Relicensing Study 3.1.2

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

Volume I – Executive Summary and Summary Report

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

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PREFACE

As part of the Federal Energy Regulatory Commission (FERC or the Commission) relicensing process for the Northfield Mountain Pumped Storage Project (FERC No. 2485) and Turners Falls Hydroelectric Project (FERC No. 1889) FirstLight Hydro Generating Company (FirstLight) conducted Relicensing Study No. 3.1.2 *Northfield Mountain / Turners Falls Operations Impacts on Existing Erosion and Potential Bank Instability* (Study No. 3.1.2). The goal of this study was to evaluate and identify the causes of erosion in the Turners Falls Impoundment (Connecticut River) and to determine to what extent they are related to Northfield Mountain and Turners Falls Project operations. The study was conducted over the period 2013-2016 and included various field data collection, analysis, and modeling efforts. In accordance with the FERC approved Revised Study Plan (RSP), this report provides a detailed discussion of all tasks identified in the RSP as well as the findings of each task.

Due to the extensive nature of the study, the robust datasets which were collected and analyzed, and the complex nature of this resource issue, the final report has been divided into three volumes to enable an easier review. These volumes include:

- Volume I – Executive Summary and Summary Report;
- Volume II – Main Report; and
- Volume III – Appendices

EXECUTIVE SUMMARY

The primary goal of Relicensing Study No. 3.1.2 *Northfield Mountain / Turners Falls Operations Impacts on Existing Erosion and Potential Bank Instability* (Study No. 3.1.2) was to evaluate and identify the causes of erosion in the Turners Falls Impoundment (TFI) and to determine to what extent they are related to Northfield Mountain Pumped Storage Hydroelectric Project (FERC No. 2485) and Turners Falls Hydroelectric Project (FERC No. 1889) operations. In order to achieve the goals and objectives of the study, the study methodology was divided into seven tasks which included data gathering and literature review; developing a geomorphic understanding of the Connecticut River; identifying the potential causes of erosion present in the TFI; conducting field studies and data collection efforts; data analyses; evaluation of the causes of erosion; and, finally, developing a final report and deliverables.

In order to identify and evaluate the causes of erosion, a list of potential causes was first identified during development of the study methodology. This list was based on past experience conducting geomorphic assessments of the Connecticut River, and other alluvial rivers, as well as from preliminary investigation of existing documentation. The list of potential causes was then divided into two categories: (1) potential primary causes of erosion, and (2) potential secondary causes of erosion. The list of potential causes provided the foundation for this study and included the following:

Potential Primary Causes of Erosion

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

Potential Secondary Causes of Erosion

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

Potential primary causes of erosion were those which were thought to be most prevalent throughout the TFI where erosion occurs. These causes were studied at a number of detailed study sites which were located throughout the geographic extent of the TFI. In addition to encompassing the geographic extent of the TFI, the detailed study sites spanned the various hydraulic reaches of the TFI and exhibited the full range of riverbank features and characteristics as observed during the 2013 Full River Reconnaissance (FRR) survey (Relicensing Study No. 3.1.1). The results from the various field investigations which occurred at each site were then incorporated into the Bank Stability and Toe Erosion Model (BSTEM) and/or were used for independent, supplemental analyses. Dominant and contributing primary causes of erosion were then identified at each detailed study site. In order to be considered a dominant cause of erosion the specific cause had to be responsible for greater than 50% of the erosion at that site. Conversely, to be considered a contributing cause the specific cause had to be responsible for greater than 5% (but less than 50%) of the erosion at that site.

Once the dominant and contributing causes of erosion were identified at each detailed study site, the results were extrapolated throughout the TFI such that every riverbank segment identified during the 2013 FRR was assigned dominant and contributing primary causes of erosion. The extrapolation process was a multi-step process that took into consideration the riverbank features and characteristics of each riverbank segment as well as the hydraulic characteristics present. At the completion of the extrapolation process summary statistics were developed for the dominant and contributing primary causes of erosion throughout the TFI.

During study plan development it was anticipated that the potential secondary causes of erosion could be present at specific locations in the TFI, however, it was likely that they would have minimal to no influence on erosion processes (other than in any specific location where they may exist). Accordingly, these causes of erosion were analyzed sufficiently to determine their relative contribution to erosion but not to the level of detail and specificity as the potential primary causes of erosion mentioned above. Any potential secondary causes of erosion that were found to be a contributing cause(s) at a specific site were taken into consideration during the extrapolation process.

Results

The results of the study found that naturally occurring high flows were the dominant primary cause of erosion, 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 basis of the conclusions of the study are set out in the paragraphs that follow.

Review of the hydraulic model results, and more specifically the Energy Grade Line slope[1], revealed four distinct hydraulic reaches within the TFI. The four hydraulic reaches included the Upper (Reach 4), Middle (Reach 3), Northfield Mountain (Reach 2), and Lower (Reach 1) reaches. The Upper reach extends from Vernon Dam to just upstream of the NH/MA border, the Middle reach from upstream of the NH/MA border to just downstream of Kidds Island, the Northfield Mountain reach from just downstream of Kidds Island to just downstream of the Northfield Mountain tailrace, and the Lower reach from just downstream of the Northfield Mountain tailrace to the Turners Falls Dam.

The results of the hydraulic and BSTEM models indicated that hydropower operations can only potentially impact erosion processes within the hydraulic reach where the project is located due to the varying hydraulic characteristics of the TFI. In other words, the models showed that Northfield Mountain operations can only potentially impact erosion processes at riverbank segments within the Northfield Mountain reach. Vernon operations can only potentially impact erosion processes within the Upper reach, and likewise Turners Falls operations can only affect the Lower reach. Although Project operations can impact flows and water levels beyond their given hydraulic reach, the impacts at flows which cause erosion (as determined by BSTEM) are minor enough that they do not alter the EGL slope, and therefore the velocity or shear stress, outside of their reach.

The models assessed the erosive impact of flows within thresholds established by the hydraulic characteristic of each reach. Through further analysis of the various modeling results two flow thresholds were established in the upper reach of the TFI (hydraulic reach 4): (1) <17,130 cubic feet per second (cfs), and (2) >17,130 cfs. This threshold value was identified as it corresponds with the hydraulic capacity of the Vernon Hydroelectric Project and is consistent with the hydraulic characteristics of this more riverine reach

[1] The Energy Grade Line is the elevation of the energy head of the water in the river and is the hydraulic grade line plus the velocity head between each model transect. Generally, a greater slope of the energy grade line indicates a higher water velocity and a higher potential for hydraulic erosion. The Energy Grade Line is an important component in the hydraulic-erosion sub-model of BSTEM as it forms the basis for calculating boundary shear stress for nodes along the wetted perimeter along with the hydraulic radius of the segmented flow and the unit weight of water.

of the TFI. In the remaining three hydraulic reaches (i.e., from just upstream of the NH/MA border to Turners Falls Dam), three flow thresholds were established, including: (1) <17,130 cfs; (2) 17,130 to 37,000 cfs; and (3) >37,000 cfs. 37,000 cfs was chosen as the high flow threshold as it represents the combined hydraulic capacity of Vernon and Northfield Mountain, is at a flow above which the French King Gorge becomes the hydraulic control for the mid and upper TFI, and represents periods when Northfield Mountain does not regularly operate. Flow thresholds represent flows as measured at a given site at a given time and can be the combination of a number of factors including hydroelectric operations, tributary inflow, or natural flows. Given that flow can vary across different locations at the same time, these flow thresholds are not based exclusively on Vernon inflow or naturally routed flow (i.e. Vernon inflow plus inflow from the Ashuelot and Millers Rivers) but are instead representative of all hydrologic influences.

For the purpose of this study, flows equal to or less than 17,130 cfs were considered low flows. This threshold was established based on the hydraulic capacity of the Vernon Hydroelectric Project which is 17,130 cfs. At flows equal to or less than this value flows and water levels throughout the TFI are controlled by hydroelectric operations (i.e., Vernon, Northfield Mountain, and/or Turners Falls operations). During these low flow periods Vernon operations can impact flow and water levels downstream to the Turners Falls Dam while water level management at the Turners Falls Dam and Northfield Mountain Project operation can impact flows and water levels upstream to Vernon. Water levels during these low flow periods are almost exclusively on the lower riverbank regardless of water level fluctuations from hydroelectric operations.

At flows between 17,130 and 37,000 cfs (i.e., moderate flows) a number of hydraulic influences are observed throughout the TFI, specifically in hydraulic reaches 3 (middle), 2 (Northfield Mountain), and 1 (lower)[2]. While Vernon and Turners Falls operations are no longer the controlling hydraulic factor they can still have a contributing impact on flows and water levels depending on the location in the TFI. Northfield Mountain operations cans also impact flows and water levels throughout the TFI during the full range of moderate flows. Additionally, water level management at the Turners Falls Dam can still impact water levels throughout the TFI up to flows of 30,000 cfs; however, as moderate flows increase, the upstream impact of water level management at the Turners Falls Dam diminishes until having no impact at all. At flows of 30,000 cfs or greater the French King Gorge becomes the hydraulic control for the middle and upper portions of the TFI. That is, Turners Falls Dam water level management has a very limited impact on flows or water levels above the French King Gorge at flows greater than 30,000 cfs. Water levels during moderate flow periods may be on either the lower or upper riverbank depending on the flow and the location in the TFI.

In hydraulic reaches 3 (middle), 2 (Northfield Mountain), and 1 (lower) flows equal to or greater than 37,000 cfs represent natural high flows.[3] At flows of this magnitude neither the Vernon or Turners Falls Project impacts flows or water levels as they are operated in run-of-river mode (i.e., inflow is equal to outflow). Additionally, the French King Gorge acts as the hydraulic control for the upper and middle portion of the TFI. While Northfield Mountain has the ability to operate at flows of this magnitude, analysis of Project operations data over the evaluation period (2000-2014) found that the Project only operated 0.025% (4 units) to 2.6% (1 unit) of the time when flows exceeded 37,000 cfs. This equates to approximately 0.1 to 9 days per year, respectively. During these high flow periods, the water level rests almost exclusively on the upper bank.

[2] While downstream hydraulic influences can have an impact on flows and water levels in hydraulic reach 4 (upper) during these moderate flow periods, the impact is not as pronounced as in the middle and downstream reaches. As such, for the purposes of this study, the upper reach has only two defined flow thresholds – those below 17,130 cfs and those above 17,130 cfs.

[3] As previously noted, the natural high flow threshold in hydraulic reach 4 (upper) is 17,130 cfs.

In order to quantify the primary causes of erosion at each detailed study site a number of analyses were conducted utilizing BSTEM. The results of these analyses were then compared against the results of various supplemental analyses (e.g., hydraulics, sediment transport, etc.) as a means of verification. Each primary cause of erosion was determined as follows:

- **Moderate or High Flows** *(hydraulic shear stress due to flowing water)*: a flow analysis was conducted which resulted in the identification of the erosion flow threshold at which 50% and 95% of all erosion occurs at a given site. Based on the results of this analysis, and the flow thresholds previously discussed, a determination was then made as to the sites where natural moderate or high flows were found to be a dominant or contributing cause of erosion;

- **Boats** *(boat waves)*: BSTEM was enhanced with a built-in boat wave module for this study. Two BSTEM runs were executed utilizing this module, one with boat waves "turned on" and the other with boat waves "turned off." The difference in observed erosion between the two model runs determined the sites where boat waves were a cause of erosion;

- **Vernon Operations** *(hydraulic shear stress due to flowing water, water level fluctuations associated with hydropower operations)*: the results of the flow analysis were used to identify areas within the Upper reach where erosion was observed at flows below 17,130 cfs;

- **Northfield Mountain Operations** *(hydraulic shear stress due to flowing water, water level fluctuations associated with hydropower operations)***:** two BSTEM runs were executed, one representing the Baseline Condition (i.e., what actually happened during the modeling period) and one representing Northfield Mountain as idle. The difference in observed erosion between the two model runs determined the sites where Northfield Mountain operations were a cause of erosion; and

- **Turners Falls Operations** *(hydraulic shear stress due to flowing water, water level fluctuations associated with hydropower operations)***:** as previously discussed, due to the hydraulic characteristics of the TFI, Turners Falls Project operations could only be a potential cause of erosion in hydraulic reach 1 (lower). Detailed study sites in the lower reach only existed in the vicinity of Barton Cove and were not located in the more riverine portion of the reach (spanning just upstream of Barton Cove to upstream of the French King Gorge). As such, a modified extrapolation approach was used to determine the causes of erosion in the Lower reach upstream of Barton Cove. The modified extrapolation approach utilized a combination of BSTEM results, geomorphic assessment, and hydraulic model analysis.

The two remaining potential primary causes of erosion (land-use and land management practices and ice) were evaluated independently of BSTEM. In regard to land-use and land management practices, while riverbank vegetative conditions were analyzed as contributing factors in BSTEM, the potential for land-use and land management practices adjacent to the riverbanks to contribute to erosion were evaluated through geospatial analysis using GIS software. Ice was evaluated primarily through a combination of TFI monitoring during the winter of 2015/2016 (as well as limited monitoring during the winter of 2014/2015) and analysis of historic information from throughout the Connecticut River (including upstream impoundments) and other river systems.

As shown below, the results of the study found that naturally occurring high flows were the dominant primary cause of erosion, 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.

Dominant Primary Causes of Erosion	% of Total Riverbank Length	Total length
Natural High Flows	78%	175,900 ft. (33 mi.)
Boat waves	13%	30,800 ft. (6 mi.)
Vernon Operations	9%	20,200 ft. (4 mi)
Northfield Mountain Operations	0%	0 ft.
Turners Falls Operations	0%	0 ft.
Ice	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 U.S. Geological Survey (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 later 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 Vermont Yankee (VY). Analysis of historic data found that ice has caused severe erosion under the right climatic and hydrologic 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.

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

Analysis of the contributing primary causes of erosion, found that the majority of riverbank segments in the TFI did not have a contributing primary cause (i.e., a cause contributing 5-50% of erosion). 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. No contributing primary causes of erosion were observed in the Middle hydraulic reach. Secondary causes of erosion (i.e., animals, wind waves, seepage and piping, or freeze-thaw) were not found to be a contributing cause of erosion at any riverbank segment.

Contributing Primary Causes of Erosion	**% of Total Riverbank Length[4]**	**Total length[5]**
None	68%	153,400 ft. (29 mi.)
Boats	16%	36,000 ft. (7 mi.)
Natural Moderate Flows	10%	23,200 ft. (4 mi.)
Natural High Flows	9%	20,200 ft. (4 mi.)
Northfield Mountain Operations	4%	8,600 ft. (1.5 mi.)
Vernon Operations	0%	0 ft.
Turners Falls Operations	0%	0 ft.
Ice	I	I

I = Indeterminate

Land-use or land management practices 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.

As demonstrated in the tables and discussion above, natural high flows are responsible for the vast majority of erosion in the TFI with hydroelectric operations playing a very limited role, if any. 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. Northfield Mountain operations were found to be a contributing primary cause of erosion at only 4% of all riverbanks or 8,600 ft. (1.5 mi.) out of a potential 227,000 ft. (43 mi.). Furthermore, the riverbank segments where Northfield Mountain operations were found to be a contributing cause of erosion are limited to the Northfield Mountain hydraulic reach (reach 2).

[4] 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%.
[5] Rounded to the nearest 100 ft. or 0.5 mi.

SUMMARY REPORT

FirstLight Hydro Generating Company (FirstLight), has initiated the process of relicensing the Turners Falls Hydroelectric Project (FERC No. 1889) and the Northfield Mountain Pumped Storage Project (FERC No. 2485) with the Federal Energy Regulatory Commission (FERC or the Commission) using FERC's Integrated Licensing Process (ILP). The current licenses for the Turners Falls and Northfield Mountain Projects were issued on May 4, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. As part of the relicensing process, FirstLight filed a Revised Study Plan (RSP) with FERC on August 14, 2013. Included in the RSP was Study No. 3.1.2 *Northfield Mountain/Turners Falls Operations Impact on Existing Erosion and Potential Bank Instability* (Study No. 3.1.2 or the Causation Study). The methodology and scope for Study No. 3.1.2 were approved with modifications by the Commission in its September 12, 2013 Study Plan Determination Letter (SPDL). Approximately one year after FERC issued its SPDL, FirstLight filed an addendum to the RSP with FERC on September 15, 2014 which detailed protocols for increased investigation of ice as a cause of erosion due to the closure of the Vermont Yankee Nuclear Power Plant (VY) located upstream in the Vernon Hydroelectric Project (Vernon) impoundment.

Study Overview

The goals of Study No. 3.1.2, as stated in the RSP, were to evaluate and identify the causes of erosion in the TFI and to determine to what extent they are related to Northfield Mountain and Turners Falls Project operations. In order to accomplish these goals the RSP (p. 3-25) included the following tasks:

- Conduct a thorough data gathering and literature review effort of existing relevant data to identify data gaps;
- Conduct field investigations and field data collection to fill data gaps. Gather the field data required to conduct detailed analyses of the causes of erosion and the forces that control them;
- Develop an understanding of the historic and modern geomorphology of the Connecticut River. A historic geomorphic assessment will be conducted to provide context for analyzing the modern geomorphology of the Connecticut River;
- Identify the causes of erosion present in the TFI, the forces associated with them, and their relative importance at a particular location. Conduct various data analyses to gain a better understanding of these causes and forces;
- Identify and establish fixed riverbank transects that will be representative of the range of riverbank features, characteristics, and conditions present in the TFI;
- Conduct detailed studies and analyses of erosion processes at the fixed riverbank transects;
- Evaluate the causes of erosion using field collected data and the results of the proposed data analyses. This evaluation will include quantifying and ranking all causes present at each fixed riverbank transect as well as in the TFI in general; and
- Develop a final report that will summarize the findings of this study and the methods used.

During development of the RSP, and continuing after issuance of FERC's September 2013 SPDL, FirstLight conducted an in-depth literature review and data gathering effort which provided the foundation for this study and allowed for the identification of potential data gaps (RSP Task 1). During development of the RSP, FirstLight developed a list of the potential causes of erosion which may be present in the TFI. The preliminary list of potential causes presented in the RSP included (in no particular order):

- Hydraulic shear stress due to flowing water;
- Water level fluctuations due to hydropower operations;
- Boat waves;
- Wind waves;
- Land management practices and anthropogenic influences to the riparian zone;
- Animals;
- Seepage and piping;
- Freeze-thaw; and
- Ice or debris

Based on past experience conducting geomorphic assessments on the Connecticut River and other alluvial rivers, as well as from information gleaned from the preliminary investigation of existing documents and the FRR, the preliminary list of potential causes of erosion was then reviewed and divided in the RSP (p. 3-44) into two categories: 1) potential primary causes of erosion, and 2) potential secondary causes of erosion. From this, the following classifications were developed (in no particular order):

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[6]

Potential Secondary Causes of Erosion

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

The causes of erosion listed above formed the basis for the field studies and data collection efforts conducted as part of this study as well as the data analysis and evaluation of causes conducted in accordance with the RSP. While all of these potential causes of erosion were investigated, special emphasis was placed on the potential primary causes of erosion (RSP Task 3). The potential primary causes of erosion, and the forces associated with them, were evaluated at 25 detailed study sites located at fixed riverbank transects throughout the geographic extent of the TFI (RSP Task 4).

