APPENDIX D
UPLAND USLE BASED SEDIMENT MODEL, SEDIMENT CONTRIBUTION FROM HILLSLOPE EROSION FOR TRIBUTAIRES OF THE UPPER JEFFERSON TMDL PLANNING AREA

Introduction

Upland sediment loading due to hillslope erosion was modeled using the Universal Soil Loss Equation (USLE) and sediment delivery to the stream was predicted using a sediment delivery ratio. This model provided an assessment of existing sediment loading from upland sources and an assessment of potential sediment loading through the application of Best Management Practices (BMPs). For this evaluation, the primary BMP evaluated includes the modification in upland management practices. When reviewing the results of the upland sediment load model it is important to note that a significant portion of the remaining sediment loads after BMPs in areas with grazing and/or silvicultural land-uses is also a component of the “natural upland load”. However, the assessment methodology didn’t differentiate between sediment loads with all reasonable BMPs and “natural” loads.

A list of land cover classifications used in the USLE model is presented in **Table D-1**, along with a description of which land-use was associated with each cover type for the purposes of sediment source assessment and load allocations.

Table D - 1. Land Cover Classifications for the USLE Model.

Land Cover Classifications	Land-use / Sediment Source
Bare Rock/Sand/Clay	Natural Sources
Deciduous Forest	Natural Sources
Evergreen Forest	Natural Sources
Mixed Forest	Natural Sources
Grasslands/Herbaceous	Grazing
Emergent Herbaceous Wetlands	Natural Sources
Logging	Silviculture
Pasture/Hay	Cropland
Shrubland	Grazing
Small Grains	Cropland
Woody Wetlands	Natural Sources

Universal Soil Loss Equation (USLE)

The general form of the USLE has been widely used for erosion prediction in the U.S. and is presented in the National Engineering Handbook (1983) as:

(1) A = RK(LS)CP (in tons acre-1 year-1)

where soil loss (A) is a function of the rainfall erosivity index (R), soil erodibility factor (K), overland flow slope and length (LS), crop management factor (C), and conservation practice factor (P) (Wischmeier and Smith 1978, Renard et al. 1991). USLE was selected for the Jefferson River Watershed due to its relative simplicity, ease in parameterization, and the fact that it has been integrated into a number of other erosion prediction models. These include: (1) the Agricultural Nonpoint Source Model (AGNPS), (2) Areal Nonpoint Source Watershed Environment Response Simulation Model (ANSWERS), (3) Erosion Productivity Impact Calculator (EPIC), (4) Generalized Watershed Loading Functions (GWLF), and (5) the Soil Water Assessment Tool (SWAT) (Doe, 1999). A detailed description of the general USLE model parameters is presented below.

The **R-factor** is an index that characterizes the effect of raindrop impact and rate of runoff associated with a rainstorm. It is a summation of the individual storm products of the kinetic energy in rainfall (hundreds of ft-tons acre-1 year-1) and the maximum 30-minute rainfall intensity (inches hour-1). The total kinetic energy of a storm is obtained by multiplying the kinetic energy per inch of rainfall by the depth of rainfall during each intensity period.

The **K-factor** or soil erodibility factor indicates the susceptibility of soil to resist erosion. It is a measure of the average soil loss (tons acre-1 hundreds of ft-tons-1 per acre of rainfall intensity) from a particular soil in continuous fallow. The K-factor is based on experimental data from the standard SCS erosion plot that is 72.6 ft long with uniform slope of 9%.

The **LS-factor** is a function of the slope and overland flow length of the eroding slope or cell. For the purpose of computing the LS-value, slope is defined as the average land surface gradient. The flow length refers to the distance between where overland flow originates and runoff reaches a defined channel or depositional zone. According to McCuen, (1998), flow lengths are seldom greater than 400 feet or shorter than 20 feet.

The **C-factor,** or crop management factor, is the ratio of the soil eroded from a specific type of cover to that from a clean-tilled fallow under identical slope and rainfall. It integrates a number of factors that effect erosion including vegetative cover, plant litter, soil surface, and land management. The original C-factor of the USLE was experimentally determined for agricultural crops and has since been modified to include rangeland and forested cover. It is now referred to as the vegetation management factor (VM) for non-agricultural settings (Brooks, 1997).

