APPENDIX E
HILLSLOPE SEDIMENT MODEL AND RIPARIAN HEALTH ADDENDUM

Erosion is the main source of nonpoint source sediment that results in siltation and habitat impairments. In addition, eroded sediment can carry nutrients, particularly phosphates, and contribute to eutrophication of lakes and streams. The two major types of erosion are geological erosion and erosion from human and animal activities (Ward and Trimble, 2004). Geological erosion results in the long-term development of topographic features such as stream channels, valleys, and canyons and contributes to soil formation. Residential and recreational development, tillage, road drainage and vegetation removal by humans and grazing animals may cause accelerated erosion. Other variables affecting erosion include climate, geology, soil properties, vegetation and topography.

Sources of sediment delivered to streams in the West Fork Gallatin River watershed include hillslope erosion, road disturbances, and stream bank erosion; each having some degree of human influence. This appendix describes development and application of a GIS-based computational model that predicts sediment eroded from hillslopes and delivered to streams.

Model Selection

Watershed models are a representation of physical processes in the natural environment. They depict, to the best of our knowledge, how these processes interact and result in landscape change. In this case, the processes are sediment erosion and deposition. The models chosen to assist with sediment TMDL development often utilize the Universal Soil Loss Equation (USLE – USDA, 1981). The USDA Soil Conservation Service (now the Natural Resources Conservation Service – NRCS) first developed the USLE in the 1960s. The USLE has evolved over time and its application has expanded. The evolution of GIS and associated spatial datasets in the last decade has allowed application of the USLE over large, watershed scale areas.

The model developed for this project is a modified version of the USLE (Universal Soil Loss Equation) model referred to as USPED (Unit Stream Power - based Erosion Deposition). This model was developed at the University of Illinois Geographic Modeling Systems Laboratory (Mitasova, et al., 2003). The model was constructed within ArcGIS, and uses the Spatial Analyst extension. The USPED model accounts for both sediment erosion and deposition in the hillslope erosion processes.

The USPED model is similar to the USLE model and is represented by the following equations.

Sediment Transport Capacity T=R*K*C*P*LS

T=Transport Capacity
R= rainfall erosivity index
K= soil erodibility index
C= soil cover factor
P= management factor
LS=$A^m \sin(\beta)^n$ (note: LS is slope length in the USLE)

Where:

A=upslope contributing area
β=Slope angle
m=1.6 (rill erosion dominant)
n=1.3 (rill erosion dominant)
m=n=1 (sheet erosion dominant)

Net erosion/deposition (ED) is then the divergence of transport capacity, T in both the downstream and perpendicular directions.

$$ED=\frac{d(T\cos a)}{dx} + \frac{d(T\sin a)}{dy}$$

ED= Net Erosion/Deposition
a= Aspect angle of terrain surface
dx, dy= Terrain Curvature (profile and tangential)

Model Construction

Model construction required identification of appropriate data sources, converting these data to a series of ESRI grid datasets with the same resolution and extent, and assembling the model grid datasets within an ArcGIS project. For this model, all grids were re-sampled to five-meter resolution.

Model construction also included segmentation of the West Fork Gallatin River watershed into sub-watersheds. Segmentation was based on the presence of major tributary streams or breaks in the 303(d) List streams. **Table E-1** below lists the sub-watersheds delineated.

Data Development

The West Fork Gallatin River was segmented into 14 sub-watersheds for load allocation purposes. Watershed breaks are based on 303(d) streams, major tributary streams, and natural and man-made breaks in watershed hydrology. The following table (**Table E-1**) lists the sub-watersheds, and **Figure E-1** shows their locations.

Table E-1. Sub-watershed delineation (upstream to downstream), West Fork Gallatin River.

ID	Sub-Watershed Name	Area (acres)	303(d) Watershed Name	Area (acres)
5	Uppermost Middle Fork West Fork Gallatin River	3,236	Middle Fork West Fork Gallatin River	11,505
1	Beehive Creek	2,065		
8	Middle Fork West Fork Gallatin River	6,204		
9	Upper South Fork West Fork Gallatin River	6,530	South Fork West Fork Gallatin River	29,654
11	Muddy Creek	5,772		
12	Third Yellow Mule Creek	2,306		
13	Second Yellow Mule Creek	2,887		
14	First Yellow Mule Creek	3,511		
10	South Fork West Fork Gallatin River	8,648		
2	North Fork West Fork Gallatin River	6,223	West Fork Gallatin River	10,078
6	Upper West Fork Gallatin River	553		
3	Crail Creek	1,366		
4	Lower West Fork Gallatin River	1,143		
7	Lowermost West Fork Gallatin River	792		

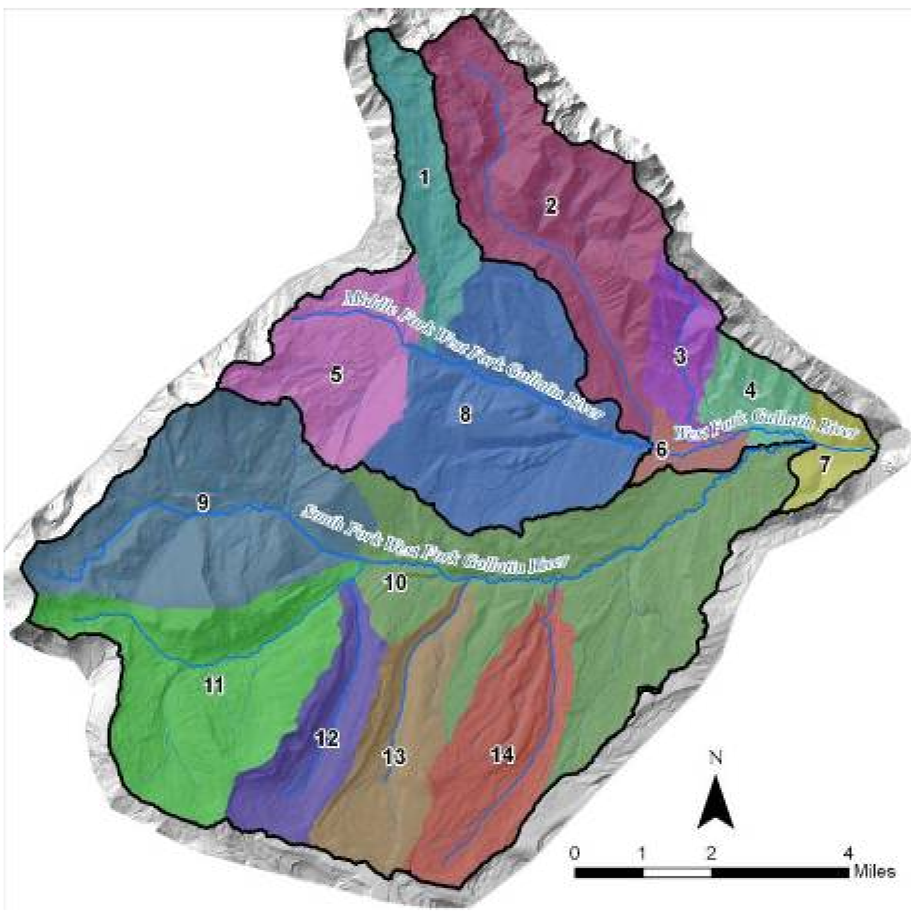

Figure E-1. Watershed segmentation.

Land Use and Land Cover

Developing the C-factor parameter for the USPED sediment model required a detailed data layer of land cover. This was derived from a 2008 MSU study (Campos, et al., 2008) that interpreted 13 land cover categories in the West Fork Gallatin River watershed using Quickbird satellite imagery and LIDAR elevation data. For this study, the MSU land cover data was simplified into six land cover categories as follows:

- Grass,
- Bare soil/sparse vegetation,
- Forest,
- Urban,
- Water, and
- Rock.

In order to determine the source of sediment loading, we developed a simple land use data layer using aerial photo interpretation, cadastral (land parcel) data from Montana Department of Revenue, and roads data. The resultant land use layer consists of three land use classes, residential, ski area, and none. None refers to no significant human land uses and is considered the naturally occurring condition. **Table E-2** summarizes land cover and land use in the three 303(d) List sub-watersheds and the entire project area. **Figures E-2** through **E-5** illustrates the distribution of land uses and land cover in the 303(d) watersheds.

Table E-2. Summary of land cover and land use data in the West Fork Gallatin River Watershed.

