ATTACHMENT B - ASSESSMENT OF UPLAND SEDIMENT SOURCES FOR TMDL DEVELOPMENT

Central Clark Fork Tributaries TMDL Project Area: Assessment of Upland Sediment Sources for TMDL Development

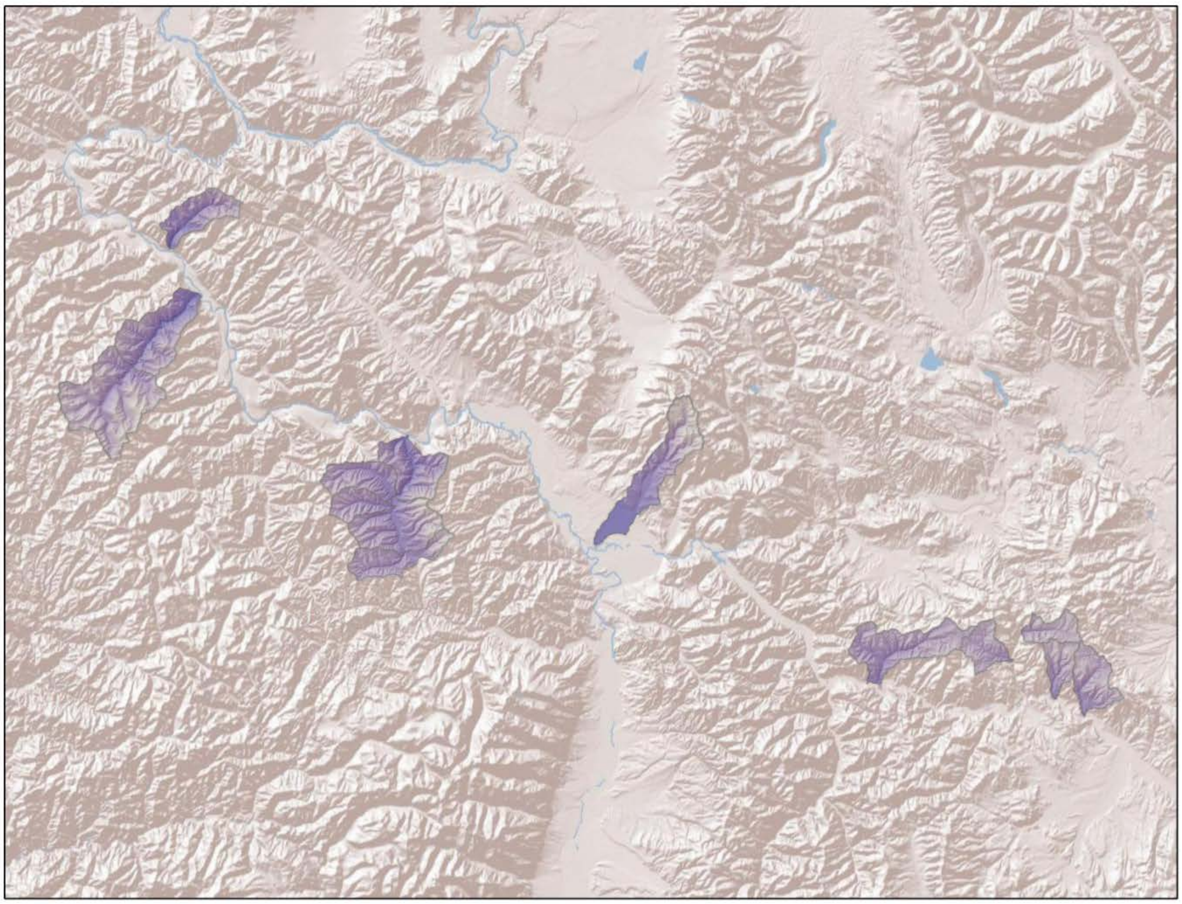

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

ATTACHMENTS

1.0 Introduction

An assessment of the sediment loading from hillslope erosion within the Central Clark Fork Tributaries TMDL Project Area (Project Area) was performed to facilitate the development of sediment TMDLs for 303(d) listed stream segments with sediment as a documented impairment. Upland sediment loading from hillslope erosion was modeled using a Universal Soil Loss Equation (USLE) based model, which was combined with a sediment delivery ratio (SDR) and riparian health assessment to predict the amount of sediment delivered to streams in the Central Clark Fork Tributaries Project Area. The USLE based model was implemented as a watershed-scale, raster-based, GIS model using ArcGIS software.

