APPENDIX H
SEDIMENT CONTRIBUTION FROM STREAMBANK EROSION

Approach
Application of the BEHI method (Rosgen 2001) allowed estimation of sediment delivery from stream banks. This methodology predicts stream erosion rate to sampled stream banks, creating an extrapolation factor from the results, and applying this extrapolation factor to the total length of streams in each 6th code HUC sub-watershed (as modified to break out 303d listed streams). The BEHI method is an empirical technique based on bank erosion rate data recorded in the Lamar River watershed of Yellowstone National Park and a variety of streams in the Colorado Front Range. Rosgen (2001) found a statistically significant relationship between the BEHI rating and bank erosion rate in the absence of any data representing the near bank shear stress. The method allows for prediction of bank erosion rates based on BEHI ratings developed from data collected in the field.

Methods
Field data collection

Field data for BEHI parameters were collected in the fall of 2004 following the quality assurance project plan (Confluence 2004). Parameters such as length of eroding bank, height of eroding bank, bankfull height, root depth, root density, bank angle, and surface protection (**Figure H-1**) were collected for each eroding bank within each assessment reach according to methods outlined by Rosgen (2004). Locations of sample reaches are shown in **Figure H-2**.

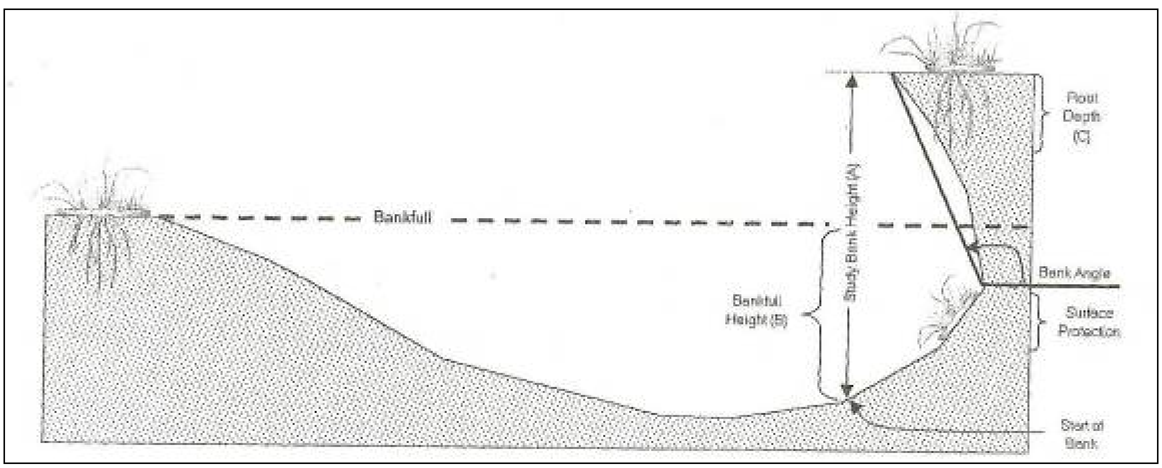

Figure H-1. BEHI Field Data Collection Methods
(Rosgen 2004)

