Relicensing Study 3.1.2


Volume III – Appendices

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

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ROBERT SIMONS, PhD, PE

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

ANDREW SIMON, PhD, PE

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

YAVUZ OZEREN, PhD, PE

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

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

JENNIFER HAMMOND

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

NICK DANIS, PE

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

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

JOHN HART

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

THOMAS SULLIVAN, PE

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

MARK WAMSER, PE

Mr. Wamser has 28 years of experience in FERC licensing and environmental and engineering studies. He has served as Project Manager for numerous FERC hydroelectric relicensing projects, as well as dam removal, water budgeting, watershed planning, water quality, and basin-wide modeling projects. In addition to his management experience, Mr. Wamser has considerable hands-on experience with operations modeling, energy analyses, instream flow studies (IFIM), water quality monitoring, fish passage analyses, impoundment level management studies, aesthetic studies, facilitation of settlement negotiations, and preparation of license applications for hydroelectric projects. Mr. Wamser’s technical background includes
the development of simulation models of basin-wide river/reservoir systems, development of HEC-RAS hydraulic models for dam removal and flood inundation studies, watershed assessments and action plans, and general hydrologic investigations. Mr. Wamser has had formal training in risk management, PHABSIM, HEC-RAS, sediment transport, and USFWS field techniques for IFIM studies.
APPENDIX B – HISTORIC AERIAL PHOTOS OF THE 20 SITES IDENTIFIED IN THE ECP
1 VERNON DAM

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

The 1952 photograph shows that the top of left bank is near the project boundary line (indicated in fuchsia). Recent photographs show that erosion has progressed beyond the line such that the bottom of the upper bank is beyond the line. The 2008-2010 and the Online Imagery were taken at relatively high flow conditions and show the turbulence and eddying associated with the release of flow through the left gates of Vernon Dam as well as the general turbulence in this reach of the river at these levels of flow.
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Vernon Dam
2014 Imagery
(Source: NAIP)
2 STEBBINS ISLAND

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

Project Boundary

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Stebbins Island
2014 Imagery
(Source: NAIP)
The 1952 photograph shows that the right bank of the river, opposite the confluence with the Ashuelot River, is eroded with no upper riverbank vegetation between the agricultural field and the river. The 2008-2010 and other recent photographs show an increase in riverbank vegetation along this same section of riverbank. On the Ashuelot side, upstream of the confluence the tip of land appears to have narrowed over time since 1952 and there is some decrease in the narrow riparian zone of upper riverbank vegetation downstream of the confluence.
4 KENDALL

In the vicinity of the railroad bridge which has been subsequently abandoned and partially removed, in 1952 the right bank downstream of the bridge supports a band of riparian vegetation while the left bank is sparsely vegetated. In 1962, in the same location on the right bank erosion is evident with the bank shifting landward and no riparian vegetation remaining. On the left bank, a small erosion scallop has formed just downstream of the bridge with segments of reduced riparian vegetation. The bridge super-structure had been removed by the 1990s photograph, with all piers left standing in the river. By the 2008-2010 set of photographs, one of the piers had fallen into the river, probably due to scour around its base and no supporting structure to provide stability from above. The right bank is the Kendall site which was stabilized in 2008 through implementation of the ECP. Subsequent photos show the stabilized right bank and increased riparian vegetation along the left bank.
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Kendall
1960's Imagery
(Source: USGS)
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Kendall
1990's Imagery
(Source: MassGIS)
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Kendall
2008-2010 Imagery
(Source: NH GRANIT)
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Kendall
2014 Imagery
(Source: NAIP)
In the 1952 photograph, a band of riparian vegetation is found along both banks of the river upstream of the Schell Bridge. The extent of vegetation appears to be relatively consistent along the right bank through the series of photographs. On the left bank; however, the 1960s photograph shows erosion and a significant reduction in riparian vegetation. This area was called the Country Road Site, which was stabilized in 2006 through the ECP as shown in the 2008-2010 and more recent photographs.
Schell Bridge (Country Road)
1990's Imagery
(Source: MassGIS)
6 WICKEY

In the 1952 and 1960s photographs, there is an eroded section of riverbank with no significant riparian vegetation. During the 1990s, this site was selected for erosion repair, known as the Wickey site (constructed in 1996).
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Wickey
1952 Imagery
(Source: North by Northeast Survey Company)
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STUDY 3.1.2

Wickey
1960's Imagery
(Source: USGS)
Legend

Project Boundary

STUDY 3.1.2
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Wickey
1990's Imagery
(Source: MassGIS)
7 MT. HERMON

The left riverbank across the river from the Mt. Hermon School was eroded and absent riparian vegetation on the 1952 and 1960s photographs. A strip of riparian vegetation has become established along this riverbank as can be seen in the 1990s and subsequent photographs.
Mt. Hermon
2008-2010 Imagery
(Source: MassGIS)

STUDY 3.1.2

Mt. Hermon
2008-2010 Imagery
(Source: MassGIS)
Mt. Hermon
2014 Imagery
(Source: NAIP)
8 ROUTE 10 BRIDGE

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

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

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

Project Boundary

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Rt. 10 Bridge
1952 Imagery
(Source: North by Northeast Survey Company)
Rt. 10 Bridge
1990's Imagery
(Source: MassGIS)

Legend
- Project Boundary

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

- Project Boundary

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

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

Project Boundary

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Urgiel
1990's Imagery
(Source: MassGIS)

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Urgiel
2008-2010 Imagery
(Source: MassGIS)
10  FLAGG - DOWNSTREAM OF OTTER RUN

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

- Project Boundary
11  FLAGG - UPSTREAM OF OTTER RUN

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

2014 Imagery

(Source: NAIP)
12 SKALSKI

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

- Project Boundary

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

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Skalski
1990's Imagery
(Source: MassGIS)
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Skalski
2008-2010 Imagery
(Source: MassGIS)
On the left bank downstream of Kidds Island the 1952 and 1960s photographs show eroded conditions with little riparian vegetation. By the 1990s, the narrow remnants of a field appear to have been eroded away and into another band of riparian vegetation.
Left Bank Downstream of Kidds Island
1990's Imagery
(Source: MassGIS)
Left Bank Downstream of Kidds Island
2008-2010 Imagery
(Source: MassGIS)
STUDY 3.1.2

Left Bank Downstream of Kidds Island
2014 Imagery
(Source: NAIP)
14 L’ETOILE

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

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Legend

- Project Boundary

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

- Project Boundary

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L'Etoile
2008-2010 Imagery
(Source: MassGIS)
15 SHEarer/BATHoRy- GaLLAGHer

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

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Shearer/Bathory-Gallagher
1952 Imagery
(Source: North by Northeast Survey Company)
Shearer/Bathory-Gallagher
1960's Imagery
(Source: USGS)

Legend

- Project Boundary

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STUDY 3.1.2
16  UPPER SPLIT RIVER

The right bank of the river in this location is eroded and has little riparian vegetation in the 1952 and 1960s photographs. The lower part of the photograph of the right bank was stabilized using rock (see discussion of tailrace in next segment) while the upper part of the photograph of the right bank was selected as the Upper Split River site and was stabilized in 2010 using a gravel beach and large woody debris as can be seen on the 2014 photograph.
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Upper Split River
1960's Imagery
(Source: USGS)
Upper Split River
1990's Imagery
(Source: MassGIS)
17 NORTHFIELD MOUNTAIN TAILRACE

The right bank across the river from the future tailrace for Northfield Mountain appears to be eroded and devoid of riparian vegetation in the 1952 and 1960s photographs, before the construction of the project. Rock from project construction was used to stabilize this eroded bank during the construction process. The rock has stabilized the toe of the bank and riparian vegetation has become established above the rock.
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Northfield Mountain Tailrace
1952 Imagery
(Source: North by Northeast Survey Company)
Legend

- Project Boundary

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Northfield Mountain Tailrace
1990's Imagery
(Source: MassGIS)
Legend

- Project Boundary

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Northfield Mountain Tailrace
2014 Imagery
(Source: NAIP)

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18 LOWER SPLIT RIVER/DURKEE POINT

The right bank in the 1952 photograph is sparsely vegetated with apparent erosion as is a segment of the left bank. By the 1960s photographs erosion of the left bank segment is apparent while the right bank remains sparsely vegetated with some erosion. The right bank sight is called the Lower Split River site which was stabilized in 2009 and the left bank segment is called Durkee Point and was stabilized in 2003, both through implementation of the ECP.
Lower Split River
1960's Imagery
(Source: USGS)
Lower Split River
1990's Imagery
(Source: MassGIS)
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Lower Split River
2014 Imagery
(Source: NAIP)
19 RIVER ROAD

On the inside of the bend along the left bank erosion has occurred over time with the bank moving landward compared to the project boundary line as noted in changes in the bank from the 1952 to 1960s and subsequent photographs. This area was stabilized in 2003 through the ECP and is called the River Road Site.
River Road
1960’s Imagery
(Source: USGS)
Legend

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River Road
1990's Imagery
(Source: MassGIS)
20 CAMPGROUND POINT

Campground Point is the peninsula that separates Barton Cove from the reach of river leading upstream to French King Gorge. Some erosion is evident in the earlier photographs such as 1952 continuing through the 2008 photograph, when it was stabilized as part of the ECP in 2008 as the Campground Point Site. The 2014 photograph shows an increase in vegetation on the stabilized site.
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Campground Point
1952 Imagery
(Source: North by Northeast Survey Company)
APPENDIX C – UPLAND EROSION FEATURES
Legend

Erosion Feature
- Project Boundary
- Elevation (NAVD88 ft)
  - >275'
  - 225' - 275'
  - 195' - 225'
  - 185' - 195'
  - 176' - 185'
  - 165' - 176'
  - <165'

Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NOAA, ESA, METI, NRCAN, GEBCO, NOAA, Increment P Corp.

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C-1 Upland Erosion near Stebbins Island

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Path: W:\gis\studies\03_1_2\map\final_report\appendix_c.mxd

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Figure C-2 Right bank upstream-most upland erosion feature (Stream)
Figure C-4. Looking downhill into ravine (Photo 272, 9/29/2015)

Figure C-5. From ravine looking uphill (Photo 288, 9/29/2015)
Figure C-6 From second ravine looking uphill (Photo 316, 9/29/2015)

Figure C-7 Divide between two ravines (Photo 325, 9/29/2015)
Legend

Erosion Feature

- Project Boundary
- Elevation (NAVD88 ft)
  - >275'
  - 225' - 275'
  - 195' - 225'
  - 185' - 195'
  - 176' - 185'
  - 165' - 176'
  - <165'

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STUDY 3.1.2

C-8 Upland Erosion Near
Kidds Island (Left Bank)
Legend

Erosion Feature
- Project Boundary
- Ravine
- Ridge
- Upland Erosion

Elevation (NAVD88 ft)
- >275'
- 225' - 275'
- 195' - 225'
- 185' - 195'
- 176' - 185'
- 165' - 176'
- <165'

C-11 Upland Erosion near Montague Rod and Gun Club

STUDY 3.1.2

FirstLight Power Resources
Figure C-12 Upland erosion feature (Photo 9517)
APPENDIX D – DETAILED STUDY SITE ASSESSMENTS
### Synopsis of Land-Based Surveys
#### 2014 Connecticut River Detailed Site Assessments

<table>
<thead>
<tr>
<th>Location ID</th>
<th>Date</th>
<th>Station (Note 1)</th>
<th>Coordinates</th>
<th>Left or Right Bank (Note 2)</th>
<th>Previously Stabilized?</th>
<th>Photo Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>11L</td>
<td>9/23/14</td>
<td>10,000+00</td>
<td>42.77306, -72.50294</td>
<td>Left</td>
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</tbody>
</table>

Notes: (1) Station is measured in feet, with Station 0+00 at Turners Fall Dam, increasing upstream.  
(2) Left and right bank is referenced facing downstream.  
(3) Transect 2L was surveyed as land-based observation point #19 (Sta. 947+50) in November 2013.  
(4) Transect 6AR was surveyed as land-based observation point #25 (Sta. 410+00) in November 2013.  
(5) Transect 8BR was surveyed as land-based observation point #23 (Sta. 321+00) in November 2013.  
(6) Transect 9R was surveyed as land-based observation point #27 (Sta. 62+00) in November 2013.  
(7) Boat-based point 12BL was surveyed as land-based observation point #28 (Sta. 65+00) in November 2013.  
(8) Land-based points #18L, 21R, 29R, and 26R were surveyed in November 2013.
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: **11L**

**Personnel:** YKC, CM, RKS

**Date:** September 23, 2014  
**Time:** 10:40 AM  
**Photo Reference Numbers:** 802 - 807

**Station Number:** 1000+00  
**Latitude:** 42.77306  
**Longitude:** -72.50294

**Left or Right Bank (Looking Downstream):** *Left*

**Previously Stabilized?** *No*

**Geologic / Geotechnical Observations:**

*Stratigraphy:*

(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

*Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, light brown.*
*Lower Bank below Gravel Bar: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, gray.*

**Observed Erosion Features:**

- Steep slope at river level (lower 10 feet of Upper Bank)
- Mass wasting with hummocky terrain in upland
- Undercuts with exposed roots
- Some leaning trees
- Numerous down timber

**Site Sketch:**

[Diagram of riverbank with detailed observations marked]
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 11L    Date: September 23, 2014

Station Number: 1000+00

Bank Vegetation:

   **Top:** Heavy (90%) cover – Broad leaved deciduous tree
   - Tree (90%): red oak*, eastern white pine, red maple, silver maple, black birch, yellow birch
   - Shrub (80%): staghorn sumac, willow, birch, dead snags (>3), multiflora rose
   - Vine: bittersweet*, Virginia creeper, grape

   **Face:** Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
   - Tree (25%): red maple*, black birch, eastern white pine, red oak, basswood
   - Shrub (70%): sumac*, red maple sapling, multiflora rose, Japanese barberry
   - Vine: oriental bittersweet*, grape, Virginia creeper
   - Herbaceous (45%): river rye*, woolgrass, boneset, beggartick (Bidens spp.), mixed goldenrods (Solidago spp.), cattails, Iris, mixed asters, purple loosestrife

   **Toe:** Sparse (<5%) – mixed emergent (broad-leaved & narrow leaved, persistent & non-persistent)
   - Herbaceous: rushes (inc. Juncus, Eleocharis), Sagittaria spp., Phalaris, Iris, mixed grasses

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Forested further back from restoration site, & Agricultural (row crop – cow corn)

Sensitive Receptor:
- No

Notes:
- Bank is densely vegetated and very steep
- Eroding bank with overhanging roots
- Bald eagle nest nearby (upstream)
- Transect continues through Stebbins Island an on to Right bank across River
- Invasive vegetation including multiflora rose, creeper, bittersweet & loosestrife
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 802

Photo No. 803
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 804

Photo No. 805
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 802 - 807
Location ID 11L – September 23, 2014

Photo No. 806

Photo No. 807
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 3L
Personnel: YKC, CM, RKS

Date: September 23, 2014
Time: 12:05 PM
Photo Reference Numbers: 808 - 814

Station Number: 795 + 00
Latitude: 42.73602
Longitude: -72.45993

Left or Right Bank (Looking Downstream): Left
Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank Upper Layer: SILTY SAND (SM) – Fine to coarse sand, approx. 10% - 20% gravel, approx. 10% - 20% low-plasticity fines, brown.
Upper Bank Lower Layer: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% very fine sand, gray.
Lower Bank: SANDY SILT (ML) – same as Lower Layer of Upper Bank.

Observed Erosion Features:
- Near vertical scarps with undercuts and exposed roots at river level
- Minor overhangs
- Leaning trees with curved trunks
- Some mass-wasting near river level

Site Sketch:
Observation Point Number: 3L    Date: September 23, 2014
Station Number: 795+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (90%): red oak*, silver maple, green ash, sycamore, elm, basswood, black birch, eastern white pine
- Shrub (85%): barberry*, multiflora rose, black birch saplings, eastern white pine saplings, red maple saplings
- Vine (45%): oriental bittersweet*
- Herbaceous (30%): cinnamon fern, sensitive fern, lady fern, mixed asters, mixed goldenrods (Solidago spp.)

**Face:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (80%): red oak*, elm, black birch, ash, sycamore, basswood
- Shrub/sapling (90%): basswood*, black birch, elm, ash, autumn olive, Japanese barberry, willow, white oak, staghorn sumac, multiflora rose
- Herbaceous (80%): Mixed grasses (Phalaris arundinacea*, Calamagrostis canadensis), mixed goldenrods (Solidago spp.), mixed asters, cutgrass (Leersia oryzoides), beggartick (Bidens spp.), purple loosestrife, panic grass, clover

**Toe:** None

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Forested & Agricultural

Sensitive Receptor:
- No

Notes:
- Near vertical erosion scarps with undercuts.
- Leaning/downed trees at river level.
- Narrow riparian forest with Japanese barberry dominating the understory, with agricultural fields (potato) at the top of the hill.
- Invasive species present (bittersweet & barberry common, some loosestrife & autumn olive present)
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 808

Photo No. 809
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 808 - 814
Location ID 3L – September 23, 2014

Photo No. 814
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 3R

Date: September 23, 2014
Time: 12:40 PM

Station Number: 795 + 00
Latitude: 42.73457

Left or Right Bank (Looking Downstream): Right

Previously Stabilized? Yes (Kandall Site, 2008)

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

SAND (SP, SP-SM) – Fine sand, approx. 5% - 10% low-plasticity fines, brown.
ROCK TOE – 1” – 4” riprap rock, angular, hard, minor deterioration.

Observed Erosion Features:
- Little erosion of stabilized slope.
- Minor near-vertical scarps near the top of rock toe

Site Sketch:
Observation Point Number: 3R  Date: September 23, 2014
Station Number: 795+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
  
  Tree (1%): pin oak (fringe)
  
  Shrub (80%): staghorn sumac*, willows, dogwoods, loosestrife, ash, red maple, Ilex glabra
  
  Herbaceous: Aster*, mixed grasses

**Face:** Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling

  Tree (0%)

  Shrub/sapling (60%): willow*, sumac, loosestrife, dogwood, quaking aspen, Ilex glabra
  
  Herbaceous (100%): mixed grasses (Phalaris arundinacea*, panic grass, Leersia spp.), mixed asters, beggartick (Bidens spp.), cinnamon fern, Polygonum spp., mixed goldenrods (Solidago spp.), lupine, jewelweed, clover

**Toe:** None
  
  rock toe

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:

Restored & Agricultural

Sensitive Receptor:

No

Notes:

Previously restored site (Kendall), with angular rip-rap stone exposed at toe.

Large patch of rooted submerged aquatic veg in LUW in front of study site

Very steep bank

Agricultural field (row crop – cow corn) at top of bank

Diverse vegetative community from restoration (includes I. glabra and lupine)
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 815 - 820
Location ID 3R – September 23, 2014

Photo No. 817

Photo No. 818
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 4L  Personnel: YKC, CM, RKS
Date: September 23, 2014  Time: 2:45 PM  Photo Reference Numbers: 821 - 824
Station Number: 737 + 00  Latitude: 42.71964  Longitude: -72.45590

Left or Right Bank (Looking Downstream): Left
Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, brown.
Lower Bank: SILTY SAND (SM) – Mostly fine sand, approx. 10% - 15% low-plasticity fines, gray.
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, mottled brown and orange, organic.