Three different kinds of effects are considered in determination of the VM-factor. These include: (1) canopy cover effects, (2) effects of low-growing vegetal cover, mulch, and litter, and (3) rooting structure. A set of metrics has been published by the Soil Conservation Service (SCS) for estimation of the VM-factors for grazed and undisturbed woodlands, permanent pasture, rangeland, and idle land. Although these are quite helpful for the Jefferson River setting, Brooks (1997) cautions that more work has been carried out in determining the agriculturally based C-factors than rangeland/forest VM-factors. Because of this, the results of the interpretation should be used with discretion.

The **P-factor** (conservation practice factor) is a function of the interaction of the supporting land management practice and slope. It incorporates the use of erosion control practices, such as stripcropping, terracing, and contouring, and is applicable only to agricultural lands. Values of the P-factor compare straight-row (up-slope down-slope) farming practices with that of certain agriculturally-based conservation practices.

Modeling Approach

Sediment delivery from hillslope erosion was estimated using a Universal Soil Loss Equation (USLE) based model to predict soil loss, along with a sediment delivery ratio (SDR) to predict sediment delivered to the stream. This USLE based model is implemented as a watershed scale, grid format, GIS model using ArcView v 9.0 GIS software.

Desired results from the modeling effort include the following: (1) annual sediment load from each of the water quality limited segments on the state's 303(d) list, (2) the mean annual source distribution from each land category type, and (3) annual potential sediment load from each of the water quality limited segments on the state's 303(d) list after the application of upland management BMPs. Based on these considerations, a GIS- modeling approach (USLE) was formulated to facilitate database development and manipulation, provide spatially explicit output, and supply output display for the modeling effort.

Modeling Scenarios

Two upland management scenarios were proposed as part of the Jefferson modeling project. They include: (1) an existing condition scenario that considers the current land use cover and management practices in the watershed and (2) an improved grazing and cover management scenario.

Erosion was differentiated into two source categories for each scenario: (1) natural erosion that occurs on the time scale of geologic processes and (2) anthropogenic erosion that is accelerated by human-caused activity. A similar classification is presented as part of the National Engineering Handbook Chapter 3 - Sedimentation (USDA, 1983). Differentiation is necessary for TMDL planning.

Data Sources

The USLE-3D model was parameterized using a number of published data sources. These include information from: (1) USGS, (2) Spatial Climate Analysis Service (SCAS), and (3) Soil Conservation Service (SCS). Additionally, local information regarding specific land use management and cropping practices was acquired from the Montana Agricultural Extension Service and the Natural Resource Conservation Service (NRCS). Specific GIS coverages used in the modeling effort included the following:

R – Rainfall factor. Grid data of this factor was obtained from the NRCS, and is based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation data. PRISM precipitation data is derived from weather station precipitation records, interpolated to a gridded landscape coverage by a method (developed by the Spatial Climate Analysis Service of Oregon State University) which accounts for the effects of elevation on precipitation patterns.

K – Soil erodibility factor. Polygon data of this factor were obtained from the NRCS General Soil Map (STATSGO) database. The USLE K factor is a standard component of the STATSGO soil survey. STATSGO soils polygon data were summarized and interpolated to grid format for this analysis.

LS – Slope length and slope factors. These factors were derived from 30m USGS digital elevation model (DEM) grid data, interpolated to a 10m pixel.

C – Cropping factor. This factor was estimated using the National Land Cover Dataset (NLCD), using C-factor interpretations provided by the NRCS and refined by Montana DEQ using SCS C-factor tables (Brooks et al. 1997). C-factors are intended to be conservatively representative of conditions in the Upper Jefferson TPA.

P – Management practices factor. This factor was set to 1, as consultation with the NRCS State Agronomist suggests that this value is the most appropriate representation of current management practices in the Jefferson River watershed (i.e. no use of contour plowing, terracing, etc).

Method

An appropriate grid for each factors' values was created, giving full and appropriate consideration to proper stream network delineation, grid cell resolution, etc. A computer model was built using ArcView Model Builder to derive the five factors from model inputs, multiply the five factors and arrive at a predicted sediment production for each grid cell. The model also derived a sediment delivery ratio for each cell, and reduced the predicted sediment production by that factor to estimate sediment delivered to the stream network.

