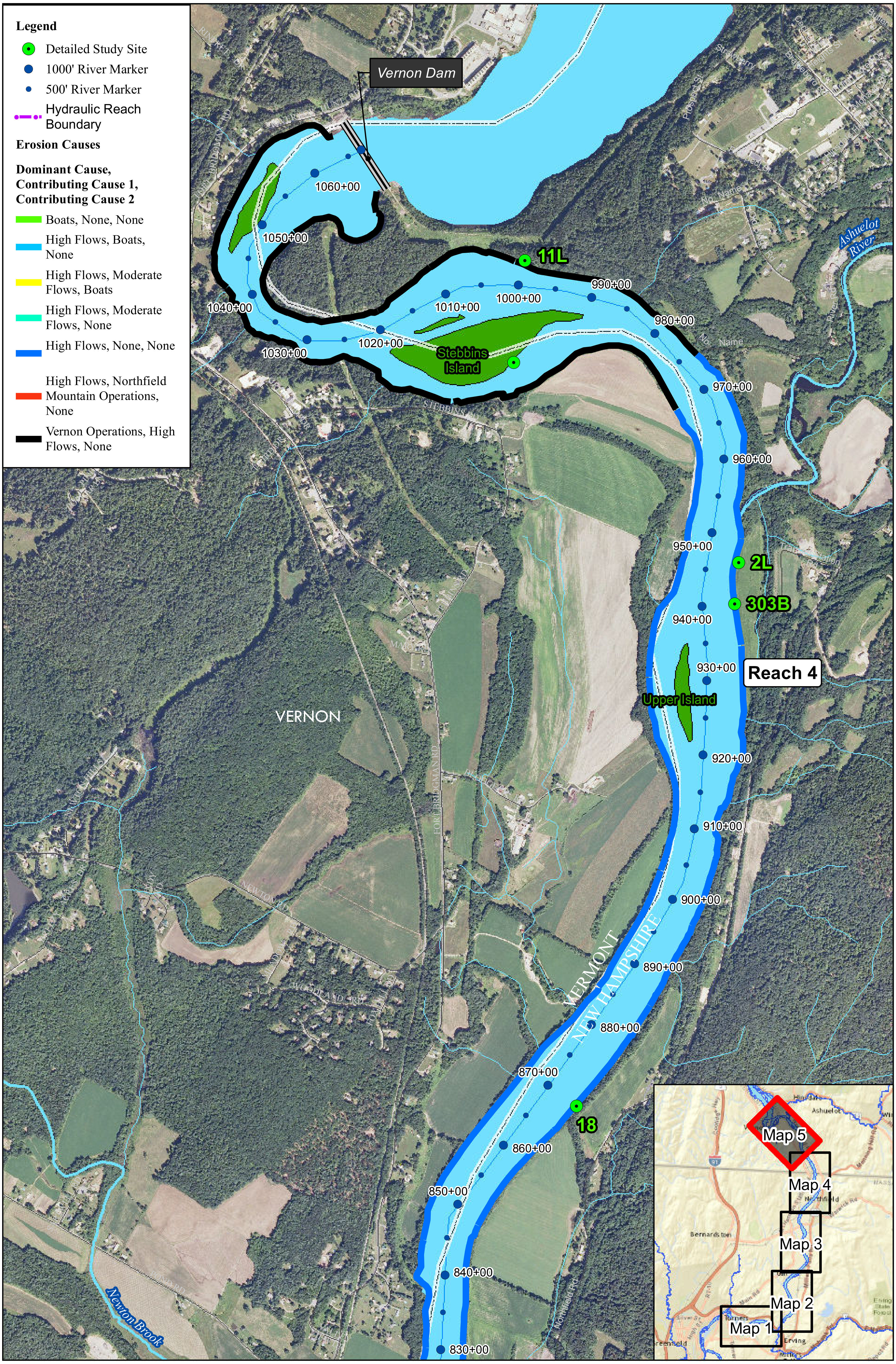
N

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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-6.mxd



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 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

Path: W:\gis\studies\3_1_2\maps\final_report\figure_6_1_2_2-6.mxd

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	5.416	19,537	32,196
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	0.3	4.505	6.601
Total Erosion <=17,130 cfs (ft^3/ft)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**0.051**	**0.166**	**0.076**
Total Erosion (ft^3/ft)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.351	4.671	6.677

[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).