Observed Erosion Features:
- Steep slope, entire Upper Bank.
- Minor erosion of recent sediment where there was no wetland vegetation.
- 6-inch deep erosion scarp at river level from boat waves.

Site Sketch:
Observation Point Number: 4L  Date: September 23, 2014
Station Number: 737+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (60%): silver maple*, red maple, elm, ash, black locust, cottonwood, basswood
- Shrub (60%): elm*, multiflora rose, ash saplings, autumn olive, black birch, glossy buckthorn
- Vine (65%): bittersweet
- Herb (60%): mixed grasses, poison ivy, jewelweed, nightshade, mixed asters & Solidago spp.

**Face:** Moderate (>50%) cover – Broad leaved deciduous shrub/vine
- Tree (15%): silver maple*, elm, red maple, cottonwood
- Shrub (40%): elm*, silver maple sampling, red maple sapling, cottonwood sapling, multiflora rose
- Vine (65%): bittersweet, some Virginia creeper
- Herbaceous (75%): mixed grasses (*Phalaris arundinacea*, Leersia spp.), poison ivy, woolgrass, boneset, Polygonum spp., sedges (inc. Carex spp.), rushes (inc. Eleocharis spp., Juncus effuses, beggartick (Bidens spp.), purple loosestrife

**Toe:** Heavy (>50%) cover – Narrow leaved persistent emergent
- Tree (5%): silver maple*, red maple, elm
- Shrub/vine (10%): loosestrife, cottonwood seedlings, red maple seedlings
- Herbaceous (85%): woolgrass*, *umbrella sedge*, Eleocharis spp., cattails, Scirpus pungens, Phalaris arundinacea, Juncus spp., Leersia spp., loosestrife, Penthorum sedoides

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Very thin riparian buffer with Agricultural (row crop: corn & sunflower) at top of the bank

Sensitive Receptor:
- No

Notes:
- Very open & sunny

Persistent & Non-persistent Emergent vegetation growing on recently deposited sediment (silt)

Largest patch of Eleocharis we’ve documented

Invasives inc. bittersweet, buckthorn, autumn olive, loosestrife, and multiflora rose
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 821 - 824
Location ID 4L – September 23, 2014

Photo No. 823

Photo 824
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 4AL  
Date: September 23, 2014  
Station Number: 738 + 00  
Left or Right Bank (Looking Downstream): Left

Personnel: YKC, CM, RKS  
Time: 3:10 PM  
Latitude: 42.71993  
Longitude: -72.45606

Previous Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:  
(Refer to Site Sketch below for locations of soil/rock layers  
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, brown.  
Lower Bank: SILTY SAND (SM) – Mostly fine sand, approx. 10% - 15% low-plasticity fines, gray.  
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, mottled brown and orange, organic.

Observed Erosion Features:

- Steep slope, entire Upper Bank.
- Leaning trees and undercuts at toe of Upper Bank, some with exposed roots
- Overhangs with exposed roots near top of Upper Bank
- Significantly less recent sediment compared with Site 4L which is just 100 feet away. Little to no wetland vegetation on recent sediment.
- 6-inch deep erosion scarp at river level from boat waves

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 4L  Date: September 23, 2014

Station Number: 738+00

Bank Vegetation:

*Top:* Heavy (>50%) cover – Broad leaved deciduous tree

Tree (90%): silver maple*, elm, green ash
Shrub (60%): silver maple*, elm, sumac
Vine (70%): bittersweet
Herb (60%): mixed grasses, poison ivy

*Face:* Heavy (>50%) cover – Broad leaved deciduous tree

Tree (65%): silver maple*, elm, green ash
Shrub: silver maple*, elm, ash
Vine (65%): bittersweet, some Virginia creeper
Herbaceous (5%): mixed grasses, poison ivy

*Toe:* none

bare ground

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Very thin riparian buffer with Agricultural (row crop: corn & sunflower) at top of the bank

Sensitive Receptor:
No

Notes:
Heavily shaded site (with large mature silver maples), located approx. 100’ upstream & 100’ downstream from more open site, each with a non-persistent/persistent emergent shelf (one of these, the area ~100’ downstream, is Site 4L)

Significant bittersweet invasion here

Exposed roots on bank face
Photo No. 825

Photo 826
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 5CR

Date: September 23, 2014  Time: 4:10 PM

Station Number: 572+50  Latitude: 42.68102

Personnel: YKC, CM, RKS

Photo Reference Numbers: 831 - 835

Longitude: -72.47197

Left or Right Bank (Looking Downstream): Right

Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, approx. 10% - 20% fine sand, gray.
Lower Bank: SAND (SP) – Fine to medium sand, <5% low-plasticity fines, brown.
Recent Sediment: SILT (ML) – Slightly plastic, <10% fine sand, brown.

Observed Erosion Features:
- Leaning trees, some with curved trunks, with exposed roots.
- Very steep slope, entire Upper Bank.
- Minor undercutts
- Recent sediment with no vegetation

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 5CR       Date: September 23, 2014
Station Number: 572+50

Bank Vegetation:

Top: **Heavy (>50%) cover – Broad leaved deciduous tree**
    Tree (60%): silver maple*, elm, ash, black locust, basswood, cottonwood, red maple, sugar maple
    Shrub: elm*, alder, multiflora rose, ash saplings
    Vine (50%): bittersweet, some grape
    Herb (5%): mixed grasses, poison ivy

Face: **Moderate (>50%) cover – Broad leaved deciduous tree**
    Tree (50%): black locust*, ash, basswood
    Shrub: black locust*, alder, ash, basswood, elm, blueberry, sugar maple saplings
    Vine: bittersweet, grape
    Herbaceous (15%): mixed grasses (Calamagrostis canadensis*), NY fern, rushes (inc. Juncus effusus), sedges (inc. Carex spp.), beggartick (Bidens spp.), meadow rue, mixed goldenrods (Solidago spp.)

Toe: **Sparse (1%) cover – Narrow-leaved persistent emergent**
    Tree: cottonwood seedlings
    Herbaceous: mixed grasses (Calamagrostis canadensis*, Phalaris arundinacea, Leersia spp.)

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
    Very thin riparian buffer with Agricultural at top of the bank

Sensitive Receptor:
    No

Notes:
    Very steep, near vertical, bank with overhangs & exposed roots

    Adjacent to Bennett Meadows agricultural & recreational area

    Invasive species, particularly bittersweet
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 831 - 835
Location ID 5CR – September 23, 2014

Photo No. 831

Photo 832
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 831 - 835
Location ID 5CR – September 23, 2014

Photo No. 833

Photo 834
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 10L  
Personnel: YKC, CM, RKS

Date: September 24, 2014  
Time: 12:15 PM  
Photo Reference Numbers: 855 - 858

Station Number: 490+00  
Latitude: 42.66099  
Longitude: -72.46698

Left or Right Bank (Looking Downstream): Left

Previously Stabilized? No

Geologic / Geotechnical Observations:

**Stratigraphy:**
(Refer to Site Sketch below for locations of soil/rock layers  
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, <10% fine sand, gray.  
Lower Bank: SAND (SP, SP-SM) – Fine sand, approx. 5% - 10% low-plasticity fines, gray.

Observed Erosion Features:

- Little to no erosion.
- Minor erosion scarps at the toe of Upper Bank where there was no wetland vegetation.

Site Sketch:

![Site Sketch Image](image-url)
Observation Point Number: 10L  Date: September 24, 2014
Station Number: 490+00

Bank Vegetation:

**Top:** Moderate (25-50%) cover – Broad leaved deciduous tree
- Tree (45%): silver maple*, ash, weeping willow, red maple
- Shrub (70%): red maple sapling*, alder, elm
- Vine: bittersweet
- Herbaceous (15%): Jerusalem artichoke, jewelweed, poison ivy, mint, mixed upland grasses

**Face:** Moderate (25-50%) cover – Broad leaved deciduous tall shrub/sapling
- Tree (15%): red maple*, silver maple, weeping willow
- Shrub (35%): willow*, purple loosestrife, red maple sapling, elm
- Herbaceous (15%): cattail*, umbrella sedge, 3-way sedge, Phalaris arundinacea, woolgrass, jewelweed, Eleocharis spp., Bidens, mixed unidentified grasses, mixed Solidago spp.

**Toe:** sparse (<10%) cover – robust persistent emergent
- Tree (0%): purple loosestrife*, willow
- Herbaceous (<10%): cattail*, sedges and rushes (inc. umbrella sedge, 3-way sedge, Carex spp., Juncus effusus, Juncus canadensis, woolgrass, Eleocharis spp.)

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

**Adjacent Land Use:**
- Agricultural (row crop – corn) with very thin riparian buffer ~1 tree width

**Sensitive Receptor:**
- No

**Notes:**
- There is a willow bench with some loosestrife mixed in
- Very thin riparian buffer (~1 tree width) along row crop (corn) field edge
- Invasive species present including purple loosestrife, multiflora rose, bittersweet, and garden escapees
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 10R  Date: September 24, 2014
Station Number: 490+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
- Tree (5%): pin oak*, cottonwood, red oak, hickory, silver maple, red maple
- Shrub (80%): staghorn sumac, winged euonymus, black locust sapling, quaking aspen, white oak sapling, raspberry, honeysuckle
- Vine: creeper*, bittersweet
- Herbaceous (45%): mixed upland grasses, mixed Solidago spp., mixed asters

**Face:** Heavy (>50%) cover – Broad leaved deciduous tall shrub/sapling
- Tree (1%): pin oak*, cottonwood
- Shrub (70%): sumac*, alder, honeysuckle, multiflora rose, dogwoods, raspberry, red maple saplings, willow
- Herbaceous (15%): mixed grasses (inc. Calamagrostis*, Phalaris arundinacea), mixed asters, mixed goldenrods (Solidago spp.)

**Toe:** none
- Bare rock

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Forested further back from restoration site, & Agricultural (row crop – cow corn)

Sensitive Receptor:
No

Notes:
- Restoration Site (Urgiel Upstream), with 2-6” angular riprap rock at toe and no erosion at toe
- Some slumping above rock toe, mid-slope and near the top of the slope of the upper bank
- The “Fuzzy Tree” site – there is a single stand-out tree at the top of the bank engulfed in Virginia creeper, which makes this site distinguishable to many. The creeper is red in the fall.
- Site is mostly vegetated with sumac at the top of the bank
- Lots of invasives here, inc: bittersweet, creeper, honeysuckle, winged euonymus, and multiflora rose
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 10R

Date: September 24, 2014
Time: 11:30 AM

Station Number: 490+00
Latitude: 42.65999
Longitude: -72.46927

Personnel: YKC, CM, RKS

Photo Reference Numbers: 850 - 854

Left or Right Bank (Looking Downstream): Right

Previously Stabilized? Yes (Urgiel Upstream, 2001)

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

SANDY SILT (ML) – Low plasticity, approx. 30% – 40% fine sand, brown.
Rock Toe – 2” to 6” riprap rock, angular, hard, little deterioration.

Observed Erosion Features:

- Little erosion at rock toe, with no depressions or movements observed.
- Some slumping above rock toe, mid-slope, and near the top of slope of Upper Bank.

Site Sketch:
Photo No. 853
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 6AL
Date: September 24, 2014
Station Number: 417+50

Personnel: YKC, CM, RKS
Time: 1:00 PM
Latitude: 42.64249

Photo Reference Numbers: 859 - 864
Longitude: -72.47578

Left or Right Bank (Looking Downstream): Left

Previously Stabilized? Yes (Skalaski, 2004)

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank, Upper Layer: SILTY SAND (SM) – Fine to coarse sand, approx. 20% - 30% nonplastic fines, brown.
Upper Bank, Lower Layer: SILT (ML) – Slightly plastic, approx. 15% - 20% fine sand, gray.
Rock Toe – 1” to 4” riprap rock, angular, hard, minor deterioration.

Observed Erosion Features:
- Little erosion at rock toe, with no depressions or movements observed.
- 1’ – 2’ high near-vertical scarps just above the rock toe, with minor undercuts.
- Very steep natural upland slope above repaired area.
- Some leaning trees in natural upland slope, some with curved trunks.

Site Sketch:

[Site Sketch Diagram]
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 6AL  Date: September 24, 2014
Station Number:  417+50

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (60%): sugar maple*, red oak, white oak, sycamore, eastern white pine, hemlock, black birch, white birch
- Shrub: hemlock*, red maple, sycamore, gray birch, sumac
- Vine: bittersweet*, some Virginia creeper
- Herbaceous: Christmas fern, hay scented fern, jewelweed

**Face:** Heavy (>50%) cover – Broad leaved deciduous shrub/sapling
- Tree (15%): sycamore*, sugar maple, red maple, hemlock, black birch, gray birch
- Shrub (90%): sumac*, hemlock, red maple, willow, sugar maple, sycamore, Viburnum, dogwoods
- Vine: bittersweet*, some creeper
- Herbaceous (15%): cinnamon fern, Christmas fern, asters, jewelweed, ostrich fern, mixed goldenrods (Solidago spp.), Japanese knotweed (including within the restoration area), horsetail (Equisetum spp.), woolgrass

**Toe:** Sparse (1%) cover – Robust persistent emergent
- Mostly rock, with sparse cattails

*Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Agricultural (potato field) at top of the bank

Sensitive Receptor:
- Yes – Kingfisher nest cavity

Notes:
- Very steep
- Skalaski restoration site with rock toe

Invasive species, particularly bittersweet but some Japanese knotweed, even within the restoration footprint (total knotweed aerial coverage <5%)
Photo No. 861
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 7L
Personnel: YKC, CM, RKS

Date: September 25, 2014
Time: 8:00 AM
Photo Reference Numbers: 871 - 877

Station Number: 375+00
Latitude: 42.63684
Longitude: -72.48664

Left or Right Bank (Looking Downstream): Left

Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, approx. 10% - 20% fine sand, gray.
Lower Bank: SANDY SILT (ML) – Low plasticity, approx. 40% to 50% fine sand, gray.

Observed Erosion Features:
- Very steep slopes near top of Upper Bank, with little vegetation.
- Leaning trees with exposed roots at river level.
- Mass wasting with slumping and exposed roots.
- Toe undercutting and localized scour holes between trees at river level.
- Overhangs with exposed roots of large trees at top of Upper Bank.

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 7L  Date: September 25, 2014
Station Number: 375+00

Bank Vegetation:

**Top**: Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (60%): red oak*, white oak, basswood, elm
- Shrub (50%): morrow’s honeysuckle*, raspberry, sumac, elm, dogwoods
- Vine (40%): bittersweet*, grape, Virginia creeper
- Herbaceous (15%): poison ivy, Solidago spp., mixed grasses & asters

**Face**: Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (60%): basswood*, elm, ash, red oak, white oak, cottonwood, ashleaf maple
- Shrub (20%): elm*, red oak sapling, white oak sapling, ash sapling, basswood sapling, barberry, honeysuckle,
- Vine (35%): bittersweet*, Virginia creeper, grape
- Herbaceous (<10%): garlic mustard, cinnamon fern, mixed goldenrods (Solidago spp.), mixed asters & mixed grasses

**Toe**: Sparse (<5%) cover – Broad leaved deciduous (mixed)
- Tree (<5%): basswood*, elm, red oak, white oak (partly fallen, overhanging trees)
- Shrub (<10%): honeysuckle*, basswood sapling, elm
- Vine (30%): bittersweet* with some grape and creeper
- Herbaceous: none

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Very thin riparian buffer (1 tree width) with agricultural land use at the top of the bank

Sensitive Receptor:
- No

Notes:
- Lots of invasive species here: barberry, morrow’s honeysuckle, garlic mustard, Virginia creeper, and oriental bittersweet is very prevalent, covering everything
Photo No. 871

2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 871 - 877
Location ID 7L – September 25, 2014

Photo No. 872
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 871 - 877
Location ID 7L – September 25, 2014

Photo No. 873
Photo No. 874
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 7R

Date: September 25, 2014

Time: 9:00 AM

Station Number: 375+00

Latitude: 42.63824

Longitude: -72.49010

Personnel: YKC, CM, RKS

Photo Reference Numbers: 879 - 884

Left or Right Bank (Looking Downstream): Right

Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, gray.
Lower Bank: SAND (SP) – Fine to medium sand, <5% nonplastic fines, brown and gray.

Observed Erosion Features:
- Undercuts with exposed roots at river level.
- Mass-wasting along entire slope.
- Trees on upland area have straight trunks, suggesting the trees post-date the mass-wasting movement.
- Leaning trees with exposed roots at river level and bottom of Upper Bank, some with curved trunks.
- Large scour hole (20’ wide x 40’ long x 15 feet deep) at mid-slope, with flowing groundwater at bottom of hole.

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 7R  Date: September 25, 2014
Station Number: 375+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (80%): sugar maple*, eastern white pine, hemlock, black birch, ash, white oak
- Shrub (2%): black birch sapling*, barberry, honeysuckle, sugar maple sapling
- Vine (2%): bittersweet*, grape
- Herbaceous (10%): mixed ferns (inc. Christmas fern, ostrich fern, Dryopteris spp., sensitive fern), poison ivy, asters

**Face:** Heavy (>50%) cover – Broad leaved deciduous shrub
- Tree (40%): black birch*, sugar maple, eastern white pine, hemlock, ash
- Shrub (60%): barberry, honeysuckle, hemlock, ash sapling, sugar maple sapling, poison ivy shrub, white oak sapling
- Vine: bittersweet*, Virginia creeper, grape
- Herbaceous (<5%): poison ivy, Christmas fern, asters

**Toe:** sparse (<5%) cover – narrow leaved persistent emergent
- Tree (10%): ash*, sugar maple, eastern white pine, red oak, black birch (partly fallen, overhanging trees)
- Shrub (<10%): honeysuckle*
- Vine (5%): bittersweet*, grape
- Herbaceous (50%): three square sedge (Scirpus americanus)

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Forested

Sensitive Receptor:
No

Notes:

There is a section on the bench where rock has been placed (see photos)

Approx. 3 m upstream there is a small patch of three square, ~5m x 5m in size (CM photo 50)

There is a gully where a tree fell mid slope up the hill (CM photo 051)

Very high bank

Mid slope is very steep – too steep to support much vegetation

Invasive species are present here, including: Japanese barberry, oriental bittersweet, and honeysuckle. However, none are dominating. The bittersweet is covering everything mid-bank but is absent from the denser forested area at the top of the bank; the barberry is sparse at the top of the bank, ~1%. Honeysuckle is denser at the lower mid slope.
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 879 - 884
Location ID 7R – September 25, 2014

Photo No. 879

Photo No. 880
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 879 - 884
Location ID 7R – September 25, 2014

Photo No. 881

Photo No. 882
Photo No. 883

Photo No. 884
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID:  BBL
Date:  September 25, 2014
Station Number:  327+50

Personnel:  YKC, CM, RKS
Time:  9:50 AM
Latitude:  42.62466
Photo Reference Numbers:  885 - 891
Longitude:  -72.48204

Left or Right Bank (Looking Downstream):  Left
Previously Stabilized?  No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

SANDY SILT (ML) – Low plasticity, approx.10% - 20% fine sand, brown.