Land Use	Land Cover	Middle Fork West Fork Gallatin River (acres)	South Fork West Fork Gallatin River (acres)	West Fork Gallatin River (acres)	Project Area (acres)	Land Cover Percent of Project Area
Residential	Grass	974	1,602	880	3,457	43.5%
	Soil/Sparse Veg	498	348	150	995	12.5%
	Forest	1,437	1,049	492	2,979	37.4%
	Urban	132	82	58	272	3.4%
	Water	3	32	30	65	0.8%
	Rock	96	85	6	188	2.4%
	TOTAL	3,140	3,198	1,617	7,956	100.0%
Ski Area	Grass	660	299	0	959	18.5%
	Soil/Sparse Veg	115	141	0	255	4.9%
	Forest	1,702	1,564	0	3,265	62.9%
	Urban	5	4	0	9	0.2%
	Rock	232	469	0	701	13.5%
	TOTAL	2,713	2,476	0	5,189	100.0%
None (Naturally Occurring)	Grass	1,546	8,568	1,804	11,919	31.3%
	Soil/Sparse Veg	289	693	85	1,067	2.8%
	Forest	3,166	12,137	5,093	20,396	53.5%
	Water	10	0	0	11	0.0%
	Rock	640	2,581	1,479	4,699	12.3%
	TOTAL	5,652	23,979	8,460	38,092	100.0%

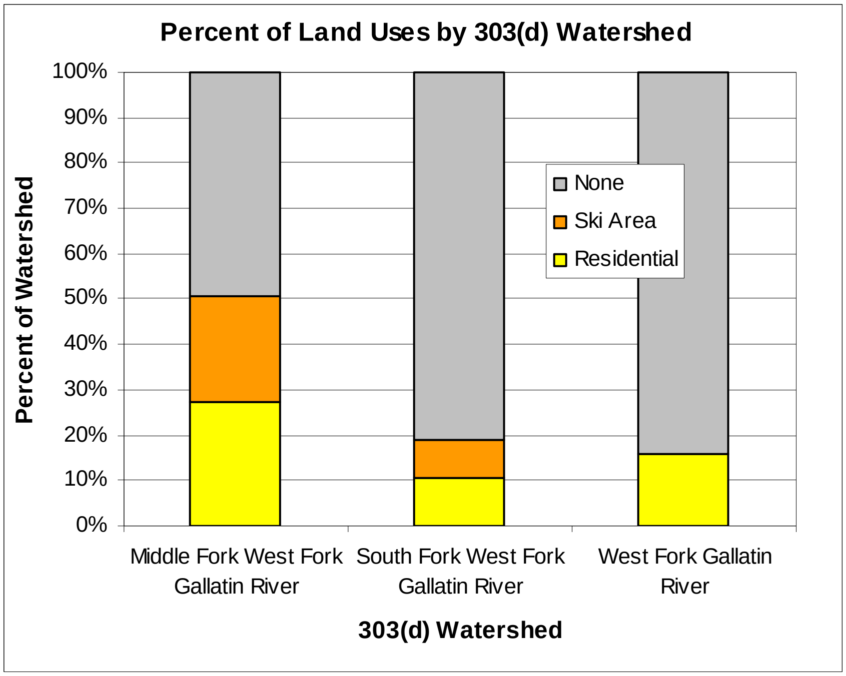

Figure E-2. Percent of land uses in the 303(d) watersheds.

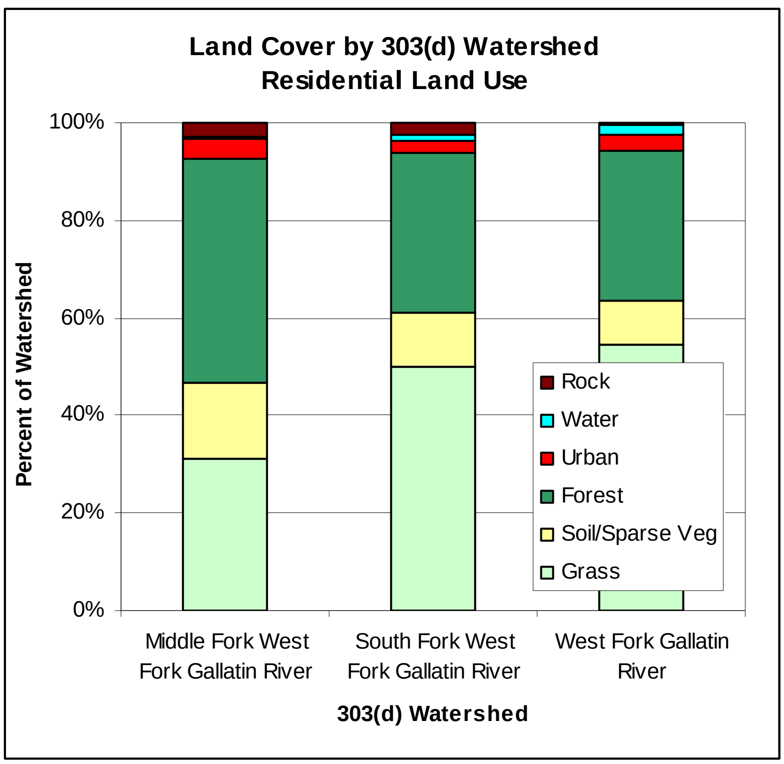

Figure E-3. Distribution of land cover in areas with residential land use in the 303(d) watersheds.

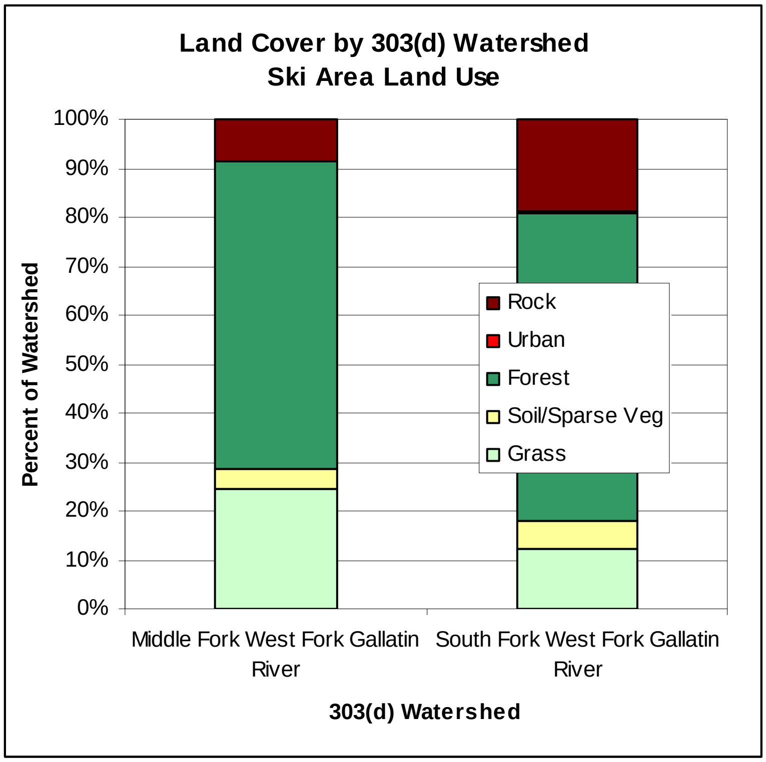

Figure E-4. Distribution of land cover in areas with ski area land use in the 303(d) watersheds.

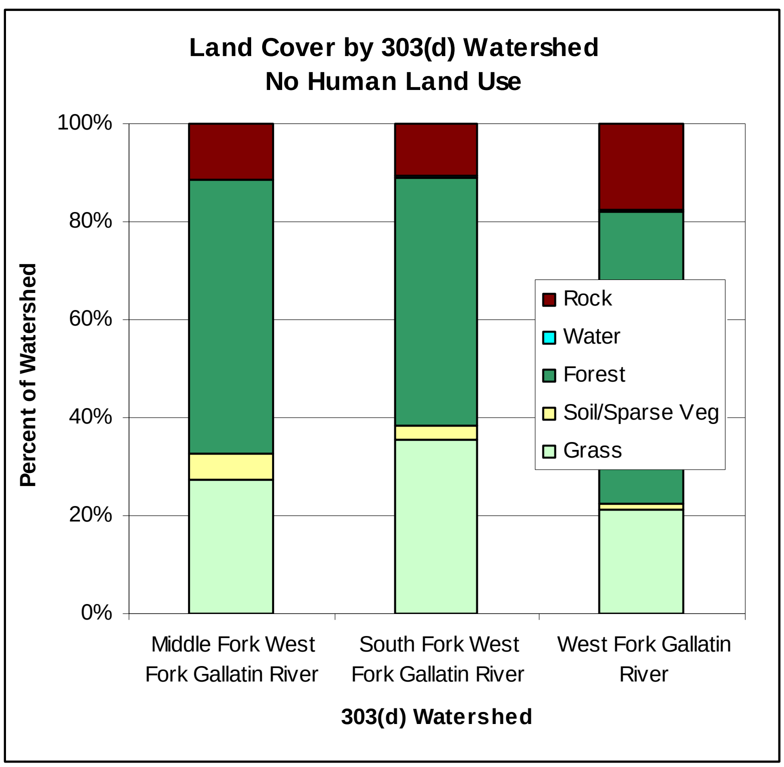

Figure E-3. Distribution of land cover in areas with no significant human land use in the 303(d) watersheds.

Table E-3 summarizes the data sources utilized for each of the model input parameters, the data processing steps, and related comments. All input datasets were downsampled to five-meter resolution and converted to ESRI grid format for use within an ArcGIS model. In hindsight, the high resolution of these datasets increased computation time and data storage requirements. A maximum resolution of ten meters for future similar modeling efforts would be sufficient.

Table E-3. Summary of data sources used to construct the West Fork Gallatin River watershed USPED hillslope erosion model.