1.1 Sediment Impairments

The Central Clark Fork Tributaries Project Area encompasses an area of approximately 2,175 square miles in Granite, Missoula and Mineral counties in western Montana. The Central Clark Fork Tributaries Project Area includes two TMDL Planning Areas (TPAs): the Middle Clark Fork Tributaries TPA and the Clark Fork – Drummond TPA. Within the Central Clark Fork Tributaries Project Area, there are ten water body segments listed on the 2012 303(d) List for sediment-related impairments (**Table 1-1**). Flat Creek, Pretty Creek, Trout Creek, and West Fork Petty Creek are listed as impaired due to sediment in the Middle Clark Fork Tributaries TPA, while Cramer Creek, Deep Creek, Grant Creek, Mulkey Creek, Rattler Gulch, and Tenmile Creek are listed as impaired due to sediment in the Clark Fork – Drummond TPA.

Table 1-1. Waterbody Segments Addressed during the USLE Assessment

TPA	List ID	Waterbody Description
Clark Fork - Drummond	MT76E004_020	CRAMER CREEK, headwaters to mouth (Clark Fork River)
Clark Fork - Drummond	MT76E004_070	DEEP CREEK, headwaters to mouth (Bear Creek, which is a tributary to Clark Fork River near Bearmouth)
Clark Fork - Drummond	MT76E004_050	MULKEY CREEK, headwaters to mouth (Clark Fork River)
Clark Fork - Drummond	MT76E004_060	RATTLER GULCH, headwaters to mouth (Clark Fork River), T11N R13W S22
Clark Fork - Drummond	MT76E004_030	TENMILE CREEK, headwaters to mouth (Bear Creek-Clark Fork River)
Middle Clark Fork Tributaries	MT76M002_180	FLAT CREEK, headwaters to mouth (Clark Fork)
Middle Clark Fork Tributaries	MT76M002_130	GRANT CREEK, headwaters to mouth (Clark Fork River)
Middle Clark Fork Tributaries	MT76M002_090	PETTY CREEK, headwaters to mouth (Clark Fork River)
Middle Clark Fork Tributaries	MT76M002_050	TROUT CREEK, headwaters to mouth (Clark Fork River)
Middle Clark Fork Tributaries	MT76M002_100	WEST FORK PETTY CREEK, headwaters to mouth (Petty Creek)

2.0 Methods

Upland sediment loading from hillslope erosion was modeled using a Universal Soil Loss Equation (USLE) based model, which was combined with a sediment delivery ratio (SDR) and riparian health assessment to predict the amount of sediment delivered to streams in the Central Clark Fork Tributaries Project Area. USLE is a soil erosion prediction tool that was originally developed for cropland and rangeland and was later modified for application to forested environments (Croke and Nethery, 2006). USLE has been widely used for sediment TMDL development and is a component of numerous more advanced models that are also used for TMDL development (e.g., SWMM, SWAT, GWLF, BASINS, AGNPS). This empirical model was selected for this source assessment because it is well suited for large watersheds since it incorporates local climate and landscape data, but is not overly data-intensive. For this project, the most simplistic uncalibrated version of the USLE model was selected because it meets the needs of the TMDL source assessment and provides the appropriate level of detail for the project. Methods used in this assessment are described in *Quality Assurance Project Plan: Assessment of Upland Sediment Sources for TMDL Development (Task Order 18: Task 2c)* (EPA and DEQ 2011) and summarized in the following sections.

2.1 SUBWATERSHED DELINEATION

Prior to USLE model development, subwatersheds were delineated in which the Central Clark Fork Tributaries Project Area upland sediment assessment would be conducted. Subwatersheds were delineated on the basis of the USGS 6th Hydrologic Unit Code (HUC12) layer and modified where necessary to delineate the subwatersheds of interest (**Table 2-1** and **Figure 2-1**). Delineated subwatersheds include the Deep Creek and Flat Creek subwatersheds, which were created using watershed delineation tools in GIS and a 30-meter DEM. Delineated subwatersheds are identified with a subwatershed ID of ‘sub6code’ in **Table 2-1** and **Figure 2-1**.

Table 2-1. Subwatersheds in the Central Clark Fork Tributaries Project Area

HUC 10 Name	HUC 12 Name	Subwatershed ID
Clark Fork River-Bear Creek	Upper Bear Creek	Deep Creek_sub6code
	Tenmile Creek	Tenmile Creek
	Mulkey Gulch	Mulkey Gulch
	Rattler Gulch	Rattler Gulch
Clark Fork River-Cramer Creek	Cramer Creek	Cramer Creek
Clark Fork River-Dry Creek	Clark Fork River-Thompson Creek	Flat Creek_sub6code
Clark Fork River-Rattlesnake Creek	Grant Creek	Grant Creek
Clark Fork River-Trout Creek	Upper Trout Creek	Upper Trout Creek
	Lower Trout Creek	Lower Trout Creek
Petty Creek	Upper Petty Creek	Upper Petty Creek
	Middle Petty Creek	Middle Petty Creek
	Lower Petty Creek	Lower Petty Creek
	West Fork of Petty Creek	West Fork of Petty Creek
	Eds Creek	Eds Creek

