Characterizing Bank Erosion on the Upper Neversink River 2012 -2014

A study to support Stream Management Activities

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Conducted by the NYCDEP Stream Management Program
in cooperation with the
Rondout Neversink Stream Program,
a Project of the Sullivan County Soil and Water Conservation District

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INTRODUCTION

A stream feature inventory conducted in 2010 on the Upper Neversink River—the mainstems of the East and West Branches and the mainstem Neversink River from Claryville to the Neversink Reservoir—identified fifty-eight eroding banks comprising a total area of 289,396 ft^2 of erosional surface. Descriptions of these erosion sites, with management recommendations for each, were provided in the Upper Neversink River Stream Management Plan (http://catskillstreams.org/stream-management-program/sm-implementation-program/). In 2012 NYC DEP Stream Management Program used this information to begin a detailed Bank Erosion Monitoring Study in partnership with the Rondout Neversink Stream Management Program, and with the assistance of SUNY Ulster County Community College Watershed Conservation Corps interns. To prioritize banks of significance for management purposes, this study focused on banks larger than 1000 square feet of exposed surface area. Banks located on New York State land were eliminated from the study. Several erosion sites were also eliminated as a result of channel and bank responses to two historically large flows in 2011 and 2012. From 2012 to 2014, forty-seven banks were evaluated using the BANCS Method (Rosgen 2006) to produce a semi-quantitative characterization of bank erosion hazards. In addition to indexing erosion hazard risk, each site was also characterized in terms of management considerations related to threats to infrastructure, private structures, and water supply and ecosystem impacts from the loading of fine sediment. The results of this study will be used to prioritize restoration efforts undertaken in the coming years by the Rondout Neversink Stream Management Program in partnership with NYCDEP. Results may also be used to validate GIS-based models of erosion risk and sediment loading.

BACKGROUND

The East and West Branches of the Upper Neversink River flow from the higher elevations of the Catskill Mountains in Ulster County, New York. Each branch winds its way to their confluence with the mainstem just beyond the Sullivan County border and from there into the NYC Neversink Reservoir. In total, this accounts for 34 miles of (mainstem) stream, contained within a 71 square mile drainage basin. This watershed is an important part of the NYC DEP water supply, which provides unfiltered drinking water for nearly half the population of New York State. Currently, the primary pollutant of concern for drinking water in this watershed is fine sediment, mobilized by the stream from in situ geologic sources.

The Catskill Mountains were formed as an eroded plateau, with deep valleys carved by millions of years of stream erosion and repeated continental glacial advances into lithified river deposits, and then covered by surficial deposits left behind as the glaciers retreated. This geologic history has set the stage for the modern day condition of the Catskill Mountains and its streams. We now see bedrock geology consisting of sedimentary sandstones, shale, siltstones and some conglomerate, and it is not unusual to see extensive reaches of bedrock in Neversink basin streambeds and banks. The surficial geology comprises: glacial till (a generally unsorted mix of boulders, cobble, gravel, silt and clays) in the terraces that bound the stream courses, in some locations layered with more stratified outwash deposits of sand to cobble sized sediment; alluvial deposits of eroded till and outwash in the valley bottoms; and isolated exposures of lacustrine silt and clay deposits, occasionally observed at the margins of alluvial fans where larger tributaries enter a relatively flat valley floor created (historically) by downstream ice impoundments at topographic pinch points. Geology in the Neversink plays a crucial role in stream channel form and function, affecting the distribution of erosion hazards, bed and suspended sediment supply, and stream ecosystem processes. As such, it is a key consideration in the characterization of a bank erosion site.

The land use history in the Neversink basin is largely characterized by its tanneries and mills in the 19th century (Kudish 2000). While the industries that once dominated the area are no longer in operation, the effects are still seen on the landscape and in the streams: floodplains laced with relict raceways that served the mills, and which still channel overbank flows, and stone walls that enclosed valley bottom pastures and cultivated fields. The current land use classifications indicate that nearly 94% of the basin is forested, 5% is non-woody vegetation and recreation, and the remaining 1% land comprising roads, infrastructure and agriculture. While the basin is largely forested, and the valley floors relatively undeveloped, anthropogenic influences such as roads, bridges, berms and land clearing influence adjacent stream bank and channel stability, interrupting continuity of streamflow and sediment transport, in some locations creating unintended flowpaths for overbank flows.

For more detailed information on the Neversink basin, refer to the Upper Neversink Stream Management Plan at the link provided above.

METHODS

This study combined field and office GIS assessments and analyses to characterize bank form, materials and erodibility, channel morphology characteristics significant to hydraulic function, and proximate cultural features (public infrastructure and private structures) potentially at risk due to the bank erosion.

Field Assessments

The erosion sites documented in the 2010 stream feature inventory were first prioritized for further study based on the size of the erosional surface. Additional field surveys were conducted during 2012 and 2013 at forty-seven eroding banks, comprising a total of 199,952 ft^2, where the erosional exposure was larger than 1,000 ft^2 based on the 2010 stream feature inventory (Figure 1). Field data collection at these sites began in 2012, and was completed in 2014. Field data collection focused on developing metrics included in the Bank Erosion Hazard Index (BEHI), a semi-quantitative model developed by David Rosgen (1996) to index bank erodibility, and geomorphic characterization using Rosgen's "Level 2" stream classification system (1996). Channel morphology at the eroding bank plays a significant role in the future evolution of the erosion site. At each site the following data were collected:

1. Longitudinal profile, used to obtain the water surface slope for classification and shear stress calculation purposes;

2. Riffle cross-section, used to classify the morphology based on the bankfull width, mean bankfull depth, and entrenchment ratio, a measure of channel confinement;

3. Channel cross-section through the eroding bank, used in developing metrics included in the BEHI and Near Bank Stress (NBS) scoring, and as baseline for long-term monitoring of bank retreat rates;

4. Bankfull channel boundary particle size distribution, using a modified Wolman pebble count (Wolman 1954), to provide various statistics on the size distribution of particles on the surface of the bankfull channel bed, for classification and sediment transport analysis;