Model Input	Source Data	Processing Steps	Comments
R- Rainfall Erosivity Index	USDA, 1981	Insert constant value (R=20) into grid calculations	USDA, 1981 indicates that the rainfall erosivity constant is equal to 20 for the region including the watershed
K – Soil Erodibility Index	K factor from NRCS digital soil surveys (Gallatin County, Madison County, and Gallatin National Forest).	Merge shapefiles, convert shapefile into 5m grid using K factor as the cell value	Some inconsistencies where datasets edge match.
C – Cover Soil Factor	MSU Land Use Land Cover (LULC) Dataset (Campos, et al. 2008)	Classification scheme simplified, data downsampled from 1m to 5m and converted to grid.	Combinations of MSU LULC simplified cover classes and major land uses for categories for C-factor determination. C-factors assigned through literature review and collaboration with MDEQ.
	Major land uses interpreted from imagery (this study).	Interpretation and heads up digitizing of major land uses (residential and ski area)	
P – Management Factor	Collaborative efforts with MDEQ to develop P-factors that represent the two model scenarios (current and desired conditions)	Reclassify the C-factor grid to create the two P-factor grids	See Table X-4 below for more detail on P-factor development.
A – Upslope contributing areas	Flow accumulation grids derived from 1m resolution LiDAR elevation dataset (Campos et al., 2008)	Downsample 1m LiDAR to 5m resolution. Fill sinks, calculate flow direction, and flow accumulation grids.	
β – Slope Angle	LiDAR elevation data	Slope function in ArcGIS	
m, n	The values for rill dominated systems were used. Sheet flow is characteristic of tilled agricultural settings and is not relevant for this setting.	m=1.6 and n=1.3 were incorporated in the raster calculations of the model.	
A – aspect angle	LiDAR elevation data	Aspect function in ArcGIS	

Figures E-6 and **E-7** below illustrate some of the critical input ESRI grid data sets for the USPED model for the West Fork Gallatin River watershed.

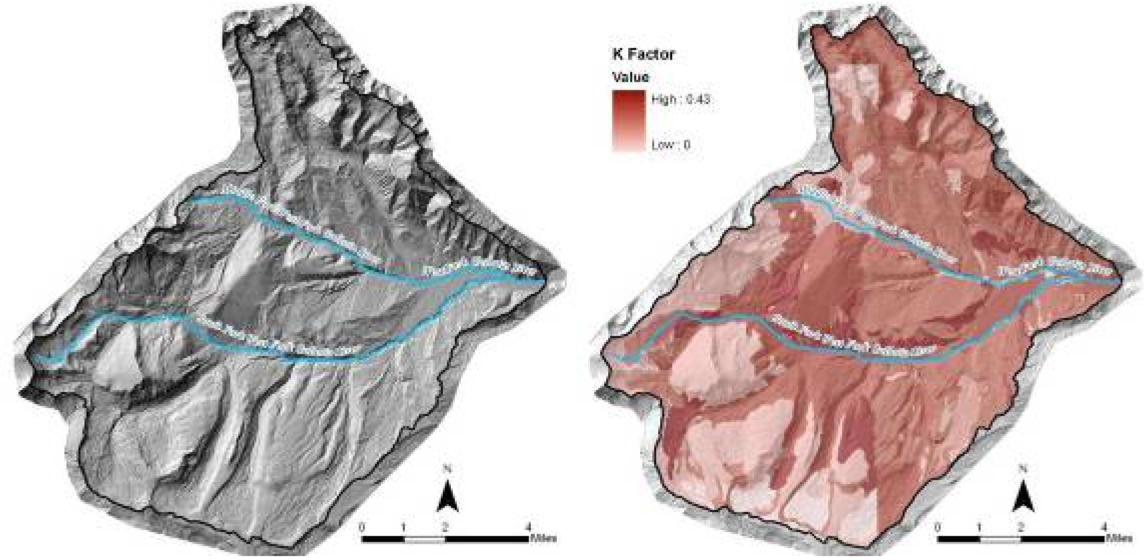

Figure E-6. Hillshade of LiDAR 5 meter DEM (left) and K factor derived from SSURGO soils (right) for the West Fork Gallatin River watershed. Examples of grid dataset inputs.

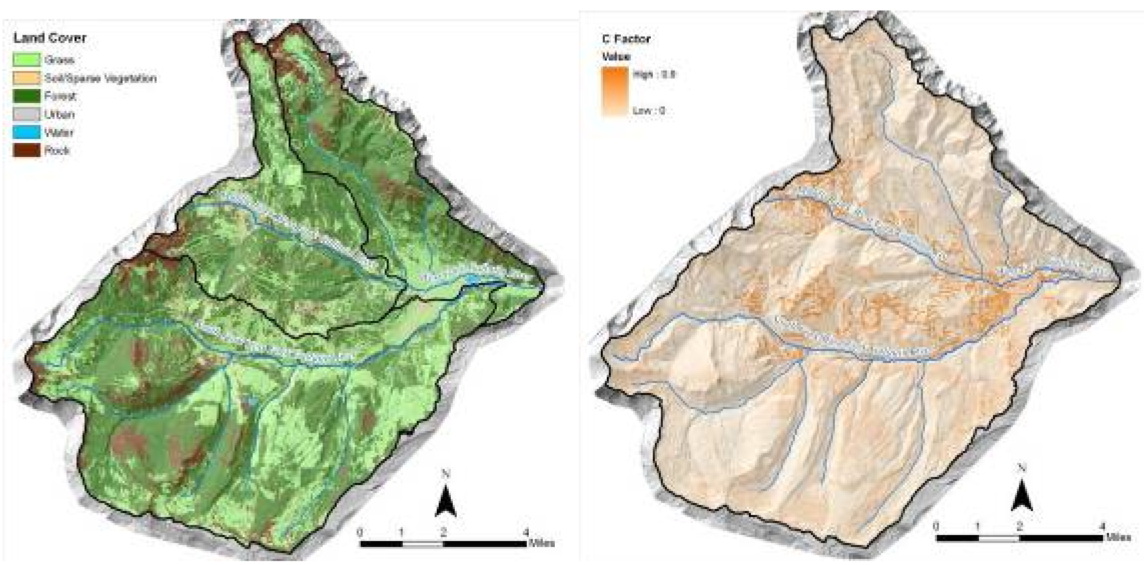

Figure E-7. Simplified land cover dataset derived from the Quickbird-LIDAR interpretation (Campos et al., 2008) (left) and C-factor dataset (right).

C-Factor

C factor in the USPED (and USLE) model is the cover and management factor. It is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land. In the model developed for this project, C-factor represents the vegetative land cover and its ability to retain sediment. For this project, the project team and Montana DEQ personnel developed C factors for the land uses and cover types in the watershed using field observations and literature values (Engel, 2001) for guidance. **Table E-4** illustrates the correlation between canopy cover, ground cover, and vegetation type with C factor from Engel, 2001, and **Table E-4** lists the C factors used for the West Fork model for both the existing condition and desired condition scenarios. These C-factors are based on estimated canopy covers for grass and bare ground dominated areas with various land uses. These values reflect expected values for areas without any BMPs or re-vegetation and are essentially a worst-case scenario.

Areas with "grass" land cover have the same C factor regardless of land use. This is because the "grass" land cover category contains areas with substantial grass cover and good sediment retention capabilities. Areas with these higher levels of grass cover should have similar sediment yields regardless of land use. Forest, urban, rock, and water land cover categories have low C-factors of 0.004, 0.03, 0.001, and 0.0 respectively, based on literature values (Ma, 2001). These are the same for both the current conditions and desired conditions scenarios. The soil/sparse vegetation land cover category can vary from completely bare soil to areas with some grass cover. The C factor for soil/sparse vegetation with a residential land use is high (0.9), and reflects ground clearing associated with construction. By comparison, the C factor for soil/sparse vegetation within ski areas is more moderate (0.3) and reflects construction and maintenance to ski areas, which is less likely to leave as much bare ground as residential/resort development.

Table E-4. C factor table for various levels of ground and canopy cover from Engel, 2001.

Vegetal Canopy			Cover That Contacts the Surface					
Type and Height	Canopy		Percent Ground Cover					
of Raised Canopy[2]	Covers[3] %	Type[4]	0	20	40	60	80	95-100
No appreciable canopy		G	0.45	0.2	0.1	0.042	0.013	0.003
		W	0.45	0.24	0.15	0.09	0.043	0.011
Canopy of tall weeds	25	G	0.36	0.17	0.09	0.038	0.012	0.003
or short brush,		W	0.36	0.2	0.13	0.082	0.041	0.011
0.5 m (1.6 ft.) fall ht.	50	G	0.26	0.13	0.07	0.035	0.012	0.003
		W	0.26	0.16	0.11	0.075	0.039	0.011
	75	G	0.17	0.1	0.06	0.031	0.011	0.003
		W	0.17	0.12	0.09	0.068	0.038	0.011
Appreciable brush	25	G	0.4	0.18	0.09	0.04	0.013	0.003
or bushes,		W	0.4	0.22	0.14	0.085	0.042	0.011
2 m 6.6 ft. fall ht.	50	G	0.34	0.16	0.085	0.038	0.012	0.003
		W	0.34	0.19	0.13	0.081	0.041	0.011
	75	G	0.28	0.14	0.08	0.036	0.012	0.003
		W	0.28	0.17	0.12	0.077	0.04	0.011
Trees but no appreciable	25	G	0.42	0.19	0.1	0.041	0.013	0.003
low brush ,		W	0.42	0.23	0.14	0.087	0.042	0.011
4 m (13.1 ft.) fall ht.	50	G	0.39	0.18	0.09	0.04	0.013	0.003
		W	0.39	0.21	0.14	0.085	0.042	0.011
	75	G	0.36	0.17	0.09	0.039	0.012	0.003
		W	0.36	0.2	0.13	0.083	0.041	0.011

[1]All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years.