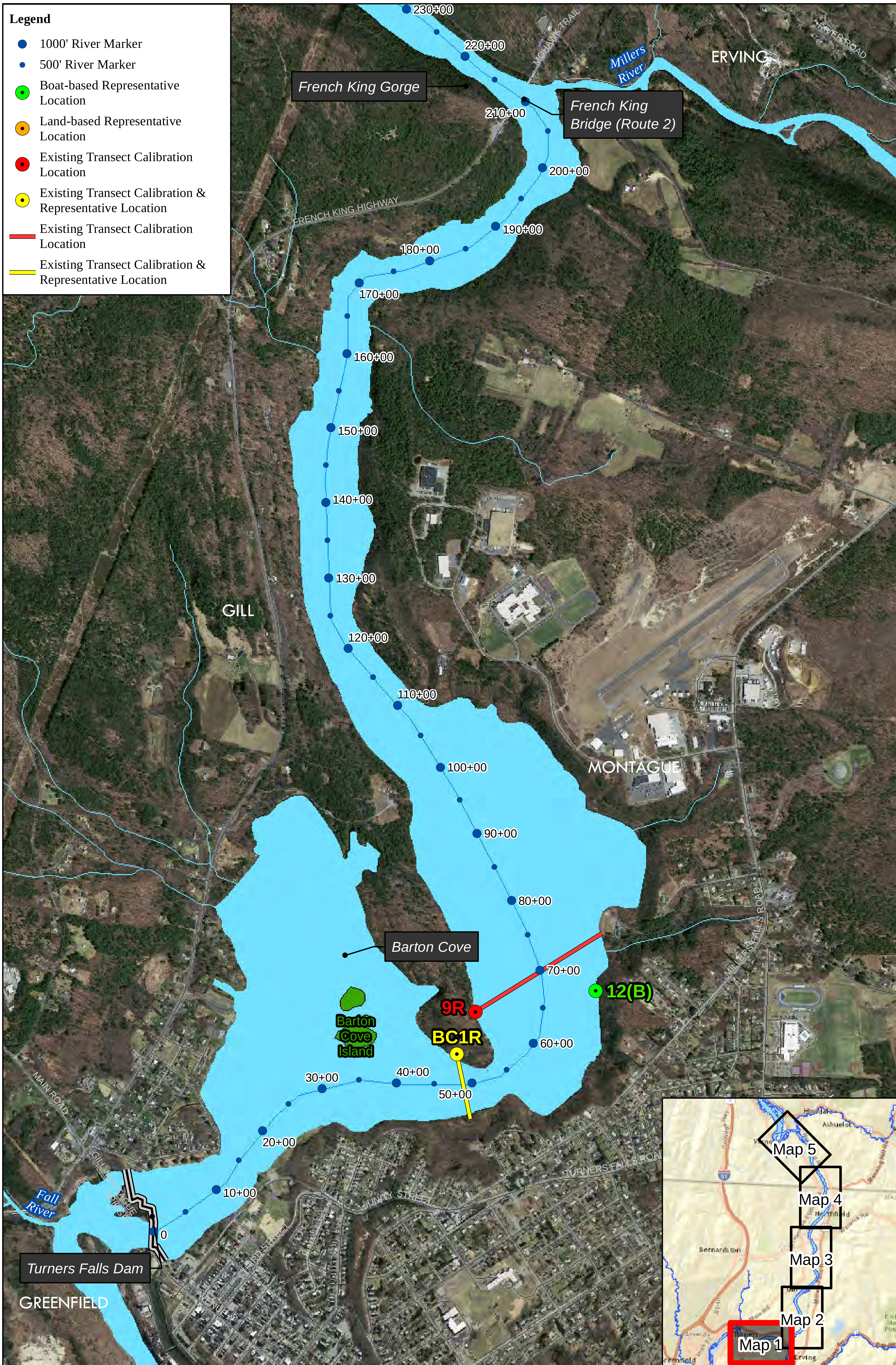
[6] Ice was originally classified in the RSP as a potential secondary cause of erosion, however, due to the closure of VY and the potential for the increased presence of ice in the TFI, and in accordance with the 2014 Addendum to Study 3.1.2 required by the SPDL, it was elevated to a potential primary cause of erosion in 2014.

The fixed riverbank transects where the potential primary causes of erosion were investigated (also referred to as detailed study sites) were selected in collaboration with stakeholders and were presented in the report titled *Study No. 3.1.2 Northfield Mountain/Turners Falls Operations Impact on Existing Erosion and Bank Instability – Selection of Detailed Study Sites – September 2014* (FirstLight, 2014b).[7] Stakeholders consulted during development of the final set of detailed study sites included: the Connecticut River Streambank Erosion Committee (CRSEC), Connecticut River Watershed Council (CRWC), Franklin Regional Council of Governments (FRCOG), Landowners and Concerned Citizens for License Compliance (LCCLC), National Marine Fisheries Service (NMFS), Massachusetts Riverways, and the Franklin Conservation District (FCD) as well as the Massachusetts Department of Environmental Protection (MADEP) and FERC.

The final set of detailed study sites included 25 locations throughout the geographic extent of the TFI. Detailed study sites encompassed a representative range of riverbank features, characteristics, and erosion conditions and included several sites that had been previously restored as a result of FirstLight's Erosion Control Plan (ECP). Sites were selected at existing, permanent transects (which have been surveyed annually since the 1990's) and at newly identified supplemental detailed study points. Supplemental detailed study points were proposed based on the results of the detailed geomorphic and geotechnical assessments conducted during the 2013 Full River Reconnaissance (FRR, Relicensing Study No. 3.1.1) land-based survey as well as the results of the 2013 FRR boat-based survey. Although the newly identified supplemental representative detailed study points were selected at only one bank, full cross-section surveys were collected at each location.

Detailed study sites were classified as either Calibration or Representative Sites. *Calibration sites* were defined as sites which were established at an existing, permanent transect location where data collection would be used to calibrate the Bank Stability and Toe Erosion Model (BSTEM). Establishing these sites at the existing, permanent transects provided the opportunity to calibrate BSTEM with actual erosion amounts or changes in bank geometry as it has occurred over a period of historic flows and water level data. *Representative sites* were defined as sites established throughout the TFI at locations that exhibit a range of representative features, characteristics, and erosion conditions. These sites did not have repetitive surveys for calibration of BSTEM. Calibration sites could only exist at existing, permanent transects while representative sites can exist anywhere in the TFI. Of the 25 detailed study sites, 16 were classified as representative (of which 7 are both calibration and representative), and 9 were classified as calibration sites. In other words, 16 detailed study sites are located at existing, permanent transects (established in the 1990's) while 9 were established at new locations identified as a result of the 2013 FRR. Figure 1 depicts the locations of the detailed study sites and transects located throughout the TFI.

[7] The *Selection of Detailed Study Sites* report was filed with FERC as part of the *Relicensing Study 3.1.2 Initial Study Report Summary* on September 15, 2014.



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 1:
Detailed Study Sites
in the Turners Falls Impoundment
Map 1

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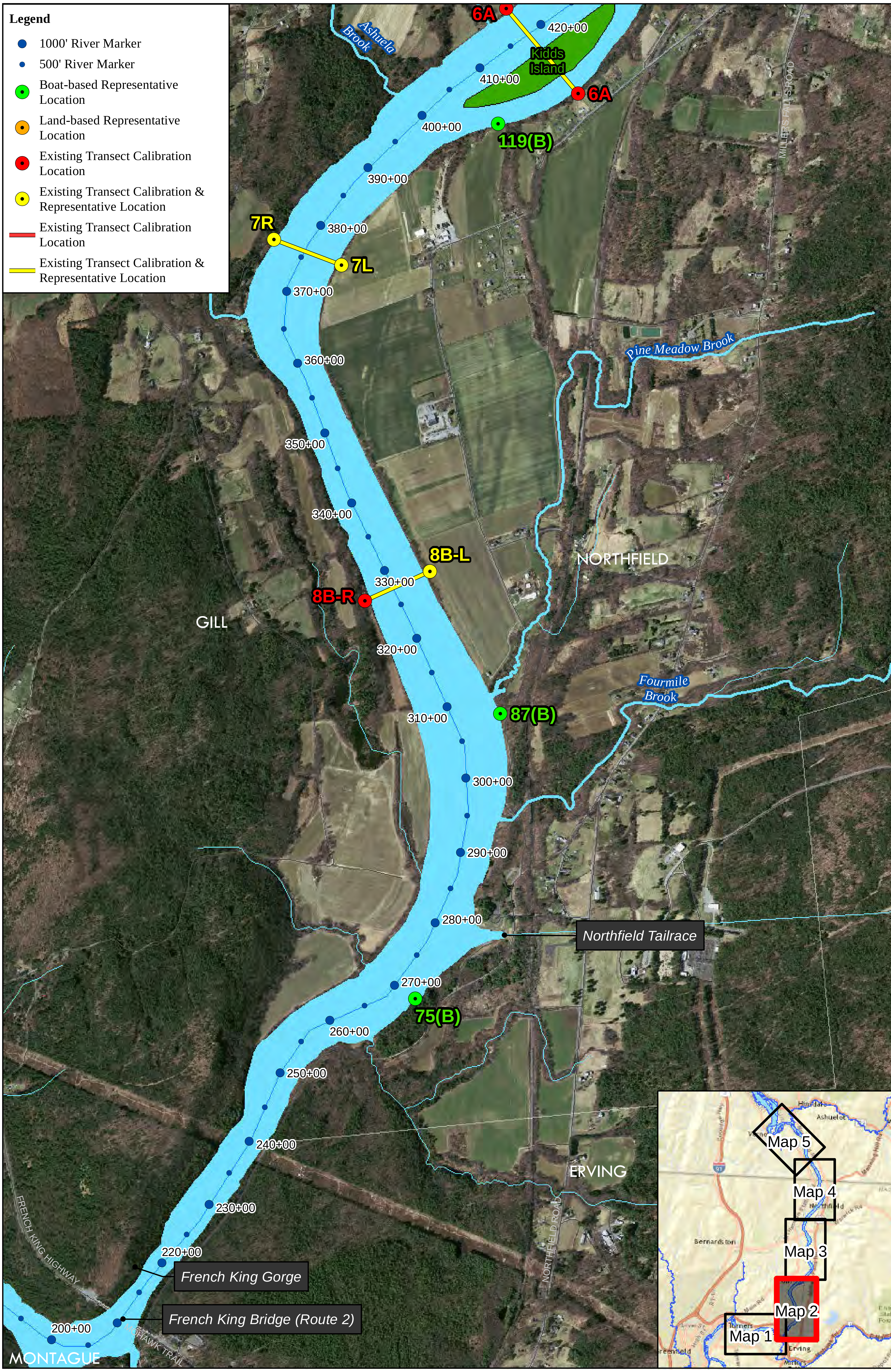

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

N

0 625 1,250 2,500 Feet

Figure 1:
Detailed Study Sites
in the Turners Falls Impoundment
Map 2

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

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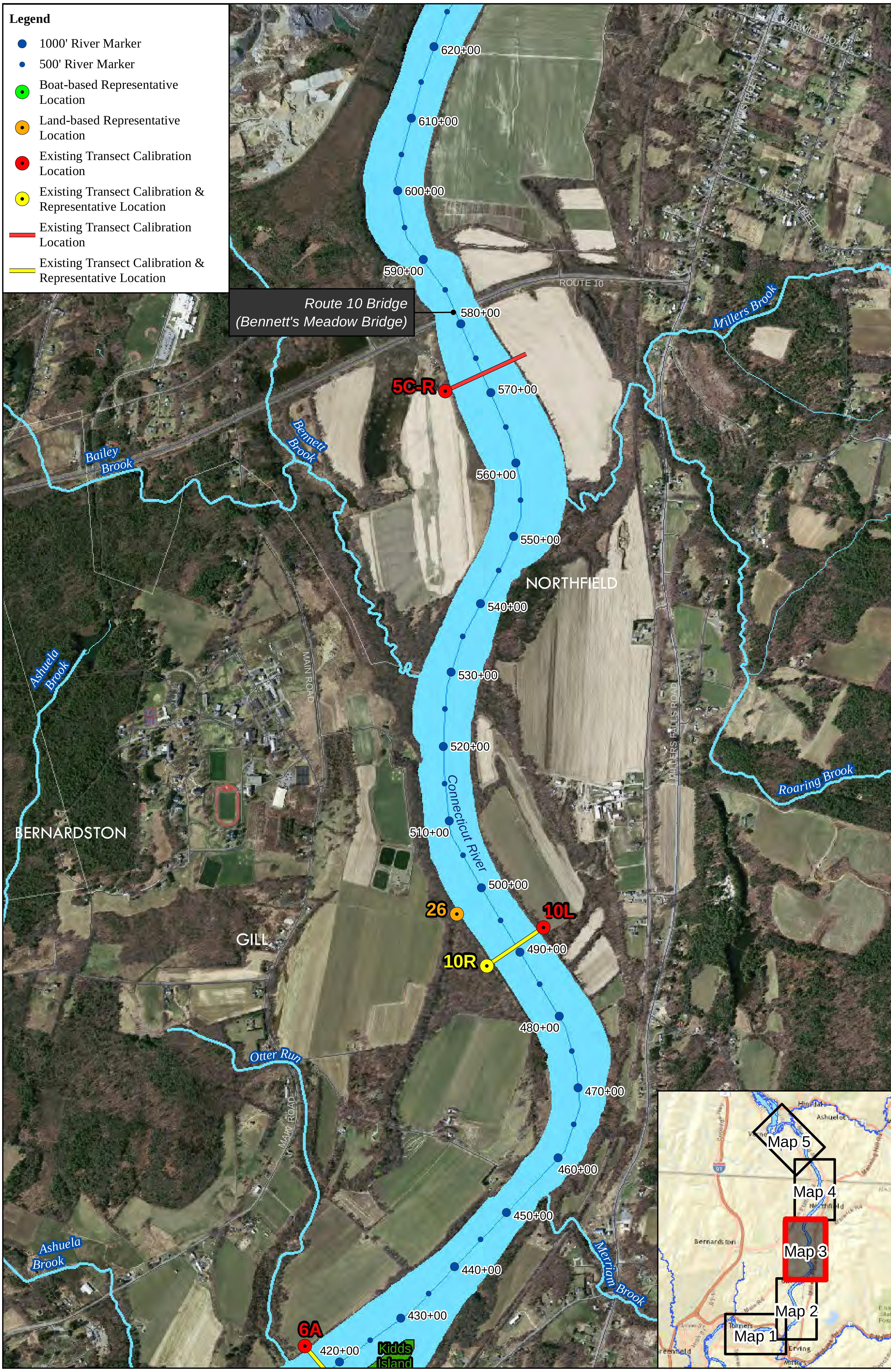

FIRSTLIGHT HYDRO GENERATING COMPANY
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STUDY 3.1.2

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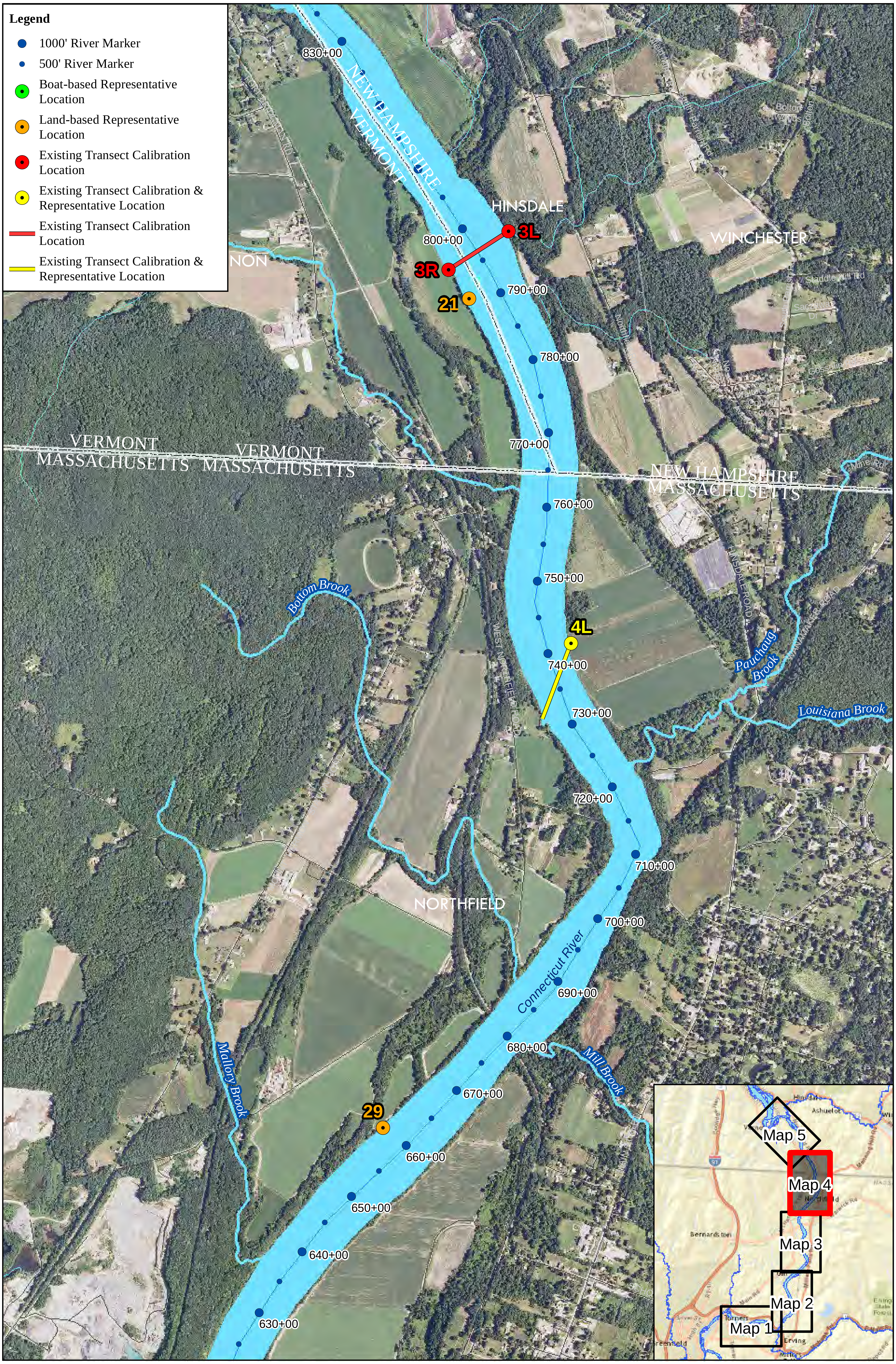

FIRSTLIGHT HYDRO GENERATING COMPANY
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STUDY 3.1.2

FirstLight Power Resources

N

0 625 1,250 2,500 Feet

Figure 1:
Detailed Study Sites
in the Turners Falls Impoundment
Map 4

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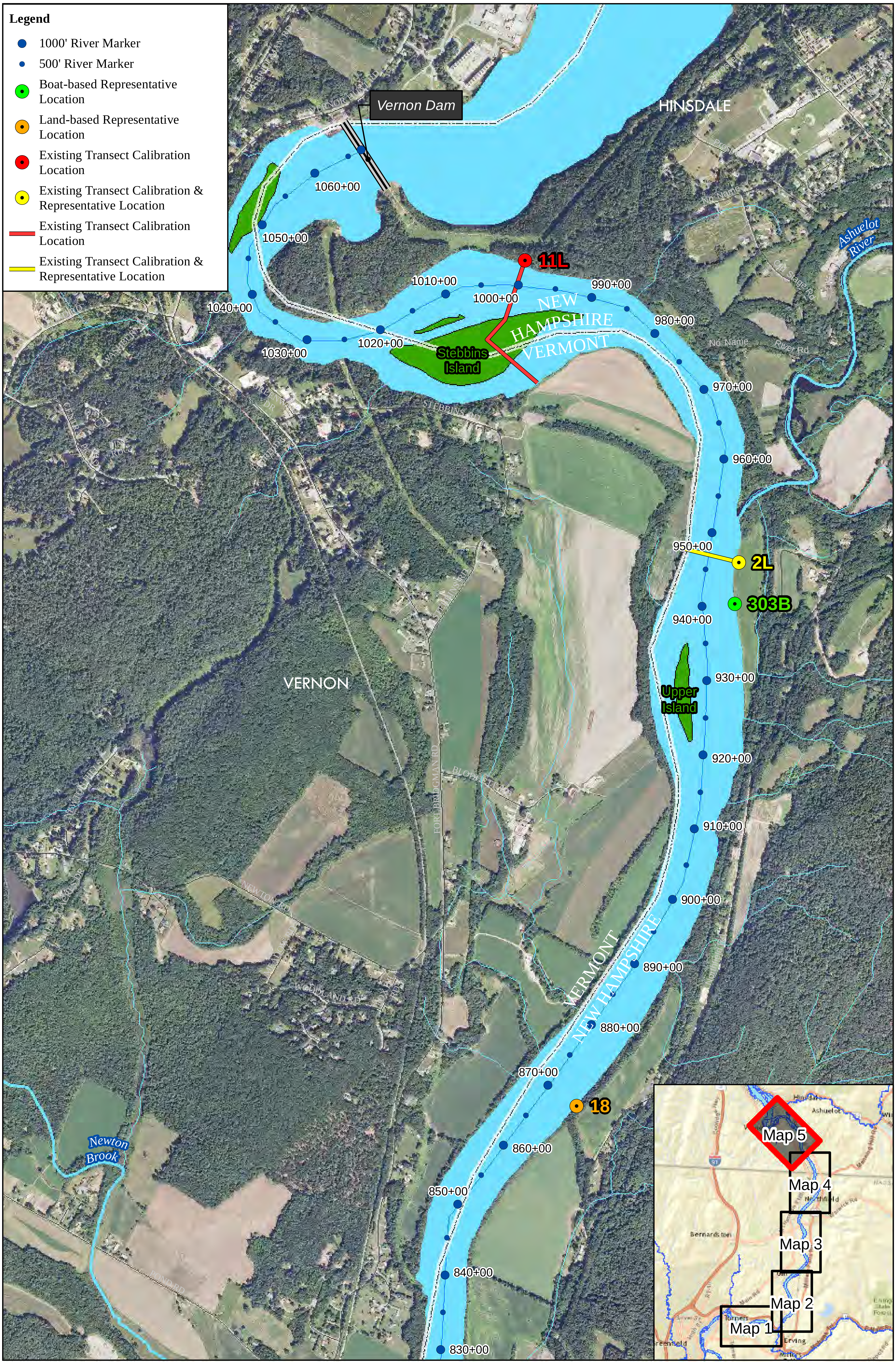

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

FirstLight Power Resources

0 625 1,250 2,500 Feet

Figure 1:
Detailed Study Sites
in the Turners Falls Impoundment
Map 5

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Once the final set of detailed study sites was established, field data collection efforts were carried out during 2014 with supplemental field work also conducted in 2015 and 2016 (ice monitoring). Field activities were conducted in accordance with Task 4 of the RSP as well as the Addendum to the RSP filed with FERC in September 2014. Field data that were collected (either as part of this study or other studies) included:

- TFI water level, flow, and Project operations data (Study No. 3.2.2);
- Bathymetric surveys of the TFI to support development of hydraulic models (Study No. 3.2.2);
- Riverbank features, characteristics, and erosion conditions as observed during the 2013 FRR (Study No. 3.1.1);
- Annual cross-section surveys at the existing, permanent transects and newly identified supplemental detailed study sites;
- BSTEM input parameters including: surface erodibility (critical shear stress), geotechnical strength (effective cohesion and friction angle), bulk unit weight, riverbank sediment particle-size distribution, maximum rooting depth of vegetation, and riparian species distribution;
- Vegetative parameters of five species including root density, distribution and root tensile-strength data;
- Boat-wave data and boat statistics for input into the BSTEM boat-wave algorithm;
- Suspended sediment concentration data (Study No. 3.1.3); and
- Ice monitoring photos

In addition, historical groundwater and boat wave data collected in the 1990's were examined as part of this study. The methodologies for all field data collection efforts are discussed in greater detail in the main report (Volume II) and appendices (Volume III). Field data were post processed and prepared for analysis or inclusion in various models throughout late 2014 and into 2015. Following the completion of the various field studies and data collection efforts, as well as completion of all post processing and quality assurance (QA), the field collected data were analyzed and model runs were executed throughout 2015 and into 2016 (RSP Tasks 5 and 6).