Specific parameterization of the USLE factors was performed as follows:

Jefferson DEM

The Digital Elevation Model (DEM) for the upper Jefferson watershed (see **Figure 1**) was the foundation for developing the LS factor, for defining the extent of the bounds of the analysis area (the upper Jefferson watershed), and for delineating the area within the outer bounds of the analysis for which the USLE model is not valid (i.e. the concentrated flow channels of the stream network). The USGS 30m DEM (level 2) for the Jefferson was used for these analyses. First the DEM was interpolated to a 10m analytic grid cell to render the delineated stream network more representative of the actual size of Jefferson watershed streams and to minimize resolution dependent stream network anomalies. The resulting interpolated 10m was then subjected to standard hydrologic preprocessing, including the filling of sinks to create a positive drainage condition for all areas of the watershed.

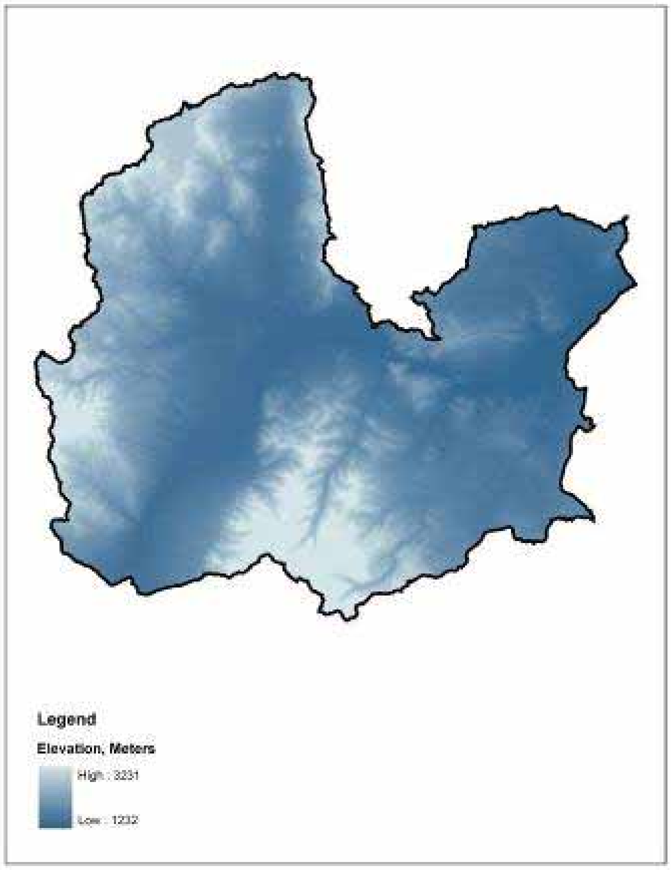

Figure 1 –Digital Elevation Model (DEM) of the Upper Jefferson Watershed, Prepared for Hydrologic Analysis

R-Factor

The rainfall and runoff factor grid was prepared by the Spatial Climate Analysis Service of Oregon State University, at 4 km grid cell resolution (see **Figure 2**). For the purposes of this analysis, the SCAS R-factor grid was reprojected to Montana State Plane Coordinates (NAD83, meters), resampled to a 10m analytic cell size and clipped to the extent of the upper Jefferson watershed, to match the project's standard grid definition.