[2]Average fall height of waterdrops from canopy to soil surface.

[3]Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a birds's-eye view).

[4]G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep. W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, and/or undecayed residue).

Table E-5. C factors developed for land use and land cover types in the West Fork Gallatin River watershed.

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	0.05	0.05	0.05
	Soil/Sparse Veg	0.9	0.3	0.1
	Rock	0.001	0.001	0.001
	Forest	0.004	0.004	0.004
	Urban	0.03	0.03	N/A
	Water	0	0	0

Existing BMP Implementation

Field observations indicate that residential and ski development areas have varying levels of BMPs installed to mitigation sediment runoff. In general, more recent construction has a higher level of BMPs than older development. However, recent development has taken place in steeper areas with more erosive soils that require more actions to mitigate sediment. Prior to model development, a coarse field review of existing BMPs was conducted. Observed BMPs include:

- Fiber wattles and straw bales at stream crossings and in drainage ditches,
- Rock lined storm water conveyance ditches,
- Storm water retention ponds with rock armored inlet and outlet channels,
- Storm water diversion channel with erosion blankets,
- Silt fencing at road crossings and active construction sites,
- Log terracing on hillslopes, and
- Inlet and outlet protection at culverts.

Photographs of these BMPs are included at the end of this appendix. (Photos 1-6)

Association Between BMPs and Desired Load Reductions

BMP efficiencies vary by the type of BMP implemented. Literature values suggest 85 percent sediment reduction is achievable with full implementation of vegetated buffer BMPs and is therefore used as the reduction capacity for the desired conditions scenario within the model. The following studies support the 85 percent BMP reduction factor:

- Oat buffer strips, six meters long, reduced sediment by 76 percent (Hall et al.., 1983).
- Mickelson et al. (2003) determined that the first few meters of the buffer strip trapped the majority of deposited sediment. Buffer strips 4.6 meters long and with a drainage area to buffer strip area ratio of 10:1 reduced sediment by 71 percent while the 9.1 meters long buffer strip with a ratio of 5:1 reduced sediment delivery by 87 percent.
- Grassed waterways reduced suspended sediment concentrations by 94 and 98 percent in wet and dry antecedent moisture conditions, respectively (Asmussen et al., 1977).
- Han et al. (2005) determined that vegetative filter strips, 10 meters in length, were effective at removing more than 85 percent of the incoming total suspended sediment from highway runoff.

P-Factor

P factor is the conservation or support practice factor. Within the USPED model used for this project, P factor is used as a coefficient that represents the level of change in C-factor associated with improvement in land condition or BMPs. Therefore, two separate sets of P factors were used for the two model scenarios: current conditions and that associated with the use of all reasonable land, soil, and water conservation practices (i.e. desired conditions). This recognizes the general level of BMP implementation currently in place and also the potential for reductions in loading associated with additional BMP usage. Because the C factor is multiplied by the P factor within the model, values within **Table E-4** were also used during the development of P factors. As shown in **Tables E-6** and **E-7**, which contain the P factors for each scenario, all P factor values are equal to one with the exception of "Soil/Sparse Vegetation" land cover located in residential or ski area land uses. Therefore, these are the only areas that will have appreciable differences in sediment production between the two model scenarios.

Table E-6. P factors developed for land use and land cover types in the west Fork Gallatin River watershed, current conditions model scenario.

		Land Use		
		Residential	**Ski Area**	**Other**
Land Cover	**Grass**	1	1	1
	Soil/Sparse Veg	0.22	0.67	1
	Rock	1	1	1
	Forest	1	1	1
	Urban	1	1	1
	Water	1	1	1

Table E-7. P factors developed for land use and land cover types in the west Fork Gallatin River watershed, desired conditions model scenario.

		Land Use		
		Residential	**Ski Area**	**Other**
Land Cover	**Grass**	1	1	1
	Soil/Sparse Veg	0.14	0.4	1
	Rock	1	1	1
	Forest	1	1	1
	Urban	1	1	1
	Water	1	1	1

Effective C-Factor

The effective C factor is the product of the C and P factors and is a result of the baseline condition modified by the use of BMPs. For example, the P factor under the current conditions scenario for soil/sparse vegetation is 0.22 for residential areas and 0.67 for ski areas, which represents the greater potential for erosion-reducing BMPs in the more highly disturbed soil/sparse vegetation of the residential areas. When multiplied by their respective C factor (0.9

for residential and 0.3 for ski areas), it yields an effective C factor of 0.2 for the current conditions scenario of both land use categories. This represents a 78 percent reduction in erosion in the model within residential areas and a 33 percent reduction in ski areas as a result of existing BMPs (the effect on deposition is variable across the landscape). The effective C factor values also correlate with the C factors in **Table E-5**; a C factor of 0.2 corresponds to an area with no appreciable canopy and 20 percent ground cover and a C-factor of 0.1 represents approximately 40 percent ground cover (grass, litter) with minimal canopy cover.

For the desired conditions scenario for sparsely vegetated ground cover in residential areas, the C factor multiplied by P factor is 0.12 (0.9*0.14=0.12). This gives an effective C factor of 0.12, which is just slightly more than the 0.1 value for the naturally occurring condition ("Other" land use category). This correlates to a C factor for no appreciable canopy cover and close to 40 percent ground cover in **Table E-5**. Note that the change in P factor from current to desired conditions reduces C factor by an additional seven percent (i.e. 78 to 85 percent reduction). This recognizes the potential for additional BMP implementation but also the significant level of BMPs and revegetation currently in place that serve to reduce sediment loading to streams. This scenario is illustrated in the flow chart in **Figure E-8**.

Current Conditions Model Scenario

C Factor
(Base Condition – No BMPs)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	0.05	0.05	0.05
	Soil/Sparse Veg	0.9	0.3	0.1
	Rock	0.001	0.001	0.001
	Forest	0.004	0.004	0.004
	Urban	0.03	0.03	0.03
	Water	0	0	0

X

P Factor
(Existing BMP Correction Factor)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	1	1	1
	Soil/Sparse Veg	0.22	0.67	1
	Rock	1	1	1
	Forest	1	1	1
	Urban	1	1	1
	Water	1	1	1

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Effective C Factor
(Existing Load)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	0.05	0.05	0.05
	Soil/Sparse Veg	0.2	0.2	0.1
	Rock	0.001	0.001	0.001
	Forest	0.004	0.004	0.004
	Urban	0.03	0.03	0.03
	Water	0	0	0

Desired Conditions Model Scenario

C Factor
(Base Condition – No BMPs)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	0.05	0.05	0.05
	Soil/Sparse Veg	0.9	0.3	0.1
	Rock	0.001	0.001	0.001
	Forest	0.004	0.004	0.004
	Urban	0.03	0.03	0.03
	Water	0	0	0

X

P Factor
(Potential BMP Correction Factor)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	1	1	1
	Soil/Sparse Veg	0.14	0.4	1
	Rock	1	1	1
	Forest	1	1	1
	Urban	1	1	1
	Water	1	1	1

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Effective C Factor
(Desired Load)

		Land Use		
		Residential	**Ski Area**	**None**
Land Cover	**Grass**	0.05	0.05	0.05
	Soil/Sparse Veg	0.12	0.12	0.1
	Rock	0.001	0.001	0.001
	Forest	0.004	0.004	0.004
	Urban	0.03	0.03	0.03
	Water	0	0	0

Figure E-8. Flow chart showing the relationship between C factor and P factor in the USPED model.

ArcGIS Model

Several preliminary models were developed in order to test the USPED model and to calibrate results with literature-based values for similar geographic and climatic settings. Two final model scenarios were then generated that provide the information necessary for TMDL development. These are a current conditions scenario and a desired conditions scenario. The desired conditions model scenario meets the criteria of "naturally occurring", which means conditions over which man has no control or from developed land where all reasonable land, soil, and water conservation practices have been applied (ARM, 2005).

The input model grids were assembled in an ArcGIS project. Numeric calculations to the grid datasets were completed using a series of grid statements input into the ArcGIS Spatial Analyst raster calculator. All grid statements are included with the portable ArcGIS project that accompanies this document. The model output consists of an erosion/deposition grid with both negative (erosion) and positive (deposition) values. Summarizing the grid values within a polygon allows tallying the net erosion or deposition within that polygon. Results were summarized by sub-watershed and by land use (see below).

Results

Table E-8 summarizes the estimated annual sediment load associated with the current condition and desired condition scenarios, and the associated reductions in sediment load. Loads are presented by land use category within each 303(d) listed watershed but also include additional sub-watersheds and the total load for each listed watershed.