The data analyses conducted for this study consisted of a mix of qualitative and quantitative methods based on RSP Tasks 2, 5, and 6 as well as RSP Table 3.1.2-3. Data analyses followed a three-level approach consisting of:

1. **Qualitative geomorphic analysis:**

   The qualitative geomorphic analysis included developing a geomorphic understanding of the Connecticut River and TFI (RSP Task 2), including: (a) geomorphology of alluvial rivers; (b) geomorphic history of the Connecticut River; (c) analysis of historic datasets; (d) geomorphic analysis of tributaries and upland erosion features; and (e) erosion comparison of the TFI and Connecticut River.

2. **Quantitative engineering and geomorphic analysis:**

   The quantitative engineering and geomorphic analysis included (RSP Task 5 and 6, RSP Table 3.1.2-3): (a) analysis of the hydrologic and hydraulic characteristics of the TFI based on field collected data and hydraulic model results; (b) sediment transport analysis; (c) analysis of hydraulic shear stress, water level fluctuations, boat waves, and ice as potential primary causes of erosion; and (d) analysis of land-use and land management practices via geospatial analysis.

3. **Computer modeling:**

   To better understand the complex hydrologic, hydraulic, and geotechnical dynamics of the TFI three models were utilized, including: a one-dimensional unsteady Hydraulic Engineering Center-River Analysis System (HEC-RAS) model, a two-dimensional River2D model, and BSTEM (RSP Task 5 and 6, RSP Table 3.1.2-3).

   As part of Study No. 3.2.2 *Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot Station* (Study No. 3.2.2), a fully-calibrated unsteady HEC-RAS model of the TFI was developed for the period 2000 to 2014. The HEC-RAS model generated historic water levels and water surface slopes on an hourly basis through the TFI and at the 25 detailed study sites for inclusion into BSTEM. Historic upstream inflows at Vernon, major tributaries (i.e., the Ashuelot and Millers Rivers), Northfield Mountain operations, and historic water levels at the Turners Falls Dam were utilized during these runs. An additional scenario (Scenario 1 – Northfield Mountain idle) was then developed and run through HEC-RAS to provide hourly water levels for BSTEM at the 25 detailed study sites to determine erosion associated with this modeling scenario.

   A River2D model of the TFI was developed to better understand the complex hydraulics of the TFI and to enhance the understanding gleaned from the HEC-RAS model. The River2D model provided information pertaining to the velocities and shear stresses in the near bank environment. The model was calibrated and then verified with three separate flow events which represented the full range of available observed flows. Once verified, six production runs were performed to investigate changes in velocity and shear stress in the near bank area at the 25 detailed study sites and at areas where unique hydraulic conditions were observed (e.g., eddying).

   BSTEM was used to better understand and evaluate erosion processes, and the forces associated with them, at each of the 25 detailed study sites for the period 2000 to 2014. BSTEM is a state-of-the-science deterministic model that simulates the hydraulic and geotechnical processes responsible for bank erosion, including the effects of vegetation, pore-water pressure, and the confining forces due to flow in the channel. BSTEM was the principal tool used to evaluate the potential primary causes of erosion including hydraulic shear stress due to flowing water, water level fluctuations, and boat waves.

The three-level approach ensures a proper understanding of the physical processes governing bank processes along the reach through the hydraulic action, transport of sediment, river form and response, interaction with infrastructure and/or biologic aspects of riverine morphology or habitat. The three-level approach allows for cumulatively supportive, scientifically justifiable results to be obtained. Each subsequent level of analysis builds on the understanding developed by the previous level.

Based on the results of the analyses discussed above, FirstLight evaluated the causes of erosion in the TFI, including the magnitude, location, and duration of the forces associated with erosion, to identify the dominant and contributing primary causes of erosion at each detailed study site. Secondary causes of erosion were also evaluated to the extent that they were found to be present at a given site. Evaluation of the causes of erosion was consistent with the approach laid out in Task 6 of the RSP. The BSTEM results from each detailed study site, combined with the results of the supplemental engineering and geomorphic analyses conducted as part of the three-level approach, were extrapolated across the TFI such that each riverbank segment identified during the 2013 FRR was assigned a cause(s) of erosion. 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 the extrapolation process 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.

Geomorphic Understanding of the Connecticut River

The Connecticut River, which has a very small portion of its drainage area in Quebec, flows in a southerly direction from the Connecticut Lakes in northern New Hampshire, through western Massachusetts and central Connecticut, and into Long Island Sound. The river forms the border between New Hampshire and Vermont prior to it entering western Massachusetts. On its journey through New England, the river is impounded by 15 dams, some of which are equipped with hydropower facilities. A few of these dams create impoundments large enough to seasonally re-regulate[8] river flows. The majority of hydropower dams are low-head facilities forming narrow impoundments that experience generally lower water velocities at low flows due to raised water levels and velocities that approach near free-flowing conditions at high flows.

The reach of river extending approximately 20 miles from the Turners Falls Dam in Montague, MA to the Vernon Dam in Vernon, VT is also known as the TFI. FirstLight owns and operates the Turners Falls Hydroelectric Project while TransCanada owns and operates the Vernon Hydroelectric Project. The Turners Falls Dam, or a dam of different vintage, has been present at its current location since approximately 1798. The Turners Falls Dam was raised approximately six feet in 1970 during construction of the Northfield Mountain Project to accommodate additional storage volume for the operation of the Project without any significant increase of river flow in the Connecticut River downstream of the dam.

Geomorphic History

During the most recent ice age (approximately 20,000 years ago), the Connecticut River Valley was covered by the Laurentide ice sheet. As the most recent ice age ended, the melting ice was trapped behind a natural dam which consisted of rock and soil that had been pushed up by the ice as it had advanced. The formation of a natural dam combined with the melting glacial water formed what is known as Lake Hitchcock. Lake Hitchcock extended from about the middle of what is now the state of Connecticut (Rocky Hill, CT), through Massachusetts, northward through about 80% of Vermont and New Hampshire to St. Johnsbury, VT; a distance of approximately 200 miles ("Glacial Lake Hitchcock" by Tammy Marie Rittenour). The Lake's water surface in the TFI area was likely more than 150 feet higher than the current level of the Connecticut River, while the bottom of the Lake was likely over 75 feet higher (Field, 2007). Glacial melt from the northern extent of the Lake combined with inflow from various tributaries resulted in the transport of significant quantities of sediment. Approximately 14,000 years ago the natural "dam" holding back Lake Hitchcock was broken and the Lake began to drain. The draining and downcutting of Lake Hitchcock formed what is now the Connecticut River. While some of the deposited lake sediment was likely eroded and transported downstream with the now flowing river, some of the relatively fine deposited sediment (clay, silt, and sand) was left behind in the existing Connecticut River valley.

Over time the watershed became forested and "normal" riverine dynamic processes took over. This history affects the current geomorphology and sediments that are found along the bed and banks of the river and is important to understand in order to provide context for the complex hydraulic and geotechnical processes

[8] Dams having sufficient storage capacity to store water during periods of high flow thereby reducing flood peaks for release during the low flow season.

which occur throughout the Connecticut River today. With the exception of rare segments (such as the French King Gorge located in the TFI), the Connecticut River is an alluvial river. As the previous and more dramatic changes faded into the past, geomorphic changes slowed and became less dramatic, however, typical alluvial river dynamics have and will continue. These dynamics are most pronounced in the previously deposited fine sediments (clay, silt, and sand) that are erodible under normal riverine processes. The fine sediments left behind by Lake Hitchcock are prevalent not only along the majority of the Connecticut River's banks but also throughout the TFI. As noted by Field (2007), most of the riverbank sediments in the TFI are naturally susceptible to erosion because, although they are fine grained, they do not contain much silt and clay which would impart additional resistance through cohesive strength into the materials. The sands and sandy loams are relatively erodible. Field (2007) further noted that natural stability is further compromised by past channel incision through older terrace and floodplain surfaces, leading to greater flow energy expended on the banks rather than having the ability to spread out across broad floodplains (Field, 2007).

As stated above, the Connecticut River is an alluvial river. As discussed in Leopold, et al. (Leopold, Wolman & Miller, 1964), alluvial river systems experience a continual adjustment by processes of aggradation, degradation, scour, deposition, lateral migration, and bank erosion. Even the concept of a river in equilibrium does not mean that a river, so classified, is static and un-changing but instead means that an equilibrium between erosion and deposition is achieved. Based on this concept, the form of the cross-section may not be constant over time and the position of the channel may change, albeit at slow rates. The processes of erosion and deposition can be characteristics of an alluvial stream in equilibrium so long as the changes do not represent large, systematic adjustments over time and space. Changing position, even while retaining overall average channel geometry, necessarily means riverbank erosion occurs even in such channels that are considered to be in equilibrium. This is also the case on the Connecticut River and, more specifically, the TFI.

In recent centuries, with the expansion of development in the region, the Connecticut River has been used as a means of transporting goods, water supply, waste disposal, recreation, and power generation. As part of this development a number of dams were constructed on the Connecticut River for the primary purposes of hydropower production or flood control. Most of the hydropower dams, with the exception of the Murphy, Moore, and Comerford Dams, are less than 60 feet high and form relatively narrow, shallow impoundments upstream of the structures. Flood control dams were constructed by the USACE mostly following the 1936 flood to reduce widespread damage throughout the Connecticut River valley. The intent of the flood control dams is to reduce flood damages that have occurred historically by reducing peak flows to the Connecticut River. Since their construction, the flood control dams have reduced the historic impacts of flood events in parts of the Connecticut River watershed.

Analysis of Historic Datasets

The geomorphic condition of the Connecticut River in general, and TFI specifically, can be further understood by examining historically available maps, aerial photographs, surveys, and reports. Aerial photographs covering the TFI are available over a period of time extending from 1929 to 2014. These photographs provide an important historic perspective over this 80+ year period. Included in this time period were photographs taken along the TFI before and after the construction of the Northfield Mountain Project and associated raising of the Turners Falls Dam.[9] In addition to aerial photographs, historic maps going back over 100 years up through recent LiDAR (Light Detection and Ranging) mapping provide insight as to the recent and existing geomorphology of this section of the river. In reviewing the results of these historic comparisons one must take into account the various accuracy limitations of using such old datasets of varying quality. Limitations associated with these comparisons are discussed at length in the

[9] Construction of the Northfield Mountain Project, including raising the Turners Falls Dam, occurred in the late 1960's and early 1970's. Commercial operation of the Northfield Mountain Project began in 1972.

main report (Volume II). While definitive conclusions or quantitative estimates cannot be drawn from these comparisons, they are still relevant to the analysis.

Analysis of historic datasets and reports which examined erosion processes from the late 1800's to the early 1900's found that significant erosion (several hundred feet in some areas) was found to occur throughout the Connecticut River watershed during this time (Reid, 1990). Comparisons made by Reid (1990) of riverbank position in the vicinity of Otter Run (located in the TFI) using maps surveyed in 1887, 1936, and 1944 found that the banks of the TFI had retreated some 400 feet between 1887 and 1944 in this area. Northrop, Devine, and Tarbell (NDT) also examined the possibility of comparing historic maps to evaluate changes in the position of the river over time (NDT, 1991). As part of this effort, NDT also observed several hundred feet of changes in riverbank position at various locations prior to 1944; however, significant changes (beyond the accuracy limits of the dataset) were not observed in recent decades (i.e. since the 1940's). Both Reid (1990) and NDT (1991) documented much smaller amounts of change in the decades since the 1940's. These relatively small changes in recent decades have been confirmed by annual transect surveys at various locations throughout the TFI which have occurred since the 1990's. Based on this analysis, it is clear that significant erosion occurred at various locations along the Connecticut River over time and prior to the 1940's. While erosion has continued throughout the watershed since the 1940's, it appears to have been reduced to much lower rates, including in the TFI as shown by the annual transect surveys.

When reviewing the historic geomorphology of the Connecticut River, three primary factors are identified as causing the reduction in erosion rates after the 1940's, including: (1) the relative lack of floods in recent decades of the magnitude of those which occurred prior to the 1940's and resulted in substantial erosion and damage (including the flood of 1936); (2) construction of flood control projects throughout the Connecticut River watershed following the flood of 1936; and (3) construction or raising of mainstem Connecticut River dams which reduced river velocities and shear stresses. In the report entitled "Connecticut River Streambank Erosion Study Massachusetts, New Hampshire and Vermont," US Army Corps of Engineers (USACE, 1979), the Corps compared reaches of the river not affected by the dams (i.e., un-impounded reaches) to those where dams formed narrow pools. The report found that dams deepened the water and slowed velocities such that bank erosion due to flowing water was reduced on the order of 34% compared to the natural river (UASCE, 1979).

Specific to the TFI, a number of historic datasets were analyzed in order to better understand changes in riverbank conditions since the 1940's. Originally, FirstLight attempted to compare the riverbank position of the TFI from the 1970's Exhibit K drawings to more recent aerial ortho-photos (as required by FERC's SPDL); however, this was not possible due to the fact that the Exhibit K drawings did not contain any information that could be used to determine the edge-of-water, top of bank, or toe of bank. Focus then shifted to analyzing historic aerial photographs from 1952 and 1961 to evaluate the condition of the 20 most severely eroded sites identified in the ECP (1999) prior to the Turners Falls Dam being raised and the Northfield Mountain Project going online. Based on the results of this analysis it was observed that of the 20 erosion sites identified in the ECP, 14 appear to be eroded prior to the raising of the Turners Falls Dam and construction/operation of the Northfield Mountain Project. Of the 6 remaining sites, one was potentially eroded prior to the raising of the dam (Urgiel Upstream - #4), while riverbank conditions are unclear based on the quality of the aerial photographs at the other five sites. A summary of the findings of this analysis is presented in Table 1.

Table 1: 1952 and 1961 Status of the 20 Erosion Sites identified in the ECP (1999)

Site #	Site Name	Current Status (2014)	Pre-Northfield Mtn. Status
1	Vernon Dam	Not selected for stabilization due to extreme hydraulic conditions associated with Vernon spillway	Eroded: Erosion evident in 1952 with continuing erosion through 2008-2010 ortho-photos.
2	Turners Falls Rod & Gun Club	Stabilized in 2004	Condition changed considerably due to raised water level and construction of club.
3	Bennett Meadow	Stabilized in 2005	Condition unknown based on aerial photos.
4	Urgiel Upstream	Stabilized in 2001	Potentially eroded: sparse riparian vegetation in 1952 photo.
5	Route 10 Bridge	Not selected for stabilization due to unique hydraulic conditions in the vicinity of the Route 10 Bridge	Eroded: Photos used in this analysis as well as earlier photos from analysis associated with Route 10 bridge show ongoing erosion.
6	Skalski	Stabilized in 2004	Condition unknown based on aerial photos: The left bank of the river in the vicinity of Kidds Island has a band of riparian vegetation in the 1952, 1961 and 1990s aerial photos. While not apparent in the aerial photos, erosion had been occurring along this bank and was identified in the ECP and stabilized in 2004 as the Skalski site.
7	Flagg	Stabilized 1999-2000	Eroded: The right bank across from Kidds Island was sparsely vegetated in 1952 and 1961 with ongoing erosion in the 1990s.
8	Un-named	Not selected for stabilization – opposite great meadow	Condition unknown based on aerial photos.
9	Kendall	Stabilized in 2007	Eroded: In 1952 there is some riparian vegetation on the right bank but by the 1961 photograph erosion is evident with no riparian vegetation remaining.
10	River Road	Stabilized in 2003	Eroded: On the inside of the bend along the left bank erosion has occurred over time with the bank moving landward compared to the project boundary line as noted in changes in the bank from the 1952 to 1961 and subsequent aerial photos.
11	Urgiel Downstream	Stabilized in 2005	Eroded: At a bend in the river upstream of Kidds Island the 1952 aerial photo shows a reach with some riparian vegetation. The 1961 aerial photo shows erosion and associated decrease in riparian vegetation.
12	Durkee Point	Stabilized in 2003	Eroded: 1952 and 1961 aerial photos show erosion and lack of riparian vegetation.
13	Split River	Stabilized in 2009 (Lower Split River) and 2010 and 2011 (Upper Split River)	Eroded: 1952 and 1961 aerial photos show erosion and lack of riparian vegetation.
14	Country Road	Stabilized in 2006 (includes site #20)	Eroded: The 1961 aerial photo shows erosion and a significant reduction in riparian vegetation.

Site #	Site Name	Current Status (2014)	Pre-Northfield Mtn. Status
15	Stebbins Island	Not selected for stabilization	Eroded: Downstream end of island has narrowed through erosion from 1952 to 2008-2010.
16	Kaufhold (split into two sites and re-named as “Bathory-Gallagher” and “Wallace-Watson”)	Upper Split River stabilized in 2010, Bathory-Gallagher and Wallace-Watson stabilized in 2012 and 2013	Eroded: Bathory-Gallagher and Wallace Watson – Upstream of the tailrace along both banks there was a band of riparian vegetation in the 1952 aerial photo. By the 1961 aerial photo the riparian zone appear to have decreased and erosion is evident. Eroded: Upper Split River – 1952 and 1961 aerial photos show erosion and lack of riparian vegetation.
17	Montague	Stabilized by preventative maintenance in 2008	Eroded: Erosion evident in 1961 photograph.
18	Campground Point	Stabilized by preventative maintenance in 2008	Eroded: Some erosion is evident in the earlier aerial photos such as 1952 continuing through the 2008 ortho-photo.
19	Right Bank Downstream of Davenport or Upper Island	Not selected for stabilization	Condition unknown based on aerial photos (incomplete imagery available).
20	Country Road	Stabilized in 2006 (included as part of site # 14)	Eroded: The 1961 aerial photo shows erosion and a significant reduction in riparian vegetation.