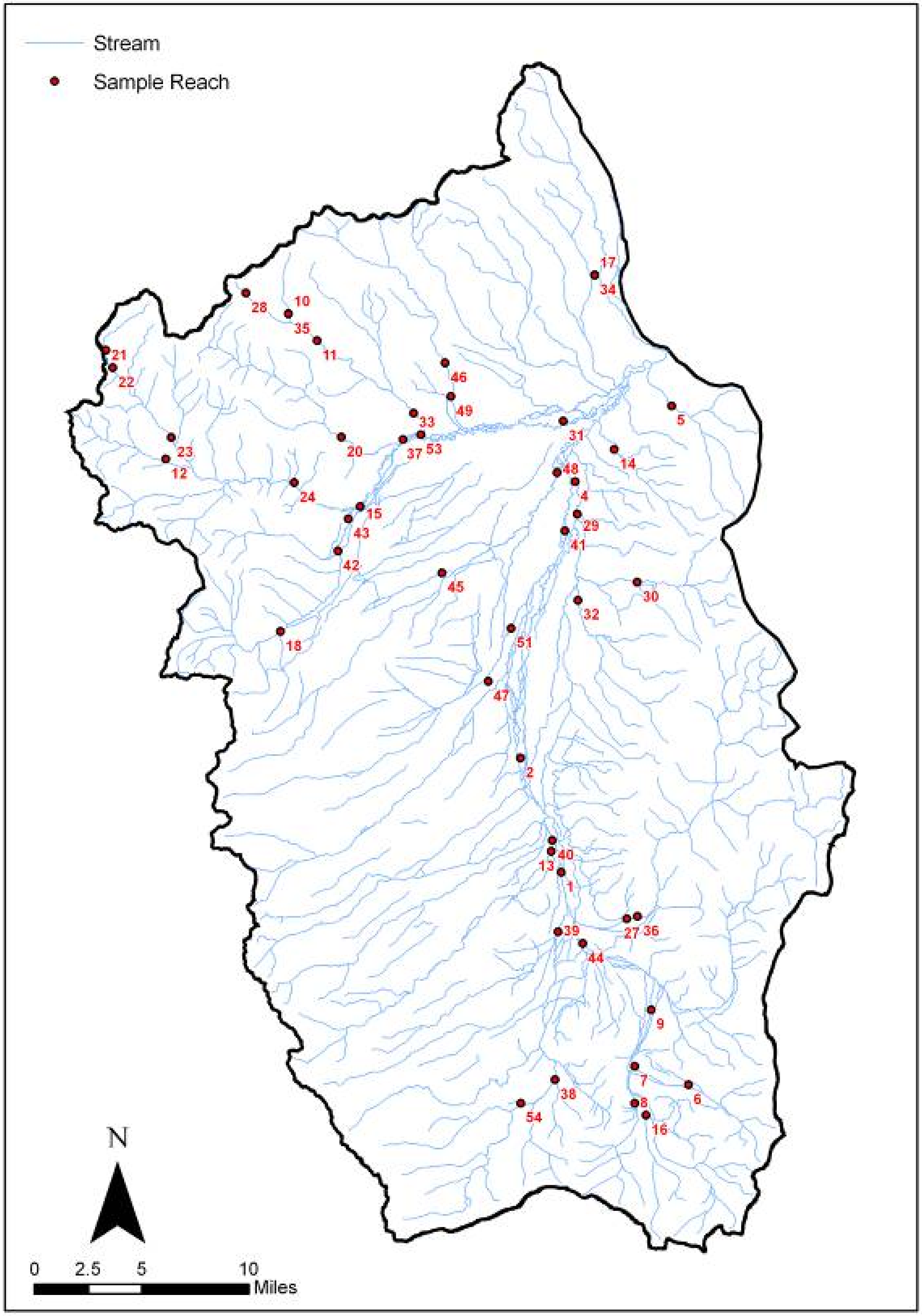

Figure H-2. Bank Erosion Assessment Sample Reach Locations

Calculation of sediment contribution from field data

Data collected in the field were used to predict the BEHI. The following data were collected for each bank.

- Bank Height, A (ft)
- Bankfull Height, B (ft)
- Root Depth, C (ft)
- Root Density, D (%)
- Bank Angle (deg.)
- Surface Protection (%)

The following erodibility variables (values) were computed and considered in ranking each bank as per Rosgen (2004).

- Bank Height / Bankfull Height, (A/B)
- Root Depth / Bank Height, (C/A)
- Weighted Root Density, (D*C/A)
- Bank Angle (deg.)
- Surface Protection (%)

The erodibility variable values were converted to numerical indices for bank erosion potential based on the relationships determined by Rosgen (2004) (**Table H-1**).