The percent reductions are the differences in predicted sediment delivered to streams between the current conditions model and the desired conditions model. Sediment reductions are listed for residential and ski area land uses within the sub-watersheds. No reductions are associated with the naturally occurring load ("none" in the land use column). The model results predict that 82,811 tons/year of sediment erodes from hillslopes and is delivered to streams annually. The model further predicts that via additional BMP implementation, the total sediment load can be reduced for the three 303(d) watersheds by 3,453 tons/year.

Examining the sediment loads by land use indicates that under current conditions, 66 percent of sediment loading is from areas without human impacted land uses, 26 percent is from residential areas, and eight percent is from ski areas. The desired condition overall represents a four percent reduction in total sediment from hillslope erosion. However, this reduction requires a 13 percent reduction in hillslope sediment from residential areas and a nine percent reduction in hillslope sediment from ski areas.

Table E-9 summarizes sediment loads by land use, 303(d) watershed, and the entire project area watershed. For the project area, desired sediment loads are 11 percent lower than existing conditions in residential areas and eight percent lower than existing conditions at ski areas. For the entire project area watershed, desired sediment loads from hillslopes are four percent lower than existing conditions. Note: **Tables E-8** and **E-9** do not account for the riparian buffer health, which is incorporated into the attached Riparian Health Addendum.

Table E-8. Results of hillslope sediment modeling, West Fork Gallatin River watershed.

Watershed Information					Current Conditions			Desired Reductions		
303(d) Watershed	**Sub-Watershed**	**Area (acres)**	**Land Use**	**Area (acres)**	**Sediment (tons/yr)**	**Sediment (tons/yr)**	**Sediment (tons/yr)**	**Sediment Reduction (tons/yr)**	**Percent Reduction from Current Conditions**	**Sediment Reduction (tons/yr)**
Middle Fork West Fork Gallatin River	Uppermost Middle Fork West Fork Gallatin River	3236	None	704	976	4,954	19,853	0		1,726
			Residential	945	1,054			92	9%	
			Ski Area	1,587	2,924			310	11%	
	Beehive Creek	2065	None	1,654	768	3,230		0		
			Residential	411	2,462			135	5%	
	Middle Fork West Fork Gallatin River	6204	None	3,205	3,570	11,669		0		
			Residential	1,873	6,702			1,088	16%	
			Ski Area	1,126	1,397			101	7%	
South Fork West Fork Gallatin River	Upper South Fork West Fork Gallatin River	6530	None	3,843	3,184	6,579	47,212	0		1,287
			Residential	626	1,458			753	52%	
			Ski Area	2,061	1,938			147	8%	
	Third Yellow Mule Creek	2306	None	2,289	1,553	1,556		0		
			Residential	17	2			0	6%	
	Muddy Creek	5772	None	5,355	6,450	7,013		0		
			Residential	2	4			0	0%	
			Ski Area	415	559			18	3%	
	Second Yellow Mule Creek	2887	None	2,865	2,558	2,570		0		
			Residential	23	12			3	22%	
	First Yellow Mule Creek	3511	None	3,511	3,689	3,689		0		
	South Fork West Fork Gallatin River	8648	None	6,115	20,542	25,805		0		
			Residential	2,533	5,263			365	7%	

Table E-8. Results of hillslope sediment modeling, West Fork Gallatin River watershed.

Watershed Information					Current Conditions			Desired Reductions		
303(d) Watershed	**Sub-Watershed**	**Area (acres)**	**Land Use**	**Area (acres)**	**Sediment (tons/yr)**	**Sediment (tons/yr)**	**Sediment (tons/yr)**	**Sediment Reduction (tons/yr)**	**Percent Reduction from Current Conditions**	**Sediment Reduction (tons/yr)**
West Fork Gallatin River	North Fork West Fork Gallatin River	6223	None	5,747	5,612	6,867	15,746	0		440
			Residential	476	1,255			149	12%	
	Upper West Fork Gallatin River	553	None	60	159	806		0		
			Residential	493	647			152	23%	
	Crail Creek	1366	None	1,093	323	749		0		
			Residential	273	426			9	2%	
	Lower West Fork Gallatin River	1143	None	904	872	2,388		0		
			Residential	239	1,516			31	2%	
	Lowermost West Fork Gallatin River	792	None	658	4,230	4,937		0		
			Residential	134	707			99	14%	
			TOTALS	51,238	82,811		82,811	3,453		3,453

Table E-9. Sediment loads summarized by land use and 303(d) watershed.

Watersheds	Current Conditions			Desired Reductions		
303(d) Watershed	**Land Use**	**Acres**	**Sediment (tons/yr)**	**Sediment Rate (tons/ac/yr)**	**Desired Load (tons/yr)**	**Percent Reduction from Current Conditions**
Middle Fork West Fork Gallatin River	None	5,563	5,314	1.0	5,314	0%
	Residential	3,229	10,218	3.2	8,903	13%
	Ski Area	2,713	4,321	1.6	3,910	10%
	All Uses	11,505	19,853	1.7	18,126	9%
South Fork West Fork Gallatin River	None	23,978	37,977	1.6	37,977	0%
	Residential	3,200	6,739	2.1	5,983	11%
	Ski Area	2,476	2,497	1.0	2,331	7%
	All Uses	29,654	47,212	1.6	46,291	2%
West Fork Gallatin River	None	8,462	11,196	1.3	11,196	0%
	Residential	1,616	4,550	2.8	4,210	7%
	Ski Area	0	0	0.0	0	0%
	All Uses	10,078	15,746	1.6	15,406	2%
Project Area (Entire West Fork Gallatin River Watershed	None	38,004	54,487	1.4	54,487	0%
	Residential	8,045	21,507	2.7	19,095	11%
	Ski Area	5,189	6,818	1.3	6,241	8%
	All Uses	51,238	82,811	1.6	79,823	4%

Model Uncertainty

Natural processes such as sediment erosion and delivery, associated with rainfall and runoff are infinitely complex. Modeling of these processes requires significant simplification. Notably, the model has limited temporal resolution, and does not account well for seasonal and event scale processes. The USPED model created for the West Fork Gallatin River provides estimates of average annual sediment loads. Examples of similar models in the literature typically over predict annual sediment loads under normal or low runoff conditions and under predict annual loads under high runoff conditions. Therefore, the intent is that the average annual sediment load predicted should be applicable over long periods of time that include both low, average, and high runoff years. It is possible that sediment delivery to streams in a watershed such as the West Fork Gallatin River can be minimal for many consecutive years and then very high during the next year.

The results of the West Fork Gallatin River model predict areas where relatively large amounts of sediment are delivered to streams. These are areas that should be examined more closely to locate areas where BMPs would be most beneficial.

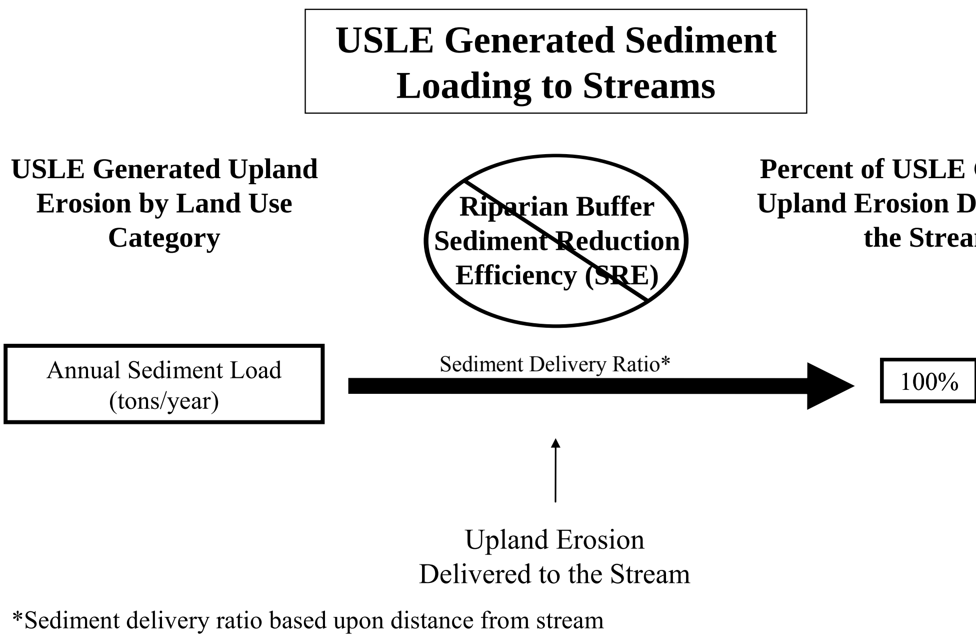
RIPARIAN HEALTH ADDENDUM

Upland Erosion Loading Corrected for Existing and Potential Riparian Buffer Condition

Introduction

The upland erosion modeling effort did not take into account the effect that vegetated riparian buffers have on reducing the upland sediment load delivered to streams. **Figure E-9** depicts the modified USLE modeling process without the influence of riparian buffers included; therefore, it models 100 percent of the USLE generated annual sediment load being delivered to the stream network. Because riparian buffers play a large role in reducing sediment (and other pollutant) loading to streams, a secondary effort to qualify and quantify the influence of riparian buffers was undertaken and is presented here.