Observed Erosion Features:

- Mass-wasting entire slope on Upper Bank.
- Undercuts and overhangs with exposed roots near river level.
- Leaning trees with exposed roots near river level.
- Very steep slope along entire Upper Bank.

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 8BL   Date: September 25, 2014

Station Number: 327+50

Bank Vegetation:

Top: Moderate (30%) cover – Broad leaved deciduous shrub/sapling
   Tree (20%): red oak*, basswood, pin oak, ashleaf maple
   Shrub (30%): elm*, black birch saplings, raspberry, Japanese barberry, alder, multiflora rose,
   Vine (<5%): Virginia creeper*, bittersweet
   Herbaceous (60%): milkweed, ragweed, asters, clover, mixed grasses (much is mown and forms the edge of the
   agricultural field)

Face: Heavy (>50%) cover – Broad leaved deciduous tree
   Tree (65%): basswood*, elm, green ash, white oak, red oak
   Shrub (5%): multiflora rose*, barberry, honeysuckle, elm, dogwoods, willow
   Vine: Virginia creeper*, bittersweet
   Herbaceous (75%): mixed asters, mixed goldenrods (Solidago spp.), garlic mustard, mixed upland grasses

Toe: sparse (1%) cover – narrow leaved persistent emergent
   Tree (0%):
   Shrub (<1%): sugar maple sapling, green ash sapling (shade from mid-slope)
   Herbaceous (1%): Scirpus spp.

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
   Forested

Sensitive Receptor:
   No

Notes:
   Gravelly beach with some cobbles

   Very thin riparian buffer at top where agricultural field edge meets top of bank

   Bank is steep with near vertical slope at top, bare slopes where it is too steep to support vegetation, undercuts and overhangs
   with exposed roots, leaning trees with curved trunks and exposed roots, and downed trees.
Photo No. 889

Photo No. 890
**Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments**

**Location ID:** BC-1R  
**Date:** September 24, 2014  
**Station Number:** 47+50  
**Left or Right Bank (Looking Downstream):** Right  
** Previously Stabilized?** No

**Geologic / Geotechnical Observations:**

**Stratigraphy:**
(Refer to Site Sketch below for locations of soil/rock layers  
Notations in parentheses are based on Unified Soil Classification System)

- **Upper Bank:** SAND (SP, SP-SM) – Fine to medium sand, approx. 5% - 10% nonplastic fines, moist, brown.
- **Lower Bank:** SAND (SP) – Mostly medium sand, <5% nonplastic fines, some gravel, brown.
- **BEDROCK** – Shale, hard, weathered.

**Observed Erosion Features:**
- Undercuts with exposed roots
- Leaning trees, some with curved trunks, at bottom of Upper Bank
- Some slumping/mass-wasting near bottom of Upper Bank
- Down timber

**Site Sketch:**

![Site Sketch](image-url)
Observation Point Number: BC1R    Date: September 24, 2014
Station Number: 47+50

Bank Vegetation:

**Top:** Heavy (>50%) cover – Needle leaved coniferous tree
- Tree (90%): eastern white pine*, hemlock, beech, red oak, black birch
- Shrub (70%): kalmia angustifolia*, alder, black birch, white oak, red maple, shadbush, hemlock, blueberry
- Herbaceous (5%): teaberry, gentian, club mosses, sparse mixed upland grasses

**Face:** Heavy (>50%) cover – Needle leaved coniferous tree
- Tree (70%): eastern white pine*, hemlock, beech, red oak, black birch
- Shrub (50%): beech*, Kalmia angustifolia, alder, black birch, white oak, red maple, shadbush, hemlock, blueberry
- Herbaceous (5%): teaberry, gentian, club mosses, sparse mixed upland grasses

**Toe:** None

*Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

**Adjacent Land Use:**
- Forested & Recreational (camping, boating, fishing)

**Sensitive Receptor:**
- No

**Notes:**

Peninsula in Barton Cove with shale at toe & a unique natural community, different than other data points

Camp Ground Area
Photo No. 842
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 303L

Date: September 22, 2014

Station Number: 940+00

Personnel: YKC, CM, RKS

Time: 2:30 PM

Latitude: 42.76950

Station Number: 940+00

Longitude: -72.48410

Photo Reference Numbers: 795 - 799

Left or Right Bank (Looking Downstream): Left

Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, gray.
Lower Bank: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, dark gray.
Recent Sediment: SILTY SAND (SM) – Mostly fine sand, approx. 10% - 20% low-plasticity fines, mottled.

Observed Erosion Features:

- No erosion observed on Lower Bank, the top of which was filled with recent sediments.
- Steep slopes, entire Upper Bank.
- Some undercuts with exposed roots.
- Leaning trees.
- Few down timber

Site Sketch:
Observation Point Number: 303L     Date: September 22, 2014

Station Number: 940+00

Bank Vegetation:

**Top:** Heavy (>50%) cover – Broad leaved deciduous tree
- Tree (60%): silver maple*, green ash, elm
- Shrub (60%): staghorn sumac*, ash, honeysuckle, elm
- Vine (35%): bittersweet*, grape
- Herbaceous (5%): sparse mixed grasses, joe-pye weed

**Face:** Moderate (25-50%) cover – Broad leaved deciduous tree
- Tree (35%): silver maple*, hickory, ash, elm
- Shrub (30%): multiflora rose*, ash saplings, sumac, maple saplings, willow
- Herbaceous (25%): Solidago spp., mixed asters, raspberry, Equisetum spp.

**Toe:** None to Very Sparse – mixed persistent & non-persistent emergent
- Herbaceous (65%): woolgrass*, reed (Phragmites australis), sedges and rushes (inc. Caladium mariscoides, Juncus canadensis, umbrella sedge, Eleocharis spp., Juncus effusus, Carex crinite), Polygonum spp., beggartick (Bidens spp.), panic grass, Sagittaria spp., purple loosestrife

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
- Agricultural

Sensitive Receptor:
- Yes – kingfisher nest cavity

Notes:
- Recent sediment deposit on bench supports diverse community of persistent & non-persistent emergent vegetation
- Sensitive receptor site in eroding vertical sandy bank face (kingfisher nest cavity)
- Bonnett Farm site
- Little riparian forested buffer separating the bank from the field edge
- Invasive species present including bittersweet, purple loosestrife & multiflora rose
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 119BL
Date: September 24, 2014
Station Number: 407+00
Left or Right Bank (Looking Downstream): Left

Personnel: YKC, CM, RKS
Time: 2:15 PM
Latitude: 42.64167
Longitude: -72.47889

Photo Reference Numbers: 866, 867, 869, 870

Previously Stabilized? No

Geologic / Geotechnical Observations:

Stratigraphy:
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank: SANDY SILT (ML) – Low plasticity, approx. 20% - 30% fine sand, brown. Pockets of clean sand with fine gravel.
Lower Bank: SILT (ML) – Low plasticity, <5% fine sand, tan.

Observed Erosion Features:
- Leaning trees at river level.
- Numerous small slumps on lower half of Upper Bank slope
- Very steep slopes at upper half of Upper Bank
- Near-vertical scarps at river level

Site Sketch:
Observation Point Number: 119(B)L  Date: September 24, 2014
Station Number: 407+00

Bank Vegetation:

Top: Moderate (25-50%) cover – Broad leaved deciduous tall shrub/sapling
- Tree (10%): ash*, red oak, basswood, elm, ashleaf maple
- Shrub (50%): staghorn sumac*, basswood, elm
- Vine (5%): bittersweet*

Face: Moderate (25-50%) cover – Broad leaved deciduous tall shrub/sapling
- Tree (5%): basswood*, elm
- Shrub (30%): staghorn sumac*, multiflora rose, elm, quaking aspen, sycamore sapling, purple loosestrife
- Herbaceous (75%): mixed grasses (inc. Phalaris arundinacea*, Calamagrostis canadensis), cattails, pokeweed, mixed goldenrods (Solidago spp.), mixed asters, common reed (Phragmites australis), raspberry, horsetail (Equisetum spp.)

Toe: None to Very Sparse – Robust persistent emergent
- Herbaceous (<5%): reed (Phragmites australis)

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
Agricultural

Sensitive Receptor:
Yes

Notes:
Very steep and actively eroding with areas of vertical sandy bank suitable for Sensitive Receptor sites

Phragmites patch present at toe

Invasive species present including multiflora rose, bittersweet, purple loosestrife, and Phragmites
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 866, 867, 869, 870
Location ID 119BL – September 24, 2014

Photo No. 866

Photo No. 867
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 87BL  
Date: September 25, 2014  
Station Number: 307+50  
Personnel: YKC, CM, RKS  
Time: 10:40 AM  
Latitude: 42.61982  
Photographic Reference Numbers: 892 - 897  
Longitude: -72.47829

Left or Right Bank (Looking Downstream): Left

Previously Stabilized? No

Geologic / Geotechnical Observations:
- Stratigraphy:
  (Refer to Site Sketch below for locations of soil/rock layers
   Notations in parentheses are based on Unified Soil Classification System)
  
  Upper Bank: SANDY SILT (ML) – Low plasticity, approx. 10% - 20% fine sand, brown.
  Lower Bank: CLAYEY SILT (ML, MH) – Medium plasticity, <10% fine sand, very soft, gray.
  Lower Bank: Rock Toe – 2” - 4” riprap rock, localized.

Observed Erosion Features:
- Overhangs with leaning trees and exposed roots on slopes just below gravel road
- Fallen live trees at river level
- Vertical scarps just above rock toe.

Site Sketch:
Observation Point Number: 87(B)L  Date: September 25, 2014

Station Number: 307+50

Bank Vegetation:

*Top*: Heavy (>50%) cover – Broad leaved deciduous tree
   Tree (85%): ash*, gray birch, elm, black birch, hickory
   Shrub (5%): Japanese barberry*, multiflora rose
   Herbaceous (40%): ostrich fern, sensitive fern, garlic mustard, mixed Solidago spp., mixed asters, Jerusalem artichoke

*Face*: Moderate (25-50%) cover – Broad leaved deciduous tree
   Tree (40%): ash*, elm, gray birch
   Shrub (30%): multiflora rose*, elm, Japanese barberry, staghorn sumac, black birch sapling, alder, purple loosestrife, highbush blueberry, Spiraea angustifolia
   Herbaceous (70%): mixed grasses (inc. Phalaris arundinacea*, river rye), ostrich fern, milkweed, mixed goldenrods (Solidago spp.), mixed asters, swamp hempweed, mixed sedges (inc. Carex stricta), garlic mustard, Juncus effusus

*Toe*: Sparse – Broad leaved deciduous tree
   Tree (<5%): basswood (overhanging/fallen tree)

*Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
   Forested & light transportation (Pine Meadow Road)

Sensitive Receptor:
   No

Notes:

Just downstream from Shearer restoration site

Bank is very high and steep here with active erosion

Very little bittersweet here (~1%), but other invasives present, such as Japanese barberry, purple loosestrife, and multiflora rose
Photo No. 896
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 892 - 897
Location ID 87BL – September 25, 2014

Photo No. 897
Connecticut River – Turners Falls Impoundment Riverbank Detailed Site Assessments

Location ID: 75L

Date: September 25, 2014
Time: 11:05 AM
Station Number: 270+00
Latitude: 42.60946
Longitude: -72.48226

Personnel: YKC, CM, RKS
Photo Reference Numbers: 898 - 904

Left or Right Bank (Looking Downstream): Left
Previously Stabilized? No

Geologic / Geotechnical Observations:

**Stratigraphy:**
(Refer to Site Sketch below for locations of soil/rock layers
Notations in parentheses are based on Unified Soil Classification System)

Upper Bank, Lower slope: SAND (SP, SP-SM) – Fine sand, approx. 5% - 10% nonplastic fines, brown.
Lower Bank: GRAVELLY SAND (SW) – Fine to coarse sand, approx. 40% - 50% rounded gravel, <5% nonplastic fines
Lower Bank: Rock Toe – 2” – 8” rounded natural cobbles, hard, durable.

Observed Erosion Features:
- Very steep slope, entire Upper Bank.
- Near-vertical slope at river level, with some undercuts, leaning trees and exposed roots
- Local slumps and mass-wasting with bare slope, lower half of Upper Bank

Site Sketch:
Connecticut River – Turners Falls Impoundment Riverbank Classification for Land Based Survey

Observation Point Number: 75L       Date: September 25, 2014
Station Number: 270+00

Bank Vegetation:

Top: Heavy (90%) cover – Needle leaved coniferous tree
  Tree (90%): hemlock*, eastern white pine, red oak, white birch, black birch, black cherry
  Shrub (5%): hemlock saplings, black birch saplings, alder, ash
  Herbaceous (2%): Christmas fern, mosses

Face: Moderate (25-50%) cover – Needle leaved coniferous tall shrub/sapling
  Tree (<5%): hemlock*, eastern white pine, birch
  Shrub (35%): hemlock*, sumac, eastern white pine, birches, barberry, box elder, multiflora rose, honeysuckle
  Herbaceous (1%): Christmas fern, mixed grasses

Toe: none
  Natural round cobble/gravel at toe

* Dominant species in each vegetative strata is marked with an *

The dominant vegetative strata is the tallest strata with >30% cover

Adjacent Land Use:
  Forested further back from restoration site, & Agricultural (row crop – cow corn)

Sensitive Receptor:
  No

Notes:
  Data point ID 35 (12/12/2013) in same location (see that data in 2013 FRR Land Based Evaluation, data point #35)
  Very little bittersweet here (1%)
  Japanese barberry, multiflora rose & honeysuckle are present
Photo No. 900
2014 Connecticut River Detailed Site Assessments
Land-Based Survey Photographs Reference No. 898 - 904
Location ID 75L – September 25, 2014

Photo No. 902
APPENDIX E – CROSS-SECTION SURVEY PLOTS
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
TRANSECT 1

Elevation (ft, NGVD29)

Station (ft) Right Bank

OHWM 193.20 EL.

Appendix E-3
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-5
Transect 2

OHWM 191.55 EL.
Transect 2

OHWM 191.55 EL.
Transect 2

OHWM 191.55 EL.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 3

OHWM 190.12 EL.

Appendix E-10
Transect 3

OHWM 190.12 EL.

Station (ft) Left Bank
Elevation (ft, NGVD29)

Appendix E-11
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 4

OHWM 189.70 EL.
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-21
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-23
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-25
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 10

OHWM 188.3 EL.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-33
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-34
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-35
Appendix E-36
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-37
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-38
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 7

OHWM 187.74 EL.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 7

Elevation (ft, NGVD29)

Station (ft) Left Bank

OHWM 187.74 EL.
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Transect 8B

OHWM 187.20 EL.

Appendix E-44
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
TRANSECT 9

OHWM 183.70 EL.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-52
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-53
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix E-56
Transect BC-3

OHWM 183.70 EL.
Transect BC-5

OHWM 183.70 EL.

Elevation (ft, NGVD29)

Station (ft) Left Bank
APPENDIX F – BSTEM TECHNICAL BACKGROUND
Hydraulic Forces Applied to the Bank

The average boundary shear stress ($\tau_o$) acting on each node of the bank material is calculated using:

$$\tau_o = \gamma_w R S$$

(1)

where $\tau_o =$ average boundary shear stress (Pa), $\gamma_w =$ unit weight of water (9.81 kN/m$^3$), $R =$ local hydraulic radius (m) and $S =$ channel slope (m/m).

The average boundary shear stress exerted by the flow on each node of the bank profile is determined by dividing the flow area at a cross-section into segments. A line is generated that separates the bed- and bank-affected segments (starting at the base of the bank and extending to the water surface) at an angle equal to the average of the bank- and bank-toe angles (Figure F-1). The hydraulic radius ($R$) of the flow on each segment is the area of the segment ($A$) divided by the wetted perimeter of the segment ($P_n$). Thus the shear stress varies along the bank surface according to equation 1 as parameters comprising the segmented areas change.

![Figure F-1 Segmentation of local flow areas and hydraulic radii.](image)

The stress actually operating on the boundary (grains of bank material) is among other things, a function of flow resistance, which is a result of viscous and pressure drag over its wetted perimeter. For a vegetated channel, this drag may be conceptually divided into three components: 1) the sum of viscous drag on the ground surface and pressure drag on particles or aggregates small enough to be individually moved by the flow (grain roughness); 2) pressure drag associated with large non-vegetal boundary roughness (form roughness); and 3) drag on vegetal elements (vegetal roughness) (Temple et al., 1987). As energy lost to the flow represents work done by a force acting on the moving water, the total boundary shear stress may also be divided into three components:
\[ \tau_0 = \tau_{og} + \tau_{of} + \tau_{ov} \]  

(2)

where the subscripts \( g, f \) and \( v \) signify the grain, form and vegetal components of the boundary shear stress, respectively.

If it is assumed that these components may be expressed in terms of a Manning’s coefficient for each, and Manning’s equation is assumed to apply for each component, equation 8 can be rewritten as (Temple, 1980):

\[ n^2 = n_g^2 + n_f^2 + n_v^2 \]  

(3)

where \( n \) = Manning’s roughness coefficient (s m\(^{1/3}\)). Grain roughness is estimated for each node on the bank profile using the equation of Strickler (Chow, 1959):

\[ n_g = 0.045 \left( \frac{D_{50}}{16} \right) \]  

(4)

Combining equations 8 and 9, the effective boundary shear stress, the component of the boundary shear stress acting on the boundary in the absence of form and vegetal roughness, may be computed as:

\[ \tau_g = \tau_0 \left( \frac{n_g^2}{n^2} \right) \]  

(5)

An average erosion rate (in m/s) is computed for each node by utilizing an excess-shear stress approach (Partheniades, 1965). This rate is then integrated with respect to time to yield an average erosion distance in centimeters. Erosion is simulated to occur normal to the local bank angle, and not horizontally:

\[ E = k \Delta t \left( \tau_0 - \tau_c \right) \]  

(6)

where \( E \) = erosion distance (cm), \( k \) = erodibility coefficient (cm\(^3\)/N-s), \( \Delta t \) = time step (s), \( \tau_0 \) = average boundary shear stress (Pa), and \( \tau_c \) = critical shear stress (Pa).

The rate of erosion of bank-face, bank-toe and bed materials can then be calculated using equations 5 and 6 (Hanson, 1990). During the dynamic simulations described herein, the horizontal erosion distance during a timestep is computed by integrating the erosion rate within the timestep by the timestep size:

\[ E = \varepsilon \Delta t \]  

(7)

where \( E \) = erosion distance (m), and \( \Delta t \) = timestep (s).