5. Pfankuch Channel Stability Rating (1975) assessment, to rank channel stability with a qualitative assessment of fifteen metrics describing reach-wide conditions;

6. Bank Erosion Hazard Index assessment, to provide a semi-quantitative index value for bank erodibility based on five metrics: ratio of bank height to bankfull height, ratio of rooting depth to bank height, rooting density, composition of bank materials, bank angle, bank material stratigraphy, and bank surface protection;

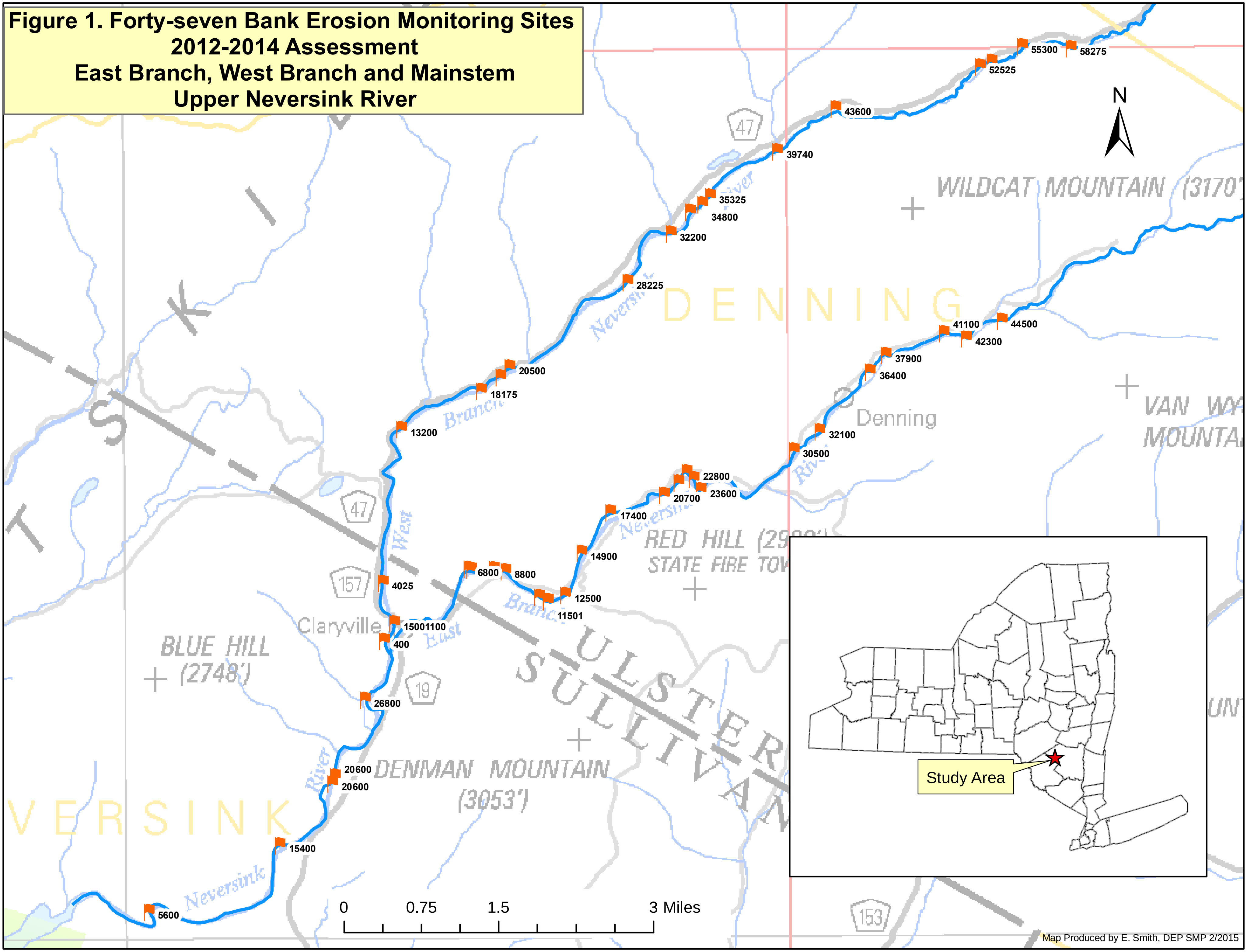


Figure 1. Forty-seven Bank Erosion Monitoring Sites 2012-2014 Assessment East Branch, West Branch and Mainstem Upper Neversink River

7. Presence/Absence of a significant volume of fine sediment (typically, glacially deposited clays and fine silts) in the visible surface of the eroding bank, which could degrade water quality for drinking water supply or in-stream habitat by increasing embeddedness in the channel substrate (this characterization was completed as part of the 2010 stream feature inventory);

8. Geospatial coordinates of the bank and control pins for the survey, collected with sub-meter resolution GPS, to support future replication and trends analysis;

9. Photodocumentation, to support future replication and trends analysis, and for quality control of BEHI characterization.

GIS-based Assessment and Data Management

As field data collection was completed, the data for each site were compiled using the software package, RiverMorph. This software supports management and analysis of survey data (cross-sections and longitudinal profiles), bed surface particle data and bank and channel characterization data. A feature of the software allows the user to generate morphometric stream variables calculated from the cross-section information provided. A screen shot (Figure 2 below) shows an example of a cross-section summary which includes the metrics used in the Rosgen Level 2 stream classification, including mean bankfull depth, floodprone width, bankfull width, and a calculated entrenchment ratio. In some instances NYC DEP 1M DEM data was used to supplement the cross-section beyond its field-surveyed bounds to obtain a more precise flood prone width and entrenchment ratio. Obtaining more precise flood prone width is particularly important as it affects the metrics generated in the RiverMorph reach summary table (Figure 3). Another of the classification criteria, bankfull water surface slope, is calculated by the software using the water surface elevations collected in the longitudinal profile survey (Figure 4).