Table H-1 Conversion from Erodibility Variable Index to Numerical Bank Erosion Potential Values

(Rosgen 2004)

Erodibility Variable		Bank Erosion Potential					
		Very Low	*Low*	*Moderate*	*High*	*Very High*	*Extreme*
Bank Height / Bankfull Height	Value	1.0 - 1.1	1.11 - 1.19	1.2 - 1.5	1.6 - 2.0	21. - 2.8	> 2.8
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Root Depth / Bank Height	Value	1.0 - 0.9	0.89 - 0.5	0.49 - 0.3	0.29 - 0.15	0.14 - 0.05	< 0.05
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Weighted Root Density	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 5.0	< 5.0
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Bank Angle	Value	0 - 20	21 - 60	61 - 80	81 - 90	91 - 119	> 119
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10
Surface Protection	Value	100 - 80	79 - 55	54 - 30	29 - 15	14 - 10	< 10
	Index	1.0 - 1.9	2.0 - 3.9	4.0 - 5.9	6.0 - 7.9	8.0 - 9.0	10

The BEHI method also allows the practitioner to modify the score based on bank material and bank material stratification. Rationale for exclusion of these factors from data collection and analysis related to the use of an average retreat rate assigned to each BEHI ranking. Addition of the bank material and bank material stratification to this analysis would have greatly complicated analyses without a commensurate increase in certainty in the results. Moreover, these qualitative assessments likely have low replicability. Therefore, the expense of collecting the additional data, combined with the lack of reliability in the results, justified the omission of these parameters.

A total score for each bank was developed by summing the bank erosion potential indices determined in the previous step. Finally, a BEHI ranking was assigned to the bank based on the following classification developed by Rosgen (2004).

Total Score	5 - 9.9	10 - 19.9	20 - 29.9	30 - 39.9	40 - 45	45.1 - 50
BEHI Rating	*Very Low*	*Low*	*Moderate*	*High*	*Very High*	*Extreme*

This classification was modified slightly to allow for analysis based on the Rosgen Colorado data set (**Figure H-3**). Shown here, the modification included elimination of the *Very Low* category (which was not recorded in either the Colorado data set or in the upper Big Hole sampling), and combining the *High* and *Very High* categories into one.

Total Score	10 - 19.9	20 - 29.9	30 - 45	45.1 - 50
BEHI Rating	*Low*	*Moderate*	*High - Very High*	*Extreme*