**Resistance to Hydraulic Forces**

Resistance of bank-toe and bank-surface materials to erosion by hydraulic shear is handled differently for cohesive and non-cohesive materials. For cohesive materials the relation developed by Hanson and Simon (2001) using a submerged jet-test device (Hanson, 1990; 1991) is used:

\[ k = 0.2 \tau_c^{-0.5} \]  

(8)

The Shields (1936) criterion is used for resistance of non-cohesive materials as a function of roughness and particle size (weight), and is expressed in terms of a dimensionless critical shear stress:
where $\tau_\ast = \tau_0 / [(\rho_s - \rho_w) g D] \quad (9)$

**Resistance to Geotechnical Forces**

Soil shear strength varies with the moisture content of the bank and the elevation of the saturated zone in the bank mass. In the part of the streambank above the “normal” level of the groundwater table, bank materials are unsaturated, pores are filled with both water and air, and pore-water pressure is negative. The difference $(\mu_a - \mu_w)$ between the air pressure, $\mu_a$, and the water pressure in the pores, $\mu_w$, represents matric suction. The increase in shear strength due to an increase in matric suction $(\mu_a - \mu_w)$ is described by the angle $\phi'$. $\phi'$ varies for all soils and with moisture content for a given soil (Fredlund and Rahardjo, 1993), but generally takes a value between $10^\circ$ and $20^\circ$, with a maximum of the effective soil friction angle, $\phi'$, under saturated conditions (Fredlund and Rahardjo, 1993). The effect of matric suction on shear strength is reflected in the apparent cohesion ($c_a$) term, which incorporates both electro-chemical bonding within the soil matrix (described by the effective cohesion, $c'$) and cohesion due to surface tension on the air-water interface of the unsaturated soil:

$$c_a = c' + (\mu_a - \mu_w)\tan\phi' \quad (10)$$

where $c_a =$ apparent cohesion (kPa), $c' =$ effective cohesion (kPa), $\mu_a =$ pore-air pressure (kPa), $\mu_w =$ pore-water pressure, $(\mu_a - \mu_w) =$ matric suction (kPa) and $\phi'$ is the angle describing the increase in shear strength due to an increase in matric suction (degrees).

As can be seen from equation 1, negative pore-water pressures (positive matric suction) in the unsaturated zone provide for cohesion greater than the effective cohesion, and thus, greater shearing resistance. This is often manifest in steeper bank slopes than would be indicated by $\phi'$. Conversely, the wetter the bank and the higher the water table, the weaker the bank mass becomes and the more prone it is to failure. Accounting for the effects of friction, the shear strength of a soil, $\tau_s$, may thus be described by the Mohr-Coulomb shear strength criterion for unsaturated soils (Fredlund et al., 1978):

$$\tau_s = \frac{1}{F_s} \left[ c' + (\mu_a - \mu_w)\tan\phi' + (\sigma - \mu_a)\tan\phi' \right] \quad (11)$$

where $F_s =$ Factor of Safety, the ratio between the resisting and driving forces acting on a potential failure block, $\sigma =$ normal stress on the shear plane (kPa) and $\phi' =$ effective angle of internal friction (degrees).

While it is assumed that the pore-air pressure is atmospheric (i.e. $\mu_a = 0$), positive and negative pore-water pressures are calculated for the mid-point of each layer based on hydrostatic pressure above and below the water table so that:

$$\mu_w = \gamma_w h \quad (12)$$

where $\mu_w =$ pore-water pressure (kPa), $\gamma_w =$ unit weight of water (9.807 kN m$^{-3}$) and $h =$ head of water above the mid-point of the layer (m).
The geotechnical driving forces are controlled by bank height and slope, the unit weight of the soil and the mass of water within it, and the surcharge imposed by any objects on the bank top. The methods used to calculate the $F_s$ are horizontal layers (Simon and Curini, 1998; Simon et al., 2000), vertical slices for failures with a tension crack (Morgenstern and Price, 1965) and cantilever failures (Thorne and Tovey, 1981). For planar failures without a tension crack, the Factor of Safety ($F_s$) for both the saturated and unsaturated parts of the failure plane is given by the ratio of the resisting and driving forces (Simon and Curini, 1998; Simon et al., 1999; 2000):

$$F_s = \frac{\sum_{i=1}^{I} \left( c_i L_i + S_i \tan \phi''_i \right) \left[ W_i \cos \beta - U_i + P_i \cos(\alpha - \beta) \right] \tan \phi'}{\sum_{i=1}^{I} \left( W_i \sin \beta - P_i \sin(\alpha - \beta) \right)}$$

(13)

where $c_i'$ = effective cohesion of $i$th layer (kPa), $L_i$ = length of the failure plane incorporated within the $i$th layer (m), $S_i$ = force produced by matric suction on the unsaturated part of the failure surface (kN/m), $\phi''_i$ = angle representing the rate of increase in shear strength with increasing matric suction (°), $W_i$ = weight of the $i$th layer (kN), $U_i$ = the hydrostatic-uplift force on the saturated portion of the failure surface (kN/m), $P_i$ = the hydrostatic-confining force due to external water level (kN/m), $\beta$ = failure-plane angle (degrees from horizontal), $\alpha$ = bank angle (degrees from horizontal), $\phi'$ = angle of internal friction (°), and $I$ = the number of layers.

The hydrostatic confining force, $P_i$, is calculated from the area of the confining pressure ($\gamma_w h$) by:

$$P_i = \frac{\gamma_w h^2}{2}$$

(14)

where $h$ = head of water in the channel (m). The loss of the hydrostatic-confining force is the primary reason bank failures often occur after the peak flow and on the recessional limb of hydrographs.

The cantilever shear failure algorithm is a further development of the method employed by Langendoen, (2000). Put simply, the $F_s$ is the ratio of the shear strength of the soil to the weight of the cantilever. The inclusion of $\alpha$-terms in equation 24 ensures that if the bank is partially or totally submerged the weights of the layers affected by water are correctly reduced irrespective of the geometry of the basal surface of the overhang. The cantilever shear-failure algorithm results from inserting $\beta = 90^\circ$ into equation 13 and simplifying. $F_s$ is given by:

$$F_s = \frac{\sum_{i=1}^{I} \left[ c_i L_i + (\mu_w - \mu) L_i \tan \phi''_i + [P_i \sin \alpha - \mu_w L_i ] \tan \phi_i \right] }{\sum_{i=1}^{I} (W_i + P_i \cos \alpha)}$$

(15)

BSTEM-Dynamic can utilize the different failure algorithms depending on the geometry and conditions of the bank. Determining whether a failure is planar or cantilever is based on whether there is undercutting and then comparing the factor of safety values. The failure mode is automatically determined by the smaller of the two values. The model is easily adapted to incorporate the effects of geotextiles or other bank stabilization measures that affect soil strength. During a given time step, the model assumes hydrostatic conditions below the water table. Matric suction above the water table (negative pore-water pressure) is calculated by linear extrapolation.
Modeling Movement of the Groundwater Table

It is apparent from the above discussion that the elevation of the groundwater table is an important parameter controlling soil shear strength. For the purposes of this study, a simplified one-dimensional (1-D) groundwater model, based on the 1-D Richards Equation, was developed to simulate the motion of the groundwater table. This model assumes that the dominant pressure gradient within a streambank is the difference between the groundwater table elevation and the in-channel water surface elevation (i.e., it neglects the influence of infiltrating precipitation) (e.g., Langendoen, 2010). Assuming that water infiltrates either into or out of the bank along a horizontal plane of unit length and computing distance-weighted mean soil properties between these two elevations, the simplified equation can be written as:

$$\frac{\partial h}{\partial t} - K_r K_{sat} |h - z|^2 = 0$$  

(16)

where $h$ = groundwater elevation (m), $z$ is the water surface elevation (m), $t$ = time (s), and $K_r K_{sat} =$ relative permeability $\times$ saturated hydraulic conductivity. $K_r$ is evaluated as $K_r = \Theta^{1/2} \left[1 - \left(1 - \Theta^{1/n}\right)^{1/3} \right]$, where $\Theta$ = soil saturation and, following Gneuchten (1980), $\Theta$ is evaluated as:

$$\Theta = \Theta_r + \frac{\Theta_s - \Theta_r}{1 + \left(\frac{z - h}{\alpha}\right)^{1/2}}$$  

(17)

where the subscripts $r$ and $s$ denote the residual moisture content and saturated moisture content (= porosity), and $\alpha$ and $n$ are curve-fitting parameters defined by van Gneuchten (1980). Note that if $h \geq z$, $K_r = 1$. The user provides the initial groundwater elevation at the start of the simulation. This is usually set to the starting surface-water elevation. Default values by material type are provided for selection by the User on the Bank Material page of the model. Values of saturated hydraulic conductivity can also be used if available.

Modeling Root-Reinforcement

Waldron (1977) extended the Coulomb equation for root-permeated soils, by assuming that all roots extended vertically across a horizontal shearing zone, and that the roots act like laterally loaded piles, with tension transferred to them as the soil is sheared. In the Waldron (1977) model, the tension developed in the root as the soil is sheared is resolved into a tangential component resisting shear and a normal component increasing the confining pressure on the shear plane. $\Delta S$ can be represented by:

$$\Delta S = T_r \sin \theta + \cos \theta \tan \phi \left( \frac{A_R}{A} \right)$$  

(18)

where $T_r$ is the average tensile strength of roots per unit area of soil (kPa), $A_R/A$ is the root area ratio (dimensionless), and $\theta$ is the angle of shear distortion in the shear zone.

Gray (1974) reported that the angle of internal friction of the soil appeared to be affected little by the presence of roots. Sensitivity analyses carried out by Wu et al. (1979) showed that the value of the first angle term in equation 6 is fairly insensitive to normal variations in $\theta$ and $\phi$ (40-90°, and 25-40°, respectively) with values ranging from 1.0 to 1.3. A value of 1.2 was, therefore, selected by Wu et al. (1979) to replace the angle term and the simplified equation becomes:

$$\Delta S = 1.2 \ T_r \left( \frac{A_R}{A} \right)$$  

(19)
According to the simple perpendicular root model of Wu et al. (1979), the magnitude of reinforcement simply depends on the amount and strength of roots present in the soil. However, Pollen et al. (2004) and Pollen and Simon (2005), found that these perpendicular root models tend to overestimate root-reinforcement due to the inherent assumption that the full tensile strength of each root is mobilized during soil shearing, and that the roots all break simultaneously. This overestimation was largely corrected by Pollen and Simon (2005) by constructing a fiber-bundle model (RipRoot) to account for progressive breaking during mass failure. Validation of RipRoot versus the perpendicular model of Wu et al. (1979) was carried out by comparing results of root-permeated and non-root-permeated direct-shear tests. The direct-shear tests revealed that accuracy was improved by an order of magnitude by using RipRoot estimates (Pollen and Simon, 2005; Mickovski et al., 2009).

A further paper by Pollen (2007) investigated the forces required to pull out roots in a field study, and the RipRoot model was modified to account for both root-failure mechanisms. The addition of pullout forces allowed for estimations of spatial variability in root-reinforcement with changes in soil texture, and temporal changes with changes in soil water. In the RipRoot model currently embedded in BSTEM, a vegetation assemblage can be created by accessing the species database contained in the sub model; the user enters species, approximate vegetation ages, and approximate percent cover of each species at each site to estimate root density. This database includes tests performed across the United States and particularly along the Turner Falls reach of the Connecticut River. Root-reinforcement values are then calculated automatically using RipRoot’s progressive breaking algorithm.
APPENDIX G – BSTEM BOAT WAVE ALGORITHM TECHNICAL BACKGROUND
Introduction

Wave action can significantly contribute to bank erosion, increase suspended sediment concentration and turbidity, and induce streambank failure in navigable inland waterways. The most important sources of waves in these streams are wind generated and boat-generate waves. In relatively narrow waterways, short fetch lengths limit the size of the wind-generated waves; therefore, waves generated by moving vessels have a larger contribution to streambank erosion. Frequent passes of high-speed vessels in shallow waterways can create velocities much larger than the mean flow velocity. Measurement in Kenai River in Alaska showed that the energy at the bankline from boat waves alone is up to 59 percent of energy at the bankline from streamflow (Maynord, 2008). Due to the popularity of recreational vessels in recent years, boat induced wave erosion became a major concern (McConchie and Toleman, 2003).

The relative contribution of boat-generated waves to erosion depends on a large number of variables and complex shoreline dynamics which make it difficult to establish effective management strategies. Most management strategies lack a comprehensive procedure to quantify boat-generated wave erosion. The most common management approach is to control boat traffic by enforcing speed limits or with similar restrictions. Wake management criteria reported in the literature are based on restricting the maximum wave height and wave energy regardless of the bank geometry and material composition (Glamore, 2008). In addition to the wave characteristics, the erosion rate due to waves depends on the bank profile, bank material characteristics, vegetation cover, and sediments supply.

In this study, a new boat-wave module to calculate the added shear stress and its contribution to the erosion rate due to boat-generated waves was developed and integrated into the Bank Stability and Toe Erosion Model (BSTEM-Dynamic). Developed at the USDA-ARS National Sedimentation Laboratory, BSTEM-Dynamic is a deterministic bank stability model to calculate factor of safety for multilayer streambanks together with a toe erosion model that estimates hydraulic erosion of the bank using hydraulic shear stress (Simon et al. 1999 and 2000).

The boat-generated wave-erosion model for BSTEM-Dynamic is comprised of three main sub-modules:

1. The boat statistics module which calculates the wave properties such as maximum wave height, wave period, divergent wave angle etc. generated by given boat traffic, using available empirical procedures for boat-induced wave prediction.

2. The connectivity module, which handles the communication between the boat wave statistics and the dynamic bank stability and erosion calculations in BSTEM,

3. Shear-stress module, which estimates the wave-induced shear stress and its contribution to wave erosion.
Theoretical Background

A boat traveling across the water surface generates water-surface waves that propagate away from the bow. The waves are generated due to the pressure variations between the stern and the bow or boat. The wave pattern consists of symmetrical pairs of divergent waves traveling obliquely out from the sailing line and transverse waves traveling in the direction of the sailing line. The wave train develops as the waves spread out until distinct individual waves are formed. The period of these waves stay constant while their height decrease (attenuate) as they travel away from the bow. Wave period, and direction of divergent wave propagation depend only on the relative vessel speed and water depth whereas wave height is a function of several parameters including the velocity of the flow relative to the vessel, shape of the boat, distance of the boat from the shoreline, channel width and water depth. Hence, even though wave period and direction of wave propagation can be estimated using analytical methods, empirical relations are often needed for wave height estimation.

As the boat moves across the water surface, it pushes the water along its path (sailing line) and creates a pressure rise around the bow. The water level also rises near the bow due to this pressure increase. Deflected water accelerates around the mid-section, reducing the pressure and the water level, and decelerates back at the stern. The pressure rise at the stern is less than the bow due to the flow separation. A wave system is created during this interaction between the boat and water, which can be divided into two components: primary and secondary waves. Primary wave (drawdown) is the single standing wave (relative to the ship) between the bow and the stern (Figure 1). Therefore, the wavelength of the primary wave is in the order of ship length independent of boat speed (Bertram, 2000). The pressure variation between the stern and the bow also causes sinking and trim (Sorensen, 1997). The impact of primary waves on the banks depends on the ratio of the boat cross-sectional area perpendicular to the sailing line, to the river flow cross-sectional area. Primary waves can be neglected for small values of this ratio (Goransson et al., 2013).

Secondary waves are caused by the disturbances due to the acceleration of the water around the ship (Bertram, 2000). Figure 2 shows the schematics of the secondary waves system in deep water (wave orbital velocities are negligible). Two sets of waves (divergent waves) move out from the sailing line on both sides with an angle \( \theta \), and a set of waves (transverse waves) move along the sailing line. The interaction of divergent and transverse waves form a line of maximum wave heights, called cups, which extends on each side of the sailing line at an angle of \( \beta \). In deep water \( \beta = 19.5^\circ \). \( \theta \) is a function of depth Froude number and \( \theta = 35.3^\circ \) for deep conditions. Both sets of waves attenuate as they travel away from the boat.
Theoretically, divergent waves attenuate at a rate inversely proportional to the square root of the distance, while transverse waves attenuate at a rate inversely proportional to the cubic root of the distance. Therefore, divergent wave prevail at longer distances (Sorensen, 1997). Inside the cups locus lines, the divergent and transverse waves are out of phase, which results in relatively smaller wave heights.

A typical water surface displacement time series for deep-water waves is illustrated in Figure 3. The wave record measured at point A in deep-water in Figure 2 would look like the plot on Figure 3. The wave record contains small height a long period followed by larger waves of shorter period, which gradually decays to smaller waves. The wave signature of a boat passage is most commonly characterized by the maximum wave height. All wave height prediction models considered here use maximum wave height.
Figure 3. Typical boat generated wave record in deep water.

The generated boat waves can be characterized by their wave height, $H$, wave period, $T$, and the angle they propagate, $\theta$. The most significant parameters involved in boat-wave generation can be listed as follows (Figure 4):

**Boat geometry and dynamics:**
- Boat length, $L_B$
- Entrance length, $L_E$
- Boat width, $B$
- Boat draft, $Z_d$
- Displaced volume, $W$
- Boat speed, $V_B$
- Relative boat speed ($V_B - V_C$, $V_C$ is the current velocity)
- Hull design

**Channel geometry and flow properties:**
- Local water depth, $h$
- Channel width, $w$
- Distance from the sailing line, $x$
- Current velocity, $V_C$
Relative importance of these parameters in terms of wave generation can be characterized by some non-dimensional numbers. Under wave train, water particle velocities decay exponentially with depth. Practically, the wave effect is not felt at the bottom if the water is deeper than half of the wavelength, which is described as ‘deep-water’ conditions. Two different Froude numbers are used to characterize the secondary wave pattern depending on weather it’s deep-water or shallow-water waves. In deep-water, a length based Froude number is defined as:

\[ F_L = \frac{V_{BC}}{\sqrt{gL}} \]  

(1)

Depth Froude number is defined as

\[ F_h = \frac{V_{BC}}{\sqrt{gh}} \]  

(2)

For small values of depth Froude numbers deep water conditions prevail and for larger values shallow water condition dominate. When \( F_d < 0.7 \), the waves no longer feel the bottom and divergent and transverse waves can be clearly seen (Figure 5a). Divergent wave angle is, \( \theta = 35.3^\circ \). This is referred as subcritical speeds. As the \( F_d \) increases, the wave heights increase, the waves become more pronounced, and divergent wave angle decreases. The range of \( 0.7 > F_d > 1 \) is achieved at trans-critical speeds. Since transverse waves are longer, they feel the bottom quicker and their wave heights increase faster. At \( F_d = 1 \), divergent wave angle, \( \theta = 0 \) and cups locus angle \( \beta = 90^\circ \). In restricted channels the wave height can increases more due to diffraction (Sorensen, 1997). The divergent and transverse waves overlap and travel along the sailing line increasing the overall wave height. At Froude numbers equal to unity, another set of waves called solitons can be generated traveling ahead of the boat (Ertekin, 1986). When, \( F_d > 1 \) transverse wave no more exist, divergent wave heights are reduced and their angle depend only on Froude number, \( F_h \). The wave pattern behind the boat becomes more slender, consisting curved lines of divergent waves (Figure 5b). This is called supercritical speeds.

Another Froude scale, Volume Froude number is defined as

\[ F_W = \frac{V_{BC}}{\sqrt{gW^{1/3}}} \]  

(3)

Appendix G-6
Volume Froude number is useful in charactering planing and semi-planing boats (Maynord, 2005, in Tan 2012).