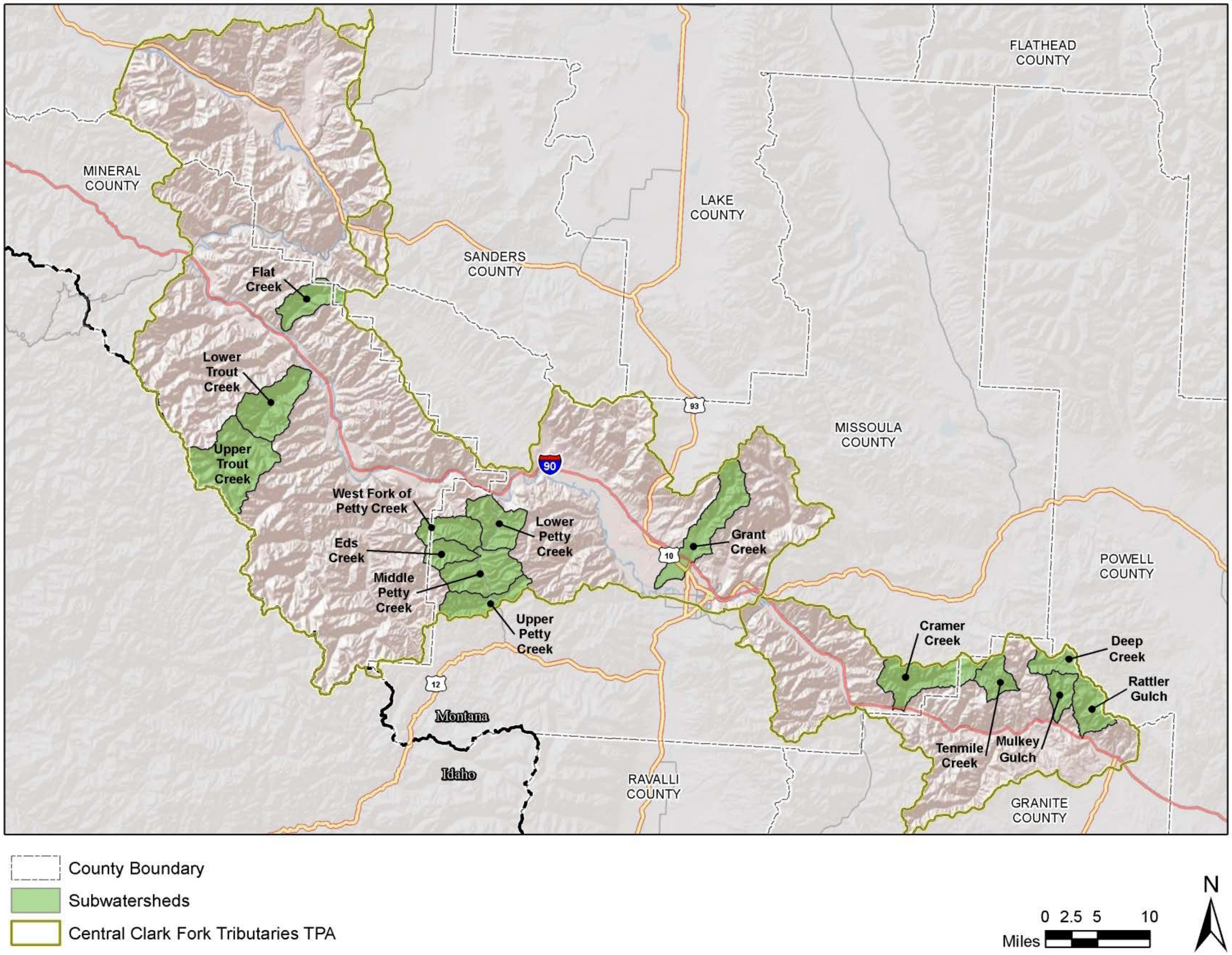

Figure 2-1. Subwatersheds in the Central Clark Fork Tributaries Project Area

2.2 USLE MODEL INPUT PARAMETERS

The USLE model requires five landscape factors that are combined to predict upland soil loss, including a rainfall factor (R), soil erodibility factor (K), length and slope factors (LS), cropping factor (C), and management practices factor (P). The general form of the USLE equation has been widely used for upland sediment erosion modeling and is presented as (Brooks et al. 1997):

$$A = RK(LS)CP \text{ (in tons per acre per year)}$$

For this assessment, the USLE based model was parameterized using a number of published data sources, including information from: (1) U.S. Geological Survey (USGS), (2) Spatial Climate Analysis Service (SCAS), and (3) Natural Resource Conservation Service (NRCS). Additionally, local information regarding specific land cover was acquired from the U.S. Forest Service (USFS) and the NRCS. Specific GIS data layers used in the modeling effort are presented in the following sections.