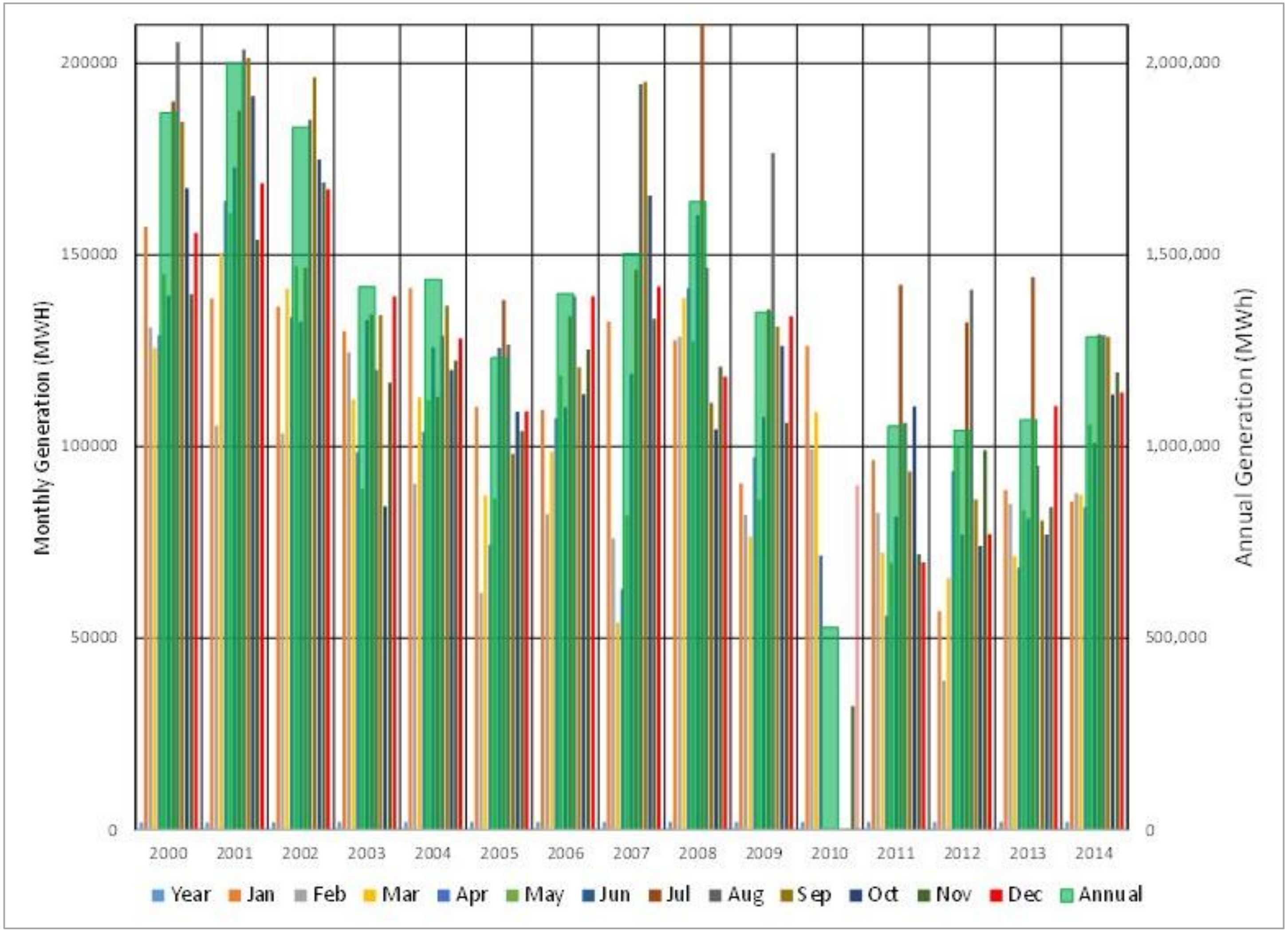


Figure 6.1.3-1: Comparison of Northfield Mountain Project Generation 2000-2014

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.