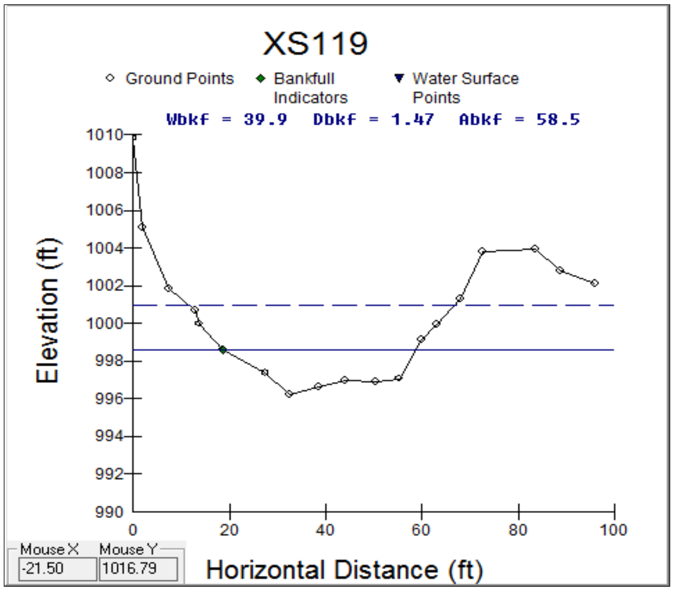
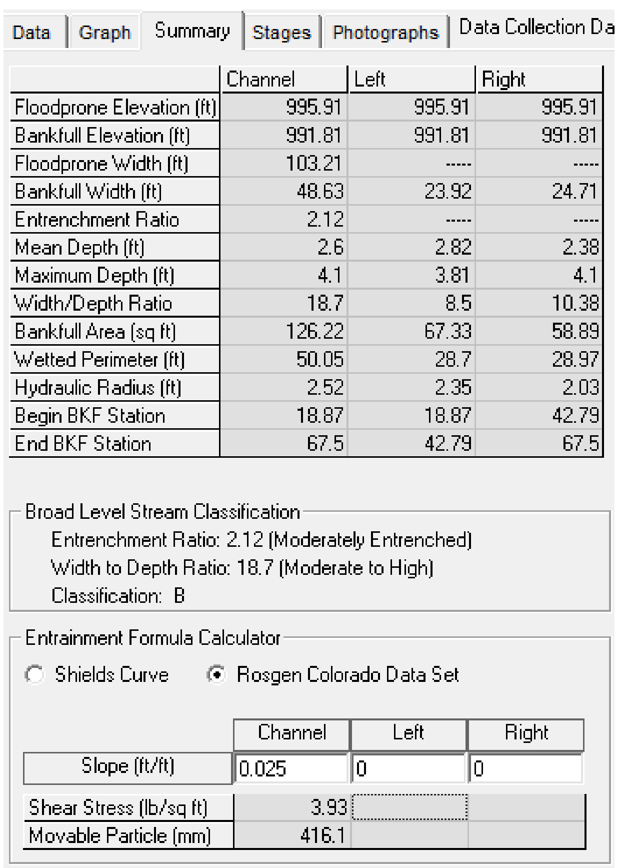


Figure 2. A cross-section as displayed in RiverMorph, with summary cross-section statistics at the top. The thin blue line represents bankfull stage, the blue dashed line represents floodprone stage.



	Channel	Left	Right
Floodprone Elevation (ft)	995.91	995.91	995.91
Bankfull Elevation (ft)	991.81	991.81	991.81
Floodprone Width (ft)	103.21	-----	-----
Bankfull Width (ft)	48.63	23.92	24.71
Entrenchment Ratio	2.12	-----	-----
Mean Depth (ft)	2.6	2.82	2.38
Maximum Depth (ft)	4.1	3.81	4.1
Width/Depth Ratio	18.7	8.5	10.38
Bankfull Area (sq ft)	126.22	67.33	58.89
Wetted Perimeter (ft)	50.05	28.7	28.97
Hydraulic Radius (ft)	2.52	2.35	2.03
Begin BKF Station	18.87	18.87	42.79
End BKF Station	67.5	42.79	67.5

Broad Level Stream Classification
Entrenchment Ratio: 2.12 (Moderately Entrenched)
Width to Depth Ratio: 18.7 (Moderate to High)
Classification: B

Entrainment Formula Calculator
Shields Curve
Rosgen Colorado Data Set

	Channel	Left	Right
Slope (ft/ft)	0.025	0	0
Shear Stress (lb/sq ft)	3.93		
Movable Particle (mm)	416.1		

Figure 3. The summary table of a classification cross-section in RiverMorph.

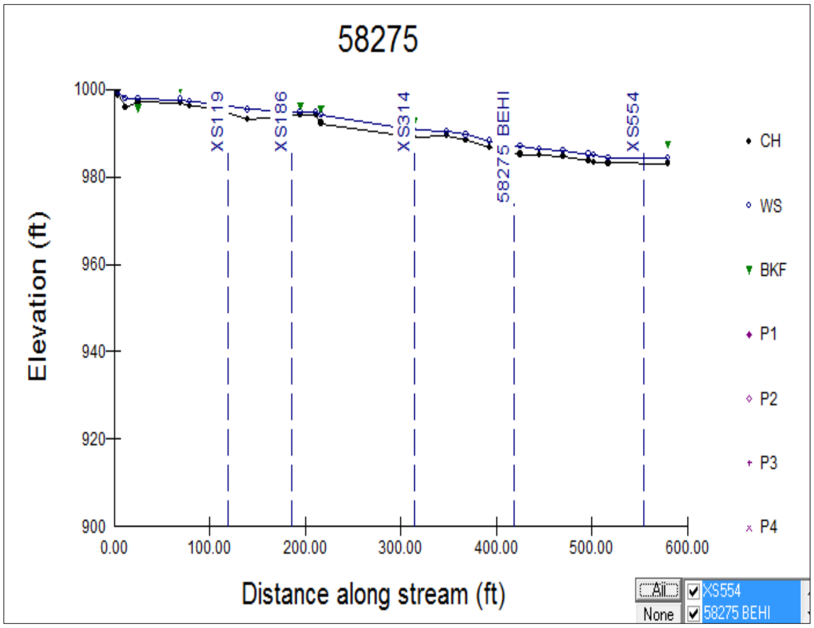


Figure 4. A longitudinal profile in RiverMorph, noting the location of each cross-section.