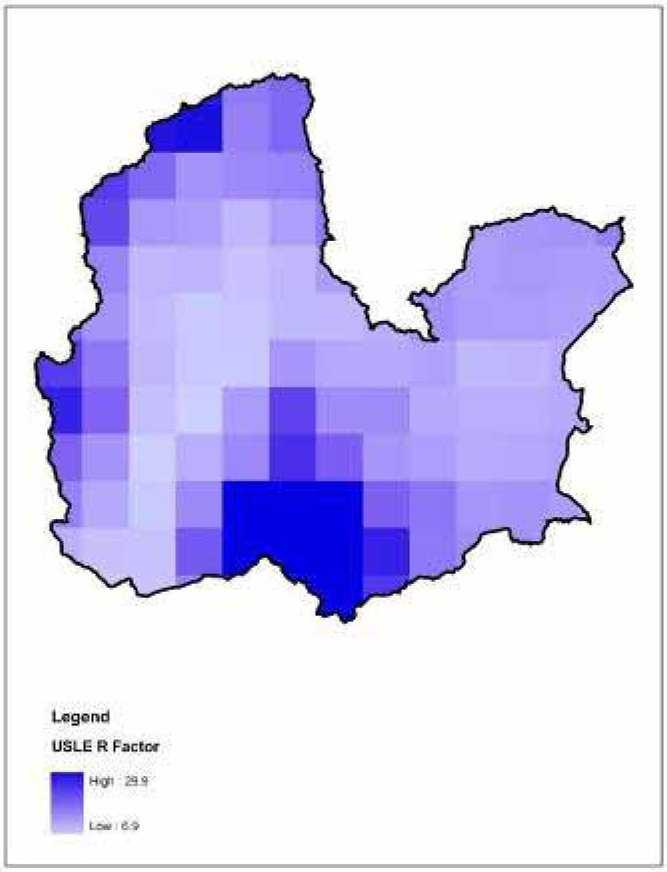

Figure 2 – ULSE R factor for the Upper Jefferson Watershed

K-Factor

The soil erodibility factor grid was compiled from 1:250K STATSGO data, as published by the NRCS (see **Figure 3**). STATSGO database tables were queried to calculate a component weighted K value for all surface layers, which was then summarized by individual map unit. The map unit K values were then joined to a GIS polygon coverage of the STATSGO map units, and the polygon coverage was converted to a 10m analytic grid for use in this analysis.

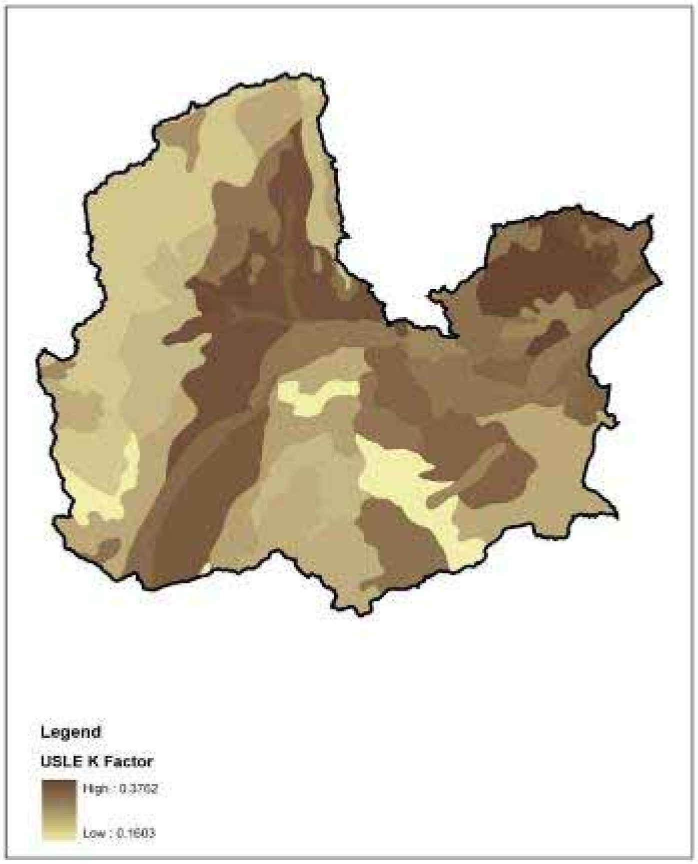

Figure 3 – ULSE K factor for the Upper Jefferson Watershed

LS- Factor

The equation used for calculating the slope length and slope factor was that given in the updated definition of USLE, as published in USDA handbook #537:

$$LS = (\lambda/72.6)^m\ (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where:

λ = slope length in feet. This value was determined by applying GIS based surface analysis procedures to the Jefferson watershed DEM, calculating total upslope length for each 10m grid cell, and converting the results to feet from meters. In accordance with research that indicates that, in practice, the slope length rarely exceeds 400 ft, λ was limited to that maximum value.

θ = cell slope cell slope as calculated by GIS based surface analysis procedures from the Jefferson watershed DEM

m = 0.5 if percent slope of the cell >= 5
= 0.4 if percent slope of the cell >= 3.5 AND < 5
= 0.3 if percent slope of the cell >= 1 AND < 3.5
= 0.2 if percent slope of the cell < 1

The LS factor grid was calculated from individual grids computed for each of these sub factors, using a simple ArcView Model Builder script.