2.2.1 R-Factor

The **R-factor** characterizes the effect of raindrop impact and runoff rates associated with a rainstorm, which is reported in 100s of ft-tons rainfall/ac-yr. The rainfall and runoff factor grid was prepared by the Spatial Climate Analysis Service of Oregon State University at a 4 km grid cell resolution based on Parameter-elevation Regressions on Independent Slopes Model (PRISM) precipitation data. The R-factor is determined using the kinetic energy of a rainfall event and the maximum 30-minute rainfall intensity for an area. For the purposes of this analysis, the SCAS R-factor grid was projected to Montana State Plane Coordinates and interpolated to a 10m grid cell (**Figure 2-2**).

2.2.2 K-Factor

The **K-factor** is a soil erodibility factor that quantifies the susceptibility of soil to erosion. It is a measure of the average soil loss from a particular soil in continuous fallow derived from experimental data (tons soil/100 ft tons rainfall). Polygon data of K-factor values in the Central Clark Fork Tributaries Project Area was obtained from the NRCS General Soil Map (STATSGO) database and the NRCS Soil Survey Geographic (SSURGO) database. While the SSURGO database is more detailed and more current than the STATSGO database, the SSURGO database for the Central Clark Fork Tributaries Project Area did not contain the required K-factor values for some areas, including Grant Creek and Upper Trout Creek. When the SSURGO database lacked K-factor values, the K-factor was derived from the STATSGO database in which the USLE K-factor is a standard component. Soils polygon data was summarized and interpolated to a 10m grid cell (**Figure 2-2**).

2.2.3 LS-Factor

The **LS-factor** is a function of the slope and flow length of the eroding slope or cell (units are dimensionless). The LS-factor was derived from 10m USGS digital elevation model (DEM) grid data and interpolated to a 10m grid cell. For the purpose of computing the LS-factor, slope is defined as the average land surface gradient per cell, while the flow length refers to the distance between where overland flow originates and runoff reaches a defined channel or depositional zone. The equation used for calculating the slope length and slope factor is given in the Revised Universal Soil Loss Equation

(RUSLE), which provides improved slope length and steepness analysis applicable to mountainous terrain, as published in USDA handbook #703 (Renard et al. 1997). According to McCuen (1998), flow lengths are seldom greater than 400 feet or less than 20 feet.

L, the slope length factor in the RUSLE equation, serves to reference the erosion estimate for a horizontally projected slope length to the experimentally measured erosion for a 72.6 foot (22.1 meters) plot.

$$L = (\lambda/72.6)^m$$

where:

λ	= the horizontal projection of slope length
72.6	= the RUSLE unit plot length in feet
m	= the variable slope length component, related to the ratio (β) of rill erosion (caused by flow) to interrill erosion (caused by raindrop impact) defined in the following equation: $= \beta/(1 + \beta)$ And $\beta = (\sin \Theta/0.0896) / [3.0(\sin \Theta)^{0.8} + 0.56]$

Soil loss increases more rapidly with slope steepness than it does with slope length. This is quantified by S, the slope steepness factor of the RUSLE.

$$S = 10.8 \sin \theta + 0.03 \quad \text{for } \theta < 9\%$$
$$= 16.8 \sin \theta - 0.50 \quad \text{for } \theta \geq 9\%$$

where:

θ = the slope angle

Combined, these factors can be written:

$$LS = S_i \, (\lambda_i^{m+1} - \lambda_{i-1}^{m+1}) / (\lambda_I - \lambda_{i-1}) \, (72.6)^m$$

where:

λ_i	= length in feet from top of slope to lower end of the ith segment. This value was determined by applying GIS based surface analysis procedures to the each DEM, calculating total upslope length for each 10m grid cell, and converting the results to feet from meters.
S_i	= slope steepness factor for the segment $= 10.8 \sin \theta + 0.03$ for $\theta < 9\%$ $= 16.8 \sin \theta - 0.50$ for $\theta \geq 9\%$

The LS-Factor examines the topography of the area, identifying areas of steepness, flow paths, flow lengths, areas of deposition, and ultimately the concentrated sediment yield. The LS-Factor was calculated using a C++ program which automatically processes the DEM input (Van Remortal et al. 2004). The program evaluates each individual grid cell based on the LS factors mentioned above. The C++ program begins with a fill function of any depressions or sinks found on the DEM input. The highest elevation points on the DEM are then identified by the program and the flow direction is determined. In situations of converging flow, the flow direction of steepest decent takes precedence. The distance between the centers of one grid cell to the next grid cell is then calculated by the C++ program as the non-cumulative slope length (NCSL). A cumulative slope length is then computed by summing the NCSL from each grid cell, beginning at a high point and moving down along the direction of steepest descent.