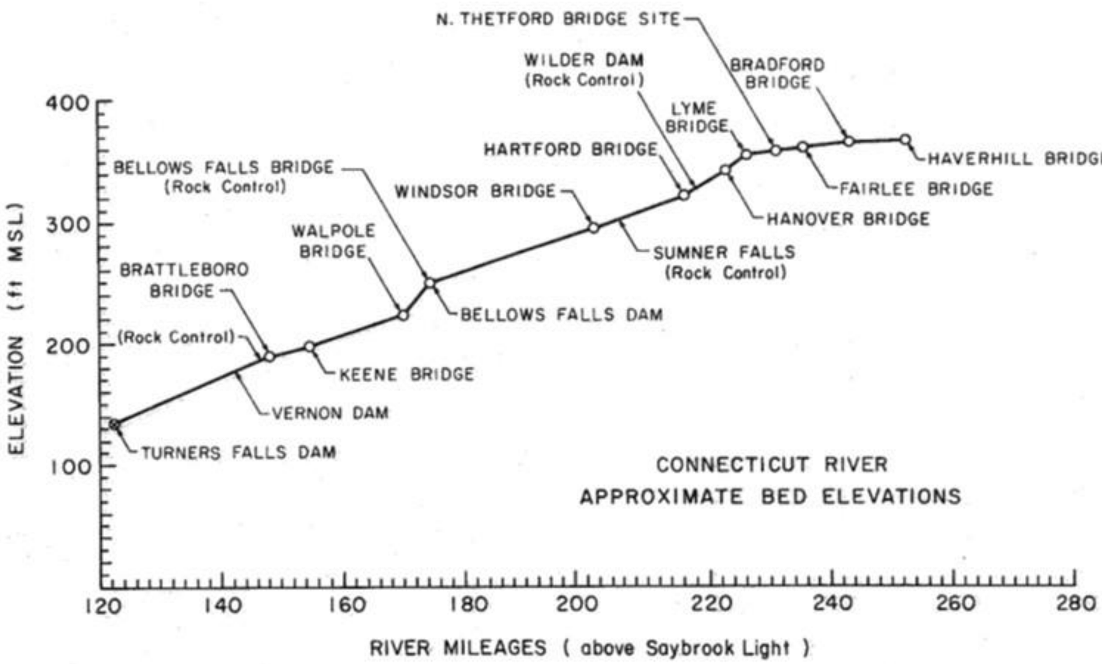


Figure 6.1.4.1-1 1979 USACE Study Reach – Connecticut River (USACE, 1979)