The wave pattern behind the boat does not change with respect to a moving observer with the boat; hence, divergent wave celerity depends on the relative boat speed in the direction of wave propagation.

\[ C = V_{bc} \cos \theta \]  

(4)

Celerity is defined as

\[ C = \frac{L}{T} \]  

(5)

where, \( L \) is the wave length. The relationship between the wave period and the wave length is governed by the dispersion relationship which is defined by:

\[ F_d < 0.7 \text{ Subcritical} \]

\[ F_d > 1 \text{ Supercritical} \]

Figure 5. Secondary wave system for subcritical and supercritical flows.
\[ \sigma = gk \tanh(kh) \]  

(6)

where, wave number \( k \) and wave angular frequency \( \sigma \) are defined as:

\[ k = \frac{2\pi}{L} \quad \text{and} \quad \sigma = \frac{2\pi}{T} \]  

(7)

therefore

\[ C^2 = g \frac{gL}{2} \tanh \left( \frac{2h}{L} \right) \]  

(8)

Eq. 8 can be solved iteratively for \( L \) and \( T \) using Eq. 5. Note that wave period \( T \) (and wave length \( L \)), and divergent wave angle, \( \theta \), depends only on depth Froude number, \( F_h \), which is a function of relative boat speed, \( V_{BA} \) and local water depth, \( h \); therefore, can be calculated analytically if these parameters are known.

Combining Eq. 2, Eq. 4 and Eq. 5, divergent wave angle can be calculated for deep water condition as:

\[ \theta = 35.2667 \left( 1 - e^{12(F_h-1)} \right) \text{ for } F_h < 1 \]  

(9)

For shallow water conditions,

\[ \theta = \frac{\pi}{2} - \arcsin \left( \frac{1}{F_h} \right) \text{ for } F_h > 1 \]  

(10)

These two functions are plotted in Figure 5 for a range of Froude numbers. In Figure 6, the measured water surface displacements at a fixed location at 2-3 m depth are shown. The wave trains in these plots are quite differed for supercritical and subcritical speeds. Since transverse waves don’t exist at supercritical speeds, cups disappear and the wave signal becomes smoother.
Figure 5. Diverging wave angle as a function of depth Froude number.

Figure 6. (a) Time series of measured surface elevation in shallow water. Left panel shows the wake wash caused by a high-speed-craft (HSC) operating in the supercritical speed range and the right panel for a transcritical speed. The water depth and distance to the navigation track are 2.4 m and 1500 m (left panel) and 3.2 m and 1100 m (right panel). (b) maximum wave height as a function of depth Froude number (Johnson, 1958).

Waves attenuate as they travel away from the sailing line due to diffraction and spreading. Due to the dispersion nature of progressive waves, longer waves travel faster and separate from the wave train at longer distances. As a result of this, the wave train spread out further from the sailing line. Havelock (1908),
showed that wave heights at cups points decay at a rate inversely proportional to the cubic root of the distance from the sailing line, $x$; whereas transverse waves decay at a faster rate which is inversely proportional to the square of the distance. Therefore the waves at the cups locus lines, which are predominantly divergent waves, can travel longer distances than transverse waves. For divergent waves:

$$H = x^{-\frac{1}{3}} \quad (11)$$

and for transverse waves:

$$H = \gamma x^{-\frac{1}{2}} \quad (12)$$

In Figure 6 maximum wave height is plotted against the perpendicular distance from the sailing line (water depth ranging between 10-30 m). Figure 6 clearly shows the exponential decay. These exponents are most accurate at subcritical speeds. Previous research shows some deviation from these values (Macfarlane, 2012).

Figure 7. Maximum wave height of the long-periodic waves versus the distance from the ship track. The measured data have been based on various field campaigns involving catamarans only. The trend line (---) is given by $H_m 16r^{-0.55}$, where $r$ (in meters, $x$ in the current study) denotes the distance from the track. (Kirkegaard, 1998)

**Wave height prediction models**

The energy of the wave is related to the square of its wave height. The total energy per wave per unit width of the wave crest according to linear wave theory is

$$E = \frac{1}{8} gH^2 \quad (13)$$
Therefore, wave height is an important parameter in determining the impact of wave on the banks. Unfortunately, boat generated wave height depends on more parameters then the wave period and divergent wave angle. The most common parameter to characterize the wave package as illustrated in Figure 3 is the maximum wave height. Most of the empirical models as well as the available field and experimental data provide the maximum wave height. There has been attempts to characterize the wave package in terms of energy density but there is no widely accepted constrain on the length of the signal to be included in the analysis. The parameters that control the wave height can be listed as follows:

$$H_m = f (V_B, V_c, h, L_B, B, L_e, w, W, z_d, x, A, \ldots )$$ (14)

The estimation of wave height requires empirical equations. There are several wave height prediction models in the literature. Many of these models predict maximum wave height, $H_m$ using a subset or all of the parameters listed in Eq. 13. Note that the empirical wave height prediction models are valid only for the data sets that were used in the regression analysis in their derivations. Therefore, they are limited to the boat type and operation conditions the data represent. The models that are used in BSTEM-wave are listed in Table 1. The descriptions, formulations and the limitations of these methods are listed in the following section.

Sorensen and Weggel (1984) reviewed the available laboratory and filed data at the time on vessel generated, and using this data, they developed a ship wave height predictor model, in the form of a series of empirical equations. The model gives the maximum wave height as a function of the vessel speed and displacement volume, water depth, and distance from the sailing line. This is an interim model that can be used for wave height prediction, but it can be improved upon given improved vessel geometry information. Also, a method is needed to predict the diverging wave period and direction of propagation out from the sailing line (Weggel and Sorensen 1986). The model is valid between $0.2 < F_h < 0.8$.

The variables considered in the model are:

$$H_m = f(V_B, h, x, W, L_B, B, z_d)$$ \hspace{2cm} (15)

Using dimensional analysis the following dimensionless numbers are defined:

$$H_m^* = \frac{H_m}{W}$$

$$x^* = \frac{x}{W}$$

$$h^* = \frac{h}{W}$$

$$F_h = \frac{V_B}{\sqrt{gh}}$$ \hspace{2cm} (16)
Dimensionless wave height is defined as:

\[ H_m^* = \alpha(\chi^*)^n \] (17)

\[ \log \alpha = (a + b \log(d^*) + c \log(d^*)) \]

\[ a = -0.6 \frac{F_h}{F_h}, \quad b = 0.75 F_h^{-1.25}, \]

\[ c = 2.653 F_h - 1.95 \]

\[ n = \beta(\delta^*)^\delta \]

\[ \beta = -2.25 F_h^{-0.699} \quad 0.2 < F_h < 0.55 \]

\[ \beta = -0.342 \quad 0.55 < F_h < 0.8 \]

\[ \delta = -0.118 F_h^{-0.356} \quad 0.2 < F_h < 0.55 \]

\[ \delta = -0.146 \quad 0.55 < F_h < 0.8 \]


Blaauw et al. (1984) give an equation for predicting the vessel-generated maximum wave height at the bank of a canal, based on Delft Hydraulics Laboratory experiments. The data was collected for a small 18.5 ft long boat passing a wave gauge at various speeds and distances from the gauge. The water was deep enough for deep-water assumption. The maximum wave height is given as a function of the vessel speed, the water depth, and the distance from the sailing line to the bank:

\[ H_m = f(V_B, h, x, B, A) \] (18)

The equations are as follows:

\[ H_m = Ah \left( \frac{x - B/2}{h} \right)^{-0.33} F_h^{2.67} \] (19)

Values of the coefficient \( A \) for a loaded pushing unit, empty pushing unit, tugboat, conventional inland motor vessel are given in Blaauw et al. (1984).

Similar to the Blaauw et al. (1984) model, the maximum wave height is given as a function of the vessel speed, the water depth, and the distance from the sailing line to the bank. For relatively low vessel speeds, the two equations yield similar results, but for higher speeds the PIANC equation yields significantly higher results than the DHL equation (Sorensen, 1996).

\[ H_m = f(V_B, h, x, B, A) \]  

(20)

The equations are as follows:

\[ H_m = Ah \left( \frac{x - B/2}{h} \right)^{-0.33} F_h^4 \]  

(21)

Table 2. Coefficient \( A \) for Blaauw et al. (1984)

<table>
<thead>
<tr>
<th>Boat type</th>
<th>Coefficient ( A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional inland motor vessel</td>
<td>0.25</td>
</tr>
<tr>
<td>Empty pushing unit</td>
<td>0.35</td>
</tr>
<tr>
<td>Loaded pushing unit</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 3. Coefficient \( A \) for PIANC (1987)

<table>
<thead>
<tr>
<th>Boat type</th>
<th>Coefficient ( A )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tugs, patrol boats, loaded motor boats</td>
<td>1</td>
</tr>
<tr>
<td>Empty European barges</td>
<td>0.5</td>
</tr>
<tr>
<td>Empty motor boats</td>
<td>0.35</td>
</tr>
</tbody>
</table>


Bhowmik et al (1991) conducted 246 controlled runs using 12 different boats at different sites in the Illinois and Mississippi Rivers. The vessels ranged in length from 3.7 to 14.3 m and included a flat bottom johnboat, a pontoon, a tri-hull, and a variety of V-hulls. The 14.3-m-long cabin cruiser had the maximum draft of 0.76 m. The waves lasted for 6 to 40 seconds during the measurements. The wave heights were measured with a pair of wave gauges set at each of four distances from the sailing line. The results are presented in terms of an empirical equation relating the vessel-generated maximum wave height as a function of the vessel speed, draft, length, and the distance from the sailing line.

\[ H_m = f(V_B, h, x, L_B, z_d) \]  

(22)

The maximum wave height was formulated as:

\[ H_m = e^{4.996 V^{0.402} g^{-0.028} V_B^{-0.346} x^{-0.345} L_B^{0.56} z_d^{0.355}} \]  

(23)

Note that although vessel speeds for many of the tests resulted in \( F_h \) greater than 0.7 (many exceeded 1.0), the water depth was not found to be significant in the regression analysis to be included in the empirical equation (Sorensen, 1996).

Kriebel and Seelig (2005) modified the Sorensen and Weggel (1984) model by using a modified Froude number, $F^*$. The model is based on previous measurements of boat generated waves from 60 individual vessels and field data collected along the Chesapeake Bay using the USNA Yard Patrol Craft. Maximum wave height was estimated based on the hull geometry, ship block coefficient and bow entry length. The model is limited to $F_h < 1$ (Tan, 2012).

$$H_m = f (V_B, V_c, h, L_B, B, L_e, w, W, z_d, x)$$  \hspace{1cm} (24)

Kriebel and Seelig (2005) defined a modified Froude number as:

$$F_h^* = F_h \exp\left(\alpha \frac{z_d}{h}\right)$$  \hspace{1cm} (25)

where

$$\alpha = 2.35(1 - C_B)$$  \hspace{1cm} (26)

and the block coefficient is

$$C_B = \frac{W}{L_B B z_d}$$  \hspace{1cm} (27)

The maximum wave height is given as:

$$H_m = \beta \frac{V^2}{g} \left( F_h - 0.1 \right)^3 \left( \frac{x}{L_B} \right)^{-1/3}$$  \hspace{1cm} (28)

In the above equation, $\beta$ is the hull form coefficient and defined by:

$$\beta = 1 + 8 \tanh^3 \left( 0.45 \left( \frac{L_B}{L_e} - 2 \right) \right)$$  \hspace{1cm} (29)

**Wave erosion and sediment transport**

In shallow water conditions, the orbital velocities of the waves near the bed become significant. The waves exert a shear force on the bed material. Wave related bed shear stress depends on the horizontal orbital velocity and the friction factor. The maximum horizontal velocity near the bed can be calculated based on linear wave theory:

$$\nabla$$
\[
U_w = \frac{\pi H_m}{T \sinh(kh)}
\]  

(30)

or, using Eq. 7:

\[
U_w = \sigma A_w
\]  

(31)

where the pea orbital excursion \(A_w\) is defined as

\[
A_w = \frac{H_m}{2 \sinh(kh)}
\]  

(32)

The peak bed shear stress is defined by:

\[
\tau_w = \frac{1}{2} \rho_w U_w^2
\]  

(33)

Note that, since \(U_w\) is oscillates, the bed shear stress also oscillates and changes direction. The friction factor in the \(f_w\) is assumed to be constant over the wave cycle (Rijn, 1993). The definition of the friction factor varies based on the flow conditions which can be characterized by the wave Reynolds number:

\[
\text{Re}_w = \frac{U_w h}{v}
\]  

(34)

The hydrodynamically smooth and rough conditions are defined by (Jonsson, 1966, 1980):

- Smooth turbulent flow: \(10^4 < \text{Re}_w < 10^6\) and \(A_w/k_s > 10^3\)
- Rough turbulent flow: \(10^5 < \text{Re}_w\) and \(A_w/k_s < 100\)

Note that only turbulent friction factor is used in this study.

where \(k_s\) is the roughness height and be approximately calculated using median grain diameter (Madsen et al., 1993):

\[
k_s = 15d_{50}
\]  

(35)

For smooth turbulent flow, the friction factor is defined as (Rijn, 1993):

\[
f_w = 0.9 \text{Re}_w^{-0.2}
\]  

(36)
For rough turbulent flows (Swart, 1976)

\[
 f_{wr} = \exp\left(-6 + 5.2 \left(\frac{A_w}{k_s}\right)^{-0.19}\right)
\] (37)

In the existence of both current and the waves, the total bed shear stress \( \bar{\tau}_T \) has two components: the oscillating wave related bed shear stress \( \bar{\tau}_w \), and flow current related bed shear stress \( \bar{\tau}_c \). Therefore, total shear stress is also time dependent and oscillates in a wave cycle. Neglecting the nonlinearities due to turbulence (Soulsby and Clarke, 2005), at any time, \( t \) the total bed shear stress is given by the vector sum of the two:

\[
 \bar{\tau}_T(t) = \bar{\tau}_c + \bar{\tau}_w(t)
\] (38)

The vector summation of the shear stress components is illustrated in Figure 8. Using sinusoidal assumption, maximum, root-mean-square and mean shear stresses defined as:

\[
 \tau_{max} = \sqrt{(\tau_c + \tau_w \cos \theta)^2 + (\tau_w \sin \theta)^2}
\] (39)

\[
 \tau_{rms} = \sqrt{2 + \frac{1}{2} \tau_w^2}
\] (40)

\[
 \tau_{mean} = \tau_c
\] (41)
Figure 8. Definition of the current and wave related bed shear stress components.
Implementation into BSTEM and programming

The new boat-wave module implemented in BSTEM calculates boat wave properties based on a boat passage table, and using the calculated wave properties, estimates the added shear stress and its contribution to the erosion rate.

The boat-generated wave erosion model consists of three main sub-modules as formerly described:

1. **The boat statistics module**: Calculates the wave properties ($H_m$, $T$, $\theta$) for each boat passage for a given boat traffic, using an available five empirical models described in the previous section. The boat statistics module also includes a sub-module to calculate the local water depth and average flow velocity for a given cross-section, energy slope.

2. **Connectivity module**: Generates the pointer array that links the boat traffic data to the flow time series. These pointer arrays enable two-way communication between BSTEM and BSTEM-wave.

3. **Shear-stress module**: Using the boat wave properties calculated by the boat statistics module, the estimates the wave-induced shear stress and its contribution wave erosion.

The subroutines of the modules described above are listed in Table 4. A flowchart is presented in Figure 8 to summarize the integration map for BSTEM-wave.

<table>
<thead>
<tr>
<th>Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ReadWaveData</td>
<td>Reads the boat passage data in the ‘Boat Waves’ worksheet and calculates the generated wave properties</td>
</tr>
<tr>
<td>BoatTimeConnect</td>
<td>Generates two connectivity arrays using the Date/time column in the ‘Boat Waves’ input worksheet and the flow Date/time in the ‘calculations’ worksheet</td>
</tr>
<tr>
<td>SailingLineHydro</td>
<td>Calculates the local water depth at the sailing line, and average flow velocity based on cross-section and stage data, calculation are done for each boat passage</td>
</tr>
<tr>
<td>waveCalculations</td>
<td>Calculates the wave properties for a given boat passage</td>
</tr>
<tr>
<td>WaveShearStress</td>
<td>Calculates the bed shear stress due to waves at a given water depth</td>
</tr>
<tr>
<td>wlength</td>
<td>Calculates the wave length for a given wave period based on dispersion relationship</td>
</tr>
</tbody>
</table>
Figure 8. Definition of the current and wave related bed shear stress components
The wave height calculation method can be selected using the pull down menu as shown in Figure 9b. Only the necessary columns for the selected model are displayed in the boat traffic input table. If the local water depth and average flow velocity is not readily available, the user can activate the ‘sailingLineHyro’ subroutine to calculate these parameters. Cross-section coordinates are required for the calculation of the average velocity and local water depth, which must be entered in ‘Cross Section’ worksheet. The bank that is being calculated on the cross-section must be specified by user the ‘left bank- right bank’ pull down menu. Left bank is the bank to the left of the observer looking downstream. Boat traffic is inserted in the ‘Boat Waves’ worksheet in ascending order.

The wave model is activated by the ‘boat wave model’ checkbox in the ‘input geometry’ worksheet. If the wave model is activated, BSTEM model first reads the input bank geometry, bank material properties and flow time series, and then executes the ‘ReadWaveData’ to read the entire boat traffic table in the ‘Boat Waves’ worksheet (Figure 8).

Before the program loops in time, the connectivity between the boat wave statistics and the flow time series is calculated. The connectivity module links the boat passages to each flow time step assuming the flow time step $\Delta t$ is much larger than boat time step $\Delta t_b$. If there no boat passages at a given time step, then the model skips the boat wave shear stress calculation. On the other hand, if multiple boats pass at a given time step, the wave shear stress is calculated for each boat passage, total boat wave induced erosion is calculated and added on top of the on top of the flow erosion. The connectivity is illustrated in the schematic diagram in Figure 10.

The total shear stress is the vector sum of the wave shear stress and the flow shear stress. Whenever the boat wave shear stress calculation is active, both $\tau_w$ and $\tau_c$ are calculated at every bank node, and added using to the relations given in the previous section. A typical continuous distribution of $\tilde{\tau}_w$ and $\tilde{\tau}_c$ is shown in Figure 11. Note that wave shear is maximum close to the surface whereas flow shear maximizes near the bed. For the erosion rate calculation, wave shear stress is applied for $8T_j$, where $T_j$ is the wave period of the $j^{th}$ boat wave in the current time step.

Upon completion of the simulation, the wave properties and wave shear stress parameter are written in the ‘boat waves’ worksheet. A list of output parameters and their definitions can be found in Table 5.
Figure 10. Schematic description of the connectivity between flow time series and boat passage data.

Figure 11. Wave and flow shear stress distributions on the bank.
### Table 5. Wave and flow shear stress distributions on the bank.