The calculated slope angle of each cell is first examined by the C++ program, and a sub-routine calls for a table lookup function. The range in which the slope angle falls within the table is indentified and a corresponding slope length exponent (m) is assigned. The program has a function called the cutoff slope angle and is defined as the ratio of change in slope angle from one grid cell to the next along the flow direction. When the slope angle decreases sufficiently, the cumulative slope length calculation stops and then resumes when the land surface extends further downhill in order to recognize areas of deposition versus erosion. The final grid produced combines the effect of these topographic factors into the LS factor given in the formula above (**Figure 2-2**).

2.2.3.1 Digital Elevation Model

The digital elevation model (DEM) is the base layer used for developing the LS factor for the USLE analysis. The USGS 10m (1/3 Arc-second) DEM was used for this analysis. The 10m DEM was projected into Montana State Plane Coordinates and interpolated to a 10m grid cell to render the delineated stream network more representative of the actual size of Central Clark Fork Tributaries Project Area streams and to minimize resolution dependent stream network anomalies. The resulting interpolated 10m DEM was subjected to standard hydrologic preprocessing, including filling of sinks to create a positive drainage condition for all areas of the watershed (**Figure 2-2**).

2.2.3.2 Stream Network Delineation

The stream network for each subwatershed in the Central Clark Fork Tributaries Project Area was derived from the 10m DEM using TauDEM (**T**errain **A**nalysis **U**sing **D**igital **E**levation **M**odels) software developed by the Utah State University Hydrology Research Group (http://hydrology.usu.edu/taudem/taudem5.0/index.html). The stream network was generated using TauDEM with the threshold adjusted to most closely mirror the 1:24,000 NHD stream layer.