Figure E-9. USLE Upland Sediment Modeling Negating the Influence of the Riparian Buffer.



This secondary effort provides an additional assessment of the sediment loading from upland sources routed through the existing riparian buffer condition, as well as an assessment of potential sediment loading reductions gained through the application of Best Management Practices (BMPs) to those activities whose actions within the near stream riparian environment have the potential to affect the buffering capacity (i.e. sediment reduction efficiency) of the vegetated riparian buffer.

Although regulations allow that loadings "may range from reasonably accurate estimates to gross allotments" (Water quality planning and management, 40 CFR § 130.2(G)), riparian buffers play a large role in reducing sediment delivery to stream channels, and adjusting the modeled upland sediment loads to reflect this should result in loading estimates that are closer in magnitude to reality. However, it is important to recognize that the results are not actual loading values and more emphasis should be placed on the potential reductions in loading that can be achieved via implementation of upland and riparian BMPs.

Effect of Riparian Buffers on Sediment Loading to Streams

Vegetated riparian buffers function as filters that protect adjoining streams and downstream receiving waters (Martin, 1999). By minimizing disturbance and encroachment, riparian buffers protect and enhance the filtering functions through which riparian corridors sequester and remove sediments, nutrients, and a range of contaminants. These water quality services result from filtration, adsorption, and entrainment by riparian vegetation. Vegetated riparian buffers disperse concentrated or channelized runoff, increasing infiltration, slowing surface runoff, and enhancing the deposition of sediment and sediment associated contaminants from both overland flows and overbank floodwaters (CRWP 2006). Buffers create complex flowpaths that slow the velocity and decrease the turbulence in overland flow. Shallow distributed flow enhances sedimentation and the removal of sediment-associated contaminants while increasing infiltration and reducing surface runoff (Leeds-Harrison, 1999 and Burt, 1999).

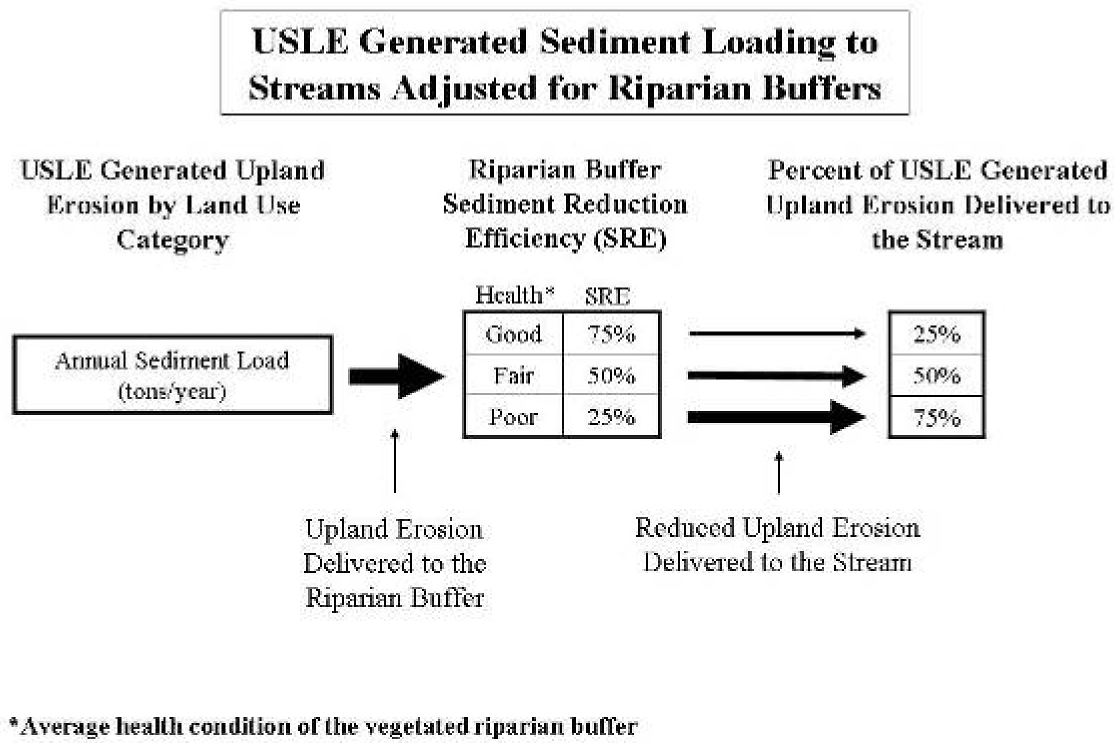
Vegetated riparian buffers maintain the connectivity and exchange of surface water and ground water between rivers and uplands. Maintaining riparian zones and effective land use practices within these zones are widely recognized as two valuable strategies to prevent the degradation of water quality services provided by these essential riparian processes (Hancock, 2002). Because of their ability to reduce upland sources of pollutants, the influence of riparian corridors on water quality is proportionately much greater than the relatively small area in the landscape they occupy. That is, the effectiveness of vegetated riparian buffers is proportional to their widths and overall health.

Sediment removal efficiency relationships developed by Castelle and Johnson (2000) estimated near 80% sediment removal and 65% particulate organic matter removal across a comparable buffer width. Results from within Montana suggest that the application of an 11 meter buffer strip can provide for a uniform loading reduction of 25% generated from upland erosional sources (Middle Blackfoot TMDL). This 25% reduction is significantly lower than those reported in the literature. Other research in southwest Montana reported greater than 90% removal of coarse textured sediment with a six meter buffer on bunchgrass uplands (Hook 2003).

For this analysis, a sediment reduction efficiency of 75% was assumed to represent the loading condition for a healthy (Good) vegetated riparian buffer. This value better reflects those reported in the literature and is closer to results reported for Montana settings while allowing for some hillslope loading from developed and disturbed land. With 75% removal, 25% of the USLE generated upland hillslope load is delivered to the stream and assumed to be the natural occurring annual maximum load from upland hillslope erosion. The remaining 75% of the load is assumed to be controllable by riparian health and associated buffering capacity.

As the condition of the vegetated riparian buffer declines or is degraded, sediment reduction efficiencies of 50% and 25% are then assumed to represent the loading condition for moderately disturbed (Fair) and heavily disturbed (Poor) conditions. That is, as the overall health of the vegetated riparian buffer is degraded, hence reducing its buffering capacity (sediment reduction efficiency), sediment loading delivered to the stream from upland sources increases. With 50% and 25% removal, 50% and 75% of the USLE generated upland erosion is delivered to the stream (**Figure E-10**).

Figure E-10. USLE Upland Sediment Load Adjusted for Riparian Buffer Capacity.



Modeling Approach and Example

This section outlines the approach that was implemented to evaluate the effect that vegetated riparian buffers have on sediment production within the Upper Gallatin TPA.

Desired results from the modeling effort include the following: (1) annual USLE based sediment load from each of the water quality limited segments on the state's 303(d) List corrected for the existing riparian buffer condition, (2) the mean annual source distribution from each land category type, and (3) annual potential USLE based sediment load from each of the water quality limited segments after the application of upland and riparian buffer BMPs.

Based on these considerations, a simple spreadsheet modeling approach was formulated to facilitate data manipulation, and supply output for this effort. The modeling approach is provided below and for clarity's sake, an example is provided for Beehive Creek, which is a tributary to the Middle Fork West Fork Gallatin River.

USLE Based Existing Upland Sediment Load Corrected for the Existing Riparian Buffer Condition

This section defines the process by which the existing USLE upland sediment loads provided in **Table E-8** were corrected for the existing riparian buffering condition to more accurately predict the existing sediment load. The existing riparian buffer condition was derived from *Aerial Assessment Reach Stratification Upper Gallatin TMDL Planning Area* (**Appendix E**), in which riparian health was qualified as Good, Fair or Poor (see example **Table E-10,** also **Figure E-11**).

Figure E-11. Existing Riparian Buffer Condition in the West Fork Gallatin River Watershed.