C-Factor

The cover management factor of the USLE reflects the varying degree of erosion protection that results from different cover types. It integrates a number of factors including vegetative cover, plant litter, soil surface, and land management. For the purpose of this study, the C-factor is the only USLE parameter that can be altered by the influence of human activity. Based on this, C-factors were estimated for the existing condition and improved management scenarios (**Table D-2**). The C-factor change for agricultural cover types between management scenarios corresponds to increases in the percent of land cover that are achievable through the application of various best management practices (**Table D-3**). For natural sources (i.e. bare rock, deciduous forest, and evergreen forest), the C-factor is the same for both scenarios. A C-factor slightly higher than deciduous/evergreen forest was used for logged areas because logging intensity within the watershed is low and because practices, such as riparian clearcutting, that tend to produce high sediment yields have not been used since at least 1991, when the MT Streamside Management Zone (SMZ) law was enacted. Additionally, the USLE model is intended to reflect long-term average sediment yield, and while a sediment pulse typically occurs in the first year after logging, sediment production after the first year rapidly declines (Rice et al. 1972; Elliot and Robichaud 2001; Elliot 2006). The logging C-factor is the same for both management scenarios to indicate that logging will continue sporadically on public and private land within the watershed and will produce sediment at a rate slightly higher than an undisturbed forest. This is not intended to imply that additional best management practices beyond those in the SMZ law should not be used for logging activities.

C-factors were defined spatially through use of a modified version of the Anderson land cover classification (1976) and the 1992 30m Landsat Thematic Mapper (TM) multi-spectral imaging (NLDC, 1992) (Figure-4). C-factor values were assigned globally to each land type and range from 0.001 to 1.0. These data were reprojected to Montana State plane projection/coordinate system, and resampled to the standard 10m grid. No field efforts were initiated as part of this study to refine C-factor estimation for the watershed.

Table D – 2. Jefferson River C-Factor; Existing Conditions

USLE C-Factor Parameter		C-factor	
Code	**Description**	**Existing Condition**	**Improved Management Condition**
41	Decidous Forest	0.003	0.003
42	Evergreen Forest	0.003	0.003
43	Mixed Forest	0.003	0.003
51	Shrubland	0.046	0.031
71	Grassland/Herbaceous	0.042	0.035
81	Pasture/Hay	0.020	0.013
83	Small Grains	0.240	0.015
84	Fallow	0.440	0.120
N/A	Logging	0.006	0.006

Table D - 3. Changes in percent ground cover for agricultural land cover types between existing and improved management conditions.

Land Cover	Existing % ground cover	Improved % ground cover
Shrubland	55	65
Grasslands Herbaceous	55	65
Pasture /Hay	65	75
Small Grains	20	40
Fallow	5	35

NLDC – Landcover

In general, the land use classification of the NLCD was accepted as is, without ground truthing of original results or correction of changes over the time since the NLCD image was taken (see **Figure 4**). Given that we are looking for watershed and subwatershed scale effects, this was considered to be a reasonable assumption, given the relative simplicity of the land use mix in the Jefferson valley, and the relative stability of that landuse over the 14 years since the Landsat image that the NLCD is based on was shot. One adjustment was made to the NLCD, however. That adjustment was to quantify the amount of logging that has occurred since 1992, and to also identify areas that are reforesting over that same period. As with other land uses in the valley, logging is a stable land use, but it is a land use that causes a land cover change that may effect sediment production.