Erosion Comparison of the Turners Falls Impoundment and Connecticut River

One of the priority recommendations identified in Field (2007) was to study patterns of erosion in other reaches of the Connecticut River as a means of comparison to the conditions of the TFI. In response to this recommendation, Simons and Associates (S&A) conducted a study in 2012 comparing bank erosion along the extent of the Connecticut River from Holyoke Dam (Holyoke, MA), upstream through various hydropower impoundments (including Turners Falls, Vernon, Bellows Falls, and Wilder), and continuing to the un-impounded, free-flowing reach from Pittsburg, NH to Gilman Dam (S&A, 2012b). The study reach was approximately 240 miles long.

The study found that riverbank features and characteristics vary considerably along the length of the river. While portions of the river consist of bedrock outcrops that are very stable, much of the riverbanks consist of hillsides or alluvial material that are formed primarily of silt to sand sized material. There are areas that consist of gravel to cobble sized material that are generally less erodible but still are alluvial or transportable by fluvial processes. Much of the riverbanks are quite well vegetated, which generally adds to riverbank stability, although there are segments where a range of erosion and mass-wasting processes remove or damage vegetation and associated riparian land. Riverbank erosion was compared among various reaches to the extent feasible with available data as well as through photographs taken over the years at erosion sites. Key conclusions from this report found that (S&A, 2012b):

- The segment of river with the greatest extent of eroding riverbanks is the un-impounded northern reach (Pittsburg, NH down to Gilman Dam). At the time of the available study, 48.4% of the riverbanks were experiencing moderate or more significant erosion (Field, 2004). Riverbanks that had been rip-rapped covered 17.1% of the length of the river.

- Several erosion sites were identified and photographed in the Bellows Falls, Vernon, Turners Falls, and Holyoke Impoundments in 1997, and again in 2008. All of the erosion sites in 1997 in the Bellows Falls and Holyoke Impoundments and all but one of the 1997 erosion sites in the Vernon Impoundment remained in essentially the same state of erosion when photographed in 2008. Many of these sites were significant in both size and severity. In contrast, most of the erosion sites identified in the TFI in 1998 have been stabilized and were no longer eroding as of 2008.

- In addition to direct stabilization of many of the erosion sites in the TFI that were identified in the 1998 ECP, there is evidence of some natural stabilization processes including increased upper bank vegetation and areas of dense low bank aquatic vegetation that are helping provide a degree of additional stability in some areas.

- Despite the fact that similar percentages of riverbank have been stabilized in the northern, free-flowing reach as in the TFI; the percentage of erosion in the TFI is only about one-third the extent of erosion that is occurring in the northern, free-flowing reach of the Connecticut River (16.7% compared to 48.4%).

- Because riverbank erosion in the TFI is significantly less than in the northern free-flowing reach, erosion sites in other impoundments (Bellows Falls, Vernon, and Holyoke) continued eroding from 1997 to 2008, and many erosion sites have been stabilized in the TFI (including evidence of natural stabilization processes) it can be concluded that the riverbanks in the TFI are in the best condition (more stable and less eroding) than in any other part of the Connecticut River that was examined as part of the 2012 study.

- The TFI, which experiences water level fluctuations due to a combination of run of river/peaking power and pumped-storage hydropower operations, has less riverbank erosion than the other impoundments (Wilder, Bellows Falls, Vernon, and Holyoke) which only experience water level fluctuations resulting from run of river and peaking power operations and do not experience additional fluctuations due to pumped-storage operations. The TFI also experiences significantly less erosion than the northern, free-flowing reach which has no hydropower operations and associated water level fluctuations.

Hydrologic and Hydraulic Characteristics of the TFI

The results of the BSTEM and hydraulic modeling found that the hydrology and hydraulics of the TFI played just as important of a role, if not more so, in erosion processes as riverbank features and characteristics do. Before analyzing and evaluating the causes of erosion it is important to understand the complex hydrologic and hydraulic characteristics of the TFI. As such, this section provides an overview of: (1) the hydrologic setting; (2) hydropower project operations and their impact on flow and water level fluctuations on an hourly basis; (3) hydrologic influences and flow thresholds present in the TFI; and (4) the location and duration of hydraulic forces. The analyses presented in this section are consistent with the approach laid out in the RSP as noted in Tasks 5 and 6 as well as RSP Table 3.1.2-3.

Hydrologic Setting

Analysis of available mean daily flow data as recorded by the U.S. Geological Survey (USGS) at the Montague, MA gage for the period 1904 to 2014 demonstrates that the Connecticut River follows a fairly typical seasonal hydrograph. During this period, mean daily flow in January through most of February averages just over 10,000 cubic feet per second (cfs), in late February to early March the mean flow rises due to spring runoff or freshet peaking to about 40,000 cfs, while the lowest flows (slightly over 5,000 cfs) occur during the late summer to early fall.

The flow on the Connecticut River on a mean daily basis over an annual cycle is unsteady and highly variable. Examination of annual hydrographs demonstrate significant variability in flow over time with changes in flow ranging from a few thousand cfs to several tens of thousands cfs occurring over relatively short periods. The Connecticut River, especially the TFI, experiences significant intraday flow and water level variability which requires examination of the data on an hourly basis. Intraday variability is typically a result of peaking hydroelectric operations and/or pumped-storage operations during periods of low to moderate flow.

Most of the analysis for this study, including BSTEM, were based on hourly hydrologic data from January 1, 2000 to December 31, 2014. This 15-year time period was used for two primary reasons: (1) it was representative of post flood control Connecticut River conditions, and (2) it marked the period of time when the most data (including repetitive cross sections) were available.

Hydropower Operations

When inflow conditions are below the hydraulic capacity of the hydroelectric projects, the facilities often store water in their impoundments on a daily cycle to allow for additional electricity generation during parts of the day when the power demand and market prices increase. When inflow exceeds the hydraulic capacity of the Vernon and Turners Falls Hydroelectric Projects, the facilities are operated in a run-of-river mode where inflow equals outflow on an instantaneous basis. Table 2 provides an overview of the hydraulic capacities of the Vernon, Northfield Mountain, and Turners Falls Hydroelectric Projects.

Table 2: Hydraulic Capacities of the Vernon, Northfield Mountain, and Turners Falls Hydroelectric Projects

Project Name	Hydraulic Capacity (cfs)
Vernon	17,130
Northfield Mountain (Pumping)	15,200
Northfield Mountain (Generating)	20,000
Turners Falls	15,938

The main source of inflow into the TFI is TransCanada's Vernon Hydroelectric Project, which normally acts as a peaking facility when inflows are low. In addition to inflow from Vernon, the TFI also has two major tributaries – the Ashuelot and Millers Rivers. The Northfield Mountain Project also uses the TFI as its lower reservoir. Northfield Mountain has four reversible pump/turbines that at maximum, can pump at 15,200 cfs or can discharge at 20,000 cfs. The Upper Reservoir currently has a FERC maximum usable storage capacity of 12,318 acre-ft. Given this, the Project can pump at maximum capacity for 9.8 hours and generate at maximum capacity for 7.5 hours; however, in reality, the Project rarely pumps or generates at its maximum capacity or utilizes all of the Upper Reservoir volume in a single day.

FirstLight's current FERC license allows the TFI water level to be fluctuated within a 9-foot band between a minimum water surface elevation of 176 and a maximum of 185 ft. NGVD 1929, as measured at the Turners Falls Dam. This 9-foot water level fluctuation provides about 16,150 acre-ft. of storage, if fully utilized; however, FirstLight rarely fluctuates the TFI by more than four feet in a day even though the TFI acts as the lower reservoir for Northfield Mountain and the headpond for the Turners Falls Project power canal (which leads to the generation facilities at Station No. 1 and Cabot Station). As discussed in the March 2015 report for Study No. 3.2.2, at higher flows (i.e. greater than 30,000 cfs) the natural constriction at the French King Gorge becomes a hydraulic control affecting water levels in the mid and upper sections of the TFI. Therefore at higher flows, the effects of water-level management at the Turners Falls Dam by FirstLight becomes much less of a controlling influence of the water surface elevations in the middle and upper parts of the TFI.

During moderate to high flow events hydroelectric generation operations shift from a peaking power operation mode to a run-of-river mode as the flow exceeds the hydraulic capacity of the power plants at Vernon and Turners Falls (17,130 cfs at Vernon and 15,938 cfs at Turners Falls). Flows in excess of the generating capacity are discharged over each dam to the river downstream of the dams. During high flow periods in excess of 30,000 cfs, per an agreement with the USACE, FirstLight lowers the water level at the Turners Falls Dam (but not below El. 176) to limit high water in the Barton Cove area and to a lesser extent, the middle section of the TFI. At flows above 65,000 cfs, as per an agreement with the USACE, if Northfield Mountain is operating, the combined usable volume of the Upper Reservoir and the TFI is required to be kept constant in order to limit discharges from Northfield Mountain adding to the outflow from Turners Falls Dam. As a result of this agreement, if Northfield Mountain is operating during such high flows the hydrologic effect in the TFI is minor.

Hydropower operations at Vernon and Turners Falls are relatively straightforward: below their hydraulic capacities they operate as peaking plants[10], above their hydraulic capacities they operate as run-of-river. During periods of low to moderate flows when peaking operations are occurring, Vernon can impact flow

[10] In the case of the Turners Falls Project, Station No. 1 is generally partially on, fully on, or fully off. FirstLight does not operate Station No. 1 as a peaking facility. Station No. 1 may at times also be operated to pass the required minimum flow.

and water levels downstream to the Turners Falls Dam while water level management at the Turners Falls Dam and Northfield Mountain Project operation can impact flows and water levels upstream to the Vernon Dam. Unlike Vernon and Turners Falls which operate as run-of-river above their hydraulic capacities, Northfield Mountain can operate at flows far greater than 17,130 cfs (i.e., the hydraulic capacity of Vernon). To understand the effect Northfield Mountain operations have on flow and water level fluctuations in the TFI a number of historic time periods and modeled operational scenarios were analyzed. From this analysis, it was observed that during low flows (i.e., flows <18,000 cfs[11]) Northfield Mountain operations accounted for a 2 ft. fluctuation at the five detailed study sites[12] which were examined as part of this analysis.

During moderate to high flows (i.e., flows greater than 18,000 cfs), the effect of Turners Falls Dam operations on water surface elevation fluctuations decreases until eventually the French King Gorge constriction becomes the dominant influence on water surface elevations in the mid and upper TFI. Based on the results of the hydraulic modeling, this typically occurs at flows equal to or greater than 30,000 cfs. The hydrologic analysis conducted during moderate to high flows found that, for the time period examined, when inflow from Vernon exceeds 30,000 cfs and Northfield Mountain operates with 2-3 units the greatest difference in water surface elevations were observed at, or near, the Northfield Mountain tailrace with progressively smaller differences observed in the upstream direction. Specifically, the analysis demonstrated:

- **Site 75BL** *(near the Northfield Mountain tailrace)*: Observed difference in water surface elevation = 1.2 feet;
- **Site 5CR** *(near the Rt. 10 Bridge)*: Observed difference in water surface elevation = 0.9 feet;
- **Site 4L** *(near Pauchaug Boat Launch)*: Observed difference in water surface elevation = 0.7 feet; and
- **Site 303BL** *(downstream of Stebbins Island)*: Observed difference in water surface elevation = 0.5 feet.

Hydrologic Influences and Flow Thresholds

Based on the results of the hydraulic modeling a number of flow thresholds of importance were established. In the upper reach of the TFI (from Vernon Dam to upstream of the NH/MA border – hydraulic reach 4, discussed in the next section) due to the hydraulic capacity of Vernon, flows below 17,130 cfs are controlled by Vernon project operations while flows greater than 17,130 cfs are naturally occurring. As such, in the upper reach of the TFI, the natural high flow threshold was found to be 17,130 cfs. This value was chosen as it represents the point at which Vernon operates in run-of-river mode (i.e. outflow equals inflow), Turners Falls or Northfield Mountain operations have limited to no hydrologic or hydraulic impact, and the upper reach of the TFI is more riverine than the downstream reaches.

For the remaining reaches (from upstream of the NH/MA border to Turners Falls Dam), three flow thresholds were identified: (1) <17,130 cfs; (2) 17,130 – 37,000 cfs; and (3) >37,000 cfs. At flows less than 17,130 cfs (the hydraulic capacity of Vernon) hydropower peaking operations are the dominant hydrologic influence at all locations in the TFI. For flows between 17,130 and 37,000 cfs the dominant hydrologic influence depends on the location in the TFI and can include a combination of Vernon, Northfield Mountain,

[11] 18,000 cfs was chosen as the threshold for this analysis as it is slightly higher than the hydraulic capacity of Vernon (17,130 cfs) in order to account for tributary inflow.
[12] Detailed study sites examined for the hydrologic analysis included: BC1-R, 75BL, 5CR, 4L, and 3030BL. These sites were selected because they spanned the geographic extent of the TFI and were representative of the other sites in their proximity.

and Turners Falls operations, natural hydraulic constrictions (e.g., Stebbins Island, French King Gorge), and/or naturally occurring moderate flows. At flows greater than 37,000 cfs the dominant hydrologic influence is natural high flows.

The natural high flow threshold for the downstream reaches (37,000 cfs) was established for four main reasons: (1) it exceeds the flows at which the French King Gorge becomes the hydraulic control for the mid and upper portion of the TFI; (2) it exceeds the hydraulic capacity of Vernon; (3) it exceeds the maximum combined hydraulic capacity for Vernon and Northfield Mountain at a given location; and (4) although Northfield Mountain may still operate at flows greater than 37,000 cfs, historical operating records indicate this is less frequent than at lower flows.

To determine how often Northfield Mountain operated during periods when flows exceeded 37,000 cfs, FirstLight reviewed the available Project operating data for the period 2000-2014. Based on the results of this analysis it was observed that the Project operated as follows:

- Generation with 1 or more units occurred 2.6% of the time;
- Generation with 2 or more units occurred 0.82% of the time;
- Generation with 3 or more units occurred 0.14% of the time; and
- Generation with 4 units occurred 0.025% of the time

This equates to approximately 9, 3, 0.5, and 0.1 days per year, respectively. Pumping operations when flows exceeded 37,000 cfs were found to follow a similar pattern. Given how infrequently Northfield Mountain historically operated when flows exceeded 37,000 cfs it was determined that 37,000 cfs was an appropriate value for the natural high flow threshold.

Hydraulic Model Results

In support of the BSTEM modeling efforts associated with this study, and in accordance with Task 5 of the RSP, the HEC-RAS model was utilized to generate historic (i.e., Baseline Condition) water levels and Energy Grade Line (EGL) slopes[13] on an hourly basis at the 25 detailed study sites. The Baseline Condition modeling scenario utilized historic upstream inflows at Vernon and tributaries (Ashuelot and Millers Rivers), Northfield Mountain generation and pumping flows, and historic water levels at the Turners Falls Dam. In addition to the Baseline Condition, an additional scenario was developed (Scenario 1 – Northfield Mountain idle) when Northfield Mountain was "turned off" to provide water level and EGL slope data for the BSTEM modeling at the 25 detailed study sites. The HEC-RAS scenarios used the January 1, 2000 to December 31, 2014 period and historic tributary inflows. Input variables for each modeling scenario are shown in Table 3.

[13] The Energy Grade Line is the elevation of the energy head of the water in the river and is the hydraulic grade line plus the velocity head between each model transect. Generally, a greater slope of the energy grade line indicates a higher water velocity and a higher potential for hydraulic erosion. The Energy Grade Line is an important component in the hydraulic-erosion sub-model of BSTEM as it forms the basis for calculating boundary shear stress for nodes along the wetted perimeter along with the hydraulic radius of the segmented flow and the unit weight of water.

Table 3: Operational Conditions and Associated Hydraulic Data for each of the Modeled Scenarios

Model Scenario	Time step	Vernon Operations (flow)	NFM Operations (flow)	TFD Operations (elevation)
Baseline	Hourly	Historic	Historic	Historic
S 1	Hourly	Historic	Idle	Historic

Based on the distribution of the EGL slope derived from the HEC-RAS model runs described above, four distinct hydraulic reaches were identified (Figures 2 and 3). These hydraulic reaches included the Upper (Reach 4), Middle (Reach 3), Northfield Mountain (Reach 2), and Lower (Reach 1) reaches. The median (50^{th} percentile) energy slope for each site is represented by the gray line with 50% of the slopes over the modeling period greater than this value and 50% less. The blue and orange lines represent the 95^{th} and 75^{th} percentiles for each site, respectively. The steepest slopes occur in the "upper" part of the TFI (Reach 4) just downstream from Vernon Dam and extending downstream to about station 80,000. Slopes for the "middle" reach, denoted as Reach 3 (downstream to station 42,000), are generally about an order of magnitude lower. Energy slopes for the Northfield Mountain Reach (Reach 2) are somewhat greater than for both Reaches 3 and the "lower" reach (Reach 1), the latter being the section just above Turners Falls Dam. Table 4 provides an overview of the detailed study sites found in each reach.

Table 4: Detailed Study Sites found in each Hydraulic Reach

Hydraulic Reach	Detailed Study Sites
4 (Upper)	11L, 2L*, 303BL, 18L, 3L, 3R*, 21R
3 (Middle)	4L, 29R, 5CR, 26R, 10L, 10R*, 6AL*, 6AR*
2 (NFM)	119BL, 7L, 7R, 8BL, 8BR*, 87BL, 75BL
1 (Lower)	9R*, 12BL, BC1-R

** Designates a site restored as part of the ECP*

EGL slope 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. 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 EGL 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 EGL 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.