Shear Stress Characterization

In addition to conditions affecting bank erodibility, characteristics of channel form that determine the distribution, through the channel cross-section, of erosional forces also play a critical role in the risk of bank erosion. Three metrics proposed by Rosgen (2006) to characterize "Near Bank Stress" (NBS) were calculated for each eroding bank to characterize the effect of channel geometry on the shear stress exerted by flows along the eroding bank. Two methods were used analyzing cross-section data in RiverMorph, and a third involved GIS-based interpretation of aerial imagery.

Rosgen's "Method #2" uses the ratio of stream channel radius of curvature (in planform) to bankfull width to scale near bank shear stress. Radius of curvature, normalized by stream width, is widely recognized as a meaningful metric for the erosive potential of the flow on the bank. A ratio less than 2 is considered to have high NBS. For this study, the "Construct Geodetic" tool in ArcGIS 10.2.2 was used to create circles with a measured radius that were fit to the curvature of each eroding bank line.

“Method #5” uses the ratio of near-bank maximum depth to bankfull mean depth. Near bank maximum depth is defined as the maximum depth in the third of the channel cross-section closest to the bank at bankfull stage.

“Method #6” uses the ratio of shear stress calculated for the third of the channel closest to the bank to bankfull channel-averaged shear stress. Rosgen uses a simplified formula for bed averaged shear stress:

$\tau=\gamma dS$ where bed averaged shear stress (τ) equals the product of the specific weight of water (γ), channel mean depth (d) and water surface slope (S). Near bank shear stress was calculated substituting, for channel mean depth, maximum depth in the third of the cross-section nearest the eroding bank.

The calculated numeric values generated by each of the three methods were classed into six levels from Very Low to Extreme. The highest level generated from the three methods is used to prioritize the sites. See Rosgen (2006) for a detailed description of the BEHI and NBS methodologies.

Stream Channel Morphology Classification

The reach in which each bank erosion site was located was classed using the Rosgen Level 2 morphological classification system. This system uses water surface slope, entrenchment, width-to-depth ratio, sinuosity and the median particle size of the channel substrate as delineative criteria to classify reaches (Rosgen 1994). Each of these variables influence hydraulics and sediment transport dynamics through the full range of flows, and collectively play a significant role in determining the long-term evolution of the channel. For example, all other things being equal, if a channel has a low entrenchment ratio (= very confined), the erosion potential at higher flows will be relatively greater. Rosgen Level 2 classification has been used to make management interpretations of channel morphology; interpretations of potential for bank erosion, channel sensitivity to disturbance and potential for recovery from disturbance, as described by Rosgen (1996), were added to the dataset.

Threats to Infrastructure and Private Structures

Threats from erosion site proximity to public infrastructure and private structures were identified using aerial photography in a GIS-based analysis, using a qualitative assessment of slope and distance from erosional surface and channel width; presence or absence of threat were added to the dataset.

RESULTS

Summary tables of the results of the analyses described above are presented below (Tables 1 -3). The data were sorted to present potential prioritization for three distinct management objectives:
1) presence of fine sediment, with an additional level of sorting by area, to indicate potential loading of fine sediment and concomitant threat to water quality; 2) presence of a threat to infrastructure or private structures; and 3) erosional surface area, as an indication of potential bedload supply, with implication for downstream channel stability. For each sort, other key variables were color coded to provide a graphic illustration of the erosion potential metrics. Fourteen sites were identified as having substantial fine sediment in the bank material, with a total erosional surface area of 88,437ft^2 (44% of the total at all sites studied). Of these, all had either Extreme or Very High BEHI index ratings, and either Extreme or Very High NBS ratings. One of these sites additionally represented a threat to Infrastructure. Eight sites in all presented threats to adjacent infrastructure or structures, with a total erosional surface of 20,382 ft^2 (10% of all sites studied). Of these, six had Extreme or Very High BEHI index ratings, and all had Extreme or Very High NBS rating. The locations of these 21 high priority sites, representing over 51% of the erosional area of all sites studied, are presented below in Figure 5. The ten largest erosion sites total 116,575 ft^2 of erosional surface area (Table 3), and account for more than 61% of the total erosional surface area of all sites.