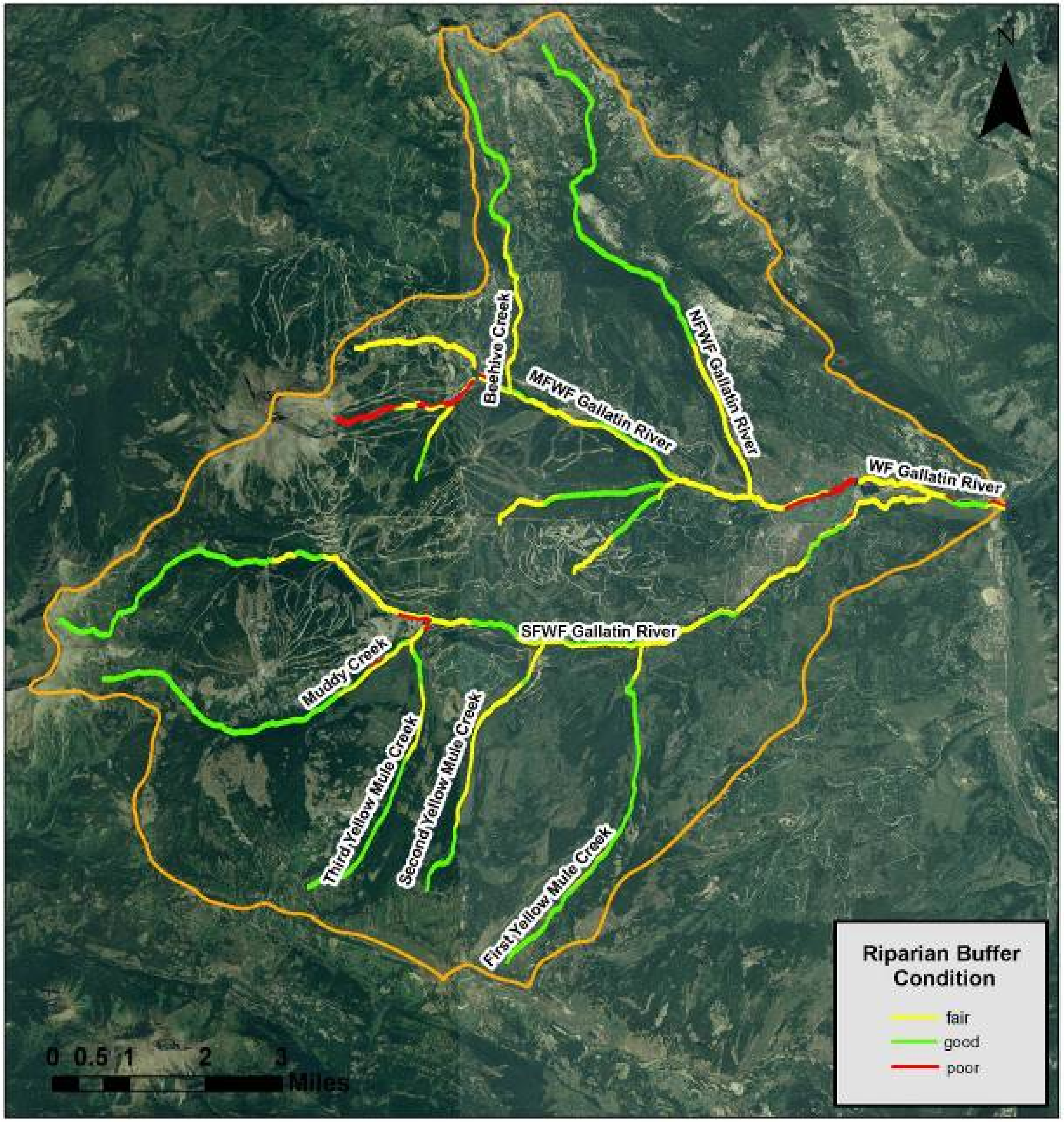


Table E-10. Existing Riparian Buffer Condition as a Percent of the Total Stream Length: Beehive Creek.		
Existing Riparian Buffer	**Stream Length (mi)**	**Percent of Total Length**
Good	5.7	60%
Fair	3.9	40%
Poor	0.0	0%
Total	9.6	100%

In the example above, Beehive Creek has a total stream length of 9.6 miles when both banks are included. Of those 9.6 miles of stream, the existing health condition of the riparian buffer was defined as consisting of 5.7 miles of Good, 3.9 miles of Fair, and 0.0 miles of Poor; representing 60, 40 and 0 percent of the total stream length, respectively.

Once the existing condition of the riparian buffer was generated by sub-watershed following the procedure above, the existing upland sediment load generated from the USLE model was partitioned by land-use into one of the three riparian health categories based upon the relative percent of the total stream length for each category. Next, the portioned load was reduced by the appropriate sediment reduction efficiency for that riparian health category and then summed to represent the delivered upland sediment load corrected for the existing riparian buffer condition (see example **Table E-11**). Note: Riparian health classifications are not spatially related to land use categories but approximate conditions at the watershed scale.

Table E-11. Upland Erosion USLE Generated Load Adjusted for the Existing Riparian Buffer Condition: Beehive Creek.

Sources	Upland Erosion USLE Generated Load: Existing Condition (tons/yr)	Load Partitioned for Existing Riparian Health Condition (tons/yr)			Delivered Load: Upland Erosion USLE Load Corrected for Existing Riparian Health Condition (tons/yr)
		Good (60%)*	Fair (40%)*	Poor (0%)*	
Natural**	768	144	96	0	240
Residential	2462	366	498	0	865
Total	3230	510	594	0	1105

*The percent value relates to the percent of the total stream length categorized as having that health category.
**Natural sources evaluated using 75% Good, 25% Fair, and 0% Poor riparian health conditions.

In the example above, Beehive Creek has a total upland USLE based modeled load of 3230 tons of sediment per year. This load represents the amount of sediment generated from the existing upland sources and their existing condition. This load was then portioned based upon the existing riparian condition. For example, the sediment load generated from residential sources of 2462 tons/year is partitioned between the riparian health categories based upon their relative watershed extent and then reduced based upon the sediment reduction efficiencies for each health category. For example, at the watershed scale of the 2462 tons/year produced in Beehive Creek from residential sources, 60% of the load was portioned and routed through a Good riparian buffer with a sediment reduction efficiency of 75%, yielding 366 tons of sediment per year for that health category. In addition, 40% of the residential load was portioned and routed through a Fair riparian buffer a sediment reduction efficiency of 50%, yielding 498 tons of sediment per year for that health category. For natural sources (which are assumed to areas where all reasonable BMPs are in place), the existing riparian condition is assumed to be meeting its potential, and the existing load was portioned as 75% Good and 25% Fair. The sediment yields were then summed to represent the delivered sediment load from residential sources corrected for the existing riparian buffer condition (865 tons/year). **Figure E-12** graphically depicts this Beehive Creek example. Therefore, in Beehive Creek, the existing USLE based upland sediment load of 3230 tons/year from all sources was reduced to 1105 tons/year representing the modeled existing upland sediment load delivered to the stream.

USLE Based Upland BMP Sediment Load Corrected for Riparian Best Management Practices

This section provides an assessment of the additional sediment loading reductions gained through the application of Best Management Practices (BMPs) on those activities whose actions within the near stream riparian environment have the potential to affect the buffering capacity (i.e. sediment reduction efficiency) of the vegetated riparian buffer.

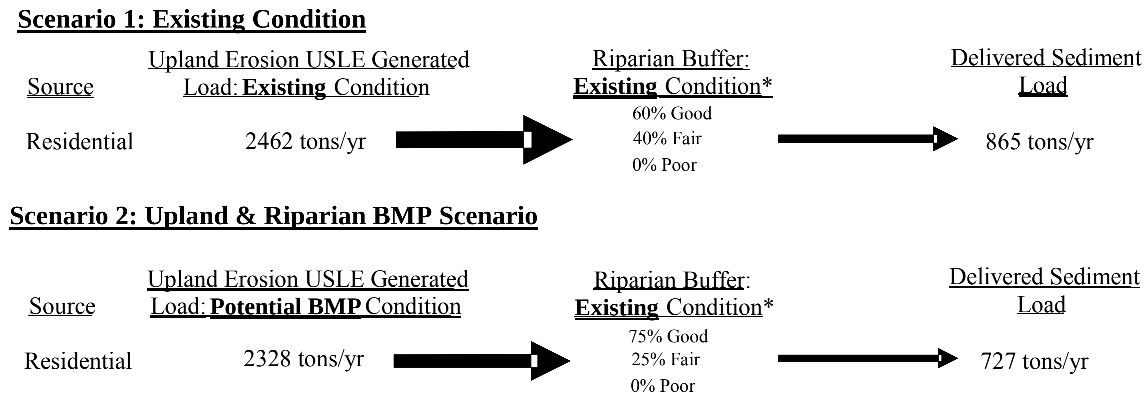
For this analysis, a sediment reduction efficiency of 75%, 50% and 25% was assumed to represent the loading condition for a healthy (Good), moderately disturbed (Fair) and heavily disturbed (Poor) vegetated riparian buffer. Under this BMP scenario, it is assumed that the implementation of BMPs increases the watershed scale buffering condition from its existing health condition to a 75% Good and 25% Fair buffering condition. The concept is that through the application of BMPs, the general health of the vegetated riparian buffer will increase, hence increasing its sediment reduction efficiency. This BMP scenario assumes that 25% of the stream will be left in Fair condition and 0% will be of a Poor condition. This scenario allows some reasonable level of disturbance while not allowing for heavily disturbed conditions.

Following the example in **Table E-11,** the upland erosion USLE generated BMP load was again partitioned and routed through the riparian buffer**.** For this analysis, the upland BMP load was routed through the riparian buffer BMP condition. The resulting load then represents the upland BMP load corrected for the riparian buffer BMP condition (see example **Table E-12 and Figure E-12**).

Table E-12. Upland BMP Load Partitioned and Reduced based upon the BMP Riparian Buffer Condition: Beehive Creek.

Source	Upland Erosion USLE Generated Load: BMP Condition (tons/yr)	Load Partitioned for BMP Riparian Health Condition (tons/yr)		Delivered Load: Upland Erosion USLE BMP Load Corrected for Riparian BMP Health Condition (tons/yr)
		Good (75%)*	Fair (25%)*	
Natural	768	144	96	240
Residential	2328	436	291	727
Total	3096	580	387	967

Figure E-12. Beehive Creek Example Scenarios.