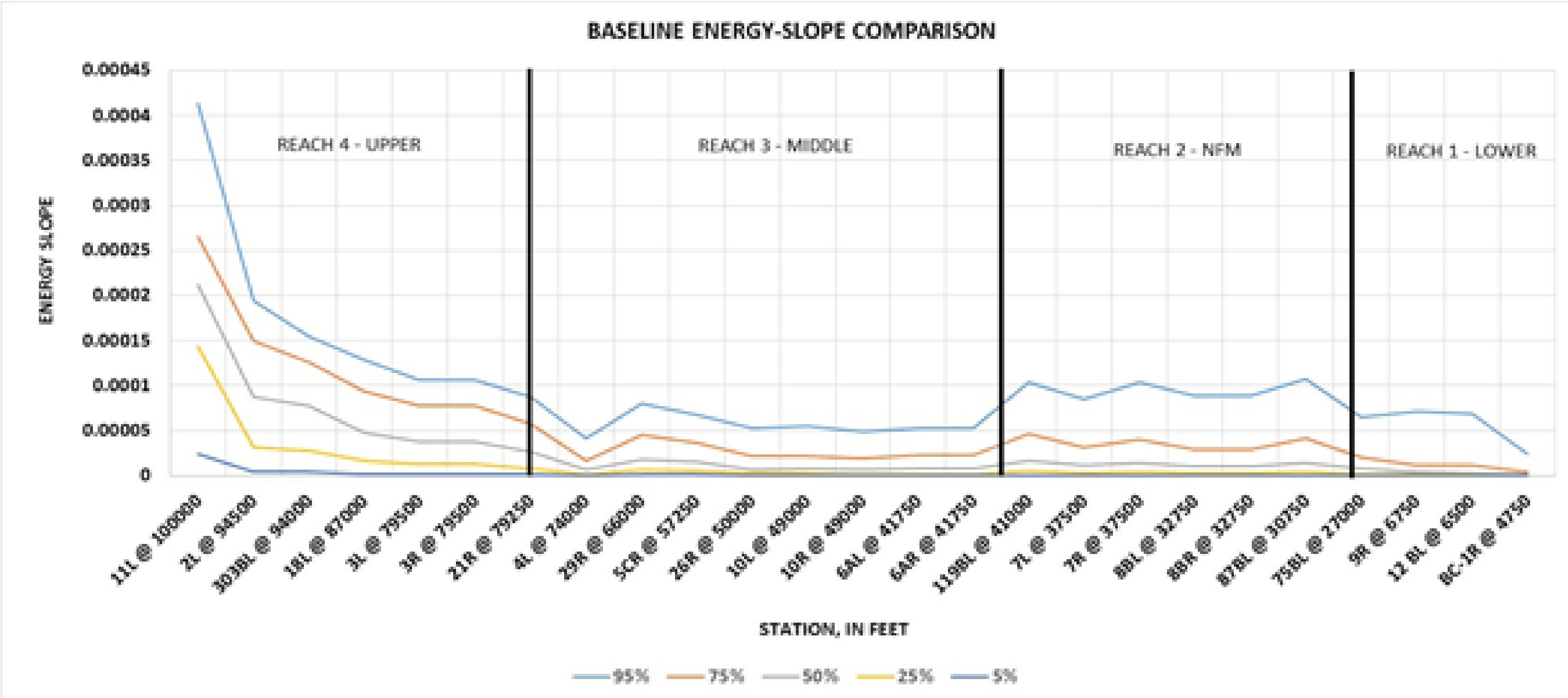
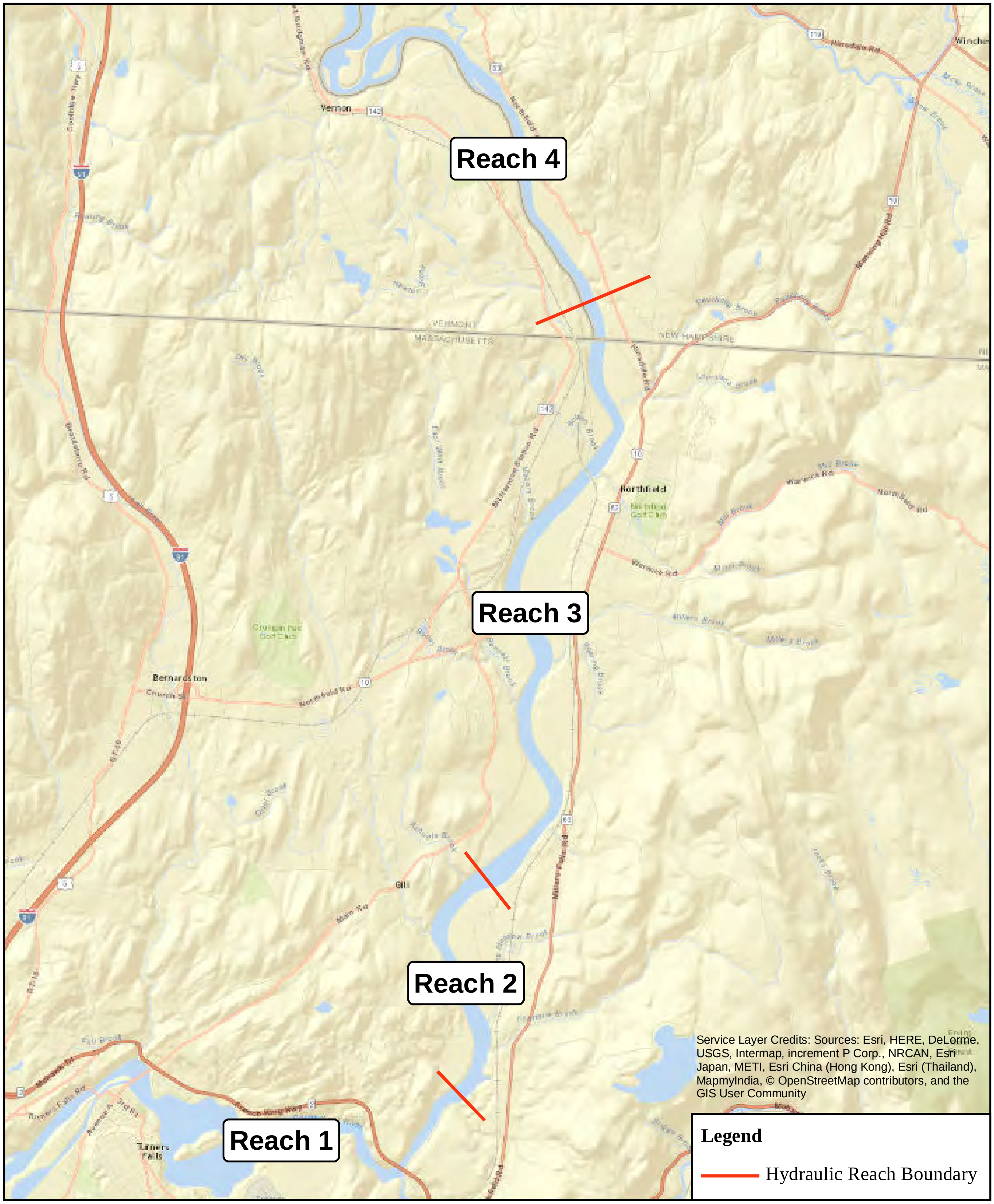


Figure 2: Distribution of Energy Grade Slope Lines throughout the Turners Falls Impoundment



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 3:
Geographic Distribution
of Hydraulic Reaches

N

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Miles

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Location and Duration of Hydraulic Forces

When analyzing and evaluating the causes of erosion in the TFI, it is important to first understand the magnitude, location, and duration of forces associated with each cause. As such, the magnitude, location and duration of forces were analyzed in-depth as part of the hydraulic modeling, BSTEM, and supplemental analyses as noted in Table 3.1.2-3 of the RSP. Results of the BSTEM modeling and supplemental analyses discussed in later sections take into account these factors. For the purpose of this section, discussion focuses on the location and duration of hydraulic forces, or more specifically, on the duration at which various water surface elevations are equaled or exceeded and the corresponding location of the water surface relative to bank position.

As noted in USACE (1979), the forces acting on the bank can be broken into two categories: (1) those acting near the surface of the flow, and (2) those acting with the greatest intensity nearer the bottom of the submerged banks. Given that erosion processes associated with (1) hydraulic shear stress due to flowing water; (2) water level fluctuations due to hydropower operations; (3) boat waves; and (4) ice occur at and/or below the water surface it is vital to understand where on the riverbank the water surface rests and for what duration.

TFI riverbanks are typically characterized by a lower and upper riverbank. The lower bank is typically a flat, beach-like feature that is submerged or experiences daily water level fluctuations during low to moderate flows as a result of hydropower peaking operations. Depending on its location in the TFI, the lower bank may or may not be vegetated. As one moves away from the normal edge-of-water, the lower bank transitions to an upper bank; the toe of which is clearly identifiable on most cross-section plots. The upper bank is typically steep, has some degree of vegetation, and is usually above the water surface except during high flows.

The distinction between the lower bank and the upper bank is an important one as the vast majority of erosion occurs only once the water surface reaches the upper bank. Although peaking hydropower operations can result in water level fluctuations up to 4 feet at a given location over the course of a day, during low to moderate flow periods the water surface in the TFI typically rests on the lower bank. As observed from the BSTEM modeling results and other supplemental analyses, it is not until the water surface reaches the upper bank that erosion processes can potentially commence and even then the flow threshold to initiate erosion processes was found to be greater than 37,000 cfs at the majority of detailed study sites.

In order to determine the amount of time the TFI water surface rests on the lower bank vs. the upper bank a water level duration analysis was conducted at a subset of the 25 detailed study sites[14]. To further understand the location and duration of hydraulic forces on the bank, stage-discharge relationships were then developed at the same sites in order to determine at what flow the water surface reaches the upper bank. TFI flow duration curves for the individual locations based on hourly data for the period 2000-2014 were then analyzed to determine the percent of time flows of that magnitude occur in the TFI. The final step in this analysis was to compare the upper bank flow and water level analysis against the erosion flow threshold found from the BSTEM modeling results at the subset of detailed study sites. The erosion flow threshold for each site was then compared against the flow duration curve to determine the amount of time that flow may be equaled or exceeded. To provide context, the corresponding water surface elevation for the erosion threshold was compared against the elevation of the toe of the upper bank as derived from the annual cross-section surveys. The results of this analysis are summarized in Table 5.

[14] Sites used for this analysis were the same sites chosen for the hydrology analysis previously discussed: BC1-R, 75BL, 5CR, 4L, and 303BL. These sites were chosen as they spanned the geographic extent of the TFI and were found to be representative of the other sites in proximity to them.

Table 5 Hydrologic Analysis at a Subset of Detailed Study Sites located throughout the TFI

Detailed Study Site	Hydraulic Reach	Toe of Upper Bank – El.*	Water Level Duration		Flow to Reach Upper Bank (cfs)	% Time Flow is Exceeded	95% Erosion Flow Threshold (cfs, from BSTEM)	% Time Threshold Flow is Exceeded	Corresponding Threshold WSEL
			% Time on Lower Bank	% Time on Upper Bank					
BC-1R	1 (lower)	184	99%	1%	NA	NA	I	NA	NA
75BL	2 (NFM)	184	90%	10%	32,000	10%	33,822	7%	184
5CR	3 (middle)	184	82%	18%	23,000	18%	47,867	4%	188
4L	3 (middle)	184	78%	22%	17,000	22%	6,991	60%	181
303BL	4 (upper)	185	79%	21%	17,500	21%	53,194	3%	192

**NGVD29, Feet I = Indeterminate*

As observed in the table, the water level rests of the lower bank the vast majority of the time (79-99%). The period of time in which the water surface rests on the lower bank also coincides with the periods when Vernon, Northfield Mountain, and/or Turners Falls are typically operating in a peaking mode (i.e. low and moderate flow periods). This is significant given that the majority of erosion in the TFI only occurs once the water level reaches the upper bank. The 95% erosion flow threshold (i.e., the flow above which 95% of erosion occurs in the TFI at a given location) provides further insight into this. At sites 75BL, 5CR, and 303BL the 95% erosion flow threshold is near or exceeds the natural high flow threshold (37,000 cfs at sites 75BL and 5CR, 17,130 cfs at site 303BL) indicating that 95% of all erosion does not occur until flows beyond the influence of hydropower operations are equaled or exceeded. As observed in the table, these flows occur only 3-7% of the time. In other words, the potential for 95% of all erosion to occur exists only 3-7% at these sites. This finding was consistent at the majority of sites throughout the TFI.

The exception to this is Site 4L where the 95% flow threshold is 6,991 cfs. Further examination of this site indicates that the average rate of annual erosion is 0.017 ft^3/ft/yr., making it the third lowest rate of erosion of all sites in the TFI. Although the 95% flow threshold at this site is very low, it is a product of how little erosion is actually occurring. By contrast, the 50% erosion flow threshold at this site was found to be 83,527 cfs which equates to a water surface elevation of El. 195, exceeded <1% of the time. It should also be noted that the erosion flow threshold at site BC-1R could not be established given that a reliable relationship between stage and discharge could not be developed in the Barton Cove area.

The results from this analysis clearly indicate: (1) the importance of the water surface elevation and its corresponding location on the bank; (2) the importance of the duration of those water surface elevations; and (3) that the window for the majority of erosion to occur is quite small and well beyond the flows at which hydropower operations have an impact on flow or water level.

The hydrology and hydraulic information presented above, combined with the riverbank features, characteristics and erosion conditions identified during the 2013 FRR, provided the foundation for the analysis and evaluation of the causes of erosion and the forces associated with them.

Analysis of the Causes of Erosion

Analysis in this section focuses on the primary causes of erosion as determined by the BSTEM modeling runs and various supplemental analyses which were conducted as part of this study. Primary Causes of erosion discussed below include hydraulic shear stress due to flowing water, water level fluctuation associated with hydropower operations, boat waves, land-use and land management practices, and ice. Results of the analysis of secondary causes of erosion including wind waves, seepage and piping, freeze-thaw, and animals are also discussed below. The analyses and modeling presented in this section were conducted in accordance with Tasks 5 and 6 of the RSP as well as RSP Table 3.1.2-3.

Potential Primary Causes of Erosion – Water level fluctuations associated with hydropower operations, Hydraulic shear stress, and Boat waves: BSTEM Simulation Results

BSTEM simulations were conducted at the 25 detailed study sites for the period 2000-2014. For those sites where stabilization has occurred as part of the ECP, simulations were conducted for the pre- and post-restoration conditions; resulting in a total of 30 simulations per modeling scenario. Three modeling scenarios were executed in order to better understand the role Northfield Mountain operations have on erosion processes. These scenarios included: (1) Baseline Condition (waves on); (2) Baseline Condition (waves off); and (3) Scenario 1 (Northfield Mountain idle). Results of the BSTEM simulations were analyzed to determine the amount of erosion that occurred over the range of discharges under the Baseline Condition. Referred to as the high-flow analysis, these calculations elucidated the role of high flows on bank-erosion rates. The combination of these model scenarios and analyses allowed for a comprehensive evaluation of the potential primary causes of erosion including: (1) water level fluctuations due to hydropower operations; (2) hydraulic shear stress due to flowing water; and (3) boat waves.

The first set of BSTEM simulations were those for the Baseline Condition (waves on) so that the calibration parameters could then be used for subsequent model scenarios. As previously discussed, the Baseline Condition was designed to represent existing conditions during the model period (2000-2014). The results of the Baseline Condition run served as a means of comparison against the other model scenarios (i.e., Scenario 1). Due to the fact that simulation periods at the detailed study sites were not all of equal duration, the results from all of the sites were normalized by dividing the total erosion over the period (in ft^3/ft of channel length) by the number of years of simulation. These values (reported in units of ft^3/ft/yr.) are then readily comparable to interpret relative degrees of bank instability along the TFI.

For the Baseline Condition (wave on), simulated rates of bank erosion along the reach range from very close to 0 ft^3/ft/ yr. to 15.4 ft^3/ft/ yr. at site 3R under pre-restoration conditions. Other sites with bank-erosion rates higher than the 75^{th} percentile for the non-restored sites include 5CR (8.6 ft^3/ft/ yr.), 8BR-pre-restoration (7.4 ft^3/ft/ yr.), 3L (6.1 ft^3/ft/ yr.), 119 BL (5.9 ft^3/ft/yr.) and 9R pre-restoration (5.4 ft^3/ft/ yr.). Of these six highest rates, three of the sites have been restored. Restoration measures have been very effective in reducing bank-erosion rates by about an order of magnitude throughout the TFI, with an average reduction of 93%. Median bank-erosion rates for the non-restored and restored sites are 1.9 and 0.21 ft^3/ft/ yr., respectively. Figure 4 depicts the spatial distribution of erosion rates for all sites under the Baseline Condition.

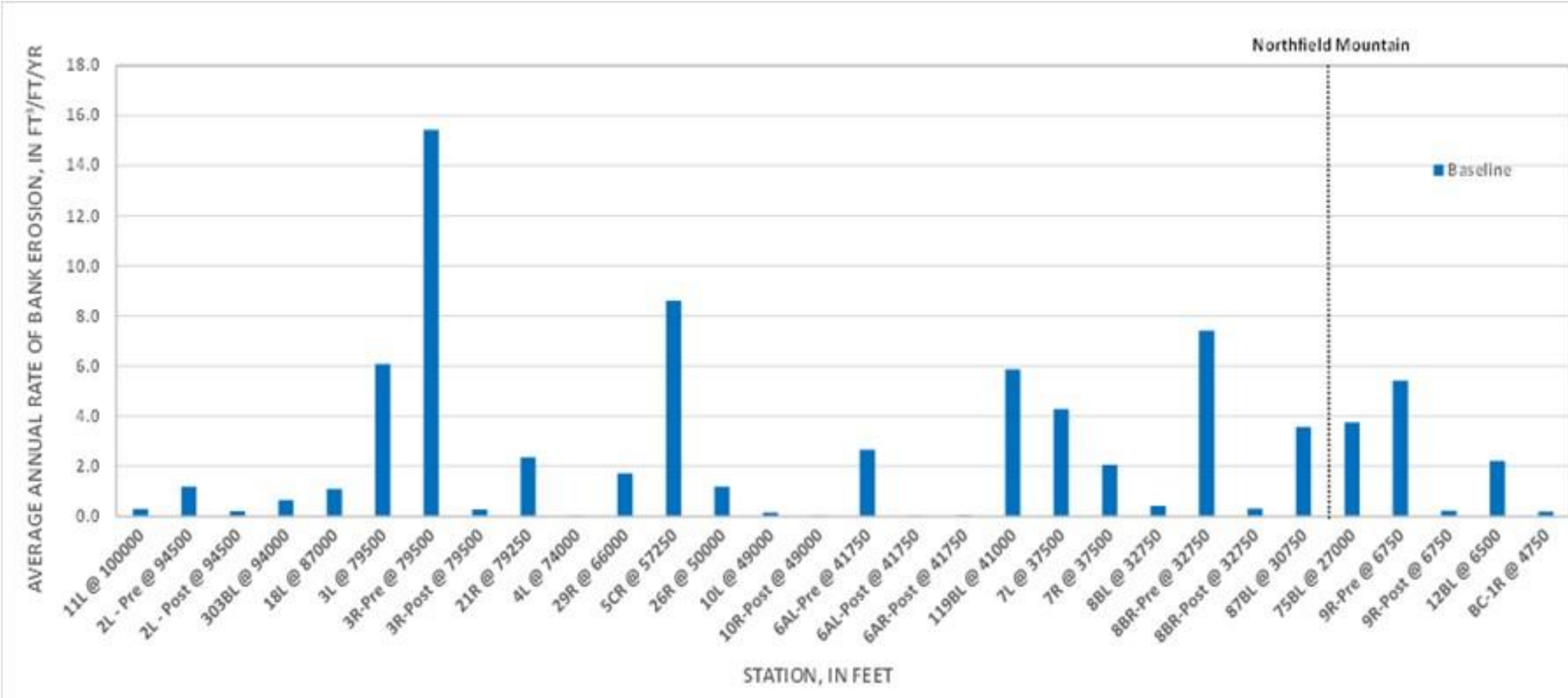


Figure 4: Spatial Distribution of Bank Erosion Rates for all Sites under the Baseline Condition (wave on)

Following completion of the Baseline Condition (wave on) scenario the Baseline Condition was repeated but this time with waves off. The BSTEM wave sub-model has the ability to be turned on or off for a given model run allowing for model results to be compared where the only difference between scenarios is wave activity. Differences between the Baseline Condition with and without waves provided a convenient way to determine the role of boat-generated waves on bank erosion. Comparison of the wave on and wave off scenarios indicated that boat waves had a significant impact on erosion processes in hydraulic reach 1 (lower TFI), minimal impact in hydraulic reach 2 (Northfield Mountain), and no impact in hydraulic reaches 3 (middle TFI) or 4 (upper TFI). The impact of waves in reach 1 can be attributed to the general lake-like conditions found in the lower TFI where water surface elevations vary across a narrow range. The narrow band of water surface elevation fluctuations focuses wave impacts in the zone where the beach/toe intersect the lower-most part of the upper bank. Table 6 demonstrates the impact boat waves have on erosion processes at the detailed study sites in the lower TFI.

Table 6: Summary of Bank Erosion Rates for Sites in the Lower TFI Demonstrating the Impact of Boat Waves

Site/Condition	Station	Dates		Baseline (Waves on)	Baseline (Waves off)	S1 (Waves on)	S1 (Waves off)
	ft	Start	End	$ft^3/ft/yr$	$ft^3/ft/yr$	$ft^3/ft/yr$	$ft^3/ft/yr$
75BL (Reach 2)	27,000	01/01/00	08/27/14	3.76	3.47	3.93	3.72
9R-Pre (Reach 1)	6,750	06/02/00	06/30/08	5.43	0.97	5.19	0.77
9R-Post (Reach 1)	6,750	07/01/08	08/26/14	0.23	0.00	0.22	0.00
12BL (Reach 1)	6,500	01/01/00	08/27/14	2.22	0.24	2.15	0.19
BC-1R (Reach 1)	4,750	06/05/00	08/26/14	0.19	0.00	0.19	0.00

To isolate the impacts of Northfield Mountain Project operations on bank erosion BSTEM Scenario 1 (S1) was executed where Northfield Mountain operations were set to an idle state. The bank erosion rates predicted for S1were subtracted from the erosion rates predicted for the Baseline Condition (wave on). The operational difference between the two scenarios was determine to identify the change in erosion rates resulting from operations at Northfield Mountain. The results of this analysis showed very small effects at every detailed study site indicating that Northfield Mountain Project operations are not a dominant cause of erosion at any location. The exception to this appears to be site 8BR pre-restoration where the model predicted 7.415 ft^3/ft/yr. of erosion under the Baseline Condition (wave on) largely attributable to Northfield Mountain Project operations. Current erosion rates at this site, however, reflect the effect of restoration activities in 2012 that greatly reduced erosion rates from 7.415 ft^3/ft/yr. to about 0.3 ft^3/ft/yr.