Table 1. Prioritization by Suspended Sediment Source

					NBS Method 2		NBS Method 5		NBS Method 6						*Management Implications by Streamtype (Rosgen, 1994)*		
Stream	ID	Bank Area	BEHI Rating	BEHI Adjective Rating	Ratio	NBS Adjective Rating	Ratio	NBS Adjective	Ratio	NBS Adjective Rating	Fine Sed	Structure Threat	Infrastructure Threat	Stream Type	Sensitivity to Disturbance	Recovery Potential	Streambank Erosion Potential
WBNS	58275	19,537	48.5	Extreme	0.92	Extreme	2.83	Very High	2.83	Extreme	Y	0	0	B4	Moderate	Excellent	Moderate
EBNS	22800	18,072	51.6	Extreme	2.64	Low	2.57	Very High	2.57	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	6800	11,170	53.6	Extreme	10.36	Very Low	1.89	High	1.89	Extreme	Y	0	0	C3	Moderate	Good	Moderate
MSNS	15400	9,254	45.8	Very High	10.28	Very Low	3.1	Extreme	3.1	Extreme	Y	0	0	C	Moderate	Good	Moderate
EBNS	41100	6,511	51.1	Extreme	28.41	Very Low	1.86	High	1.86	Extreme	Y	0	Y	B3c	Low	Excellent	Low
WBNS	400	3,672	50.3	Extreme	3.04	Very Low	2.27	High	2.27	Extreme	Y	0	0	B4c	Moderate	Excellent	Moderate
EBNS	7000	3,599	56.8	Extreme	10.58	Very Low	2.09	High	2.09	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	42300	3,556	49.8	Extreme	1.3	Extreme	2.15	High	2.15	Extreme	Y	0	0	B3c	Low	Excellent	Low
MSNS	26800	3,361	42.9	Very High	2.23	Low	1.86	High	1.86	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	8200	3,157	57.3	Extreme	3.28	Very Low	1.49	Low	1.49	Very High	Y	0	0	F3	Moderate	Poor	Very High
WBNS	28225	2,224	21.7	Moderate	4.78	Very Low	2.99	Very High	2.99	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	53150_2	1,525	56.3	Extreme	0.89	Extreme	1.48	Low	1.48	Very High	Y	0	0	C4	Very High	Good	High
WBNS	53150_1	1,525	42.5	Very High	0.83	Extreme	3.1	Extreme	3.1	Extreme	Y	0	0	C4	Very High	Good	High
WBNS	18975	1,274	44.5	Very High	1.72	Very High	2.15	Moderate			Y	0	0	B3c	Low	Excellent	Low
EBNS	20700	18,234	40.6	Very High	2.25	Low	2.43	High	2.43	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	12500	11,851	43.9	Very High	2.46	Low	1.89	high	1.89	Extreme	N	0	0	C4	Very High	Good	High
WBNS	1500 1100	8,085	29.3	Moderate	1.13	Extreme	2.9	Very High	2.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	39750	7,229	50.6	Extreme	1.02	Extreme	2	high	2	Extreme	N	0	0	F3	Moderate	Poor	Very High
WBNS	43600	6,576	42.5	Very High	0.82	Extreme	2.09	High	2.09	Extreme	N	0	0	D3	Very High	Poor	Very High
WBNS	13200	6,568	21.3	Moderate	8.7	very low	1.35	Low	1.35	Very High	N	0	0	F3	Moderate	Poor	Very High
EBNS	8800	3,277	46.1	Extreme	2.21	Low	2.28	High	2.28	Extreme	N	Y	0	F3	Moderate	Poor	Very High
EBNS	22400	3,261	48.4	Extreme	2.07	Moderate	1.9	High	1.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	19425	2,939	47	Extreme	2.19	Moderate	1.69	Moderate	1.69	Extreme	N	0	0	C3	Moderate	Good	Moderate
MSNS	20600	2,695	48.5	Extreme	3.06	Very Low	1.36	Low	1.36	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	14900	2,673	52.5	Extreme	11.14	Very Low	1.49	Low	1.49	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	52525	2,601	56.9	Extreme	2.8	Low	1.39	Low	1.39	Very High	N	0	0	C4	Very High	Good	High
MSNS	5600	2,541	46.9	Extreme	2.57	Low	3.1	Extreme	3.1	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	23600	2,397	40.4	Very High	2.05	Moderate	1.42	Low	1.42	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	37900	2,392	32.9	High	0.85	High	2.36	High	2.36	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	30500	2,267	56.6	Extreme	1.12	Extreme	1.7	Moderate	1.7	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	21600	2,245	47.9	Extreme	5.85	Very Low	2.13	High	2.13	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	35450	2,117	39.5	Very High	1.01	Extreme	3.4	Extreme	3.4	Extreme	N	0	0	E3	High	Good	Low
EBNS	11500	2,084	49.4	Extreme	1.72	Very High	1.6	Moderate	1.6	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	11501	2,084	43.6	Extreme	4.6	Very Low	2.08	High	2.08	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	20500	2,079	50.2	Extreme	1.27	Extreme	2.07	High	2.07	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	17400	2,031	46.9	Extreme	2.39	Extreme	1.58	Moderate	1.58	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	4025	1,892	16.5	Low	6.13	Very Low	2.7	Very High	2.7	Extreme	N	0	Y	F3	Moderate	Poor	Very High
WBNS	32200	1,873	41.4	Very High	1.05	Extreme	1.48	Low	1.48	Very High	N	0	Y	F3	Moderate	Poor	Very High
EBNS	32100	1,672	49.4	Extreme	8.43	Very Low	1.48	Low	1.48	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	32100_2	1,672	49.4	Extreme	32.49	Very Low	1.53	Moderate	1.53	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	36400	1,633	35.6	High	1.43	Extreme	1.96	High	1.96	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	55300	1,302	41.5	Very High	3.86	Very Low	1.67	Moderate	1.67	Extreme	N	0	Y	C3b	Moderate	Good	Moderate
WBNS	33975	1,181	35.6	High	0.6	Extreme	3.45	Extreme	3.45	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	11100	923	46	Extreme	28.85	Very Low	1.73	Moderate	1.73	Extreme	N	0	0	B3c	Low	Excellent	Low
WBNS	34700	589	40.5	Very High	0.69	Extreme	2.53	Very High	2.53	Extreme	N	0	0	E3	High	Good	Low
EBNS	44500	555	27.6	Moderate	37.05	Very Low	1.57	Moderate	1.57	Very High	N	0	0	B3c	Low	Excellent	Low