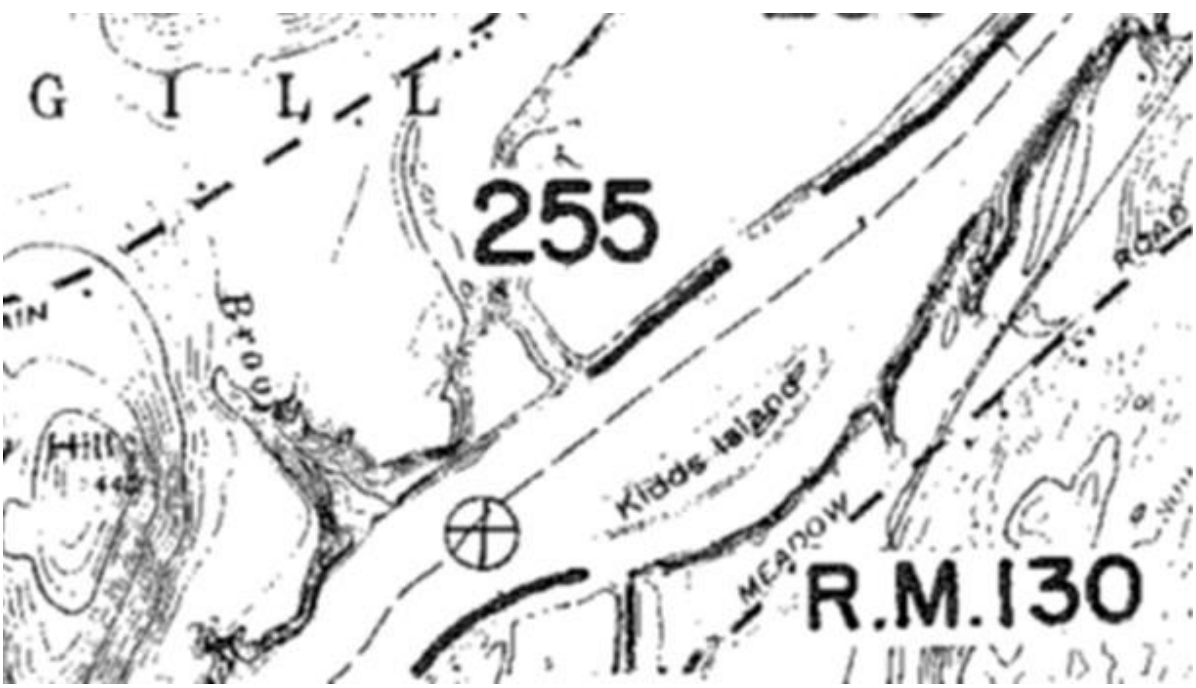
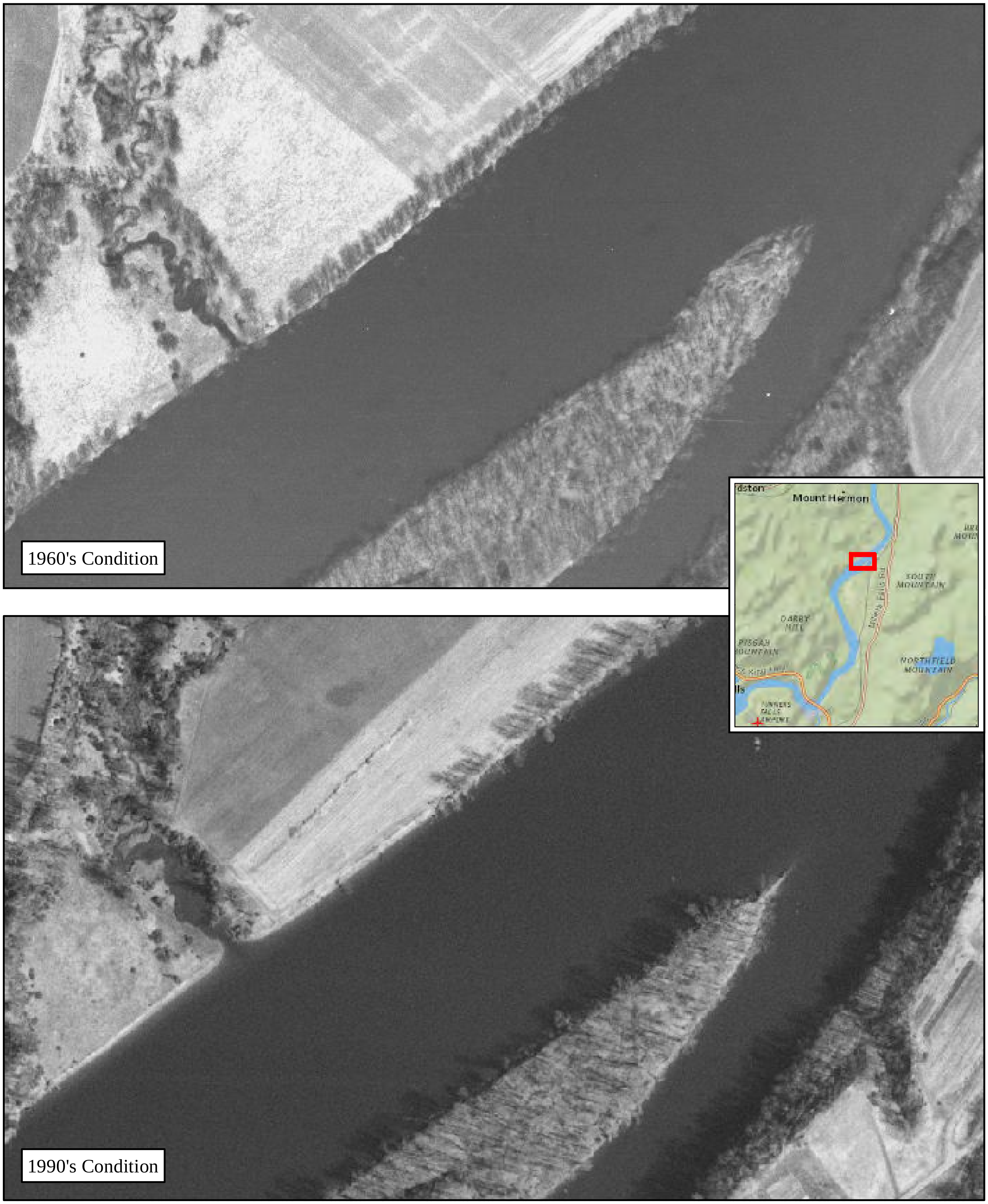


Figure 6.1.4.1-2 TFI USACE Index Site 255 (USACE, 1979)



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.