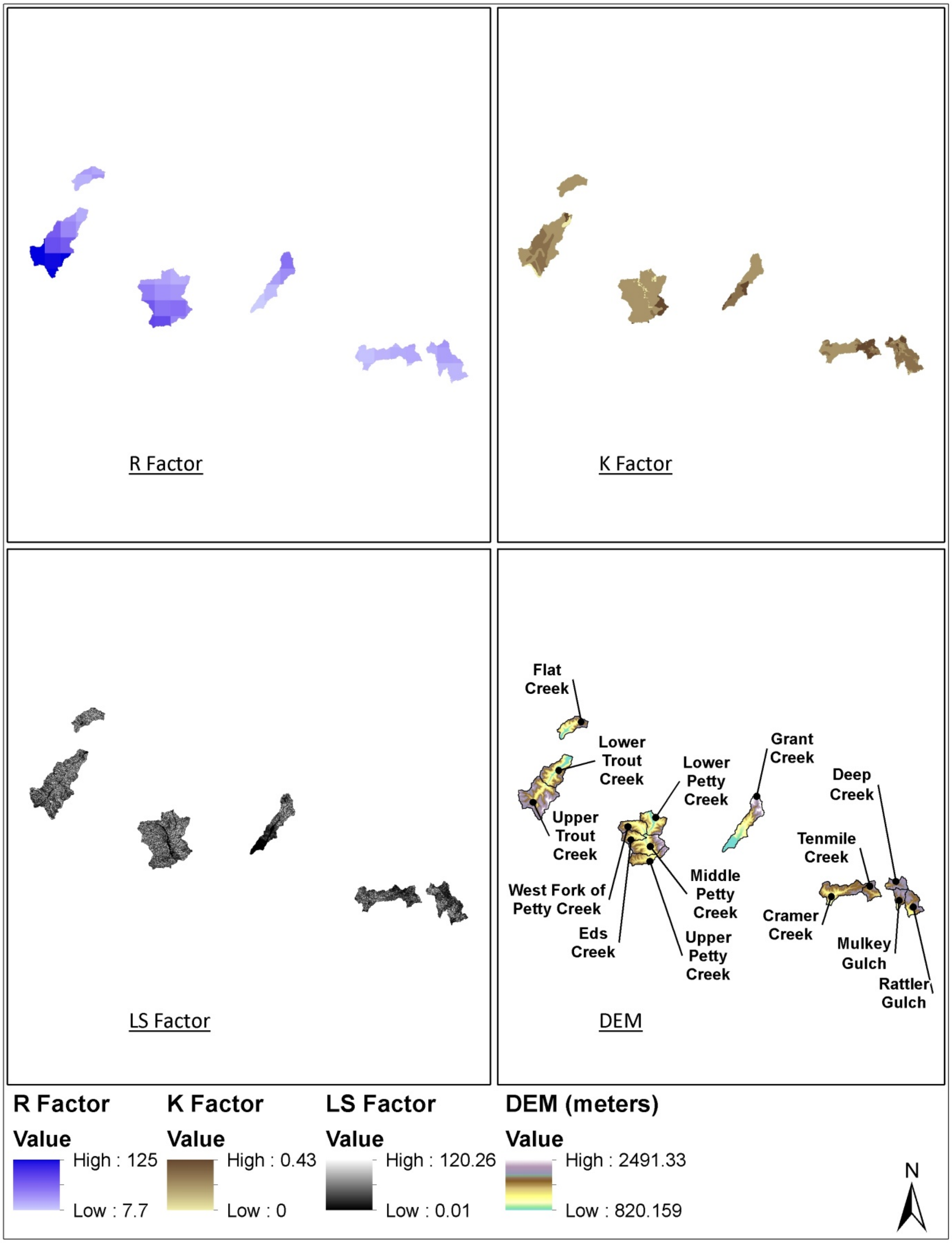

Figure 2-2. R-Factor, K-Factor, LS-Factor, and DEM for the Central Clark Fork Tributaries Project Area

2.2.4 C-Factor

The **C-factor** is a crop management value that represents the ratio of soil erosion from a specific cover type compared to the erosion that would occur on a clean-tilled fallow under identical slope and rainfall. The C-factor integrates a number of variables that influence erosion including vegetative cover, plant litter, soil surface, and land management. Original USLE C-factors were experimentally determined for agricultural crops and have since been modified to include rangeland and forested land cover types. For this assessment, the C-factor was estimated for various land cover types using the National Land Cover Database and C-factor interpretations applied during previous USLE modeling projects conducted for sediment TMDL development. C-factors are intended to be conservatively representative of conditions within the Central Clark Fork Tributaries Project Area.

2.2.4.1 National Land Cover Database

The 2006 National Land Cover Database (NLCD) was obtained from the Multi-Resolution Land Characteristics (MRLC) Consortium and used for establishing USLE C-factors in the Central Clark Fork Tributaries Project Area. The 2006 NLCD is a categorized 30 meter Landsat Thematic Mapper image shot in 2006. The NLCD image was projected to Montana State Plane Coordinates and interpolated to a 10m grid cell (**Figure 2-3**). For this analysis, areas described as 'cultivated crops' in the NLCD database were redefined as 'hay/pasture' to better represent agricultural practices in the Central Clark Fork Tributaries Project Area based on input from the local Natural Resources Conservation Service representative (Bret Bledsoe, personal communication). NLCD land cover types for the Central Clark Fork Tributaries Project Area are described in **Attachment A**.

2.2.4.2 C-Factor Derivation

USLE C-factors for existing conditions were assigned to the NLCD land cover types in the Central Clark Fork Tributaries Project Area based on ground cover percentages in *Table 10 – Factor C for permanent pasture, range, and idle land* as presented in Predicting Rainfall Erosion Losses: A Guide to Conservation Planning (USDA 1978) and summarized in **Table 2-2** for the Clark Fork-Drummond TPA and **Table 2-3** for the Middle Clark Fork Tributaries TPA and in **Attachment B**. In order to estimate the potential sediment reduction that might be achieved under a Best Management Practices (BMP) scenario, the USLE-based model was also run using C-factors representing desired conditions. In the Clark Fork Drummond TPA, land cover types identified as 'shrub/scrub', 'grasslands/ herbaceous' and 'hay/pasture' were conservatively adjusted to reflect a 10% improvement in ground cover over existing conditions based on input from the local Natural Resources Conservation Service representative as depicted in **Table 2-4** (Bret Bledsoe, personal communication). In the Middle Clark Fork Tributaries TPA, land cover types identified as 'grasslands/ herbaceous' and 'hay/pasture' were conservatively adjusted to reflect a 10% improvement in ground cover over existing conditions based on input from the local Natural Resources Conservation Service representative as depicted in **Table 2-5** (Don Feist, personal communication).