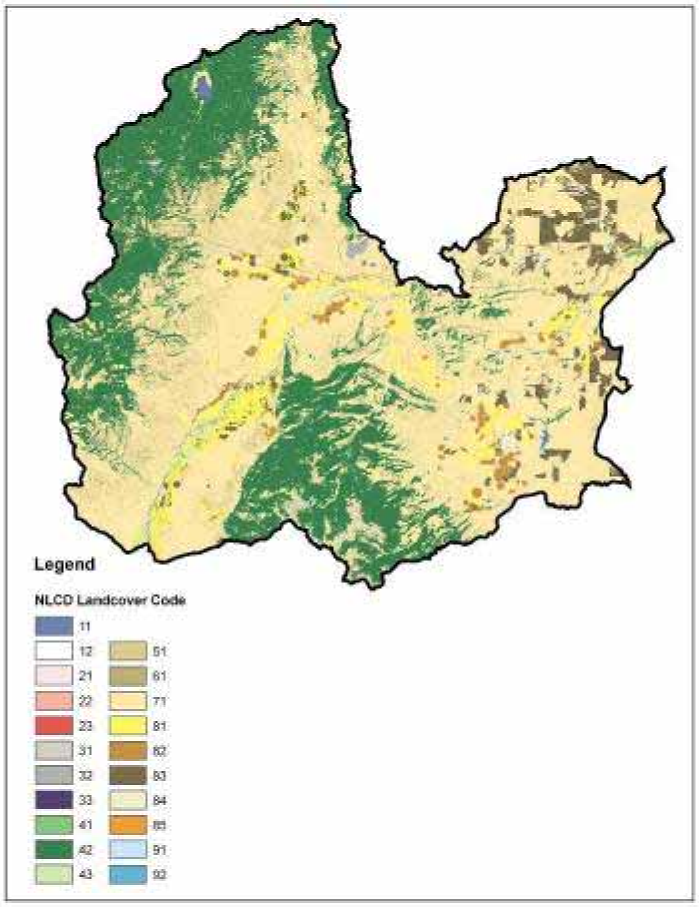

Figure 4 – NLCD Landcover for the Upper Jefferson Watershed

Adjustment for logging and reforestation was accomplished by comparing the 1992 NLCD grid for the upper Jefferson with the 2005 NAIP aerial photography. Areas which were coded as a forest type (41 or 42) on the NLCD were recoded to 'logged' if:

- They appeared to be otherwise (typically bare ground, grassland, or shrubland) on the NAIP photos, and
- There were indications of logging activity (proximity to forest or logging roads, appearance of stands, etc).

Sediment Delivery Ratio

A sediment delivery ratio factor was created for each grid cell, based on the relationship between distance from the delivery point to the stream established by Dube, Megahan & McCalmon in their development of the WARSEM road sediment model for the State of Washington. This relationship was developed by integrating the results of several previous studies (principally those of Megehan and Ketchison) which examined sediment delivery to streams downslope of forest roads. They found that the proportion of sediment production that is ultimately delivered to streams declines with distance from the stream (**Table D-4**) with the balance of the sediment being deposited between the point of production and the stream. We believe the use of this relationship to develop a sediment delivery ratio for a USLE based model is a conservative (i.e.

tending toward the high end of the range of reasonable values) estimate of sediment delivery from hillslope erosion, especially in light of the fact that the USLE methodology does not account for gully erosion. This factor was applied to the results of the USLE model to estimate sediment delivered from hill slope sources, by calculating the distance from each cell to the nearest stream channel, and multiplying the sediment production of that cell by the corresponding distance based percentage of delivery.

Table D – 4 Sediment Delivery vs. Distance

Distance from Culvert (ft)	Percent of Total Eroded Sediment Delivered
0	100
35	70
70	50
105	35
140	25
175	18
210	10
245	4
280	3
315	2
350	1

Results

Figures 5 and **6** present the USLE based hillslope model's prediction of existing and potential conditions graphically for the entire Upper Jefferson TMDL Planning Area (TPA). **Table D - 5** presents the prediction of existing and potential conditions numerically by landcover type, broken out by sub-watershed for all 303(d) listed tributaries within the Upper Jefferson TPA.