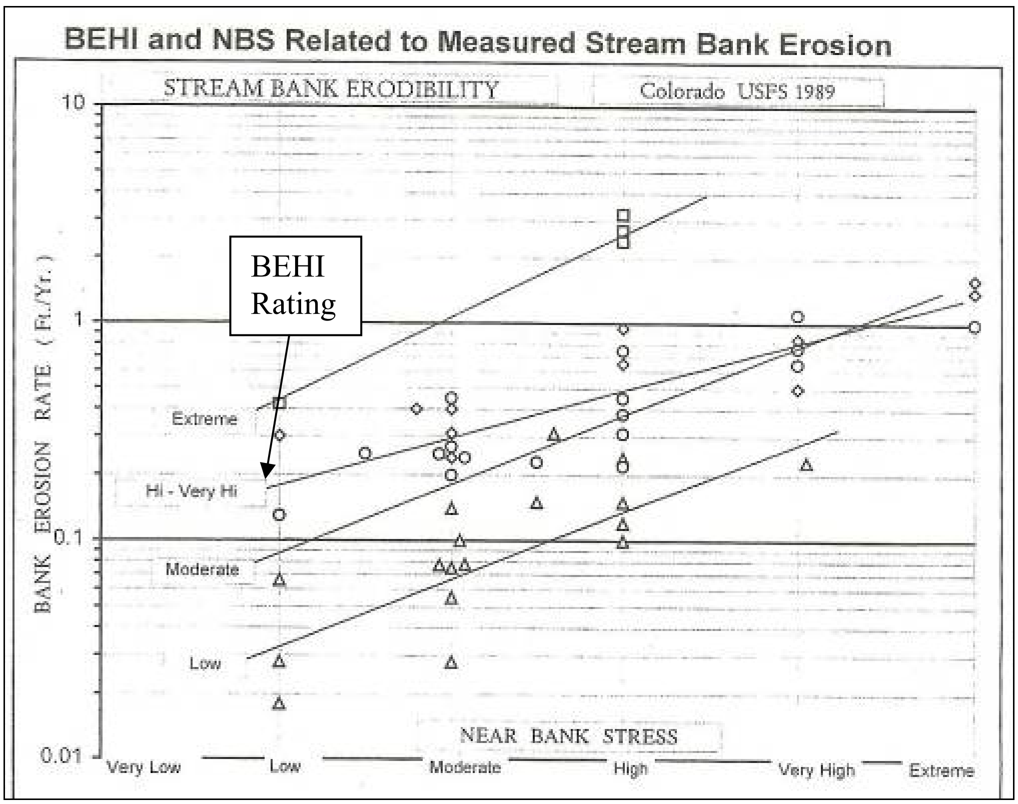

Figure H-3. Rosgen BEHI-NBS Model Developed from Colorado data (Rosgen 2001). Triangle (Δ) represents Low BEHI rating. Circle (○) represents Moderate BEHI rating. Diamond (◊) represents High/Very High BEHI rating. Square (□) represents Extreme BEHI rating.

Lateral bank erosion rate was predicted based on the modified BEHI Rating. Rosgen (2001) concluded that “there are significant differences in two or more of the means (p=0.0001) in both cases for both parameters [BEHI and NBS], thus both BEHI and NBS are highly significant predictors of bank erosion rate." This implies that BEHI rating alone can be used to estimate bank erosion rates. To apply this principle, Rosgen's Colorado dataset was reconstructed based on **Figure H-3** and reanalyzed. Mean erosion rate values were determined for each of the four BEHI rating categories described by Rosgen – Low, Moderate, High/Very High, and Extreme. The results are presented in **Table H-2**and graphically in **Figure H-4**.

Table H-2. Mean Bank Erosion Rate Based only on BEHI Rating

BEHI Rating	Mean Bank Erosion Rate (ft/yr)
Low (10-19.9)	0.096
Moderate (20-29.9)	0.438
High-Very High (30-45)	0.619
Extreme (45.1-50)	2.003