The only other locations/conditions that show even a minor impact (> 0.1 ft^3/ft/yr) from Northfield Mountain Project operations are sites 7L at station 37,500 (0.17 ft^3/ft/yr) and perhaps 119BL at station 41,000 (0.09 ft^3/ft/yr). These are all very low erosion rates and if considered in the context of average, annual-erosion rates for non-restoration sites under the Baseline Condition, these contributions fall at or below the 10^{th} percentile of erosion rates. At site 7L bank erosion due to Northfield Mountain Project operations (Baseline minus S1) accounts for about 4% of the erosion under Baseline Conditions while 95% of the erosion occurs at flows greater than 47,700 cfs. At site 119BL the contribution from Northfield

Mountain Project operations is about 1.5%. Table 7 presents a summary of BSTEM results for the various operational scenarios.

Table 7: Summary of BSTEM Results for the Various Operational Scenarios

Site/Condition	Hydraulic Reach	Station	Dates		Baseline (Waves On)	Baseline (Waves off)	S1
		(ft)	Start	End	(ft^3/ft/yr.)	(ft^3/ft/yr.)	(ft^3/ft/yr.)
11L	4 (Upper)	100000	7/15/2005	9/10/2014	0.297	0.296	0.303
2L-Pre		94500	6/20/2000	6/30/2012	1.197	1.184	1.194
2L-Post		94500	7/1/2012	8/28/2014	0.214	0.204	0.213
303BL		94000	1/1/2000	8/27/2014	0.647	0.645	0.674
18L		87000	1/1/2000	8/27/2014	1.092	1.092	1.080
3L		79500	1/1/2000	8/28/2014	6.086	6.090	6.042
3R-Pre		79500	1/1/2000	6/30/2006	15.425	15.407	15.458
3R-Post		79500	7/1/2006	8/28/2014	0.285	0.281	0.282
21R		79250	1/1/2000	8/27/2014	2.359	2.291	2.355
4L	3 (Middle)	74000	1/1/2000	8/28/2014	0.017	0.014	0.017
29R		66000	1/1/2000	8/27/2014	1.718	1.709	1.718
5CR		57250	7/8/2002	9/3/2014	8.606	8.500	8.566
26R		50000	1/1/2000	8/27/2014	1.194	1.145	1.196
10L		49000	1/1/2000	8/27/2014	0.160	0.158	0.158
10R-Post		49000	7/1/2001	8/27/2014	0.000	0.000	0.000
6AL-Pre		41750	1/1/2000	6/30/2004	2.668	2.635	2.736
6AL-Post		41750	7/1/2004	8/27/2014	0.000	0.000	0.000
6AR-Post		41750	6/21/2000	8/27/2014	0.021	0.000	0.020
119BL	2 (NFM)	41000	1/1/2000	8/27/2014	5.876	5.722	5.789
7L		37500	1/1/2000	8/26/2014	4.291	4.242	4.125
7R		37500	1/1/2000	8/26/2014	2.058	2.037	2.047
8BL		32750	6/2/2000	8/26/2014	0.427	0.427	0.399
8BR-Pre		32750	6/2/2000	6/30/2012	7.415	7.394	1.954
8BR-Post		32750	7/1/2012	8/26/2014	0.312	0.312	0.248
87BL		30750	1/1/2000	8/27/2014	3.568	3.607	3.595
75BL		27000	1/1/2000	8/27/2014	3.755	3.475	3.927
9R-Pre	1 (Lower)	6750	6/2/2000	6/30/2008	5.426	0.967	5.192*
9R-Post		6750	7/1/2008	8/26/2014	0.227	0.002	0.224*
12BL		6500	1/1/2000	8/27/2014	2.221	0.239	2.150*
BC-1R		4750	6/5/2000	8/26/2014	0.190	0.000	0.189*

** % in this reach also includes wave influences*

The role of high flows on bank-erosion rates was investigated by analyzing the hourly outputs from each time step in BSTEM. The output data were sorted by the amount of bank erosion during each time step to determine what water elevations and discharges were responsible for bank erosion along the reach. The water elevation data were converted to discharge by developing polynomial regression relations using data from HEC-RAS. Erosion data for each site were thus sorted into 10,000 cfs discharge classes to determine how much erosion had occurred in each discharge class without biasing the classes because of different sizes. Data from each class were then summed to develop a cumulative frequency distribution for each model run. The resulting database of erosion totals provides an opportunity to investigate the relative amounts of erosion that occur at different discharges.

Flows above which 5%, 50%, and 95% of all erosion occurs were then identified for each site (also referred to as erosion flow thresholds). Erosion flow thresholds were then compared against the flow thresholds discussed in the previous section (Upper Reach: below or above 17,130 cfs, remaining reaches: <17,130 cfs, 17,130 – 37,000 cfs, and >37,000 cfs) to identify sites where natural or moderate high flows were the dominant cause of erosion and as a way to confirm the Baseline-S1 analysis. Based on the results of this analysis, the dominant cause of erosion at the vast majority of sites in the TFI was found to be natural high flows. Table 8 presents the distribution of discharges responsible for 5%, 50%, and 95% of bank erosion at the 25 detailed study sites. As previously discussed, Northfield Mountain Project operations can only have a potential impact on erosion in hydraulic reach 2 due to the hydraulic characteristics of the TFI. As shown in Table 8, the erosion flow threshold at which the majority of erosion occurs (i.e., the 50% threshold) is higher than the natural high flow threshold (37,000 cfs) at all sites in reach 2. In other words, the majority of erosion in this reach occurs at flows beyond the influence of Northfield Mountain Project operations.

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 later sections as well as in the main report (Volume II).

Table 8: Distribution of Discharges Responsible for 5%, 50%, and 95% of the Bank Erosion in at the 25 Detailed Study Sites

Site	Hydraulic Reach	Station	Total Erosion Under Baseline, $ft^3/ft/yr$	Baseline Scenario Discharge, cfs		
				5% of erosion occurs at flows greater than	50% of erosion occurs at flows greater than	95% of erosion occurs at flows greater than
11L	4 (Upper)	100,000	0.297	56,869	4,985	500
2L - Pre		94,500	1.197	89,294	64,854	49,906
2L - Post		94,500	0.214	71,465	65,195	51,924
303BL		94,000	0.647	79,881	64,684	53,194
18L		87,000	1.092	73,352	54,485	17,824
3L		79,500	6.086	98,234	78,682	37,098
3R-Pre		79,500	15.425	73,365	61,470	39,229
3R-Post		79,500	0.285	87,760	54,420	36,411
21R		79,250	2.359	63,852	46,345	22,928
4L	3 (Middle)	74,000	0.017	95,042	83,527	6,991
29R*		66,000	1.718	11,968	11,968	11,923
5CR		57,250	8.606	76,391	76,391	47,867
26R		50,000	1.194	80,503	60,282	43,294
10L		49,000	0.160	98,882	79,003	58,922
10R-Post		49,000	0.000	49,015	48,156	46,944
6AL-Pre		41,750	2.668	77,664	65,442	56,264
6AL-Post		41,750	0.000	65,167	63,310	62,287
6AR-Post		41,750	0.021	29,662	11,191	7,051
119BL	2 (NFM)	41,000	5.876	70,557	53,969	24,796
7L		37,500	4.291	98,753	65,338	47,731
7R		37,500	2.058	98,463	65,880	53,614
8BL		32,750	0.427	84,451	84,138	77,997
8BR-Pre		32,750	7.415	99,458	99,458	64,443
8BR-Post		32,750	0.312	72,009	69,312	66,504
87BL		30,750	3.568	63,968	42,875	17,849
75BL		27,000	3.755	71,586	48,054	33,822
9R-Pre	1 (Lower)	6,750	5.426	I	I	I
9R-Post		6,750	0.227	I	I	I
12BL		6,500	2.221	I	I	I
BC-1R		4,750	0.190	I	I	I

Note: "I" = indeterminate because a reliable stage-discharge relationship could not be developed

Potential Primary Causes of Erosion - Ice

When initially developing the causes of erosion for the RSP, ice was listed as a potential secondary cause of erosion. For decades ice had not been a significant factor affecting erosion in the TFI due largely to the operation of Vermont Yankee Nuclear Plant (VY) located immediately upstream in the Vernon Impoundment. When in operation, the plant used water from the Connecticut River for cooling after which heated water was discharged back to the river. As a result, the TFI would rarely ice over completely during the winter months.

In 2013, when Entergy announced the closing of VY by December 29, 2014, FERC issued an Interim ILP schedule for Study Plan Determination. During this period, FirstLight elevated ice from a potential secondary cause of erosion to a potential primary cause of erosion to account for the fact that ice may play a more significant role in riverbank erosion processes in the future. FirstLight filed an addendum to the RSP for Study No. 3.1.2 with FERC in September 2014 which highlighted the methodology to be used to more thoroughly examine ice as a potential primary cause of erosion.

Photographs were taken at a number of predetermined locations throughout the TFI to monitor ice conditions during the 2014/2015 winter (partial set of photos) and 2015/2016 winter (full set of photos), including:

- Vernon Dam;
- Confluence of Ashuelot River;
- Pauchaug Boat Launch;
- Route 10 Bridge;
- Northfield Tailrace;
- French King Bridge;
- Confluence of Millers River; and
- Turners Falls Dam

These sites were selected for two primary reasons: (1) they were easily and safely accessible during winter conditions, and (2) they covered the geographic extent of the TFI. In preparation for the 2015-2016 ice season, some photographs were taken of ice conditions that occurred the preceding winter (2014-2015) when conditions were more conducive to the formation of ice. During the 2014/2015 winter much of the TFI was covered with ice. In the later winter/early spring of 2015 ice break-up was uneventful as the ice simply melted in place. No significant riverbank damage or erosion was observed as a result of the ice formation or break-up. Although no erosion was observed, valuable insights were still gained as to the conditions that could potentially lead to ice related erosion.

During the course of the 2015/2016 winter, photos were taken on eight separate occasions starting December 15, 2015 and ending on March 8, 2016. Photos were generally taken every 1-2 weeks. The intent of the photos was to observe: (1) when sheet ice developed; (2) during formation of sheet ice; (3) during ice break-up; and (4) after ice break-up occurred. While ice development was observed during the monitoring period, due to an unseasonably mild winter the TFI never completely iced over.

In discussions with the USGS in Vermont and New Hampshire, they observed that ice typically does not cause erosion if the ice simply melts in place without significant break-up and if ice floes moving down river causing ice jams and impacting the banks do not occur. This is consistent with the observations made following the 2014/2015 winter. 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. Not only is ice formation a necessary component of erosion caused by ice, but so is how the ice breaks up in determining the potential for erosion caused by ice.

In addition to observations made during winter monitoring in 2014, 2015, and 2016 and discussion with the USGS, the analysis of ice as a primary cause of erosion focused on historic observations made in the TFI, upstream impoundments (i.e., Vernon, Bellows Falls, and Wilder), and other river systems (including un-impounded rivers). Ice dynamics in the upper impoundments provided insight 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 from the upstream impoundments, and other river systems (including un-impounded rivers), found that, given the right climatic and hydrologic conditions (i.e. high flows), ice has caused severe erosion and has contributed to bank instability and damage to riparian vegetation or limitation of the establishment and growth of vegetation, which can eventually lead to erosion. The results of this analysis found that ice has caused significant erosion and contributed to bank instability in both impounded and un-impounded rivers.

The results of the ice analysis found that ice can have the greatest potential impact on erosion if significant break-up occurs and if ice floes moving down river create ice jams or scrape along the banks. In addition to directly causing erosion these processes can also greatly effect riverbank vegetation thus also impacting the stability of the bank. If on the other hand, the ice simply melts in place and no significant break-up occurs it is unlikely that the ice would cause significant erosion. 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.

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

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

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

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

Potential Primary Causes of Erosion –Land Management Practices and Anthropogenic Influences

Analysis of the potential impact of land management practices and anthropogenic influences on erosion processes in the TFI focused on a number of factors in the area adjacent to the riverbank, including: (1) land-use; (2) width of riparian buffer; (3) agricultural practices; and (4) animal activity (discussed in the next section). As defined in RSP Task 5 and RSP Table 3.1.2-3, analysis of land management practices and anthropogenic influences focused on various geospatial analyses, including GIS and aerial imagery analysis. Special emphasis was placed on riverbank segments where the adjacent land-use was classified as Agriculture or Developed and the width of riparian buffer was less than 50 ft.

As part of the 2013 FRR, the land-use and width of riparian buffer within 200 ft. of adjacent riverbanks throughout the TFI were identified and classified through a combination of desktop GIS analysis and field investigation/validation. Land-use classifications identified during this effort are summarized in Table 9 while width of riparian buffers are summarized in Table 10.

Table 9: Summary of Turners Falls Impoundment Land-use (200 ft. Buffer)

Land-use	Acres	Percentage of Total
Cropland	275	26
Pasture	15	1.5
Barren	1	0.1
Developed	86	8.2
Transportation	22	2.1
Forest	631	60.3
Non-forested wetland	4	0.4
Restored	11	1.1

Table 10: Forested Riparian Buffer Widths (within 500 ft.)

Width (ft.)	Length (mi)	Percentage of Total
0-25	14	31
25-50	3	7
50-100	5	11
100-200	7	15
200-500	16	36

Various types and degrees of erosion found in the TFI can be observed at locations with a wide variety of adjacent land-uses. The strongest correlation between land-use and erosion has been observed in agricultural areas. Agriculture along the river typically is located on relatively flat floodplain terraces with only a narrow or virtually non-existent zone of riparian vegetation. Riparian vegetation along a river corridor plays a significant role in riverbank stability as it damps out or attenuates hydraulic forces of flowing water or waves, provides structure to bind soils together through its fine-root system and provides root reinforcement. To the extent that riparian vegetation is adversely affected, riverbank stability is likewise adversely affected.

As observed in the tables above, 27.5% of TFI riverbanks were classified as either cropland or pasture with 38% of riverbanks exhibiting a riparian buffer less than 50 ft. Frequently riverbanks in areas with narrow or non-existent riparian buffers consist of steep to overhanging banks consisting of silty/sandy soils that are easily erodible unless sufficient vegetation is present to reinforce the soil and provide some buffering of hydraulic forces.

Agricultural irrigation practices can also impact riverbank processes. In relatively recent years, irrigation has been increasingly utilized on a number of agricultural fields adjacent to the Connecticut River. Some irrigation water comes from groundwater pumping and some comes directly from the river. Water is applied on relatively flat terraces adjacent to the river where agricultural fields have been developed. Irrigation water is used to supplement rainfall which adds to wetter soil conditions. Some of the irrigation water provides water to crops and, in this process, a portion of the water goes to evapo-transpiration while some of it infiltrates deeper into the soil and flows back towards the river. Irrigation therefore increases soil moisture and the quantity of water that may seep through the banks which could adversely affect riverbank stability in these localized areas. Additionally, when significant rainfall occurs, water may pond on relatively flat agricultural fields and infiltrate into the ground which also adds to soil saturation (compared to hillslopes where more rainfall tends to occur as runoff and less infiltration into the soil). A greater degree of saturation in these soils would then result in additional seepage through the riverbank and back to the river.

In addition to agriculture, erosion has also been observed in areas where houses and other associated development are located in close proximity to the river. In several instances throughout the TFI where development has occurred in close proximity to the bank, undercutting, overhanging banks, and exposed roots have been observed. It has also been observed that riparian vegetation has also been cleared in these areas, which can adversely affect riverbank stability.

Many of the eroded sites where stabilization has occurred in accordance with the ECP are found at locations where the adjacent land-use is classified as either agricultural or some other type of development thus indicating the adverse effect land-use and land management practices can have on riverbank stability. As a result of the correlation observed between adjacent land-use and bank stability any riverbank segment where the adjacent land-use was classified as Agriculture or Developed and the riparian buffer width was 50 feet or less was classified as having land-use or land management practices as a potential contributing cause of erosion. This equated to approximately 101,000 feet (19 mi.) or 44% of all riverbank segments in the TFI.

Furthermore, riparian vegetation provides a stabilizing influence to riverbanks damping out hydraulic forces and providing soil stability through its supporting root structure. Where land-use removes or reduces vegetation in the riparian corridor, riverbank stability is generally decreased. A riparian buffer zone between land-use such as agriculture and a river provides an important component that adds to riverbank stability. The Connecticut River Joint Commissions (CRJC), in a brochure entitled "Introduction to Riparian Buffers," state

> *Riparian buffer vegetation helps stabilize streambanks and reduce erosion. Roots hold bank soil together, and stems protect banks by deflecting the cutting action of waves, ice, boat wakes, and storm runoff.*

They warn that *"Natural riparian buffers have been lost in many places over the years,"* and recommend a minimum width of riparian buffer of *"at least 50 feet"* to stabilize eroding riverbanks. They further state that *"Riparian buffers are the single most effective protection for our water resources in Vermont and New Hampshire,"* and that restoring riparian buffers will be *"an important step forward"* regarding riverbank stability.

Erosion rates were computed at several detailed study sites both before restoration and after. This provides a direct comparison at a set of sites where hydraulic conditions are similar since they are at the same location in the river with the only change potentially being different flow conditions over time from pre- to post-restoration. Typically a component of restoration included planting of riparian vegetation. Table 11 compares computed pre- and post-restoration erosion rates from BSTEM, along with the changes in vegetation and other characteristics. The post-restoration rates are significantly lower than pre-restoration rates, with reductions in erosion rate ranging from 82% to 100%. Upper riverbank vegetation for post-restoration sites is typically 'Heavy' compared to 'Little' to 'Very Sparse' for pre-restoration conditions. While restoration at some sites includes a rock toe, gravel, woody debris or lower riverbank vegetation; there typically is a significant increase in upper riverbank vegetation. Given that 44% of the length of riverbanks in the TFI are characterized as being affected by development or agriculture with associated narrow to non-existent riparian vegetation zones and given a large reduction in erosion rates for a well vegetated riverbank (82 to 100%), the potential effect of this length of riverbank lacking in riparian vegetation represents a significant adverse condition regarding erosion and riverbank stability.

Table 11. Erosion rate comparison: pre- to post-restoration

Site	Erosion Rate Pre-Restoration ($ft^3/ft/yr$)	Upper Riverbank Vegetation Pre-Restoration	Erosion Rate Post-Restoration ($ft^3/ft/yr$)	Upper Riverbank Vegetation Post-Restoration	Other Restoration Components	Percentage Reduction in Erosion Rate
2L	1.2	Very Sparse	0.214	Heavy	none	82%
3R	15.4	Sparse	0.285	Heavy	Rock toe	98%
6AL	2.67	Little	5.5E-05	Heavy	Rock toe	100%
8BR	7.42	Sparse	0.312	Heavy	Gravel, woody debris, lower riverbank vegetation	96%
9R	5.43	Sparse	0.227	Heavy	Coir log	82%

Potential Secondary Causes of Erosion

During study plan development it was believed that potential secondary causes of erosion such as animals, wind waves, seepage and piping, and freeze-thaw could be present at specific locations in the TFI. Based on the geomorphic understanding of the study area, these potential causes of erosion were likely to have minimal to no influence on erosion in the TFI (other than in any localized locations where they may exist). Given this, these potential causes of erosion were analyzed sufficiently to determine their relative contribution to erosion but not to the level of detail and specificity as the potential primary causes of erosion discussed above (RSP Task 3).

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:

- 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 previously discussed. 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** on the Connecticut River are relatively small and typically do not form breaking waves since the wind cannot act over a significant length of water (called fetch) because the river lies at the bottom of a valley protected on both sides by mountains. This is particularly true of winds that blow in the west to east direction, across the river that primarily flows north to south. Fetch is also relatively short for winds that blow in the north-south direction because the river flows around bends thereby limiting the length over which wind can build waves. Given this, wind waves were generally not found to be a factor in erosion processes throughout the TFI.

- 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.

Summary Evaluation of the Causes of Erosion

In accordance with Task 6 of the RSP, a summary evaluation of the findings discussed in the previous section is presented below. Given that the secondary causes of erosion were found to be insignificant in contributing to erosion (other than at the localized areas where they may exist), this section focuses on the evaluation of the primary causes of erosion. This summary evaluation is the culmination of the findings of the hydraulic modeling, BSTEM, and independent supplemental analyses as noted in Table 3.1.2-3 of the RSP. Discussion in this section is broken into two sub-sections, (1) the causes of erosion at each detailed study site, and (2) the extrapolation of the causes of erosion to each riverbank segment identified during the 2013 FRR.