*The percent values relate to the percent total stream length categorized as having that health category.

In the Beehive Creek example, the current estimated annual upland sediment load is 3230 tons/year. Through the application of upland BMPs, it is estimated that the upland USLE based sediment load can be reduced by 4% from 3230 tons/year to 3096 tons/year (**Table E-13**). The annual upland sediment load was reduced from 3230 tons/year to 1105 tons/year when existing riparian vegetation conditions are considered. The annual upland BMP sediment load was reduced from 3096 tons/year to 967 tons/year by applying riparian BMPs. Overall, a 12% reduction is achieved when the existing upland sediment load corrected for existing riparian conditions (1105 tons/year) is compared to the upland BMP load combined with riparian BMP conditions (967 tons/year).

Table E-13. Beehive Creek Summary.

Land Use	Upland Erosion USLE Generated Load: Existing Condition (tons/yr)	Upland Erosion USLE Generated Load: BMP Condition (tons/yr)	Upland BMP Load Reduction (Percent)	Upland Erosion USLE Load Corrected for Existing Riparian Health Condition (tons/yr)	Upland Erosion USLE BMP Load Corrected for Riparian BMP Health Condition (tons/yr)	Upland & Riparian BMP Load Reduction (Percent)
Natural	768	768	0%	240	240	0%
Residential	2462	2328	5%	865	727	16%
Total	3230	3096	4%	1105	967	12%

Results

This section presents the results of this analysis. Again, this data builds upon the upland USLE based sediment modeling results. **Table E-14** includes the existing riparian buffer condition, the existing USLE sediment load corrected for existing riparian conditions, the USLE BMP sediment load corrected for BMP riparian conditions, and the percent reduction that can be achieved through upland and riparian BMPs. Total sediment loads and percent reductions are also provided for the three main sub-watersheds in the Upper Gallatin TPA. Sediment loads for the entire West Fork Gallatin River watershed are summarized at the bottom of **Table E-14**.

Table E-14. Upland Sediment Loading Summary and Percent Reductions by Sub-watershed.

303(d) Watershed	Sub-Watershed	Land Use	Riparian Buffer Existing Condition			Upland Erosion USLE Load Corrected for **Existing** Riparian Health Condition (tons/yr)	Upland Erosion USLE **BMP** Load Corrected for Riparian **BMP** Health Condition (tons/yr)	Upland & Riparian BMP Load Reduction (Percent)
			Good (%)	Fair (%)	Poor (%)			
Middle Fork West Fork Gallatin River Sub-watershed	Uppermost Middle Fork West Fork Gallatin River	Natural	75%	25%	0%	305	305	0%
		Residential	6%	64%	30%	589	301	49%
		Ski Area	6%	64%	30%	1633	817	50%
		Total				2527	1422	44%
	Beehive Creek	Natural	75%	25%	0%	240	240	0%
		Residential	60%	40%	0%	865	727	16%
		Total				1105	967	12%
	Middle Fork West Fork Gallatin River	Natural	75%	25%	0%	1116	1116	0%
		Residential	38%	61%	0%	2715	1754	35%
		Ski Area	38%	61%	0%	566	405	28%
		Total				4396	3275	26%
	Sub-watershed Total	**Natural**				**1661**	**1661**	**0%**
		Residential				**4168**	**2782**	**33%**
		Ski Area				**2199**	**1222**	**44%**
		Total				**8027**	**5664**	**29%**
West Fork Gallatin River Sub-watershed	North Fork West Fork Gallatin River	Natural	75%	25%	0%	1754	1754	0%
		Residential	71%	29%	0%	405	346	15%
		Total				2159	2099	3%
	Upper West Fork Gallatin River	Natural	75%	25%	0%	50	50	0%
		Residential	0%	53%	47%	399	155	61%
		Total				449	204	54%
	Crail Creek	Natural	75%	25%	0%	101	101	0%
		Residential	70%	25%	5%	144	130	9%
		Total				245	231	5%
	Lower West Fork Gallatin River	Natural	75%	25%	0%	272	272	0%
		Residential	0%	100%	0%	758	464	39%
		Total				1030	736	29%
	Lowermost West Fork Gallatin River	Natural	75%	25%	0%	1322	1322	0%
		Residential	49%	33%	17%	297	190	36%
		Total				1619	1512	7%
	Sub-watershed Total	**Natural**				**3499**	**3499**	**0%**
		Residential				**2004**	**1284**	**36%**
		Total				**5502**	**4783**	**13%**
South Fork West Fork Gallatin River Sub-watershed	Upper South Fork West Fork Gallatin River	Natural	75%	25%	0%	995	995	0%
		Residential	59%	38%	4%	527	220	58%
		Ski Area	59%	38%	4%	701	559	20%
		Total				2223	1775	20%
	Third Yellow Mule Creek	Natural	75%	25%	0%	485	485	0%
		Residential	73%	27%	0%	1	1	7%
		Total				486	486	0.01%
	Muddy Creek	Natural	75%	25%	0%	2016	2016	0%
		Residential	77%	19%	4%	1	1	1%
		Ski Area	77%	19%	4%	177	169	4%
		Total				2194	2186	0.4%
	Second Yellow Mule Creek	Natural	75%	25%	0%	799	799	0%
		Residential	44%	56%	0%	5	3	37%
		Total				804	802	0.2%
	First Yellow Mule Creek	Natural	79%	21%	0%	1117	1117	0.0%
		Total				1117	1117	0.0%
	South Fork West Fork Gallatin River	Natural	75%	25%	0%	6419	6419	0%
		Residential	28%	71%	1%	2281	1530	33%
		Total				8700	7950	9%
	Sub-watershed Total	**Natural**				**11832**	**11832**	**0%**
		Residential				**2815**	**1755**	**38%**
		Ski Area				**878**	**729**	**17%**
		Total				**15524**	**14316**	**8%**
West Fork Gallatin River Watershed	**Watershed Total**	**Natural**				**16991**	**16991**	**0%**
		Residential				**8986**	**5822**	**35%**
		Ski Area				**3077**	**1950**	**37%**
		Total				**29054**	**24764**	**15%**

Photos of BMP Examples within the West Fork Gallatin River Watershed

Photo 1. Fiber wattles used at a road crossing.

Photo 2. Fiber wattles used along a road ditch.

Photo 3. Rock lined storm water conveyance channel.

Photo 4. Rock lined storm water conveyance channel and sediment retention pond.

Photo 5. Silt fence installed at road crossing.

Photo 6. Hillslope terracing with logs and inlet protection at culvert.

References Cited

ARM. 2005. Administrative Rules of Montana. Title 17 – Environmental Quality, Chapter 30 – Water Quality, Sub-Chapter 6, 17.30.602(17) – Surface Water Quality Standards and Procedures. http://arm.sos.state.mt.us/17/17-2501.htm

Asmussen, L.E., A.W. White Jr., E.W. Hauser, and J.M. Sheridan. 1977. Reduction of 2,4-D Load in Surface Runoff Down a Grassed Waterway. Journal of Environmental Quality. 6(2): 159-162.

Campos, N., Lawrence, R.L., McGlynn, B. and Gardner, K., 2008. Comparing the Effects of Fused and Non-Fused Imagery on Object Oriented Classification. ASPRS Annual Conference, Portland Oregon, April 29-May 2, 2008.

Engel, B., 2001. Estimating Soil Loss with USLE. Purdue University. http://cobweb.ecn.purdue.edu/~sedspec/sedspec/doc/usleapp.doc

Hall, J.K., N.L. Hartwig, and L.D. Hoffman. 1983. Application mode and alternative cropping effects on atrazine losses from a hillside. Journal of Environmental Quality. 12(3): 336-340.

Han, J., J.S. Wu, and C. Allan. 2005. Suspended Sediment Removal by Vegetative Filter Strip Treating Highway Runoff. Journal of Environmental Science and Health. 40:1637-1649.

Ma, Jianguo, 2001. Combining the USLE and GIS/ArcView for Soil Erosion Estimation in Fall Creek Watershed in Ithaca, New York. CSS620- Spatial Modeling and Analysis. www.css.cornell.edu/courses/620/stassign/ma.ppt.

Mickelson,S.K., J.L. Baker, and S.I. Ahmed. 2003. Vegetative Filter Strips for Reducing Atrazine and Sediment Runoff Transport. Journal of Soil and Water Conservation. 58(6): 359-367.

Mitasova, H., Brown, W.M., Hohmann, M., and Warren, S., 2003. Using Soil Erosion Modeling for Improved Conservation Planning: A GIS-based Tutorial. Web documentation: http://skagit.meas.ncsu.edu/~helena/gmslab/reports/CerlErosionTutorial/denix/default.htm

USDA, 1981. Predicting Rainfall Erosion Losses, A Guide to Conservation Planning. US Department of Agriculture Handbook 537. US Government Printing Office, Washington, DC.

Ward, A.D, and Trimble, S.W. 2004. Environmental Hydrology, Second Edition. Boca Raton, FL: CRC Press LLC.