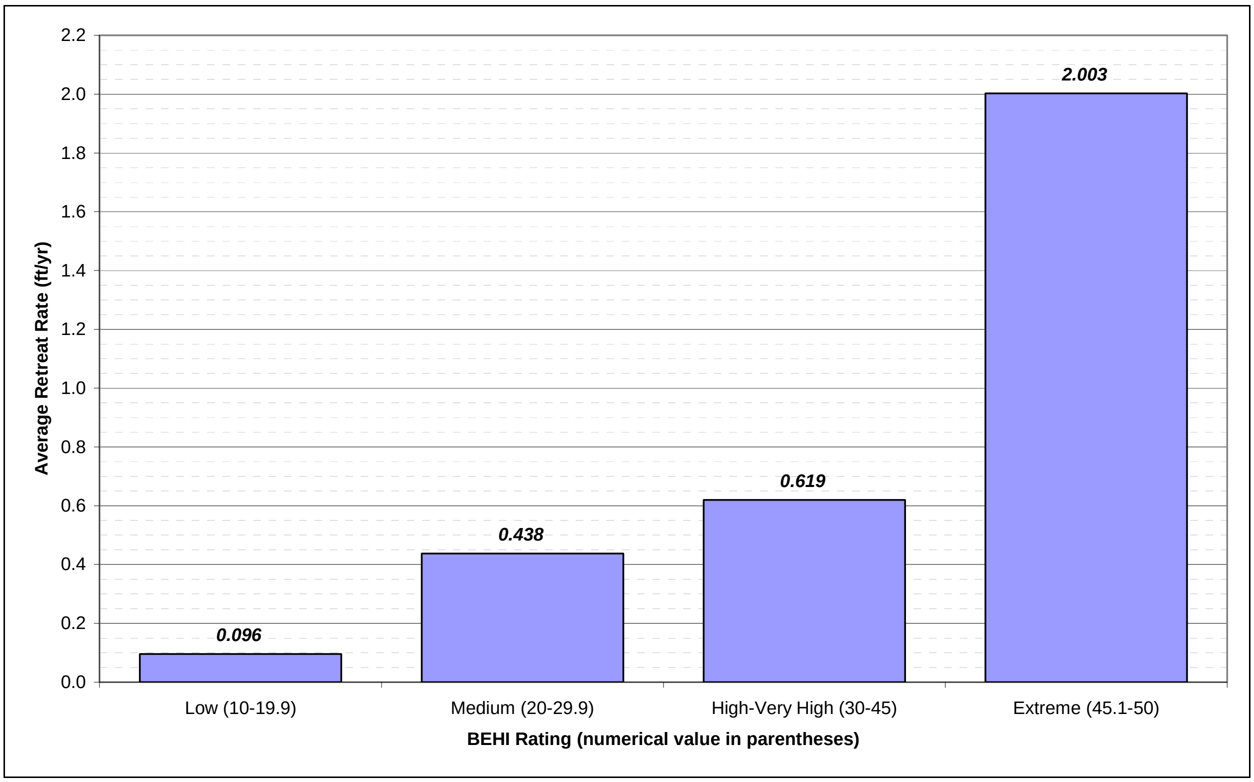

Figure H-4. Mean bank erosion rates based on BEHI rating only.

Sediment contribution from measured bank erosion sites was estimated by assigning the mean bank erosion rate to each bank based on BEHI rating, and applying Equation 1.

$$S = c \times R \times A \qquad (1)$$

Where: S = sediment load (ton/year)
c = bulk density of soil (0.084 ton/cubic foot)
R = bank erosion rate (feet/year)
A = eroding bank area (square feet)
And: A = eroding bank length (feet) x eroding bank height (feet)

The volume of all observed eroding banks was summed for each sampling reach, and divided by the length of the sampled stream reach, to arrive at an annual sediment contribution from that reach in tons/ft/yr.

Extrapolation

The average annual sediment contribution of the sampled stream reaches was used, in combination with data from an aerial photo based assessment of the streams of the upper Big Hole Watershed, to create a matrix of extrapolation factors. These extrapolation factors were then multiplied by the total length of streams within each extrapolation classification, and the results broken out by 6^{th} Code HUC boundary (modified to reflect 303d listed stream drainages) to arrive at a predicted annual sediment contribution for each watershed.

To derive and apply the extrapolation factors, an aerial photo based assessment was performed on stream channel data for the entire upper Big Hole watershed using the National Hydrologic Dataset (NHD), overlain on USGS Digital Orthophoto Quarter Quad (DOQQ) aerial photos. Stream segments were broken out to be homogenous for, and categorized by, the following attributes:

- current Rosgen stream channel type (valley slope, valley confinement, stream slope, stream sinuosity, indications of entrenchment),
- potential Rosgen stream channel type,
- current near bank vegetation density,
- potential near bank vegetation density,
- current near bank vegetation type,
- potential near bank vegetation type, and
- current landuse.

Rosgen level 1 channel types were assigned to reaches based on the following criteria:

- B channels – low sinuosity, relatively confined, narrow floodplain, high valley and stream gradients, no extensive bar formation, relatively narrow channel widths.

- C channels – moderate sinuosity, low to moderate valley and stream gradients, gravel deposition common on point bars.

- E channels – high sinuosity, wide, low valley and stream gradients, unconfined floodplain, few observable gravel point bars.

- F channels – areas obviously altered by mechanical channelization. Although it is impossible to determine entrenchment ratio by aerial photos, channelized reaches are typically incised due to vertical erosion resulting from channelization and artificial berms along the channel margin placed during the channelization process.

- G channels – areas obviously altered by mechanical channelization and are much wider than adjacent reaches. These channels have begun the evolution from an F channel to a stable channel type and are widening to establish an inset floodplain.

The Rosgen classification assigned to each reach was ultimately not used in extrapolating sediment loads between sampled and non-sampled reaches.

The potential condition for Rosgen channel type, near bank vegetation density and near bank vegetation type were intended to reflect the state that could be achieved under best management practices. Possible values for the vegetation density assessments (both current and potential) were ‘sparse,’ ‘moderate,’ and ‘dense.’ Possible values for the vegetation type assessments (both current and potential) were ‘coniferous trees,’ ‘deciduous trees,’ ‘willow shrubs,’ and ‘herbaceous vegetation.’ Possible values for the land use assessment were ‘crop,’ ‘forested,’ ‘grazing,’ ‘hay,’ ‘logging,’ and ‘residential.’