Hydraulic Shear Stress due to Flowing Water, Water Level Fluctuations due to Hydropower Operations, and Boat Waves: Site specific summary

The results of the BSTEM modeling runs were used to analyze and evaluate primary causes of erosion, including: (1) hydraulic shear stress due to flowing water; (2) water level fluctuations due to hydropower operations; and (3) boat waves. From this analysis dominant and contributing primary causes of erosion were identified and bank erosion rates were calculated at the 25 detailed study sites. For those sites that were restored during the modeling period as part of the ECP, the causes of erosion were determined for both the pre- and post-restoration periods.

To interpret causes and contributing factors to bank erosion, detailed study sites that have had measureable/significant rates of bank erosion were first identified. In order to be classified as having measurable/significant rates of bank erosion, the rate of erosion at a given site must be greater than the erosion rate that represents the lowest 5% of all rates or 0.163 ft^3/ft/yr. Table 12 provides a summary of the distribution of mean annual erosion rates by site.

Table 12: Distribution of Mean Annual Erosion Rates by Site

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

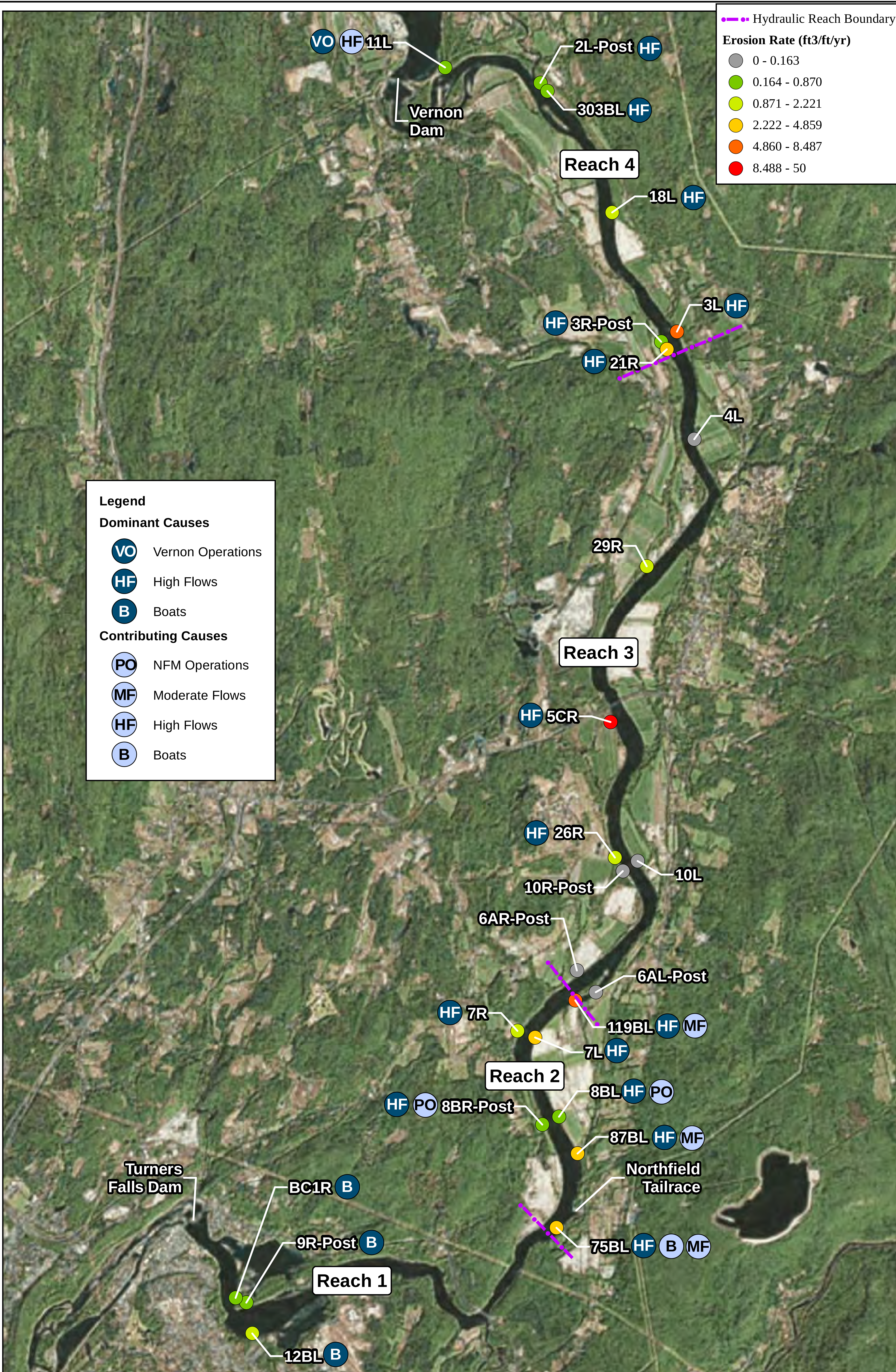
As observed in the table, current condition erosion rates (i.e., not including pre-restoration conditions) at five sites fell below the 5% threshold value (0.163 ft^3/ft/yr.). Of those five sites, only two (4L and 10L) represented non-restored conditions. Overall, values of current conditions ranged from 0.0 ft^3/ft/yr. at two post-restoration sites (10R and 6AL) to 8.61 ft^3/ft/yr. at Site 5CR, with a median value of 2.22 ft^3/ft/yr.

Based on the BSTEM results and using current erosion rates, a matrix of dominant and contributing primary causes, contributing factors, and contributing processes was developed for the detailed study sites (Table 13). The results of this matrix were then overlaid on aerial imagery to geographically show the dominant and contributing primary causes of erosion, contributing factors, and contributing processes found at each site throughout the TFI (Figures 5 and 6). 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. When reviewing the matrix and figures it should be noted that dominant and contributing causes attributed to Northfield Mountain or Vernon operations include both hydraulic shear stress due to flowing water and water level fluctuations due to hydropower operations. Similarly, causes attributed to high or moderate flows include hydraulic shear stress due to flowing water and naturally occurring water level fluctuations, while causes attributed to boats include boat waves.

Table 13: 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, 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



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0 0.625 1.25 2.5 Miles

Figure 5:
Dominant and Contributing Causes
of Erosion at each Detailed Study Site

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

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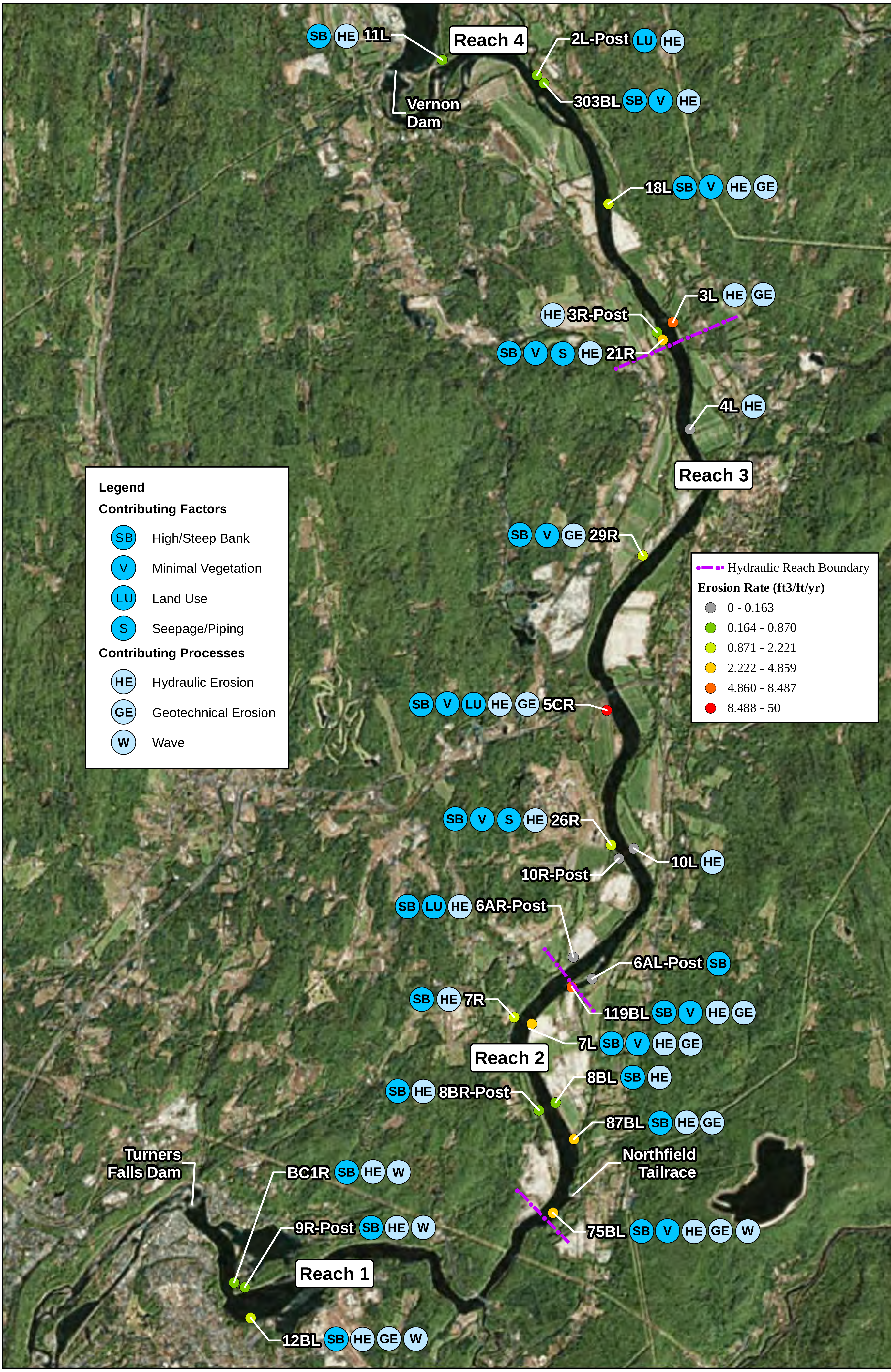

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Figure 6:
Contributing Erosion Factors and Processes at each Detailed Study Site

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

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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:

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

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 reach 4) and in excess of 37,000 cfs in reaches 3, 2, and 1. Sites classified as having Boats as a cause of erosion indicate the impact of boat waves on bank erosion. Although not included in the list above, land management practices (i.e. riverbank vegetative conditions) were analyzed as contributing factors in BSTEM via the RipRoot sub-model.

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 flow rates greater than 17,000 cfs for reach 4 and 37,000 cfs for reaches 3 and 2 as determined from the high-flow analysis[15]. 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 criterion 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 discussed at the beginning of this section 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.

As previously noted, there are seven (7) detailed study sites that lie within the Northfield Mountain Reach (reach 2), located between stations 27,000 and 41,000. Sites within the Northfield Mountain Reach include:

- 119BL
- 8BL
- 7L
- 8BR
- 75BL
- 7R
- 87BL

[15] Due to the fact that reliable stage-discharge relationships were not able to be developed in Reach 1 a high flow analysis was not possible in this area.

Although technically not included in this reach because of its generally flatter EGL slopes, Sites 6AL and 6AR at station 41,750 are 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 12). 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 be even 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 12).

Hydraulic Shear Stress due to Flowing Water, Water Level Fluctuations due to Hydropower Operations, Boat Waves, and Land Management Practices: Extrapolation of Results

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 fixed riverbank transect and the TFI overall.

The extrapolation methodology utilized in this study was consistent with that which was laid out in the RSP and the regulatory goals 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)."

The extrapolation approach consisted of seven main steps, including:

1. Analyze the variability of hydraulic forces throughout the TFI;
2. Analyze and review the site specific BSTEM results;
3. Analyze riverbank features, characteristics, and erosion conditions – which included the following sub-steps:

   a. Identify the detailed study sites where hydropower operations (i.e., Vernon, Northfield Mountain, or Turners Falls) 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.
   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 each riverbank segment identified in the 2013 FRR dominant and contributing causes of erosion – which included the following sub-steps:
   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;
   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;
6. Analyze land-use and width of riparian buffers adjacent to the riverbanks;
7. Create a map identifying the causes of erosion for each riverbank segment; and
8. Finalize the map and calculate summary statistics

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

The variability of hydraulic forces throughout the TFI was analyzed as part of the hydrologic and hydraulic analysis previously discussed. The results of those analyses confirmed that the hydraulic reaches established via the EGL slope accurately represented the geographic extent of which a hydropower project could have a potential impact on riverbank erosion processes. Based on these findings, Vernon operations can only have a potential impact on erosion in reach 4, Northfield Mountain in reach 2, and Turners Falls in reach 1.

Step 2: Analyze and review the site specific BSTEM results

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. Causal determinations for the extrapolation process followed the same criteria discussed earlier. 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. Table 14 presents a summary of the BSTEM results used for the extrapolation process.

Table 14: Causes of erosion at detailed study sites summarized from BSTEM

Site	Hydraulic Reach	Station	Dominant Primary Causes					Contributing Primary Causes			
			Project Operations	High Flows	Vernon Operations	Qe_{95} (cfs)	Boats	Project Operations	High Flows	Moderate Flows	Boats
11L	4 - Upper	100,000			X	500			X		
2L - Pre		94,500		X		49,906					
2L - Post		94,500		X		51,924					
303BL		94,000		X		53,194					
18L		87,000		X		17,824					
3L		79,500		X		37,098					
3R-Pre		79,500		X		39,229					
3R-Post		79,500		X		36,411					
21R		79,250		X		22,928					
4L	3 - Middle	74,000	-	-	-	6,991	-	-	-	-	-
29R*		66,000	Failure occurs at first time step, cannot determine primary cause(s)								
5CR		57,250		X		47,867					
26R		50,000		X		43,294					
10L		49,000	-	-	-	58,922	-	-	-	-	-
10R-Post		49,000	-	-	-	46,944	-	-	-	-	-
6AL-Pre		41,750		X		56,264					
6AL-Post		41,750	-	-	-	62,287	-	-	-	-	-
6AR-Post		41,750	-	-	-	7,051	-	-	-	-	-
119BL	2 - NFM	41,000		X		24,796				X	
7L		37,500		X		47,731					
7R		37,500		X		53,614					
8BL		32,750		X		77,997		X			
8BR-Pre		32,750	X			64,443			X		
8BR-Post		32,750		X		66,504		X			
87BL		30,750		X		17,849				X	
75BL		27,000		X		33,822				X	X
9R-Pre	1 - Lower	6,750				I	X		I		
9R-Post		6,750				I	X		I		
12BL		6,500				I	X		I		
BC-1R		4,750				I	X		I		

As shown in the table 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).

Step 3: Analyze the Riverbank Features, Characteristics, and Erosion Conditions

As observed in the Table 14, 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. Based on these results, the corresponding 2013 FRR riverbank segments and their features, characteristics, and erosion conditions for each site mentioned above were identified and summarized. 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.

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. Although 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.

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.

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).

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, FRR segments 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 vary 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.

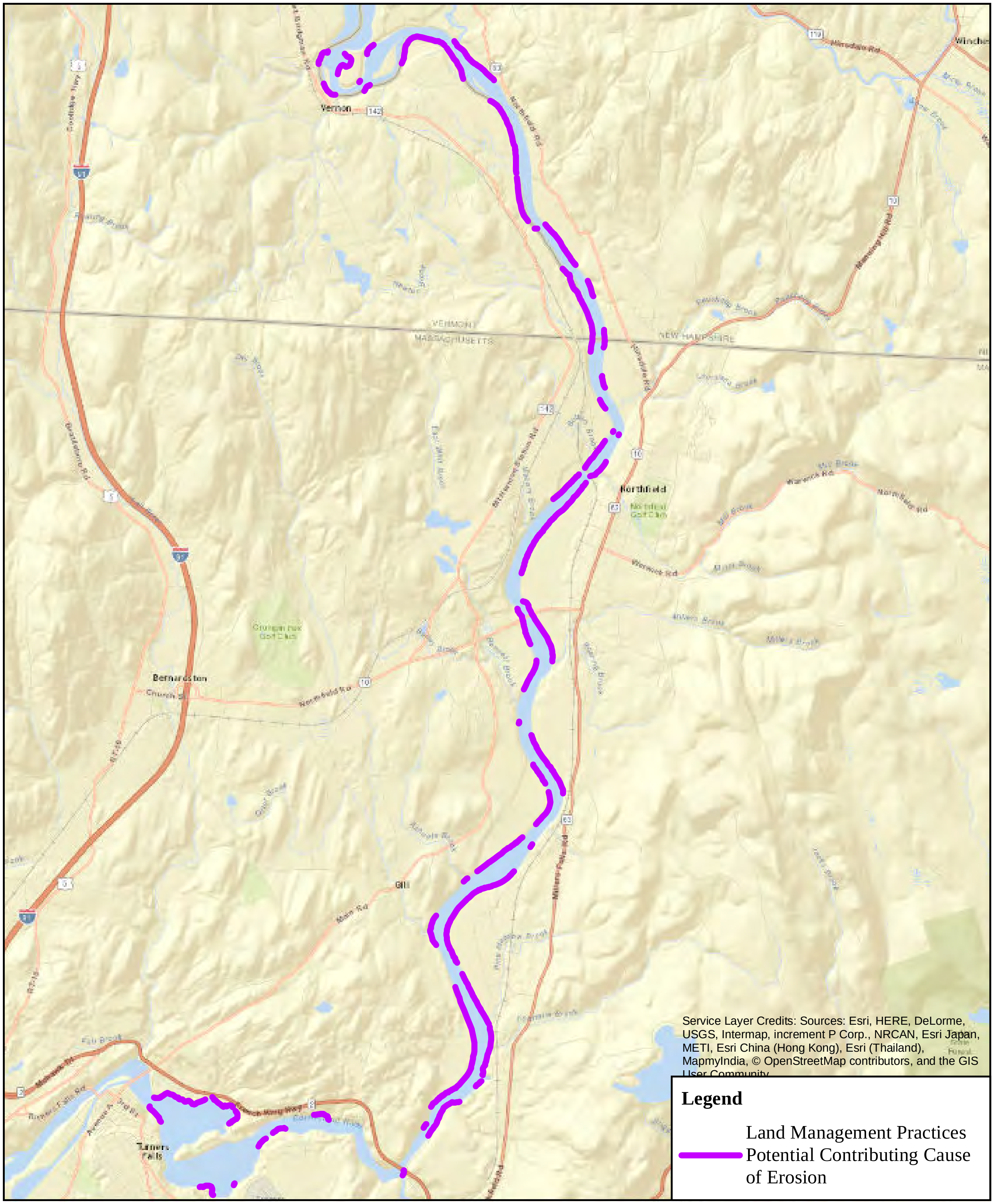
Based on an extensive set of time-stamped photos collected in associated with the 2013 FRR and corresponding water surface elevation data FirstLight was able to determine the elevation of the lower bank -upper bank transition. Once this elevation was determined, FirstLight could then determine the amount 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

Once each riverbank segment was classified with the appropriate erosion cause(s), land-use, land management practices, and anthropogenic influences were evaluated to determine their potential impact as a 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 252 segments (101,000 ft. or 19 mi.) were identified where land management practices, anthropogenic influences, and/or land-use are a potential contributing cause of erosion (Figure 7).



Legend

Land Management Practices Potential Contributing Cause of Erosion

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N

0 0.75 1.5 3 Miles

Figure 7:
Location of Turners Falls Impoundment Riverbank Segments where Land Management Practices are a Potential Contributing Cause of Erosion

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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 riverine section in reach 1from the French King Bridge to upstream of the entrance to Barton Cove where boat waves were a contributing cause.

Once all extrapolation steps were completed, the dominant and contributing primary causes of erosion were quantified based on the total number of FRR segments, the total length of those segments (in both feet and miles), and the % of total TFI riverbank length for each primary cause (excluding ice). These results are presented in Tables 15 and 16.

Table 15: Quantification of the Dominant Primary Causes of Erosion in the Turners Falls Impoundment

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

Table 16: Quantification of the Contributing Causes of Erosion in the Turners Falls Impoundment

Contributing Primary Cause of Erosion	No. FRR Segments	Total Length (ft.)	Total Length (mi.)	% of Total Riverbank Length[16]
None	401	153,400	29	68%
Boats	96	36,000	7	16%
Natural Moderate Flows	53	23,200	4	10%
Natural High Flows	59	20,200	4	9%
Northfield Mountain Operations	20	8,600	1.5	4%
Vernon Operations	0	0	0	0%
Turners Falls Operations	0	0	0	0%
Land Management Practices *(potential contributing cause)*	249	101,000	19	44%

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). Based on the results of this analysis:

- 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%); and
- Northfield Mountain operations were not found to be a dominant cause of erosion at any riverbank segment in the TFI.