<table>
<thead>
<tr>
<th>Output parameter</th>
<th>Unit</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave period, $T$</td>
<td>(s)</td>
<td>The period of the divergent waves</td>
</tr>
<tr>
<td>Wave length, $L$</td>
<td>(m)</td>
<td>Wavelength near the boat</td>
</tr>
<tr>
<td>Maximum wave height, $H_n$</td>
<td>(m)</td>
<td>Maximum wave height at the bank (at a distance of $x$ from the sailing line)</td>
</tr>
<tr>
<td>Diverging wave angle, $\theta$</td>
<td>(deg)</td>
<td>The angle that the waves approach to the shore</td>
</tr>
<tr>
<td>Length Froude number, $F_L$</td>
<td>[-]</td>
<td>Length Froude number</td>
</tr>
<tr>
<td>Depth Froude number, $F_h$</td>
<td>[-]</td>
<td>Depth Froude number</td>
</tr>
<tr>
<td>Volume Froude number, $F_W$</td>
<td>[-]</td>
<td>Volume Froude number</td>
</tr>
<tr>
<td>Max. max. wave shear stress</td>
<td>Pa</td>
<td>The highest of the wave-induced shear stress amplitude along the bank nodes</td>
</tr>
<tr>
<td>Max. RMS wave shear stress</td>
<td>Pa</td>
<td>The highest of the rms wave-induced shear stress along the bank nodes</td>
</tr>
<tr>
<td>Flow shear at Max. wave shear stress</td>
<td>Pa</td>
<td>Corresponding flow shears stress at the Max. max. wave shear stress node.</td>
</tr>
<tr>
<td>Wave shear duration</td>
<td>s</td>
<td>Total time of application of the wave shear stress on the bank</td>
</tr>
<tr>
<td>Max flow shear stress (Pa)</td>
<td>Pa</td>
<td>Max. flow shear stress on the bank nodes</td>
</tr>
<tr>
<td>Total max wave momentum</td>
<td>kg/s</td>
<td>$M_{w\text{max}} = \sum_j \tau_{\text{max}}^j</td>
</tr>
<tr>
<td>Total rms wave momentum</td>
<td>kg/s</td>
<td>$M_{\text{w rms}} = \sum_j \tau_{\text{rms}}^j</td>
</tr>
<tr>
<td>Total flow momentum</td>
<td>kg/s</td>
<td>$M_c = \tau_c t</td>
</tr>
<tr>
<td>Total momentum</td>
<td>kg/s</td>
<td>$M_T = M_c + M_{\text{w rms}}$</td>
</tr>
</tbody>
</table>
Example solution

The model is tested for an artificial bank material properties and a boat passage data on a simple cross-section. In the example a single boat moved 9 times a day, every two hours from 8:00am. Sorensen and Weggel (1984) model was used for wave height prediction. The boat properties are shown in Table 6. The cross-section is plotted in Figure 12.

Bank material is selected as medium silt for all the layers. Simulations with different combinations of parameters were carried out: current only, wave only, current + wave with energy slope = 0.0005 – 0.001, boat speeds 4 m/s, 5 m/s and 6m/s. The flow elevation was 8 m and time step size was 1 day for all of the simulations.

Table 6. Boat properties.

<table>
<thead>
<tr>
<th>Local water depth</th>
<th>Distance to the shoreline</th>
<th>Length</th>
<th>Draft</th>
<th>Beam</th>
<th>Hull entrance length</th>
<th>Displaced volume</th>
<th>Hull type coeff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m)</td>
<td>(m)</td>
<td>(m)</td>
<td>(m)</td>
<td>(m)</td>
<td>(m)</td>
<td>(m³)</td>
<td>[-]</td>
</tr>
<tr>
<td>6.96</td>
<td>42</td>
<td>88</td>
<td>4.5</td>
<td>13</td>
<td>13</td>
<td>382</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Figure 12. Definition sketch of the example solution.

The results of the simulations are compared in Figures 13 through 17. Figure 13 compares 1-month-long simulations with energy slopes of 0.0005 and 0.01, and 2 months long simulation with an energy slope of 0.01. The purpose of these simulations was to test the normal operation of the updated BSTEM model. The boat wave algorithm is not activated in these simulations.
In order to isolate the boat wave algorithm, the energy slope is set to a very small value and the boat data in Table 6 is applied 9 passes a day for 2 months. The simulations were carried out at three different boat speeds 4 m/s, 5 m/s and 6 m/s. Figure 14 shows the comparison of the eroded profiles with waves. Also, in Table 7 the input and output wave properties are listed.

In Figure 15, both toe erosion and boat wave erosion algorithms are activated at $S_0 = 0.0005$. The undercutting boat by the wave and current actions can be seen clearly. No bank failure was observed for this case. When the energy slope is steeper in Figure 16, bank failure was observed for the 2-month period.

Finally, one and two month simulations with and without the boat wave model are plotted in Figure 17, the boat wave data was 1-month-long for all of the simulations in this plot. It can be seen in the figure that, bank retreat without the boat waves appears to be faster than the case with the waves. This counterintuitive result is can be explained as follows: wave erosion is highest close to the water surface, hence expected to be at a higher elevation compared to the toe erosion. Eroded material reduces the weight of the block, therefore increases factor of safety. Further research is needed to understand the physical basis of the phenomenon.

![Eroded bank profile without boat waves.](image-url)
Figure 14. Eroded bank profile with boat waves only.

Figure 15. Boat wave erosion and toe erosion at $S_0 = 0.0005$. 
Figure 16. Bank erosion for 1 month and 2 month simulation periods.

Figure 17. Comparison of failure profiles with and without boat waves.
Table 6. Simulations results

| Ground speed | Average flow velocity | Distance to the shoreline | Length | Draft | Beam | Hull entrance length | Displaced volume | Local water depth | Average flow velocity | Distance to the shoreline | Ground speed | Length | Draft | Beam | Hull entrance length | Displaced volume | Wave period | Wave length | Maximum wave height | Diverging wave angle | Length Froude number | Depth Froude number | Volume Froude number | Max. max wave shear stress | Max. RMS wave shear stress | Flow shear at Max. wave shear stress | Flow shear duration | Max flow shear stress (Pa) | Total max wave momentum | Total rms flow momentum | Total flow momentum |
|---------------|----------------------|---------------------------|--------|-------|------|----------------------|------------------|------------------|----------------------|------------------------|----------------|--------|-------|------|----------------------|------------------|-------------|-------------|---------------------|---------------------|----------------------|----------------------|----------------------|-----------------------|-----------------------|---------------------|---------------------|
| (m/s)         | m/s                  | (m)                       | (m)   | (m)   | (m)  | (m)                  | (m^3)            | (m)              | m/s                  | (m)                   | (m/s)         | (m)    | (m)   | (m)  | (m)                  | (m^3)            | (m)         | (m)         | (m)                 | (deg)               | [-]                  | [-]                    | [-]                  | Pa                    | Pa                   | kg/s                | kg/s                |
| 6             | 0.000413             | 43                        | 88    | 4.5   | 13   | 13                   | 382              | 6.96             | 0.000413             | 43                    | 6              | 88     | 4.5   | 13   | 13                   | 382              | 3.20        | 15.94       | 0.53                | 33.95                | 0.204                | 0.726                | 0.711                | 1567.96               | 1108.71              | 0.00                  | 25.62               | 0.18                  | 7401.15              | 5217.03              | 30.15                | 24.72               | 19.72                |
REFERENCES


SUPPLEMENTAL BOAT WAVE DATA 1997 & 2008

Boat wave data were collected by Simons & Associates in May and July 1997 and July 2008. In May 1997, data were collected at the Flagg site in the vicinity of Transect 6A; and in July 1997 data were collected just downstream of the Route 10 Bridge adjacent to Bennett Meadow. These data included video photography of boat waves with a staff gage and collection of suspended sediment samples. In July 2008, boat wave data were collected on the right bank in the vicinity of the Northfield Mountain tailrace. Data collection included video photography of boat waves.

These data were previously distributed to the stakeholders via email on March 31, 2015 and filed with FERC on May 26, 2015.
Comparison of Water Surfaces in Monitoring Wells with River Surface

- Well 3 (210 ft from river)
- Well 2 (65 ft from river)
- Well 1 (52 ft from river)
- River
Comparison of Water Surfaces in Monitoring Wells with River Surface

- Well 1 (210 ft from river)
- Well 2 (65 ft from river)
- Well 1 (92 ft from river)
- River

Water Surface Elevation (ft a.m.l.)

10 Aug 97 - 17 Aug 97

Appendix I-5
Comparison of Water Surfaces in Monitoring Wells with River Surface

[Graph showing water surface levels over time for different wells in relation to river levels, with a timeline from August 24 to September 7, 1997.]
Comparison of Water Surfaces in Monitoring Wells with River Surface


Water Surface Elevation (ft. a.m.s.l.)

Well 3 (210 ft. from river)
Well 2 (86 ft. from river)
Well 1 (62 ft. from river)
River

Appendix I-14
Comparison of Water Surfaces in Monitoring Wells with River Surface

Water Surface Elevation (ft. amsl)

178 179 180 181 182 183 184 185 186 187 188 189 190 191

15-Feb-98 16-Feb-98 17-Feb-98 19-Feb-98 20-Feb-98 21-Feb-98 22-Feb-98

Wells 1 (92 ft from river) Wells 2 (65 ft from river) Wells 3 (210 ft from river) River
APPENDIX J – ICE DATA AND SUPPLEMENTAL INFORMATION
APPENDIX J-1: TEMPERATURE DATA

Temperature data recorded at the Vernon, VT (1893-1998); Keene, NH (1893-2016); Hanover, NH (1884-2016); and Amherst, MA (1893-2016) monitoring stations is available upon request.

NOTE: Pictures taken before 12/15/2015 are numbered. Vantage points vary throughout the time pictures were taken prior to 12/15/2015. Pictures taken between 12/15/2015 and 3/8/2016 have consistent vantage points assigned with letters. Each letter indicates a vantage point that remains the same throughout time (i.e., picture A at Pauchaug Boat Launch on 12/15/2015 is the same location as picture A at Pauchaug Boat Launch on 1/5/2016).
Vernon Dam
1/29/2015

1. Upstream
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Vernon Dam
3/3/2015

1.

2.

3.

4.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Vernon Dam

12/15/2015

A.

B.

C.

D.
Vernon Dam
1/5/2016

A. No Picture

B.

C.

D.
Vernon Dam
1/14/2016

A. No Picture

B. 

C. 

D. 
Vernon Dam
1/21/2016

A. No Picture

B.

C.

D.
Vernon Dam
1/28/2016

A. No Picture

B.

C.

D.
Vernon Dam
2/11/2016

A. No Picture

B.

C.

D.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Vernon Dam
2/19/2016

A. No Picture

B.

C.

D.
Vernon Dam
3/8/2016

A. No Picture

B.  Image 1

C.  Image 2

D.  Image 3
Downstream of Vernon Dam (Eddy view)
1/29/2015

1. 

2. 

Appendix J-2
Downstream of Vernon Dam (Downstream end of Upper Island)

3/3/2015
Power Line Crossing Upstream of Stebbins Island
3/3/2015
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

5.

6.

7.

8.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

13.

14.

15.

16.
Midway between Upper Island and Stebbins Island (Downstream of Vernon Dam)
3/3/2015
Downstream Davenport Island
3/3/2015
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Ashuelot River near Hinsdale
3/3/2015

1.

2.

3.

4.
Ashuelot Confluence
12/15/2015
Ashuelot Confluence

1/5/2016 (Note: Locations changed after December 2015)
Ashuelot Confluence
1/14/2016

A.  

B. (east)

C. (west)

D.
Ashuelot Confluence
1/21/2016

A.

B. (east)

C. (west)

D.
Ashuelot Confluence
2/11/2016

A. 

B. (east) 

C. (west) 

D. 

Appendix J-2
Ashuelot Confluence
2/19/2016

A.

B. No Picture

C. No Picture

D.
Ashuelot Confluence

3/8/2016

A.

B. (east)

C. (west)

D.
Active Railroad Bridge (near Pauchaug Boat Launch)
3/3/2015

1.

2.

3.

4.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Pauchaug Boat Launch

1/5/2015

1. South

1/29/2015

1. Towards Schell Bridge

2. Upstream
Pauchaug Boat Launch
3/3/2015
Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Pauchaug Boat Launch
12/15/2015
Pauchaug Boat Launch

1/5/2016

A.  
B.  
C.  
D.
Pauchaug Boat Launch

1/14/2016

A. 

B. 

C. 

D. No Picture
Pauchaug Boat Launch
1/21/2016

A.

B.

C.

D.
Pauchaug Boat Launch
1/28/2016

A. 

B. 

C. 

D. No Picture
Pauchaug Boat Launch
2/11/2016
Pauchaug Boat Launch
2/19/2016

A.

B.

C.

D.
Pauchaug Boat Launch
3/8/2016

A.

B.

C.

D. No Picture
Between MA State Line and Pauchaug Boat Launch

3/3/2015
Just Downstream of MA State Line

3/3/2015
Upstream Route 10 Bridge
3/3/2015

1.  
2.  
3.  
4.  

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Route 10 Bridge
1/5/2015

1. (ne)

2. (se)

3. (sw)

4. (n)
1/29/2015

1. Upstream

2. Downstream
Route 10 Bridge

3/3/2015

1. 

2. 

3. 

4. 

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Route 10 Bridge
12/15/2015

A.

B.

C.

D.
Route 10 Bridge
1/5/2016
E. No Picture
Route 10 Bridge

1/14/2016

A. [Image]

B. [Image]

C. No Picture

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
Route 10 Bridge
1/21/2016

A.

B.

C.

D.
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E. No Picture

F. [Image of a river scene]
Route 10 Bridge
1/28/2016

A.

B.

C.

D.
Route 10 Bridge
2/11/2016

A. 

B. 

C. 

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Route 10 Bridge

2/19/2016

A.

B.

C.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E. No Picture

F. [Image of a river with ice]
Route 10 Bridge

3/8/2016
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E. No Picture

F. [Image of a riverbank]
Northfield Mountain Tailrace

1/5/2015

1. (NW)

1/29/2015

1. Upstream

2. Tailrace
Northfield Mountain Tailrace
2/25/2015
Northfield Mountain Tailrace

3/3/2015

1.

2.

3.

4.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

5.

6.

7.

8.
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Tailrace
12/15/2015
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E.  

F.  

G.  

Appendix J-2
Northfield Mountain Tailrace
1/5/2016

A. No Picture
B. No Picture

drainage area above Northfield Mountain Pumped Storage Project

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Northfield Mountain Tailrace
1/14/2016

A. No Picture

B.

C. No Picture

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Tailrace
1/21/2016

A.

B.

C.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E. No Picture

F. No Picture

G. No Picture
Northfield Mountain Tailrace
1/28/2016

A.  

B.  

C.  

D.
Northfield Mountain Tailrace
2/11/2016

A.

B.

C.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E.  

F.  

G.  

Appendix J-2
Northfield Mountain Tailrace
2/19/2016

A. 

B. 

C. 

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Northfield Mountain Tailrace

3/8/2016

A.

B.
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

D. No Picture

C.

E.

F.
French King Bridge
1/29/2015
French King Bridge
3/3/2015
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
French King Bridge

12/5/2015 – 1/21/2016
French King Bridge
Millers River Confluence
12/15/2015
Millers River Confluence

1/5/2016

A.

B.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Millers River Confluence
1/14/2016

A.

B.

C.
Millers River Confluence

1/21/2016

A. 

B. 

C.
Millers River Confluence
1/28/2016
Millers River Confluence

2/11/2016

A.

B.

C.
Millers River Confluence
2/19/2016

A.

B.

C.
Millers River Confluence

3/8/2016
Barton Cove

1/5/2015

1/29/2015

1.
2.
Upstream Turners Falls Dam
1/29/2015
Barton Cove

3/3/2015

A.  

B.  

C.  

D.  

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Turners Falls Dam

12/15/2015

A. 

B. 

C. 

D. 

Appendix J-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-2
Turners Falls Dam
1/5/2016

A.

B. No Picture

C.

D.
E. No Picture
Turners Falls Dam
1/14/2016
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
Turners Falls Dam
1/21/2016

A. 

B. 

C. No Picture

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Turners Falls Dam

1/28/2016

A. 

B. 

C. 

D. 

Appendix J-2
E. No Picture
Turners Falls Dam

2/11/2016

A.

B.

C.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E.
Turners Falls Dam

2/19/2016

A.

B.

C.

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

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

E.
Turners Falls Dam
3/8/2016

A.

B.

C.