This same aerial assessment was performed on the stream reaches that had been field sampled for bank erosion. Deriving extrapolation factors from these sample data involved looking for relationships between combinations of aerial assessment attributes and the measured erosion rate for those combinations on the sample reaches. For example, one might examine the combination of current vegetation density and land use. Given three possible values for current vegetation density (sparse, moderate, dense), and five possible values for land use (crop, forested, grazing, hay, logging, and residential), there are fifteen possible combinations of these two attributes. One may then divide the sample reach data into those fifteen categories, calculate measured bank erosion for each category, and evaluate the results to determine if the relationship between the categories and their measured erosion rates is appropriate for use in extrapolating the sample results to the watershed as a whole.

Previous work on the Upper Big Hole Valley river watershed in Southwest Montana showed that the best relationship between the aerial assessment parameters and measured erosion rates involved the combination of current vegetation density, current vegetation type, and potential vegetation type. We believe this reflects the known effect of vegetation density and type on stream bank stability (dense willow stands hold banks more strongly than sparse herbaceous vegetation, for example) as well as the effect that riparian land cover modification has on stream bank stability (streams that developed their morphology in an area of sparse herbaceous vegetation are likely to be more stable than those that developed in an area of dense woody vegetation that has since been removed).

Given that there are three possible values for current vegetation density (sparse, moderate, dense) and four possible values for both current and potential vegetation type (coniferous, deciduous, willow, herbaceous), there are 48 possible combinations of those three attributes. Some of those combinations do not 'make sense' and do not actually occur, however. For example, a stream segment should not have a current vegetation type of 'willow' and a potential vegetation type of 'herbaceous' as that does not reflect the expected result of best management practices. This reduces the number of possible combinations to 30, still too many for a meaningful extrapolation based upon 52 sample reaches – most of the possible combinations would have too few (or no) corresponding samples. A further reduction in possible combinations can be achieved by considering that, with respect to current and potential vegetation type, what is important from the standpoint of streambank erosion is whether or not the site is achieving its potential vegetation type. For example, sites that currently have herbaceous vegetation might have the potential to have herbaceous, willow, deciduous, or coniferous vegetation – four potential categories. These four categories can be reduced to two by considering a herbaceous site to be 'achieving its potential' if its potential is to support herbaceous vegetation and 'not achieving' if it has the potential to support any of the other three higher seral stages.

Reclassifying the vegetation type combinations according to 'achieving' or 'underachieving' results in 24 combinations. The number of samples corresponding to each of these 24 combinations is shown in **Figure H-5**.

Vegtype & Vegtype Potential & VegDensity

Sparse Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving		6		
Underachieving	6			

Moderate Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving	3	15		1
Underachieving				

Dense Veg

	Herbaceous	Willow	Deciduous	Coniferous
Achieving		17		2
Underachieving				2

Figure H-5. Extrapolation Matrix Showing the Distribution of Vegetation Type, Density, and Potential for Sample Sites

Of the 24 possible combinations, only eight are represented in the sample data. However, not all of the combinations are found in the watershed, and thus in need of an extrapolation factor. In **Figure H-5**, green cells represent combinations for which samples exist. Grey cells represent combinations which do not appear in the data for the watershed as a whole. Red cells represent combinations which do appear in the data for the watershed as a whole, but for which there are no samples. Thus, the sample data cover seven of the twelve combinations found in the watershed as a whole.

To judge whether or not this coverage is sufficient to develop a meaningful extrapolation, we looked at the proportion of the watershed as a whole that were covered by the sampled combinations.

Vegtype & Vegtype Potential & VegDensity

Sparse Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving	648,755	432,942	0	5,293
Underachieving	740,135	0	0	0

Moderate Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving	495,475	1,252,851	0	356,656
Underachieving	60,793	0	0	0

Dense Veg	Herbaceous	Willow	Deciduous	Coniferous
Achieving	142,133	853,325	1,881	2,322,971
Underachieving	0	0	0	0

Figure H-6. Extrapolation Matrix Showing the Length of Stream Channel for each Vegetation Type, Density, and Potential for the Upper Big Hole Watershed

As shown in **Figure H-6**, approximately 88% of the stream segments (by length) in the valley were represented by the sampled categories, and 90% of the remainder were in a single category (sparse, herbaceous, achieving), for which an appropriate factor could be easily derived from the sample data. A meaningful extrapolation to the watershed as a whole can be performed using these data.