In regard to contributing primary causes of erosion:

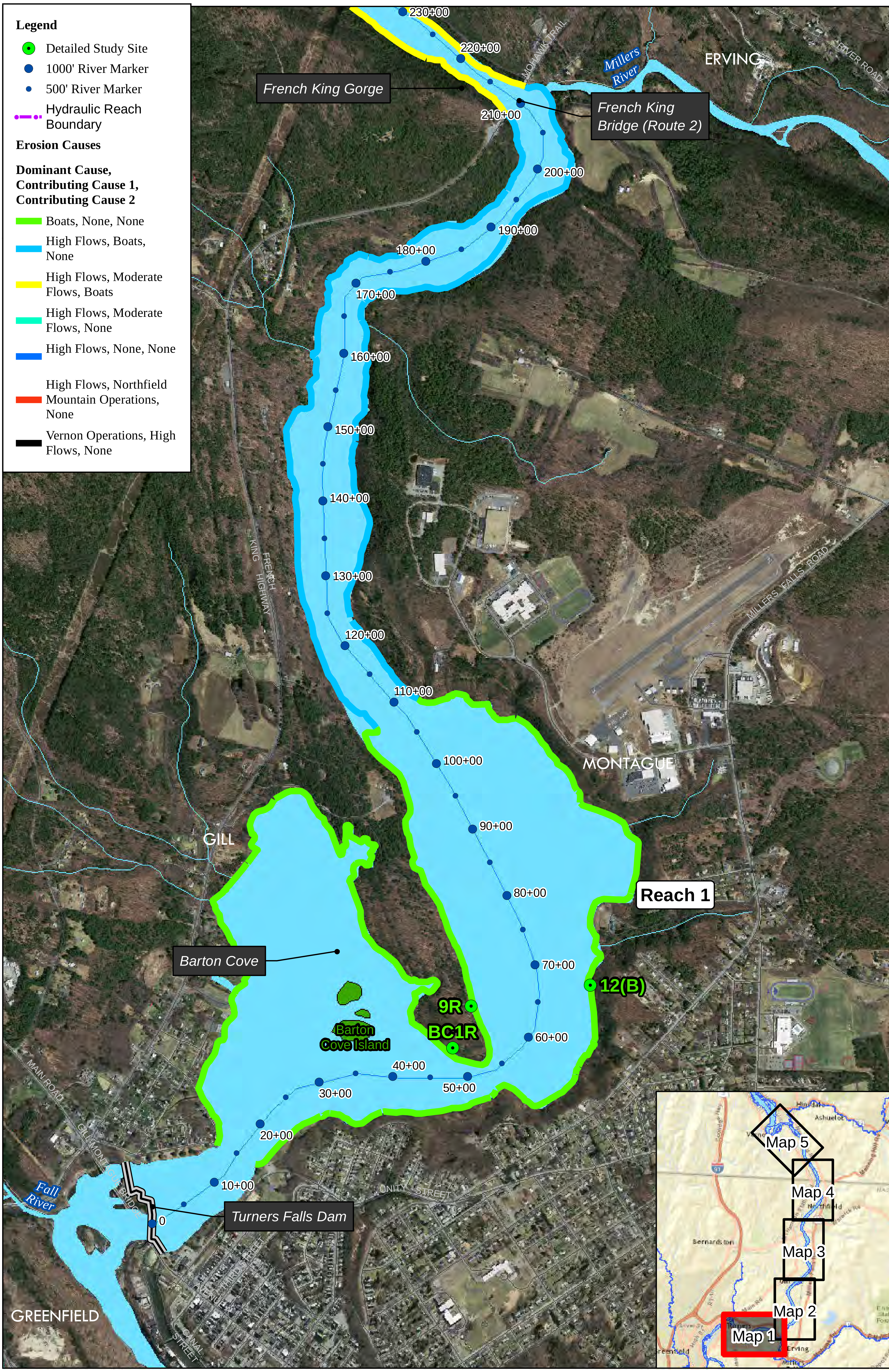
- The majority of the riverbank segments in the TFI (68%) did not have a contributing cause of erosion;
- Boats were a contributing cause at 16% of all riverbank segments followed by moderate flows (10%), High Flows (9%), and Northfield Mountain operations (4%);

[16] 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%.

- 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 spatial distribution of the causes of erosion throughout the TFI are shown in Figure 8.



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0 625 1,250 2,500 Feet

Figure 8:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 1

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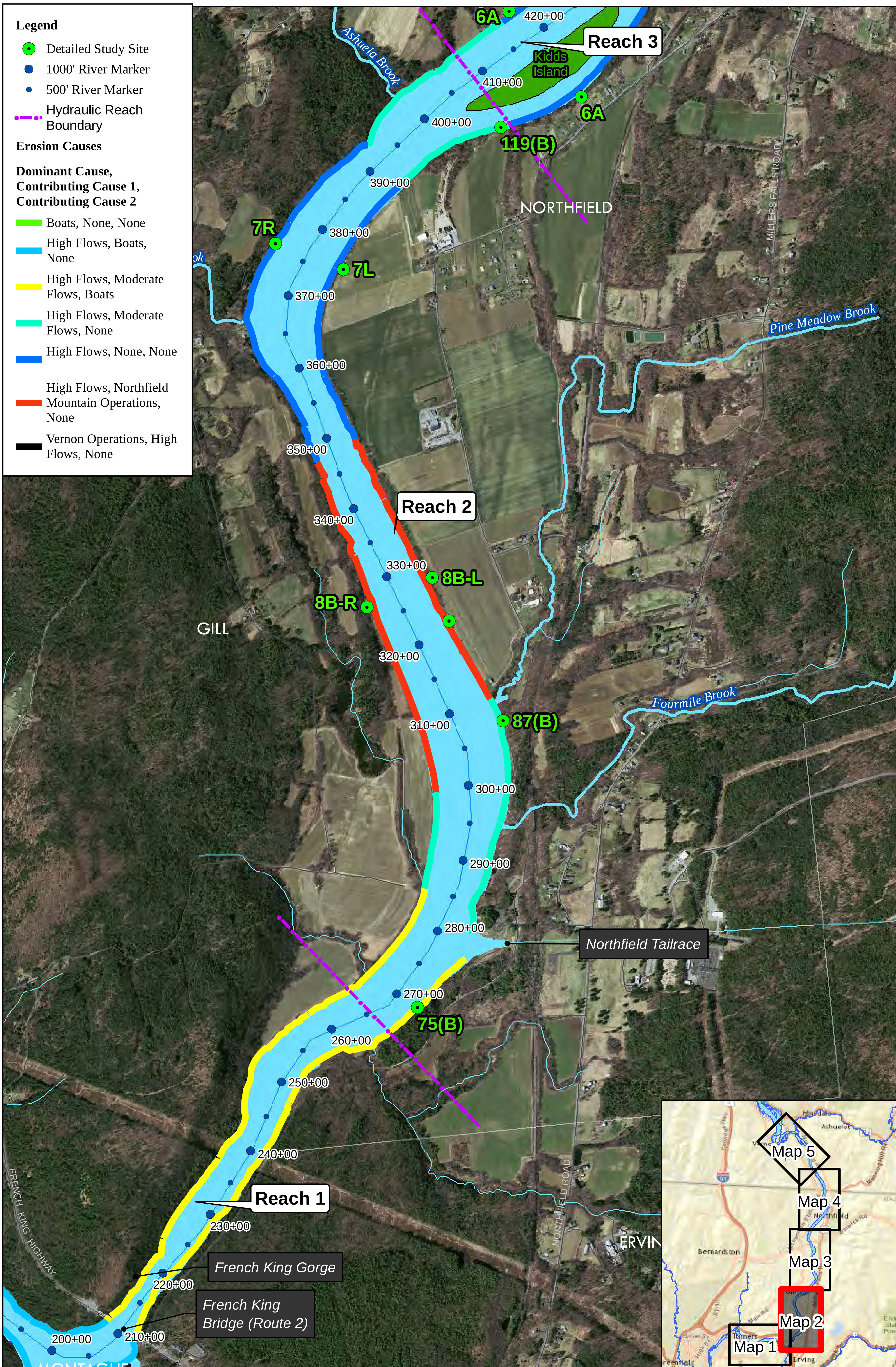

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0 625 1,250 2,500 Feet

Figure 8:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 2

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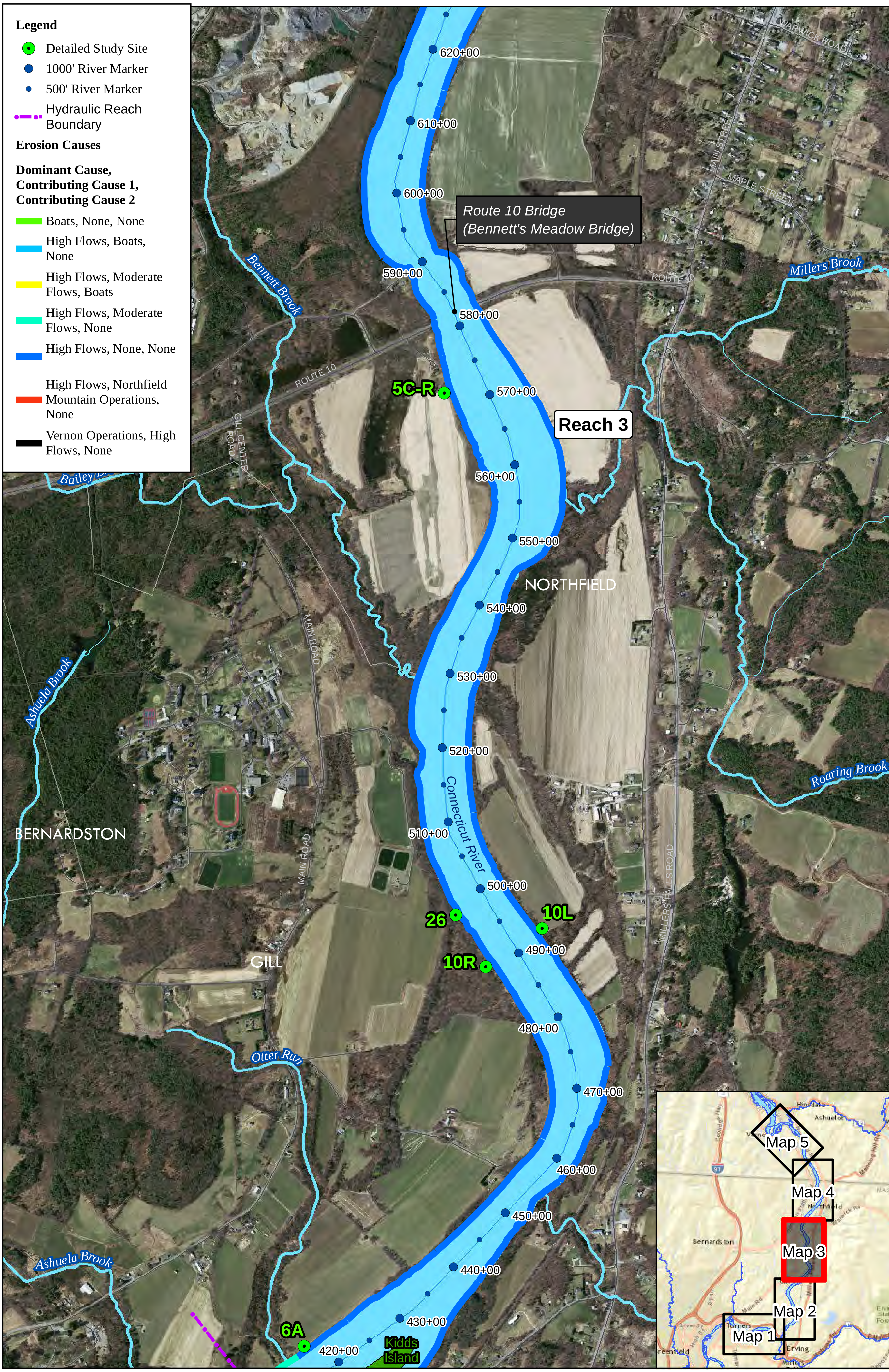

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Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

STUDY 3.1.2

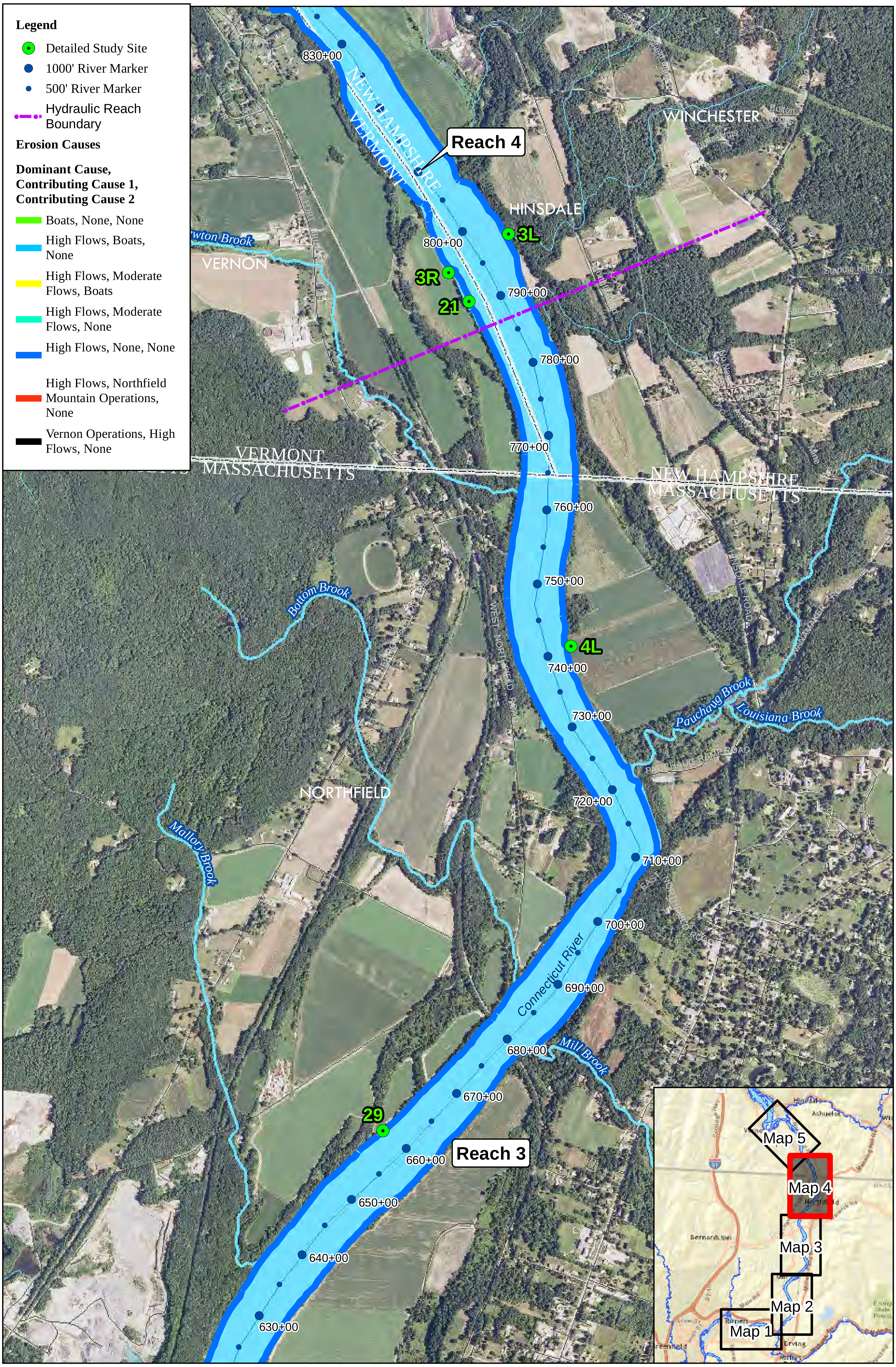
N

0 625 1,250 2,500 Feet

Figure 8:
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-8.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 8:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 4

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

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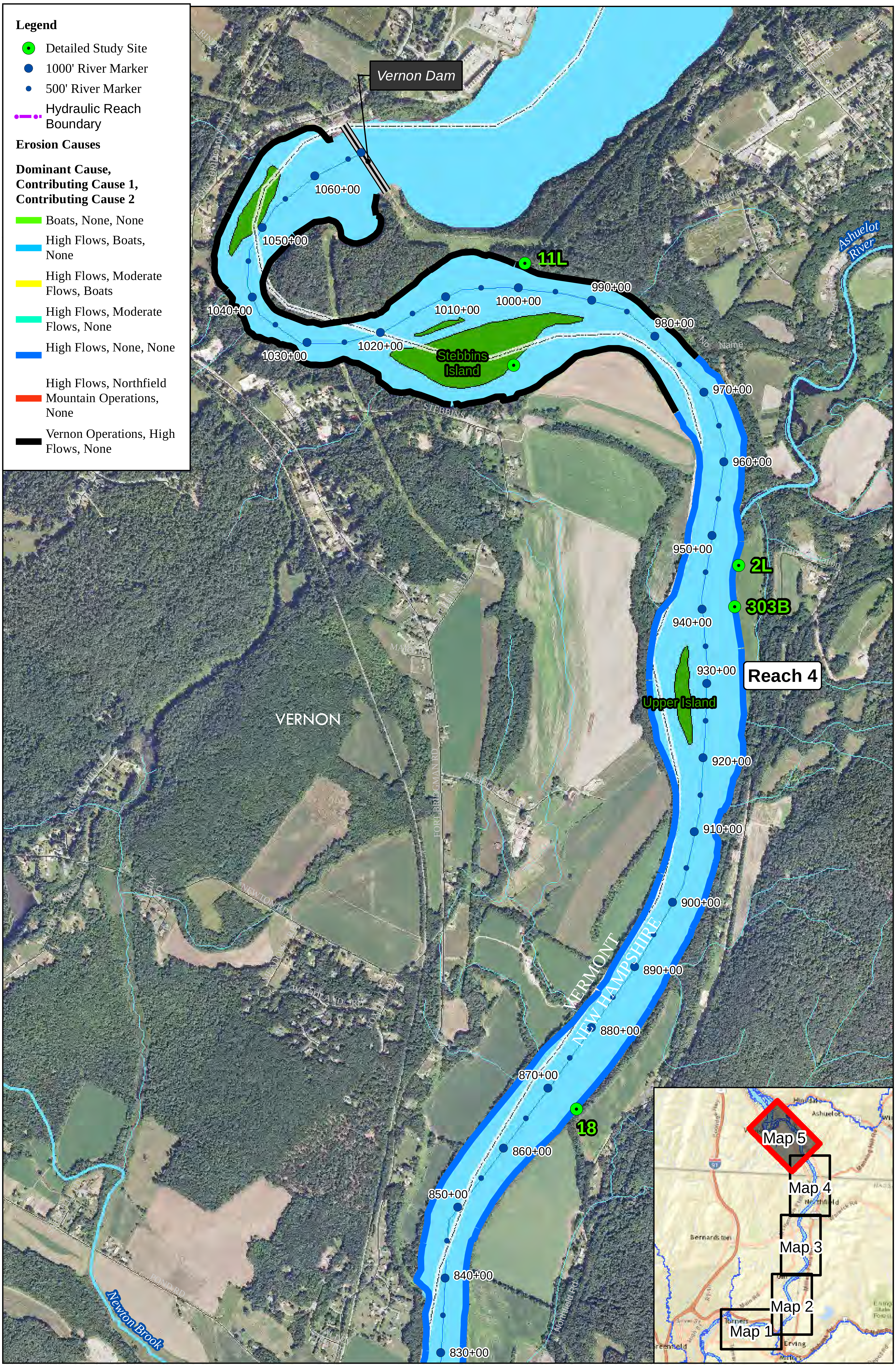

FirstLight Power Resources

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 8:
Final Extrapolation of the Causes of Erosion for each Riverbank Segment in Turners Falls Impoundment
Map 5

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

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Conclusions

The causes of erosion in the TFI were identified via state-of-the-science modeling and supplemental engineering analyses at 25 detailed study sites located throughout the study area. 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, if not more so, to erosion processes than riverbank features and characteristics were.

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 limited to no impact 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.);

- 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;

- 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.); 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 FERC and MADEP approved RSP using a robust dataset which spanned a 15-year period, proven analysis methods, and state-of-the-science modeling platforms. 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.