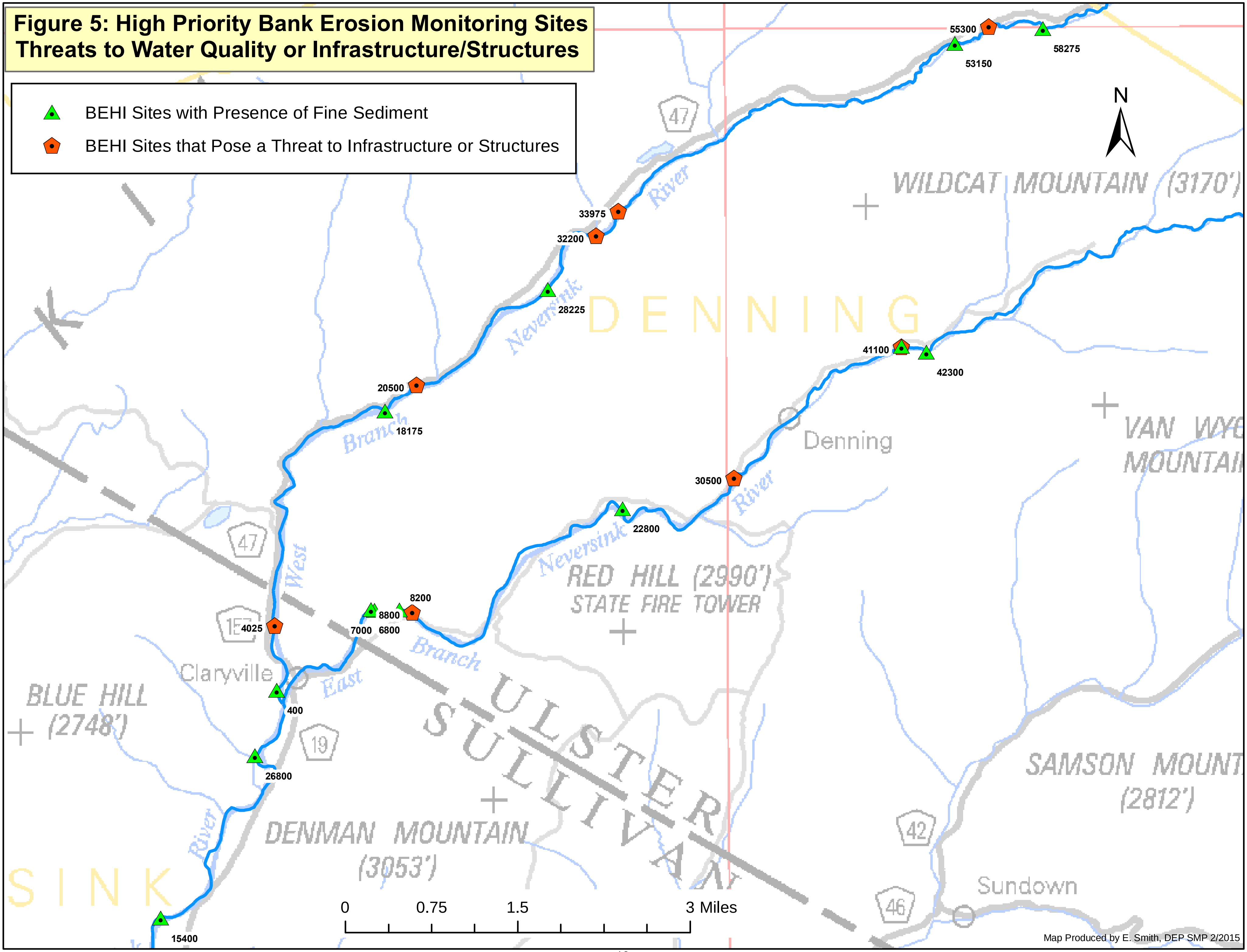
Table 2. Prioritization by Infrastructure / Structure Threat

					NBS Method 2		*NBS Method 5*		*NBS Method 6*						*Management Implications by Streamtype (Rosgen, 1994)*		
Stream	**ID**	**Bank Area**	**BEHI Rating**	**BEHI Adjective Rating**	**Ratio**	**NBS Adjective Rating**	**Ratio**	**NBS Adjective**	**Ratio**	**NBS Adjective Rating**	**Fine Sed**	**Structure Threat**	**Infrastructure Threat**	**Stream Type**	**Sensitivity to Disturbance**	**Recovery Potential**	**Streambank Erosion Potential**
EBNS	30500	2,267	56.6	Extreme	1.12	Extreme	1.7	Moderate	1.7	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	41100	6,511	51.1	Extreme	28.41	Very Low	1.86	High	1.86	Extreme	Y	0	Y	B3c	Low	Excellent	Low
WBNS	20500	2,079	50.2	Extreme	1.27	Extreme	2.07	High	2.07	Extreme	N	0	Y	C3	Moderate	Good	Moderate
WBNS	55300	1,302	41.5	Very High	3.86	Very Low	1.67	Moderate	1.67	Extreme	N	0	Y	C3b	Moderate	Good	Moderate
WBNS	32200	1,873	41.4	Very High	1.05	Extreme	1.48	Low	1.48	Very High	N	0	Y	F3	Moderate	Poor	Very High
WBNS	33975	1,181	35.6	High	0.6	Extreme	3.45	Extreme	3.45	Extreme	N	0	Y	C3	Moderate	Good	Moderate
WBNS	4025	1,892	16.5	Low	6.13	Very Low	2.7	Very High	2.7	Extreme	N	0	Y	F3	Moderate	Poor	Very High
EBNS	8800	3,277	46.1	Extreme	2.21	Low	2.28	High	2.28	Extreme	N	Y	0	F3	Moderate	Poor	Very High
MSNS	20600	2,695	48.5	Extreme	3.06	Very Low	1.36	Low	1.36	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	8200	3,157	57.3	Extreme	3.28	Very Low	1.49	Low	1.49	Very High	Y	0	0	F3	Moderate	Poor	Very High
WBNS	52525	2,601	56.9	Extreme	2.8	Low	1.39	Low	1.39	Very High	N	0	0	C4	Very High	Good	High
EBNS	7000	3,599	56.8	Extreme	10.58	Very Low	2.09	High	2.09	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	53150_2	1,525	56.3	Extreme	0.89	Extreme	1.48	Low	1.48	Very High	Y	0	0	C4	Very High	Good	High
EBNS	6800	11,170	53.6	Extreme	10.36	Very Low	1.89	High	1.89	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	14900	2,673	52.5	Extreme	11.14	Very Low	1.49	Low	1.49	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	22800	18,072	51.6	Extreme	2.64	Low	2.57	Very High	2.57	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	39750	7,229	50.6	Extreme	1.02	Extreme	2	high	2	Extreme	N	0	0	F3	Moderate	Poor	Very High
WBNS	400	3,672	50.3	Extreme	3.04	Very Low	2.27	High	2.27	Extreme	Y	0	0	B4c	Moderate	Excellent	Moderate
EBNS	42300	3,556	49.8	Extreme	1.3	Extreme	2.15	High	2.15	Extreme	Y	0	0	B3c	Low	Excellent	Low
EBNS	32100	1,672	49.4	Extreme	8.43	Very Low	1.48	Low	1.48	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	32100_2	1,672	49.4	Extreme	32.49	Very Low	1.53	Moderate	1.53	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	11500	2,084	49.4	Extreme	1.72	Very High	1.6	Moderate	1.6	Very High	N	0	0	C3	Moderate	Good	Moderate