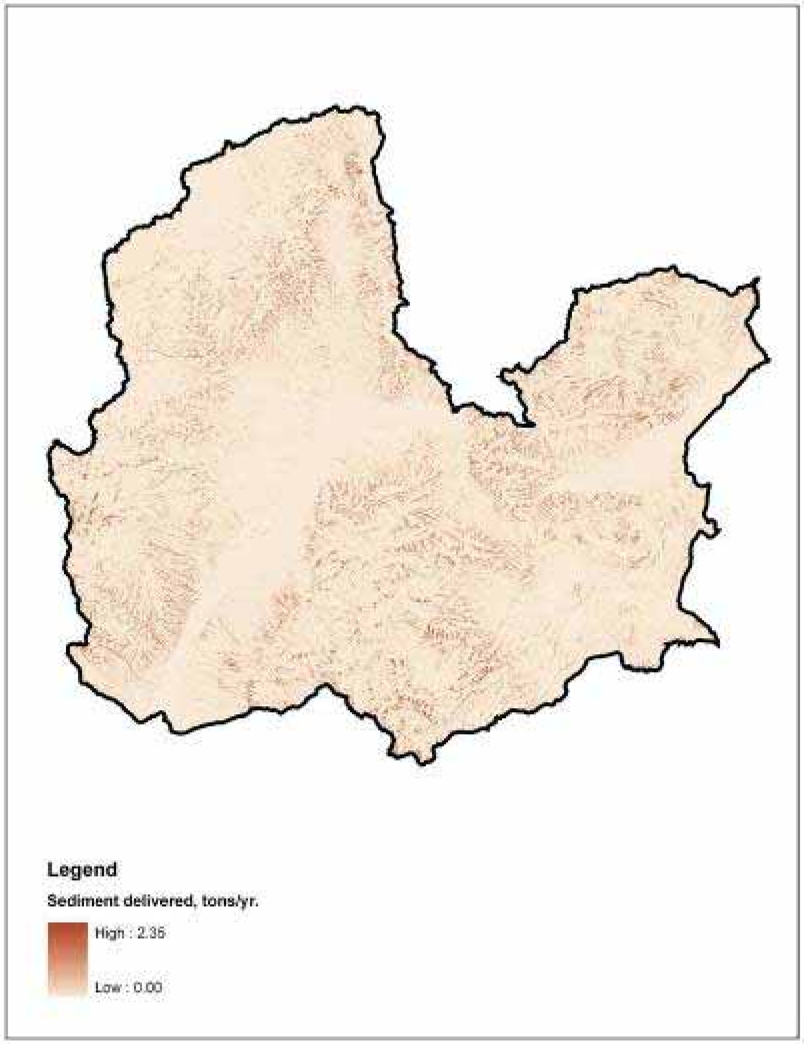

Figure 5 – Predicted Sediment Delivery from Hill Slopes, Existing Condition

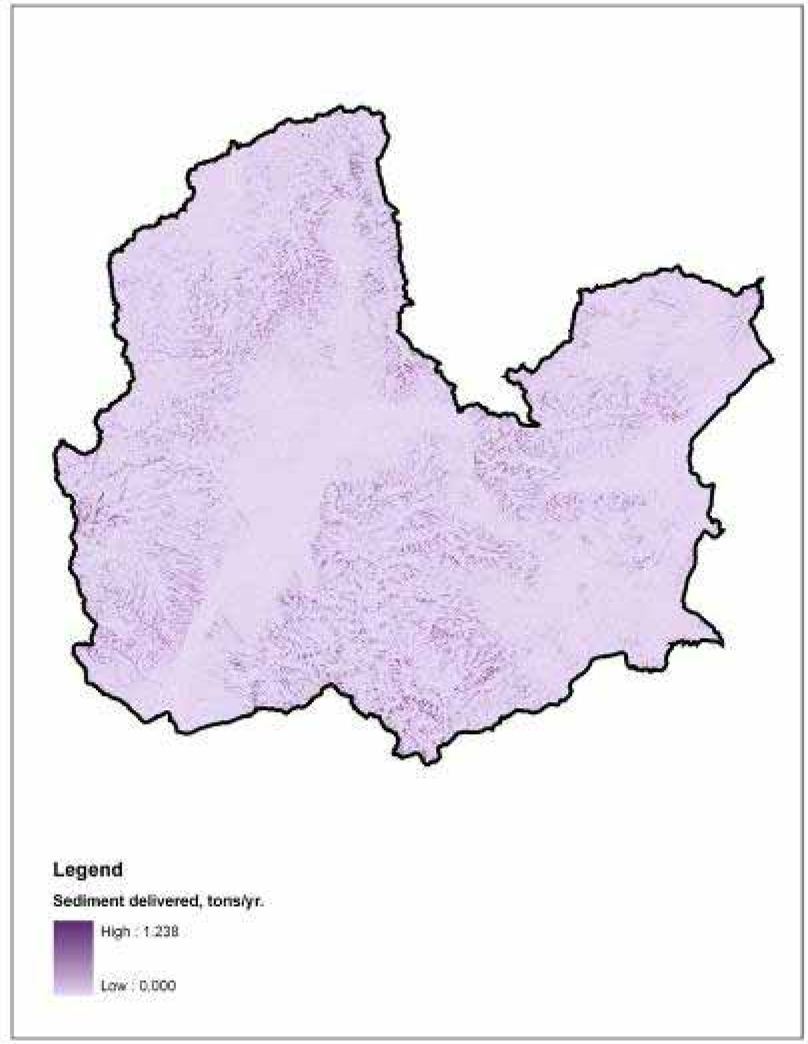

Figure 6 – Predicted Sediment Delivery from Hill Slopes, BMP Conditions

Table D – 5. Existing and Potential Sediment Delivery by 303(d) Listed Tributary (Sub-Watershed) of the Upper Jefferson TPA.