The average erosion rate (tons/ft/yr) was calculated for all of the combinations that had been sampled, resulting in **Figure H-7**.

Vegtype & Vegtype Potential & VegDensity

	Herbaceous	Sparse Veg Willow	Deciduous	Coniferous
Achieving		0.033814066		*
Underachieving	0.034815185			

	Herbaceous	Moderate Veg Willow	Deciduous	Coniferous
Achieving	0.016274753	0.013261281		0
Underachieving	*			

	Herbaceous	Dense Veg Willow	Deciduous	Coniferous
Achieving		0.015713095	*	0.001784176
Underachieving				

Figure H-7. Extrapolation Matrix – The Average Erosion Rate Tons/ft/yr) for each Site Type Sampled Asterisks denote categories with minimal representation in the watershed.

From this starting point, a final extrapolation factor matrix was derived using best professional judgment, as follows:

- Herbaceous:

In all cases, reaches exhibiting an "achieving" potential were assigned a lower loading rate than those exhibiting an "underachieving" potential Likewise, reaches exhibiting dense vegetation were assigned a lower erosion rate than moderate and sparse densities. All herbaceous categories were assigned higher sediment loads than the corresponding density and potential for willow stands (i.e. a moderate density, herbaceous reach achieving its vegetation potential was assigned a higher sediment load than a moderate density, willow dominated reach achieving its vegetation potential) because herbaceous stands typically exhibit higher erosion rates than willow stands.

- Willow

All three willow vegetation density categories were field measured and assigned an "achieving" potential. However, the sediment load measured for the dense category of willows indicated a higher sediment load than the moderate density category. Best professional judgment was used to infer that a dense stand of willows should exhibit a lower sediment load than a moderate stand. Therefore, the dense, achieving reaches were reassigned a sediment load rate slightly lower than the moderate, achieving reaches. These dense, achieving reaches were assigned a sediment load of 0.010 tons/ft/year (measured load was 0.016 tons/ft/year). Moderate and sparse reaches with achieving potential loads were not altered from their measured loading rates.

- Deciduous

Only one category of deciduous dominated vegetation reaches existed; a dense stand exhibiting its potential density. This reach type was not field measured, therefore a sediment load value was assigned based on other sediment load values. Best professional judgment was used to infer that a dense stand of deciduous vegetation likely exhibits a moderate, herbaceous understory. Therefore, the assigned sediment load rate (0.018 tons/ft/yr) was chosen to closely match the moderate density, achieving potential, herbaceous reaches (0.0163 tons/ft/yr). Although deciduous roots provide some bank stability due to their massive root systems, they are typically not as effective as the fibrous network of shrub and herbaceous roots. Therefore a slightly higher loading rate was assigned to the dense, deciduous-dominated stand versus the moderate, herbaceous stand.

- Coniferous

Reaches exhibiting a coniferous-dominated vegetation type almost exclusively fall within a hillslope classification of greater than 4% in the Upper and North Fork Big Hole Watershed. Streams flowing across slopes >4% are A and B channels, which typically exhibit cobble and boulder bed morphology in this study area. These bed forms generally provide excellent bank stability in the form of narrow, step pools and steep riffles. Erosion rates in these streams are typically very low due to the bed material preventing vertical and lateral scouring. Not surprisingly, stream bank sediment loads measured within dense, coniferous reaches achieving their vegetation potential were lower than all other reach types (0.0018 tons/ft/yr).

As coniferous stand density is reduced from dense to sparse, sediment loads should not significantly change, because in steeper drainages in this watershed area bed features control erosion rather than vegetation types and density. Therefore, sediment loads in reaches exhibiting moderate and sparsely vegetated conifer stands were assigned slightly higher loads than the densely vegetated stands.

The resulting extrapolation factor matrix is given in **Figure H-8**.