WBNS	58275	19,537	48.5	Extreme	0.92	Extreme	2.83	Very High	2.83	Extreme	Y	0	0	B4	Moderate	Excellent	Moderate
EBNS	22400	3,261	48.4	Extreme	2.07	Moderate	1.9	High	1.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	21600	2,245	47.9	Extreme	5.85	Very Low	2.13	High	2.13	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	19425	2,939	47	Extreme	2.19	Moderate	1.69	Moderate	1.69	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	17400	2,031	46.9	Extreme	2.39	Extreme	1.58	Moderate	1.58	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	11100	923	46	Extreme	28.85	Very Low	1.73	Moderate	1.73	Extreme	N	0	0	B3c	Low	Excellent	Low
MSNS	15400	9,254	45.8	Very High	10.28	Very Low	3.1	Extreme	3.1	Extreme	Y	0	0	C	Moderate	Good	Moderate
WBNS	18975	1,274	44.5	Very High	1.72	Very High	2.15	Moderate			Y	0	0	B3c	Low	Excellent	Low
EBNS	12500	11,851	43.9	Very High	2.46	Low	1.89	high	1.89	Extreme	N	0	0	C4	Very High	Good	High
EBNS	11501	2,084	43.6	Extreme	4.6	Very Low	2.08	High	2.08	Extreme	N	0	0	C3	Moderate	Good	Moderate
MSNS	26800	3,361	42.9	Very High	2.23	Low	1.86	High	1.86	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	53150_1	1,525	42.5	Very High	0.83	Extreme	3.1	Extreme	3.1	Extreme	Y	0	0	C4	Very High	Good	High
WBNS	43600	6,576	42.5	Very High	0.82	Extreme	2.09	High	2.09	Extreme	N	0	0	D3	Very High	Poor	Very High
EBNS	20700	18,234	40.6	Very High	2.25	Low	2.43	High	2.43	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	34700	589	40.5	Very High	0.69	Extreme	2.53	Very High	2.53	Extreme	N	0	0	E3	High	Good	Low
EBNS	23600	2,397	40.4	Very High	2.05	Moderate	1.42	Low	1.42	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	35450	2,117	39.5	Very High	1.01	Extreme	3.4	Extreme	3.4	Extreme	N	0	0	E3	High	Good	Low
EBNS	36400	1,633	35.6	High	1.43	Extreme	1.96	High	1.96	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	37900	2,392	32.9	High	0.85	High	2.36	High	2.36	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	1500 1100	8,085	29.3	Moderate	1.13	Extreme	2.9	Very High	2.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	44500	555	27.6	Moderate	37.05	Very Low	1.57	Moderate	1.57	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	28225	2,224	21.7	Moderate	4.78	Very Low	2.99	Very High	2.99	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	13200	6,568	21.3	Moderate	8.7	very low	1.35	Low	1.35	Very High	N	0	0	F3	Moderate	Poor	Very High
MSNS	5600	2,541	46.9	Extreme	2.57	Low	3.1	Extreme	3.1	Extreme	N	0	0	C3	Moderate	Good	Moderate