			Upland Sediment Load (tons/yr)	
303(d) Listed Sub-Watershed	**Land-use / Sediemtn Source**	**Existing Landcover Classification**	**Existing**	**Potential**
Big Pipestone Creek (Halfway Creek and Little Pipestone Creek)	Cropland	Fallow	14.68	4.00
	Cropland	Pasture/Hay	8.40	5.46
	Cropland	Small Grains	57.23	3.60
	Grazing	Grasslands/Herbaceous	1239.19	1032.01
	Grazing	Shrubland	1474.41	993.40
	Natural Sources	Evergreen Forest	495.18	495.18
	Silviculture	Silviculture	4.00	4.00
		Total	**3293.08**	**2537.64**
Cherry Creek	Cropland	Pasture/Hay	0.65	0.42
	Grazing	Grasslands/Herbaceous	256.97	214.14
	Grazing	Shrubland	184.11	124.08
	Natural Sources	Evergreen Forest	33.35	33.35
	Natural Sources	Woody Wetlands	1.10	1.10
		Total	**476.18**	**373.09**
Fish Creek	Cropland	Pasture/Hay	3.95	2.57
	Cropland	Small Grains	1.98	0.12
	Grazing	Grasslands/Herbaceous	591.07	492.45
	Grazing	Shrubland	723.06	487.27
	Natural Sources	Bare Rock/Sand/Clay	1.77	1.77
	Natural Sources	Evergreen Forest	230.41	230.41
	Silviculture	Silviculture	4.00	4.00
		Total	**1556.25**	**1218.59**
Fitz Creek	Cropland	Small Grains	7.93	1.00
	Grazing	Grasslands/Herbaceous	161.58	134.63
	Grazing	Shrubland	74.39	50.13
	Natural Sources	Evergreen Forest	16.00	16.00
		Total	**259.90**	**201.76**
Halfway Creek	Grazing	Grasslands/Herbaceous	34.07	28.39
	Grazing	Shrubland	149.63	100.84
	Natural Sources	Evergreen Forest	51.81	51.81
		Total	**235.50**	**181.03**
Hells Canyon Creek	Grazing	Grasslands/Herbaceous	1001.06	834.21
	Grazing	Shrubland	525.57	354.19
	Natural Sources	Evergreen Forest	126.97	126.97
	Natural Sources	Mixed Forest	2.30	2.30
	Natural Sources	Woody Wetlands	1.06	1.06
		Total	**1656.95**	**1318.72**
Little Pipestone Creek	Cropland	Pasture/Hay	1.11	0.72
	Cropland	Small Grains	1.23	0.08
	Grazing	Grasslands/Herbaceous	438.82	365.68
	Grazing	Shrubland	392.33	264.40
	Natural Sources	Evergreen Forest	113.60	113.60
	Silviculture	Silviculture	0.62	0.62
		Total	**947.71**	**745.10**
Whitetail Creek (Little Whitetail Creek)	Cropland	Pasture/Hay	17.28	11.23
	Cropland	Small Grains	151.70	9.48
	Grazing	Grasslands/Herbaceous	2843.09	2368.90
	Grazing	Shrubland	1810.75	1220.17
	Natural Sources	Emergent Herbaceous Wetlands	1.00	1.00
	Natural Sources	Evergreen Forest	502.00	502.00
	Natural Sources	Woody Wetlands	1.00	1.00
	Silviculture	Silviculture	4.41	4.41
		Total	**5331.23**	**4118.19**

REFERENCES

Brooks, K.N., 1987. Hydrology and the Management of Watersheds – second edition. Iowa State University Press. Ames, Iowa 50014.

Doe, W.W. III, Jones D.S., Warren, S.D. 1999. The Soil Erosion Model Guide for Military Land Mangers: Analysis of Erosion Models for Natural
and Cultural Resources Applications. Technical Report ITL 99-XX. U.S. Army Engineer Waterways Experiment Station.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No. 703, 404 pp.

Wischmeier, W.H., and Smith, D.D., 1978, Predicting rainfall erosion losses, a guide to conservation planning. Agriculture Handbook No. 537, US Department of Agriculture, Washington D.C.