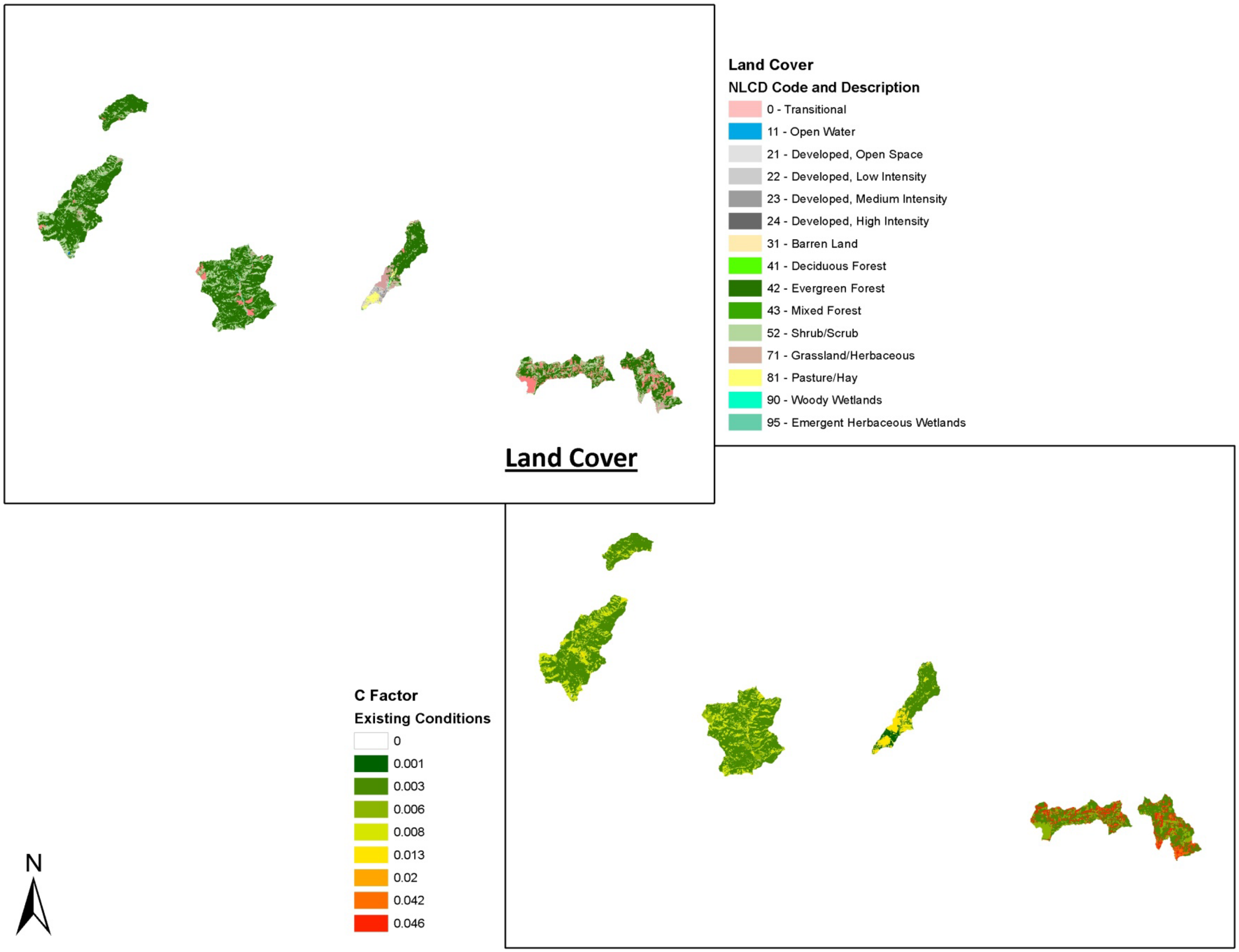

Figure 2-3. Land Cover and C-Factors for the Central Clark Fork Tributaries Project Area

Table 2-2. C-factors for Existing and Desired Conditions in the Clark Fork-Drummond TPA

NLCD Code	Description	C-Factor Existing Conditions	C-Factor Desired Conditions
0*	Transitional*	0.006	0.006
11	Open Water**	-	-
21	Developed, Open Space	0.003	0.003
22	Developed, Low Intensity	0.001	0.001
23	Developed, Medium Intensity	0.001	0.001
24	Developed, High Intensity	0.001	0.001
31	Barren Land	0.001	0.001
41	Deciduous Forest	0.003	0.003
42	Evergreen Forest	0.003	0.003
43	Mixed Forest	0.003	0.003
52	Shrub/Scrub	0.046	0.031
71	Grassland/Herbaceous	0.042	0.035
81	Hay/Pasture	0.020	0.013
90	Woody Wetlands	0.003	0.003
95	Emergent Herbaceous Wetlands	0.003	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest
**Open water will not be counted as contributing erosion

Table 2-3. C-factors for Existing and Desired Conditions in the Middle Clark Fork Tributaries TPA

NLCD Code	Description	C-Factor Existing Conditions	C-Factor Desired Conditions
0*	Transitional*	0.006	0.006
11	Open Water**	-	-
21	Developed, Open Space	0.003	0.003
22	Developed, Low Intensity	0.001	0.001
23	Developed, Medium Intensity	0.001	0.001
24	Developed, High Intensity	0.001	0.001
31	Barren Land	0.001	0.001
41	Deciduous Forest	0.003	0.003
42	Evergreen Forest	0.003	0.003
43	Mixed Forest	0.003	0.003
52	Shrub/Scrub	0.008	0.008
71	Grassland/Herbaceous	0.013	0.008
81	Hay/Pasture	0.013	0.008
90	Woody Wetlands	0.003	0.003
95	Emergent Herbaceous Wetlands	0.003	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest
** Open water will not be counted as contributing erosion