Table 3. Prioritization by Erosional Surface Area

					NBS Method 2		*NBS Method 5*		*NBS Method 6*						*Management Implications by Streamtype (Rosgen, 1994)*		
Stream	**ID**	**Bank Area**	**BEHI Rating**	**BEHI Adjective Rating**	**Ratio**	**NBS Adjective Rating**	**Ratio**	**NBS Adjective**	**Ratio**	**NBS Adjective Rating**	**Fine Sed**	**Structure Threat**	**Infrastructure Threat**	**Stream Type**	**Sensitivity to Disturbance**	**Recovery Potential**	**Streambank Erosion Potential**
WBNS	58275	19,537	48.5	Extreme	0.92	Extreme	2.83	Very High	2.83	Extreme	Y	0	0	B4	Moderate	Excellent	Moderate
EBNS	20700	18,234	40.6	Very High	2.25	Low	2.43	High	2.43	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	22800	18,072	51.6	Extreme	2.64	Low	2.57	Very High	2.57	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	12500	11,851	43.9	Very High	2.46	Low	1.89	high	1.89	Extreme	N	0	0	C4	Very High	Good	High
EBNS	6800	11,170	53.6	Extreme	10.36	Very Low	1.89	High	1.89	Extreme	Y	0	0	C3	Moderate	Good	Moderate
MSNS	15400	9,254	45.8	Very High	10.28	Very Low	3.1	Extreme	3.1	Extreme	Y	0	0	C	Moderate	Good	Moderate
WBNS	1500 1100	8,085	29.3	Moderate	1.13	Extreme	2.9	Very High	2.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	39750	7,229	50.6	Extreme	1.02	Extreme	2	high	2	Extreme	N	0	0	F3	Moderate	Poor	Very High
WBNS	43600	6,576	42.5	Very High	0.82	Extreme	2.09	High	2.09	Extreme	N	0	0	D3	Very High	Poor	Very High
WBNS	13200	6,568	21.3	Moderate	8.7	very low	1.35	Low	1.35	Very High	N	0	0	F3	Moderate	Poor	Very High
EBNS	41100	6,511	51.1	Extreme	28.41	Very Low	1.86	High	1.86	Extreme	Y	0	Y	B3c	Low	Excellent	Low
WBNS	400	3,672	50.3	Extreme	3.04	Very Low	2.27	High	2.27	Extreme	Y	0	0	B4c	Moderate	Excellent	Moderate
EBNS	7000	3,599	56.8	Extreme	10.58	Very Low	2.09	High	2.09	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	42300	3,556	49.8	Extreme	1.3	Extreme	2.15	High	2.15	Extreme	Y	0	0	B3c	Low	Excellent	Low
MSNS	26800	3,361	42.9	Very High	2.23	Low	1.86	High	1.86	Extreme	Y	0	0	C3	Moderate	Good	Moderate
EBNS	8800	3,277	46.1	Extreme	2.21	Low	2.28	High	2.28	Extreme	N	Y	0	F3	Moderate	Poor	Very High
EBNS	22400	3,261	48.4	Extreme	2.07	Moderate	1.9	High	1.9	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	8200	3,157	57.3	Extreme	3.28	Very Low	1.49	Low	1.49	Very High	Y	0	0	F3	Moderate	Poor	Very High
WBNS	19425	2,939	47	Extreme	2.19	Moderate	1.69	Moderate	1.69	Extreme	N	0	0	C3	Moderate	Good	Moderate
MSNS	20600	2,695	48.5	Extreme	3.06	Very Low	1.36	Low	1.36	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	14900	2,673	52.5	Extreme	11.14	Very Low	1.49	Low	1.49	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	52525	2,601	56.9	Extreme	2.8	Low	1.39	Low	1.39	Very High	N	0	0	C4	Very High	Good	High
MSNS	5600	2,541	46.9	Extreme	2.57	Low	3.1	Extreme	3.1	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	23600	2,397	40.4	Very High	2.05	Moderate	1.42	Low	1.42	Very High	N	0	0	B3c	Low	Excellent	Low
EBNS	37900	2,392	32.9	High	0.85	High	2.36	High	2.36	Extreme	N	0	0	C3	Moderate	Good	Moderate
EBNS	30500	2,267	56.6	Extreme	1.12	Extreme	1.7	Moderate	1.7	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	21600	2,245	47.9	Extreme	5.85	Very Low	2.13	High	2.13	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	28225	2,224	21.7	Moderate	4.78	Very Low	2.99	Very High	2.99	Extreme	Y	0	0	C3	Moderate	Good	Moderate
WBNS	35450	2,117	39.5	Very High	1.01	Extreme	3.4	Extreme	3.4	Extreme	N	0	0	E3	High	Good	Low
EBNS	11500	2,084	49.4	Extreme	1.72	Very High	1.6	Moderate	1.6	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	11501	2,084	43.6	Extreme	4.6	Very Low	2.08	High	2.08	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	20500	2,079	50.2	Extreme	1.27	Extreme	2.07	High	2.07	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	17400	2,031	46.9	Extreme	2.39	Extreme	1.58	Moderate	1.58	Very High	N	0	0	B3c	Low	Excellent	Low
WBNS	4025	1,892	16.5	Low	6.13	Very Low	2.7	Very High	2.7	Extreme	N	0	Y	F3	Moderate	Poor	Very High
WBNS	32200	1,873	41.4	Very High	1.05	Extreme	1.48	Low	1.48	Very High	N	0	Y	F3	Moderate	Poor	Very High
EBNS	32100	1,672	49.4	Extreme	8.43	Very Low	1.48	Low	1.48	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	32100_2	1,672	49.4	Extreme	32.49	Very Low	1.53	Moderate	1.53	Very High	N	0	0	C3	Moderate	Good	Moderate
EBNS	36400	1,633	35.6	High	1.43	Extreme	1.96	High	1.96	Extreme	N	0	0	C3	Moderate	Good	Moderate
WBNS	53150_2	1,525	56.3	Extreme	0.89	Extreme	1.48	Low	1.48	Very High	Y	0	0	C4	Very High	Good	High
WBNS	53150_1	1,525	42.5	Very High	0.83	Extreme	3.1	Extreme	3.1	Extreme	Y	0	0	C4	Very High	Good	High
WBNS	55300	1,302	41.5	Very High	3.86	Very Low	1.67	Moderate	1.67	Extreme	N	0	Y	C3b	Moderate	Good	Moderate
WBNS	18975	1,274	44.5	Very High	1.72	Very High	2.15	Moderate			Y	0	0	B3c	Low	Excellent	Low
WBNS	33975	1,181	35.6	High	0.6	Extreme	3.45	Extreme	3.45	Extreme	N	0	Y	C3	Moderate	Good	Moderate
EBNS	11100	923	46	Extreme	28.85	Very Low	1.73	Moderate	1.73	Extreme	N	0	0	B3c	Low	Excellent	Low
WBNS	34700	589	40.5	Very High	0.69	Extreme	2.53	Very High	2.53	Extreme	N	0	0	E3	High	Good	Low
EBNS	44500	555	27.6	Moderate	37.05	Very Low	1.57	Moderate	1.57	Very High	N	0	0	B3c	Low	Excellent	Low

Figure 5: High Priority Bank Erosion Monitoring Sites
Threats to Water Quality or Infrastructure/Structures



Discussion

This semi-quantitative analysis is intended to support management decisions regarding future efforts to monitor the bank erosion sites, as well as allocation of funds for stream channel improvements undertaken by the Rondout Neversink Stream Program. The study serves to complement the recommendations made in the Upper Neversink Stream Management Plan, as well as the Local Flood Analysis currently being conducted to identify flood hazards from inundation, and their potential mitigation, in the hamlet of Claryville. It is not intended to provide a single algorithm to determine the order in which projects will be undertaken or sites identified for further study, but rather to present data from all of the sites in a format that supports comparative consideration of key variables for management decisions. Decisions regarding funding for restoration work will be made in cooperation with the town and county highway departments, the RNSP Watershed Advisory Group, as well as individual landowners on whose property the erosion sites are located. These decisions will necessarily need to reflect, in addition to the results of the preceding analysis, the potential benefits and costs of projects, their technical complexity and prognosis for project sustainability, staging and permit considerations, and program resources.

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References

Kudish, Michael. 2000. The Catskill Forest: A History. Fleischmanns, NY: Purple Mountain Press.

Rondout Neversink Stream Program. 2013. The Upper Neversink River Stream Management Plan. http://catskillstreams.org/stream-management-program/sm-implementation-program/

Rosgen, Dave. 1994. A Classification of Natural Rivers. Catena, Catena 22: 169-199.

Rosgen, Dave and Lee Silvey. 1996. Applied River Morphology. Pagosa Springs: Wildland Hydrology.

Rosgen, Dave. 2006. Watershed Assessment of River Stability and Sediment Supply. Pagosa Springs: Wildland Hydrology.

Wolman, M.G., 1954. A Method of Sampling Coarse River-Bed Material. Transactions of the American Geophysical Union 35(6):951-956.