D. No Picture
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY
APPENDIX J-3: LIST OF SCANNED DOCUMENTS FROM TRANSCANADA

TransCanada allowed access to review and scan files with ice information. The following list of individual file names and content are listed below:

20160229105422918.pdf  Vernon Dam 11/4/1927  High Water Book #55
20160229105505732.pdf  Vernon Dam
20160229105927758.pdf  Vernon Dam 11/6/1927
20160229110117022.pdf  Vernon Dam 11/7/1927
20160229110207358.pdf  Vernon Dam 11/5/1927  RR Line Erosion N Walpole
20160229110316112.pdf  N Walpole Flood and Erosion 11/5/1927
2016022911101104563.pdf  Conn R High Water Book #123-Ice by Liscomb Brook 1/35
20160229111104563.pdf  Erosion 11/23/1936 Bellows Falls (BF)
20160229111353344.pdf  1936-1939 Incl TFI and Bridges
20160229111511775.pdf  1938-1940 82000 CFS TFI
20160229111608606.pdf  1940 93000 and N Field
20160229111653870.pdf  TFI High Q 1940
20160229111835664.pdf  TFI 1939
20160229112100264.pdf  Conn R Book 158-Survey Pole 1927 and 1936 Flood Heights, Walpole
20160229112224526.pdf  Ice Photos 1942
20160229112323926.pdf  3/1942 Ice
20160229112410508.pdf  4/23/1942 Erosion Photos
20160229112453674.pdf  3 and 4/1942 Ice-Erosion
20160229112730250.pdf  1942 and 1943 Photos-Erosion ER
20160229112856407.pdf  March-June 1943 Ice and Erosion
20160229113021786.pdf  1939-1945 Some Ice, Erosion
20160229113123090.pdf  1945-1946 Ice, Flooding, Erosion
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<tr>
<th>Date</th>
<th>Description</th>
<th>Document ID</th>
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<tr>
<td>1946 and 1947</td>
<td>Erosion</td>
<td>20160229113316675.pdf</td>
</tr>
<tr>
<td>Book #299</td>
<td>Erosion</td>
<td>20160229113509995.pdf</td>
</tr>
<tr>
<td>1862 or 1869</td>
<td>Flood-Motes, Photos of places where houses washed away</td>
<td>20160229113709288.pdf</td>
</tr>
<tr>
<td>3/30/1913 RR Washout</td>
<td></td>
<td>20160229113838470.pdf</td>
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<tr>
<td>3/30/1913 RR Washout</td>
<td></td>
<td>20160229113921716.pdf</td>
</tr>
<tr>
<td>1915 Erosion-Farm</td>
<td>Vernon Dam, Ice 1915, Stockwell Farm</td>
<td>20160229114041975.pdf</td>
</tr>
<tr>
<td>3/3/1915 Ice, East</td>
<td>Putney</td>
<td>20160229114148231.pdf</td>
</tr>
<tr>
<td>Feb/March 1915</td>
<td>Ice, Putney, Demerston Ferry</td>
<td>20160229114235249.pdf</td>
</tr>
<tr>
<td>3/1-8/1915 Ice</td>
<td>Suspension Bridge, Matthews Barn</td>
<td>20160229114325357.pdf</td>
</tr>
<tr>
<td>2/28-3/1/1915</td>
<td>Ice, Matthews, Crowell Pumping Station</td>
<td>20160229114408623.pdf</td>
</tr>
<tr>
<td>2/28/1915 Ice</td>
<td>Asylum Meadow, West River</td>
<td>20160229114454627.pdf</td>
</tr>
<tr>
<td>2/28/1915 Ice</td>
<td>Brattleboro Damage to structures</td>
<td>20160229114632538.pdf</td>
</tr>
<tr>
<td>2/27-28/1915 Ice</td>
<td>Brattleboro</td>
<td>20160229114721709.pdf</td>
</tr>
<tr>
<td>Bank Erosion and</td>
<td>Ice</td>
<td>20160229115748717.pdf</td>
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<td>20160229120203566.pdf</td>
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<td>20160229120348824.pdf</td>
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Appendix J-3
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

20160229144939157.pdf  Ice measurements January 30, 1945
20160229145016656.pdf  Ice survey-Wells R to Wilder VT 1944, 1945- Graph
20160229145304468.pdf  January 4, 1945 Newspaper article re: Ice and Thaw
20160229145458618.pdf  River conditions, spring breakup March 17-25, 1945
20160229145809207.pdf  1945 Ice survey
20160229150123205.pdf  River conditions, spring breakup March 17-25, 1945
20160229152242735.pdf  Observations of March 1943 with photos
20160229154835640.pdf  1940 Ice survey Wells R – White R
20160229154916139.pdf  Ice measurements February 8-10, 1944
20160229154958592.pdf  Ice measurements February 8-10, 1944
20160229155138255.pdf  Ice measurements February 8-10, 1944 and March 14-17, 1944
20160229155232683.pdf  Ice measurements February 8-10, 1944 and March 14-17, 1944
20160229155353684.pdf  Spring breakup OBS 1944
20160229155518213.pdf  Spring breakup OBS 1944
20160301073455703.pdf  Trail Tampering Article re: 1936 and 1938 Flood damage and flies
20160301074145590.pdf  1940 Ice jam- maps and photos
20160301074906643.pdf  1940 Log of OBS
20160301075055202.pdf  River conditions u/s Whiter April 13, 1940
20160301075533461.pdf  Summary Inspection of Ice spring 1940
20160301080134738.pdf  Ice jams at Waterford April 10, 1941-maps and photos
20160301080946446.pdf  Field notes, March 1946
20160301081323525.pdf  Ice conditions January 7-12, 1946
20160301081658914.pdf  1946 Ice survey Wells R to Windsor VT
20160301081931315.pdf  1946 Ice map
20160301082038899.pdf  Ice measurements 1946
20160301083515697.pdf  Flood and ice report 1946
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix J-3

20160301084646101.pdf Notes of 1946 Spring runoff- notes on TFI
20160301084948876.pdf Report of January 1946 river and ice conditions January 7-13, 1946
20160301085402351.pdf Conn River ice March 1946
20160301090012441.pdf 1946 High water and ice March 15-18, 1946
20160301090028260.pdf High water OBS Spring 1946
20160301090625807.pdf 1946 High water OBS
201603010909848758.pdf April 23, 1946 Connect R Inspection Trip-comments on erosion
20160301091151433.pdf Q- USGS March 19, 1946
20160301091326041.pdf Ice map March 18, 1946
20160301091436580.pdf Ice map March 15, 1946
20160301091559541.pdf Newspaper March 11, 1946
20160301091852616.pdf Newspaper March 11, 1946
20160301092027183.pdf Newspaper March 11, 1946
20160301092237336.pdf Erosion photos
20160301092339399.pdf Erosion and ice scar photos
20160301092430587.pdf Erosion and ice scar photos
20160301092602381.pdf Erosion and ice scar photos
20160301092634823.pdf Erosion and ice scar photos April 23, 1946
20160301092727395.pdf Erosion and ice scar photos
20160301092907337.pdf Erosion and ice scar photos
20160301093002604.pdf Erosion and ice scar photos
20160301093052399.pdf Erosion and ice scar photos
20160301093142877.pdf Erosion and ice scar photos
20160301093237044.pdf Erosion and ice scar photos
20160301093324785.pdf Erosion and ice scar photos
20160301093350688.pdf Erosion and ice scar photos

Appendix J-3
20160301093433938.pdf Erosion and ice scar photos
20160301094047760.pdf 9/21/1938 Stricken Area
20160301094523267.pdf 9/24/1938 Newspaper-500 dead in flood
20160301094625111.pdf 9/24/1938 Newspaper-500 dead in flood
20160301095550532.pdf Ice breakup exp 1939
20160301095918614.pdf Ice breakup Hold harmless- history of ice jam floods 1936 and more
20160301100549570.pdf Ice breakup News release
20160301100900108.pdf CRREL Ice breakup paper
20160301101457855.pdf EA-Ice breakup-Fonsi
20160301101601499.pdf EA-Ice breakup-Fonsi
20160301102118200.pdf CRREL paper re: Ice breakup (mentions ice breakup 1936)
20160301102828840.pdf CRREL-options for management of dynamic breakup (historic info)
2016030110327188.pdf Ice out Windsor BR 3/16-17/1989 – photos
20160301103442262.pdf Ice exp March 1989 photos
20160301103903920.pdf CRREL ice test field notes March 1989
20160301104265111.pdf “A Study of Dynamic Ice Breakup” 1987
20160301105117632.pdf Bank erosion photos
20160301105402958.pdf Contract docs 1977 for USACE study
20160301106019731.pdf Newspaper article re: Corps erosion study – some discussion of ice
20160301106334857.pdf Newspaper article – some info on tree clearing – Northfield
2016030110630947.pdf Newspaper article on erosion
2016030110746388.pdf News article re: erosion – north field
2016030111854501.pdf Lake Champlain erosion study
2016030112746788.pdf Conn R stream bank erosion study 1947
2016030113043018.pdf Wilder erosion study 1974
2016030113538535.pdf Erosion photos – non impounded reach 1973
20160301113914177.pdf  News article 1975 erosion
20160301120636295.pdf  Bank erosion study NH, VT – USGS 1974
20160301120828271.pdf  Erosion maps (sites on USGS)
20160301120906892.pdf  Erosion sites on USGS map
20160301121051972.pdf  Erosion sites on USGS map
20160301121228722.pdf  Erosion sites on USGS map
20160301121340786.pdf  Erosion sites on USGS map
20160301121509906.pdf  Erosion sites on USGS map
20160301121538662.pdf  Erosion sites on USGS map
20160301121723089.pdf  Erosion sites on USGS map
20160301121743901.pdf  Erosion sites on USGS map
20160301125827778.pdf  1952 weather snow and ice info
20160301130549449.pdf  Ice measurements March 1958
20160301131629028.pdf  1952 Slide/RR
20160301132028550.pdf  1952 Ice survey Conn and White R (goes back to 1946)
20160301132908741.pdf  Conn River OBS- Wilder to BF 1952
20160301133334129.pdf  1951 Conn River OBS White R to BF
20160301133801375.pdf  1952 Ice survey
20160301133953805.pdf  Conn R high water and ice OBS
20160301134315936.pdf  Conn R OBS, BF Basin March 16-18, 1953
20160301134628934.pdf  1953 Ice survey Conn and White R's
20160301134736970.pdf  1953 Ice conditions – upper Wilder Pond
20160301134920483.pdf  Bellows Falls Pond ice conditions February 1953
20160301135028753.pdf  High water notes January 25-26, 1953 Windsor BF
20160301135146940.pdf  Wilder Pond OBS January 26, 1953

Appendix J-3
20160301135840581.pdf  High water at BF 2/23/1954
20160301140030302.pdf  OBS – upper Conn R 6/21/1954
20160301140631602.pdf  Upper Conn R ice conditions March 1954
20160301141519889.pdf  February 1954 – notes and OBS Conn River
20160301141636662.pdf  Conn R OBS March 1954
20160301141912553.pdf  1955 Ice survey Conn and White R
20160301142319573.pdf  1955 Ice survey Conn and White R
20160301142726085.pdf  Wilder high water OBS April 1955
20160301143141189.pdf  Conn R OBS bank inspection April 1955 (14th and 15th)
20160301143209911.pdf  Conn R OBS 4/7/1955
20160301143307898.pdf  Up river ice OBS 03/30/1955
20160301143540795.pdf  1955 Ice survey
20160301143844089.pdf  Ice measurements ABV Waterford BR 2/17/1955
20160301143941344.pdf  Conn R OBS 3/17/1955
20160301144211271.pdf  River OBS notes 1955
20160301145028887.pdf  1956 Ice survey Conn and White R's
20160301145203823.pdf  Conn R OBS 4/17/1956
20160301145533825.pdf  Bellows Falls and Vernon Spring high water OBS April-May 1956
20160301145717043.pdf  White R ice survey 1956
20160301150145370.pdf  1956 Ice survey Conn and White R
20160301150803413.pdf  OBS Ice formation, Moore-Wilder Winter 1956-1957
20160301150953277.pdf  1957 Ice survey Conn and White R
20160301151323111.pdf  4/4/1959 Ice photos
20160301151423896.pdf  4/4/1959 Ice photos
20160301151506762.pdf  4/5/1959 Ice photos
20160301151557382.pdf  4/5/1959 Ice photos

Appendix J-3
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

20160301151703222.pdf  4/1/1959 Conn R OBS
20160301151837647.pdf  April 3-7, 1959 Conn R OBS
20160301152153905.pdf  March 31-April 6, 1959 Conn R OBS
20160301152506664.pdf  Newspaper: Ice and water surge 3/12/1992
20160301152829969.pdf  Newspaper: Ice on Deerfield 1/31/1992
20160301153108445.pdf  Newspaper: Ice on Deerfield 1/26/1994
20160301154544626.pdf  Slope movement problems Windsor City, VT 1984
20160301154649750.pdf  Slope movement problems Windsor City, VT 1984
20160301155618495.pdf  Conn R bank survey
201603011555659934.pdf  Conn R bank survey April 1947 – Desc of erosion
20160301155738298.pdf  Conn R bank survey April 1947 – Desc of erosion
20160301155826865.pdf  Conn R bank survey May-June 1947 – Desc of erosion
20160301160050193.pdf  Conn R bank survey May-June 1947 – Desc of erosion
20160301160202780.pdf  Conn R bank survey May-June 1947 – Desc of erosion
20160301160610850.pdf  BF to White R 1947 Bank erosion survey
20160301160717676.pdf  BF to White R 1947 Bank erosion survey
20160301160832805.pdf  BF to White R 1947 Bank erosion survey
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20160301161238269.pdf  BF to White R 1947 Bank erosion survey
20160301161342125.pdf  BF to White R 1947 Bank erosion survey
20160301161438456.pdf  BF to White R 1947 Bank erosion survey
APPENDIX J-4: DOCUMENTATION OF THE ESTABLISHMENT AND GROWTH OF NEW RIPARIAN VEGETATION

Aerial photographs from 1929 to 1952 showed severely eroded areas in the upper TFI followed by increased riparian vegetation documented in the 2008-2010 aerial images and confirmed by the 1998, 2008 and 2013 FRRs in these same previously eroded areas of the river. The 2008 FRR presented several examples of the natural stabilization process in Appendix F of the 2008 FRR, which included this same location downstream of Vernon Dam as well as a large area of new aquatic vegetation on the lower riverbank at another location. The 2013 FRR discussed the ongoing recruitment of new vegetation on the lower riverbank and presented examples showing the increase in lower riverbank vegetation. A comparison of 2008 to 2013 showed an increase in lower riverbank vegetation from 5.1% in 2008 to 11.7% in 2013 (an increase of approximately 16,000 linear feet).

In previous years, observations of herbaceous and aquatic vegetation on the lower riverbank had been made. During recent visits in 2014 and 2015 for data collection at detailed study sites; observations were made of the fact that seeds, seedlings and saplings of woody vegetation have recently been establishing and growing on the lower riverbank at various locations along the TFI. Woody vegetation that has recently been observed in this establishment and growth phase from seeds, seedlings and saplings include maples and cottonwoods. The establishment of woody vegetation represents a new phase of natural stabilization that includes the type of root structure associated with trees rather than just herbaceous or aquatic vegetation that was observed in the 2008 and 2013 FRRs. The process of the recruitment of woody vegetation indicates that in recent years (2014 and 2015); trees have been recently established and are beginning to grow. Examples of this process and locations are provided.
Figure J-4.1 Maple seeds (photo 0202, 9/28/2015)

Figure J-4.2 Location of photo #0202
Figure J-4.3 Maple seedlings (photo 0203, 9/28/2015)

Figure J-4.4 Location of photo #0203
Figure J-4.5 Cottonwood seedlings (photo 0204, 9/28/2015)

Figure J-4.6 Location of photo #0204
Figure J-4.7 Cottonwood seedlings (photo 0206, 9/28/2015)

Figure J-4.8 Location of photo #0206
Figure J-4.9 Cottonwood seedlings (photo 6576, 7/15/2014)

Figure J-4.10 Location of photo #6576
Figure J-4.11 Lower riverbank vegetation (photo 6779, 7/17/2014)

Figure J-4.12 Location of photo #6779
Figure J-4.13 Lower riverbank vegetation with seedlings (photo 9203, 9/22/2014)

Figure J-4.14 Location of photo #9203
Figure J-4.15 Maple seedling (photo 9217, 9/22/2014)

Figure J-4.16 Location of photo #9217
Figure J-4.17 Maple seedling (photo 9218, 9/22/2014)

Figure J-4.18 Location of photo #9218
Figure J-4.19 Maple sapling (photo 9219, 9/22/2014)

Figure J-4.20 Location of photo #9219
Figure J-4.21 Lower riverbank vegetation with seedlings (photo 9297, 9/23/2014)

Figure J-4.22 Location of photo #9297
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Figure J-4.23 Cottonwood seedlings (photo 9298, 9/23/2014)

Figure J-4.24 Location of photo #9298
Figure J-4.27 Maple seedlings (photo 9300, 9/23/2014)

Figure J-4.28 Location of photo #9300
Figure J-4.29 Maple sapling (photo 9307, 9/23/2014)

Figure J-4.30 Location of photo #9307
APPENDIX K – ANNUAL HYDROGRAPHS AT MONTAGUE, MA (2000-2014)
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

2014

Average Daily Flow (cfs)

Date

1/1 2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1 12/1

2014 Average (2000-2014)
2013

Average Daily Flow (cfs)

Date

1/1 2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1 12/1

2013 Average (2000-2014)

Appendix K-2
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

2011

Average Daily Flow (cfs)

Date

1/1 2/1 3/1 4/1 5/1 6/1 7/1 8/1 9/1 10/1 11/1 12/1

2011 Average (2000-2014)
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

2008

Average Daily Flow (cfs)

Date

2008
Average (2000-2014)
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix K-8
STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

2005

Average Daily Flow (cfs)

Date

2005
Average (2000-2014)
2003

Average Daily Flow (cfs)

Date

2003

Average (2000-2014)
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

Appendix K-14
APPENDIX L – BSTEM INPUT DATA
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<th>f° (degrees)</th>
<th>Chemical concentration (kg/kg)</th>
<th>Hydraulic Conductivity k_s (m/s)</th>
<th>van Genuchten a (1/m)</th>
<th>van Genuchten n</th>
<th>τc (Pa)</th>
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*τc* *10 for exposed roots, c' added 6.2 due to roots, from d₅₀ of 0.1 mm * 10 for roots

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<th>Hydraulic Conductivity k_s (m/s)</th>
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*τc* *10 for exposed roots, c' added 6.2 due to roots, from d₅₀ of 0.1 mm * 10 for roots

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<th>van Genuchten n</th>
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Based on MJ4 and MJ1 and 2 and 2000 geometry

**Appendix L.1**
### 3R Pre Restoration

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<th>Layer Number</th>
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<th>Friction angle $f'$ (degrees)</th>
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<th>van Genuchten $a$ (1/m)</th>
<th>van Genuchten $n$</th>
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<th>$k$ (cm$^3$/Ns)</th>
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<th>Chemical concentration (kg/kg)</th>
<th>Hydraulic Conductivity $k_{sat}$ (m/s)</th>
<th>van Genuchten $a$ (1/m)</th>
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- $\tau_c\times10$ for exposed roots
- $\tau_c\times10$ for exposed roots, $c'$ added 5.2 due to roots

**Appendix L-2**
### Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

**STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY**

**Appendix L-3**

#### Layer Depth

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f^o$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|-------------------------------|--------------------|----------------------------------|----------------|-----------------------------|-------------------------------------|------------------------|----------------|---------------|--------------|----------------|-------------------------|----------|
| Layer 1      | 1.00        | 29.5                          | 0.0                | 18.0                             | 10.0          | 2.82E-05                    | 1.5073                              | 1.8413                 | 8.70           | 0.068         | 0.030        | avg MJ 6 & 7              | tc*10 for exposed roots |
| Layer 2      | 1.85        | 33.3                          | 0.0                | 18.0                             | 10.0          | 9.170E-05                   | 3.2066                              | 2.1662                 | 0.54           | 0.272         | 0.030        | avg MJ 1 and 6            |                      |
| Layer 3      | 3.58        | 33.7                          | 0.0                | 18.0                             | 10.0          | 9.170E-05                   | 3.2066                              | 2.1662                 | 0.80           | 0.223         | 0.030        | Avg MJ 3 and 4            |                      |
| Layer 4      | 1.07        | 33.7                          | 0.0                | 18.0                             | 10.0          | 9.170E-05                   | 3.2066                              | 2.1662                 | 0.71           | 0.237         | 0.030        | Avg MJ 1 and 6            |                      |

#### Material Descriptors

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f^o$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|-------------------------------|--------------------|----------------------------------|----------------|-----------------------------|-------------------------------------|------------------------|----------------|---------------|--------------|----------------|-------------------------|----------|
| Layer 1      | 5.12        | 33.2                          | 0.0                | 18.0                             | 10.0          | 9.150E-06                   | 0.6577                              | 1.6788                 | 0.44           | 0.291         | 0.060        | Avg MJ 3 & 4              |                      |
| Layer 2      | 2.32        | 33.2                          | 0.0                | 18.0                             | 10.0          | 9.150E-06                   | 0.6577                              | 1.6788                 | 0.44           | 3.198         | 0.016        | Avg MJ 3 & 4 + High k   |                      |
| Layer 3      | 2.55        | 33.2                          | 0.0                | 18.0                             | 10.0          | 9.150E-06                   | 0.6577                              | 1.6788                 | 0.44           | 2.000         | 0.016        | Avg MJ 3 & 4 since Restoration and assume sand sized material from upper tests | assume $d_{50}$=1 mm (1998) |
| Layer 4      | 1.22        | 29.5                          | 8.0                | 18.0                             | 10.0          | 9.150E-06                   | 0.6577                              | 1.6788                 | 0.71           | 0.237         | 0.040        |                      |                      |