	Vegtype & Vegtype Potential & VegDensity			
		Sparse Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	0.02	0.0338		0.01
Underachieving	0.0348			
		Moderate Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	0.0163	0.0133		0.005
Underachieving	0.03			
		Dense Veg		
	Herbaceous	Willow	Deciduous	Coniferous
Achieving	0.012	0.01	0.018	0.0018
Underachieving				

Figure H-8. Extrapolation Matrix of the Average Loading Rate (tons/ft/yr) for each Site Type

These factors were applied to all of the stream channel segments for the Big Hole watershed, total sediment load from existing conditions calculated, and the results summarized by sub-watershed.

To estimate the sediment produced under best management practices, each stream segment in the watershed was assigned an extrapolation factor based upon that segment's potential vegetation type and density, total sediment load from BMP conditions calculated, and the results summarized by sub-watershed.

Example: A stream segment was classified by the aerial assessment as currently having moderate, herbaceous vegetation cover. This stream segment was also classified as having the potential to support dense willow cover. This stream segment would be assigned the extrapolation factor for moderate, herbaceous, underachieving (0.03 tons/ft/yr) to reflect its sediment delivery under existing conditions, and the factor for dense, willow, achieving (0.01) to reflect its potential sediment delivery under BMP.

Results

Table H-3 presents the existing and potential bank erosion loads by 6th code HUC sub-watershed. **Table H-4** presents the results reported by surface land ownership classification.

Table H-3. Bank erosion loads by 6th code HUC sub-watershed.

6th Code Huc WS (Mod for 303d)	Length of Streams in WS (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr)
Andrus Creek	158,037	3,106	1,411
Berry Creek	63,938	115	115
Big Swamp Creek	160,963	1,175	644
Big Hole River-Big Swamp Creek	219,221	4,645	2,034
Big Hole River-McVey Homestead	206,932	3,647	3,101
Big Hole River-Saginaw Creek	164,496	2,972	1,461
Big Hole River-Spring Creek	221,595	3,563	2,592
Big Hole River-Squaw Creek	88,626	1,252	902
Big Hole River-Wisdom	278,607	6,012	3,166
Big Lake Creek	279,616	5,167	2,373
Bull Creek	248,229	4,534	2,569
Doolittle Creek	104,967	596	360
Englejard Creek	166,425	1,392	953
Fox Creek	95,167	1,671	745
Francis Creek	139,896	1,625	1,203
Headwaters Big Hole River	150,887	909	741
Howell Creek	137,297	1,864	850
Johnson Creek	166,451	1,135	810
Joseph Creek	89,420	662	469
Little Lake Creek	155,528	1,525	1,013
Lower Governor Creek	237,202	5,645	2,735
Lower Rock Creek	91,825	2,500	1,766
Lower Trail Creek	178,277	772	759
Lower Warm Springs Creek	273,215	4,306	2,852
May Creek	110,953	409	409
McVey Creek	101,633	1,339	866
Miner Creek	173,301	1,326	1,152
Mussigbrod Creek	153,143	1,058	857
North Fork Bighole River	348,852	5,039	3,843
Old Tim Creek	109,531	1,581	1,198
Pine Creek	40,745	604	227
Pintler Creek	160,145	1,222	1,140
Plimpton Creek	277,692	3,225	2,307
Ruby Creek	238,309	1,715	1,598
Schulz creek	17,672	32	32
Stanley Creek	131,206	2,844	1,674
Steel Creek	164,910	1,755	910
Swamp Creek	281,630	4,123	2,889
Tie Creek	194,539	876	656
Upper Governor Creek	133,856	2,251	1,112
Upper Rock Creek	164,268	2,409	1,366
Upper Trail Creek	174,824	1,283	970
Upper Warm Springs Creek	121,202	1,460	1,133
West Fork Ruby Creek	137,982	878	832
Total for Upper Big Hole Watershed	7,313,208	96,218	60,796

Table H-4. Bank erosion rates by land ownership.

Ownership Classification	Length of Streams on ownership (ft)	Estimated Current Sediment Delivery (ton/yr)	Estimated Potential Sediment Delivery (ton/yr)
OTHER	3,315,581	67,915	39,037
State Government	315,199	6,236	4,201
US Government	1,502	20	18
USDA Forest Service	3,669,892	21,901	17,430
USDI National Park Service	11,034	147	110
Grand Total	7,313,208	96,218	60,796

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