**6AL Pre Restoration**
### Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

**STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY**

#### Appendix L-4

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**Material Descriptors**

- **Bank Model Input Data**
- **Groundwater Model Input Data**
- **Toe Model Input Data**
- **Roughness**

**Comments**

- Avg. MJ1 & 2
- Avg. MJ1 & 2
- Avg. MJ 3 & 4
- $d_{50}$ particle Count = 57.0 mm

---

**Layer Number**

**Layer Depth**

**Friction angle $f'$ (degrees)**

**Cohesion $c'$ (kPa)**

**Saturated unit weight (kN/m$^3$)**

**Layer Depth**

**Friction angle $f'$ (degrees)**

**Cohesion $c'$ (kPa)**

**Saturated unit weight (kN/m$^3$)**

**Hydraulic Conductivity $k_s$ (m/s)**

**van Genuchten $a$ (1/m)**

**van Genuchten $n$**

**$\tau_c$ (Pa)**

**$k$ (cm$^3$/Ns)**

**Manning n $s^{-1/3}$**

**d$_{50}$ particle Count = 57.0 mm**

---

**Layer 1**

**Layer Depth**

**Friction angle $f'$ (degrees)**

**Cohesion $c'$ (kPa)**

**Saturated unit weight (kN/m$^3$)**

**Layer Depth**

**Friction angle $f'$ (degrees)**

**Cohesion $c'$ (kPa)**

**Saturated unit weight (kN/m$^3$)**

**Hydraulic Conductivity $k_s$ (m/s)**

**van Genuchten $a$ (1/m)**

**van Genuchten $n$**

**$\tau_c$ (Pa)**

**$k$ (cm$^3$/Ns)**

**Manning n $s^{-1/3}$**

**Comments**

- Avg. MJ1 & 2
- Avg. MJ1 & 2
- Avg. MJ 3 & 4
- $d_{50}$ particle Count = 57.0 mm
## Study 3.1.2 Northfield Mountain / Turners Falls Operations Impacts on Existing Erosion and Potential Bank Instability

### Material Descriptors

| Layer Number | Layer Depth (m) | Friction angle f' (degrees) | Cohesion c' (kPa) | Saturated unit weight (kN/m³) | Chemical concentration (kg/kg) | Hydraulic Conductivity k_s (m/s) | van Genuchten a (1/m) | van Genuchten n | τc (Pa) | k (cm³/Ns) | Manning n (s/m¹/³) | Comments |
|--------------|----------------|----------------------------|-------------------|-----------------------------|-------------------------------|-------------------------------|----------------------------|----------------|---------|----------|----------------|----------------|----------|
| Layer 1      | 1.00           | 28.1                       | 6.1               | 18.0                        | 10.0                          | 2.82E-06                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 2      | 1.80           | 33.2                       | 3.2               | 18.0                        | 10.0                          | 2.82E-06                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 3      | 1.69           | 32.9                       | 14.4              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.810    | 0.016          | c' added 1.7 kPa for veg |
| Layer 4      | 1.37           | 32.9                       | 12.7              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.253    | 0.030          | Avg, MJ1 & 2    |

---

### 8R Pre Restoration

| Layer Number | Layer Depth (m) | Friction angle f' (degrees) | Cohesion c' (kPa) | Saturated unit weight (kN/m³) | Chemical concentration (kg/kg) | Hydraulic Conductivity k_s (m/s) | van Genuchten a (1/m) | van Genuchten n | τc (Pa) | k (cm³/Ns) | Manning n (s/m¹/³) | Comments |
|--------------|----------------|----------------------------|-------------------|-----------------------------|-------------------------------|-------------------------------|----------------------------|----------------|---------|----------|----------------|----------------|----------|
| Layer 1      | 1.00           | 28.1                       | 6.1               | 18.0                        | 10.0                          | 2.82E-06                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 2      | 1.80           | 33.7                       | 3.2               | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 3      | 1.69           | 32.9                       | 14.4              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.810    | 0.016          | c' added 1.7 kPa for veg |
| Layer 4      | 1.37           | 32.9                       | 12.7              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.253    | 0.030          | Avg, MJ1 & 2    |

---

### 8R Post Restoration

| Layer Number | Layer Depth (m) | Friction angle f' (degrees) | Cohesion c' (kPa) | Saturated unit weight (kN/m³) | Chemical concentration (kg/kg) | Hydraulic Conductivity k_s (m/s) | van Genuchten a (1/m) | van Genuchten n | τc (Pa) | k (cm³/Ns) | Manning n (s/m¹/³) | Comments |
|--------------|----------------|----------------------------|-------------------|-----------------------------|-------------------------------|-------------------------------|----------------------------|----------------|---------|----------|----------------|----------------|----------|
| Layer 1      | 1.00           | 28.1                       | 6.1               | 18.0                        | 10.0                          | 2.82E-06                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 2      | 1.80           | 33.7                       | 3.2               | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 2.380    | 0.016          | Avg, MJ1 & 2    |
| Layer 3      | 1.69           | 32.9                       | 14.4              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.810    | 0.016          | Avg, MJ1 & 2    |
| Layer 4      | 1.37           | 32.9                       | 12.7              | 18.0                        | 10.0                          | 2.82E-05                      | 1.5073                     | 1.8413          | 0.63    | 0.253    | 0.030          | Avg, MJ1 & 2    |
### 9R Pre Restoration

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f_b$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|------------------------------|--------------------|-------------------------------|---------------|--------------------------------|----------------------------------------|--------------------------|----------------|----------------|---------------|----------------|------------------------|----------|
| Layer 1      | 12.54       | 32.3                         | 3.9                | 18.0                          | 10.0          |                                | 9.174E-05                            | 3.2066                   | 2.1662         | 0.09           | 0.667         | 0.020                  | from PS sample (.12 mm) + Rip Root value of 3.9 for $c'$ |
| Layer 2      | 2.59        | 33.1                         | 3.6                | 18.0                          | 10.0          |                                | 9.174E-05                            | 3.2066                   | 2.1662         | 0.29           | 11.782        | 0.016                  | d$50 = 0.41 mm + Rip Root value of 3.6 for $c'$ |
| Layer 3      | 1.92        | 28.2                         | 18.3              | 18.0                          | 10.0          |                                | 9.150E-06                            | 1.6788                   | 2.0037         | 0.31           | 5.500         | 0.016                  | MJ average (new) + Rip Root value of 3.6 for $c'$ |
| Layer 4      | 1.47        | 28.2                         | 14.7              | 18.0                          | 10.0          |                                | 9.150E-06                            | 1.6788                   | 2.0037         | 0.21           | 3.500         | 0.035                  | $d_{50} = 0.30$ mm |

### 9R Post Restoration

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f_b$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|------------------------------|--------------------|-------------------------------|---------------|--------------------------------|----------------------------------------|--------------------------|----------------|----------------|---------------|----------------|------------------------|----------|
| Layer 1      | 12.54       | 32.3                         | 1.1                | 18.0                          | 10.0          |                                | 9.174E-05                            | 1.5073                   | 1.8413         | 3.47           | 0.581         | 0.016                  | from PS sample (12 mm) + Rip Root value of 3.9 for $c'$ |
| Layer 2      | 4.00        | 31.0                         | 1.1                | 18.0                          | 10.0          |                                | 9.174E-05                            | 1.5073                   | 1.8413         | 3.47           | 0.581         | 0.016                  | $d_{50} = 0.41$ mm + Rip Root value of 3.6 for $c'$ |
| Layer 3      | 3.03        | 25.6                         | 15.0              | 18.0                          | 10.0          |                                | 9.150E-06                            | 1.6788                   | 2.0037         | 14.45          | 1.000         | 0.016                  | MJ average (new) + Rip Root value of 3.6 for $c'$ |
| Layer 4      | 1.45        | 42.0                         | 15.0              | 20.0                          | 10.0          |                                | 9.150E-06                            | 1.6788                   | 2.0037         | 0.21           | 0.436         | 0.035                  | $d_{50} = 0.30$ mm |

### 10R Post Restoration

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f_b$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|------------------------------|--------------------|-------------------------------|---------------|--------------------------------|----------------------------------------|--------------------------|----------------|----------------|---------------|----------------|------------------------|----------|
| Layer 1      | 1.00        | 31.0                         | 1.1                | 18.0                          | 10.0          |                                | 2.823E-05                            | 1.5073                   | 1.8413         | 3.47           | 0.581         | 0.016                  | Avg. MJ 1 and 2 |
| Layer 2      | 4.00        | 31.0                         | 1.1                | 18.0                          | 10.0          |                                | 2.823E-05                            | 1.5073                   | 1.8413         | 3.47           | 0.581         | 0.016                  | Avg. MJ 1 and 2 |
| Layer 3      | 3.03        | 25.6                         | 15.0              | 18.0                          | 10.0          |                                | 2.823E-05                            | 1.5073                   | 1.8413         | 3.47           | 0.107         | 0.045                  | Avg. MJ 1 and 2 |
| Layer 4      | 1.45        | 42.0                         | 15.0              | 20.0                          | 10.0          |                                | 2.823E-05                            | 1.5073                   | 1.8413         | 57.35          | 0.026         | 0.045                  | Partial Count $d_{50} = 59$ mm |
### Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

#### STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f''$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|-------------------------------|--------------------|---------------------------------|----------------|-----------------------------|------------------------------------------|---------------------|----------------|-----------------|----------------|----------------------|------------------|----------|
| 11L          |             |                               |                    |                                 |                |                             |                                          |                     |                |                 |                |                      |                   |          |
| Layer 1      | 1.00        | 33.2                          | 0.4                | 18.0                            | 10.0           | -                           | 9.150E-06                               | 0.6577              | 1.6788          | 2.91            | 0.117           | 0.030                | MJ 3              |
| Layer 2      | 2.30        | 33.2                          | 4.4                | 18.0                            | 10.0           | -                           | 9.150E-06                               | 0.6577              | 1.6788          | 2.91            | 0.117           | 0.050                | MJ 3 + Rip Root value of 4.0 for $c'$ |
| Layer 3      | 4.41        | 31.8                          | 0.0                | 18.0                            | 10.0           | -                           | 9.150E-06                               | 0.6577              | 1.6788          | 2.91            | 0.117           | 0.045                | MJ 3              |
| Layer 4      | 0.50        | 31.8                          | 0.0                | 18.0                            | 10.0           | -                           | 9.150E-06                               | 0.6577              | 1.6788          | 2.91            | 0.117           | 0.045                | Avg. MJ1&2         |
| 12BL         |             |                               |                    |                                 |                |                             |                                          |                     |                |                 |                |                      |                   |          |
| Layer 1      | 1.00        | 25.4                          | 4.5                | 18.0                            | 10.0           | -                           | 1.411E-04                               | 4.0563              | 2.3286          | 0.08            | 0.707           | 0.050                | $d_{50} = 0.11$ mm |
| Layer 2      | 9.56        | 31.4                          | 4.7                | 18.0                            | 10.0           | -                           | 9.174E-05                               | 3.2066              | 2.1662          | 0.08            | 0.707           | 0.035                | $d_{50} = 0.11$ mm |
| Layer 3      | 4.15        | 29.2                          | 5.3                | 18.0                            | 10.0           | -                           | 1.411E-04                               | 4.0563              | 2.3286          | 0.08            | 6.500           | 0.016                | $d_{50} = 0.11$ mm |
| Layer 4      | 0.85        | 29.2                          | 5.3                | 18.0                            | 10.0           | -                           | 1.411E-04                               | 4.0563              | 2.3286          | 0.16            | 1.500           | 0.016                | $d_{50} = 0.23$ mm |
| 18L          |             |                               |                    |                                 |                |                             |                                          |                     |                |                 |                |                      |                   |          |
| Layer 1      | 1.00        | 31.0                          | 0.0                | 18.0                            | 10.0           | -                           | 2.823E-05                               | 1.5073              | 1.8413          | 2.13            | 0.137           | 0.050                | MJ 3              |
| Layer 2      | 3.02        | 31.0                          | 0.0                | 18.0                            | 10.0           | -                           | 2.823E-05                               | 1.5073              | 1.8413          | 2.13            | 0.137           | 0.050                | MJ 3              |
| Layer 3      | 2.00        | 31.0                          | 0.0                | 18.0                            | 10.0           | -                           | 2.823E-05                               | 1.5073              | 1.8413          | 10.24           | 0.063           | 0.020                | MJ 1&2            |
| Layer 4      | 1.05        | 31.0                          | 0.0                | 18.0                            | 10.0           | -                           | 2.823E-05                               | 1.5073              | 1.8413          | 0.71            | 0.270           | 0.030                | assume 1mm sand    |
### Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

#### STUDY 3.1.2 NORTHFIELD MOUNTAIN / TURNERS FALLS OPERATIONS IMPACTS ON EXISTING EROSION AND POTENTIAL BANK INSTABILITY

| Layer Number | Layer Depth | Friction angle $f'$ (degrees) | Cohesion $c'$ (kPa) | Saturated unit weight (kN/m$^3$) | $f_b$ (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity $k_{sat}$ (m/s) | van Genuchten $a$ (1/m) | van Genuchten $n$ | $\tau_c$ (Pa) | $k$ (cm$^3$/Ns) | Manning n (s/m$^{1/3}$) | Comments |
|--------------|-------------|-------------------------------|--------------------|----------------------------------|----------------|-------------------------------|----------------------------------------|-------------------|----------------|---------------|----------------|-------------------|----------------|----------|
| Layer 1      | 1.00        | 24.2                          | 18.4               | 18.0                             | 10.0           | -                             | 2.823E-05                              | 1.5073            | 1.8413         | 0.96          | 0.205         | 0.050            | MJ 3 & 4       |
| Layer 2      | 0.90        | 31.4                          | 0.0                | 18.0                             | 10.0           | -                             | 9.150E-06                              | 0.6577            | 1.6788         | 0.20          | 0.447         | 0.040            | d$_{50}$ = 0.1mm |
| Layer 3      | 5.77        | 35.4                          | 4.4                | 18.0                             | 10.0           | -                             | 9.174E-05                              | 3.2066            | 2.1662         | 0.03          | 1.212         | 0.050            | MJ 3 & 4       |
| Layer 4      | 0.87        | 35.4                          | 4.4                | 18.0                             | 10.0           | -                             | 9.174E-05                              | 3.2066            | 2.1662         | 0.30          | 0.365         | 0.050            | d$_{50}$ = 0.42 mm |

Appendix L-8
### Study 3.1.2 Northfield Mountain / Turners Falls Operations Impacts on Existing Erosion and Potential Bank Instability

#### Appendix L-9

| Layer Number | Layer Depth | Friction angle \( f' \) (degrees) | Cohesion \( c' \) (kPa) | Saturated unit weight (kN/m\(^3\)) | \( f_b \) (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity \( k_{sat} \) (m/s) | van Genuchten \( a \) (1/m) | van Genuchten \( n \) | \( \tau_c \) (Pa) | \( k \) (cm\(^3\)/Ns) | Manning n (s/m\(^{1/3}\)) | Comments |
|--------------|-------------|---------------------------------|----------------------|-------------------------------|-------------------|-----------------------------|-------------------------------|-----------------------------|----------------|--------------|----------------|-------------------|----------------|----------|
| 75BL         | Layer 1     | 1.00                            | 36.7                 | 1.9                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.11         | 0.603         | 0.050             | MI3                 |
|              | Layer 2     | 8.82                            | 36.7                 | 1.9                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.11         | 0.603         | 0.035             | MI3                 |
|              | Layer 3     | 9.04                            | 33.8                 | 0.0                           | 18.0              | 10.0                        | 2.823E-05                     | 1.5073                      | 1.8413        | 6.70         | 0.077         | 0.035             | MI2                 |
|              | Layer 4     | 0.92                            | 33.8                 | 0.0                           | 18.0              | 10.0                        | 2.823E-05                     | 1.5073                      | 1.8413        | 0.11         | 0.603         | 0.030             |                    |

Particle count: \( D_{50} = 28.5 \) mm.

Used \( SP = 0.16 \) mm based on field observations.

#### 87L

| Layer Number | Layer Depth | Friction angle \( f' \) (degrees) | Cohesion \( c' \) (kPa) | Saturated unit weight (kN/m\(^3\)) | \( f_b \) (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity \( k_{sat} \) (m/s) | van Genuchten \( a \) (1/m) | van Genuchten \( n \) | \( \tau_c \) (Pa) | \( k \) (cm\(^3\)/Ns) | Manning n (s/m\(^{1/3}\)) | Comments |
|--------------|-------------|---------------------------------|----------------------|-------------------------------|-------------------|-----------------------------|-------------------------------|-----------------------------|----------------|--------------|----------------|-------------------|----------------|----------|
|              | Layer 1     | 1.40                            | 33.1                 | 5.3                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.19         | 0.455         | 0.050             | MI3 & 4            |
|              | Layer 2     | 2.00                            | 27.5                 | 16.2                          | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.19         | 0.455         | 0.050             | MI3 & 4            |
|              | Layer 3     | 2.27                            | 27.5                 | 16.2                          | 18.0              | 10.0                        | 2.823E-05                     | 1.5073                      | 1.8413        | 0.19         | 0.455         | 0.050             | MI3 & 4            |
|              | Layer 4     | 0.53                            | 27.5                 | 16.2                          | 18.0              | 10.0                        | 2.823E-05                     | 1.5073                      | 1.8413        | 0.07         | 0.748         | 0.035             |                    |

#### 119BL

| Layer Number | Layer Depth | Friction angle \( f' \) (degrees) | Cohesion \( c' \) (kPa) | Saturated unit weight (kN/m\(^3\)) | \( f_b \) (degrees) | Chemical concentration (kg/kg) | Hydraulic Conductivity \( k_{sat} \) (m/s) | van Genuchten \( a \) (1/m) | van Genuchten \( n \) | \( \tau_c \) (Pa) | \( k \) (cm\(^3\)/Ns) | Manning n (s/m\(^{1/3}\)) | Comments |
|--------------|-------------|---------------------------------|----------------------|-------------------------------|-------------------|-----------------------------|-------------------------------|-----------------------------|----------------|--------------|----------------|-------------------|----------------|----------|
|              | Layer 1     | 1.00                            | 35.8                 | 0.0                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.52         | 0.277         | 0.050             |                    |          |
|              | Layer 2     | 1.60                            | 35.8                 | 0.0                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.52         | 0.277         | 0.040             |                    |          |
|              | Layer 3     | 4.91                            | 33.0                 | 2.8                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.52         | 0.277         | 0.060             |                    |          |
|              | Layer 4     | 1.15                            | 33.0                 | 2.8                           | 18.0              | 10.0                        | 9.150E-06                     | 0.6577                      | 1.6788        | 0.26         | 0.392         | 0.038             |                    |          |

\( \tau_c * 10 \) for exposed roots

Avg. MI 3&4

\( d_{50} = 0.068 mm \)
### 303BL Material Descriptors

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<th>Cohesion ( c' ) (kPa)</th>
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### BC1R Material Descriptors

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<td>BANK</td>
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<td>HEIGHT</td>
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