Table 2-4. Percent Ground Cover for Existing and Desired Land Cover Types in the Clark Fork-Drummond TPA

Land Cover	Existing % ground cover	Desired % ground cover
Shrub/Scrub	55	65
Grassland/Herbaceous	55	65
Hay/Pasture	75	85

Table 2-5. Percent Ground Cover for Existing and Desired Land Cover Types in the Middle Clark Fork Tributaries TPA

Land Cover	Existing % ground cover	Desired % ground cover
Grassland/Herbaceous	80	90
Hay/Pasture	80	90

It is acknowledged that land cover is variable within and across watersheds and changes seasonally. The C-factors used for the USLE-based model are intended to represent typical annual conditions at a coarse scale and the percent of improvement achievable via the implementation of BMPs.

2.2.4.3 Fire and Timber Harvest Adjustments

The 2006 NLCD layer was adjusted to quantify the amount of fire and timber harvest that have occurred since 2006 and also to identify previously disturbed areas that have become reforested over that same period. Adjustments on U.S. Forest Service lands were performed based on fire and timber harvest polygons provided by the U.S. Forest Service. Areas with fire or timber harvest within the past five years (2006-2011) we coded as 'transitional', while areas older than five years (pre-2006) were coded based on the NLCD cover type (**Figure 2-4**). On non-USFS property, a polygon layer of fire and timber harvest was digitized in GIS by comparing the 2006 NLCD layer with the 2011 NAIP aerial imagery. As with National Forest lands, areas with fire or timber harvest identified within the past five years (2006-2011) were coded as 'transitional' (**Figure 2-4**). Adjustments for reforestation were also examined by comparing the 2006 NLCD layer with the 2011 NAIP aerial imagery, though no areas of reforestation were observed.

Areas identified as 'transitional' due to recent fire or timber harvest were assigned a C-factor of 0.006 (**Table 2-2** and **Figure 2-3**). This C-factor is slightly higher than a 'deciduous/evergreen forest' and was used for logged areas (i.e. 'transitional') because logging intensity within the watershed is generally low and because practices, such as riparian clear-cutting, that tend to produce high sediment yields have not been used since at least 1991, when the Montana Streamside Management Zone (SMZ) law was enacted. However, since timber harvest has the potential to double the background erosion rate from an undisturbed forest (Elliot 2007), a conservative C-factor was applied. 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). Thus, the 'transitional' value was applied to areas of timber harvest under the assumption that a portion of a given watershed is always being harvested while other areas are recovering. The same C-factor was applied for both the existing conditions and BMP scenarios to indicate that logging will continue sporadically on public and private land within the watershed and will produced 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.

While upland erosion following fire tends to be greater than erosion following timber harvest (Elliot and Robichaud 2001), the same C-factor was applied to both disturbance types because of the unpredictable nature of wildfire and the difficulty of estimating the long term average sediment inputs from it. As with timber harvest, the C-factor for fire is the same for both management scenarios since disturbance is expected from periodic forest fires.

2.2.5 P-Factor

The **P-factor,** or 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 strip-cropping, terracing and contouring, and is applicable only to agricultural lands. Values of the P-factor compare straight-row farming practices with that of certain agriculturally based conservation practices. The P-factor was set to one for this analysis based on existing practices within the Central Clark Fork Tributaries Project Area.

2.3 Distance and Riparian Health Assessment based Sediment Delivery Ratio

The USLE assessment estimates the amount of sediment generated from the landscape, but the distance that sediment must travel to the stream channel, as well as the sediment removal capacity (i.e., the health) of the riparian vegetation, are important factors for estimating the sediment load that actually enters the stream network. Therefore, results from the USLE hillslope erosion assessment were combined with a sediment delivery ratio (SDR) and riparian health assessment to predict the amount of sediment delivered to streams in the Central Clark Fork Tributaries Project Area. Soil lost from one area on a hillslope due to erosive processes is typically re-deposited a short distance downslope and therefore not all of the sediment produced from a hillslope erosion event is delivered to a stream channel. In the Central Clark Fork Tributaries Project Area, sediment re-deposition is accounted for through the application of a sediment delivery ratio (SDR) which estimates the percentage of hillslope sediment produced that is ultimately delivered to the stream. This distance based sediment delivery ratio reflects the relationship between downslope travel distance and ultimate sediment delivery. In addition to sediment re-deposition during hillslope transport processes, riparian zones also reduce sediment inputs to stream channels. The width and quality of the riparian vegetation buffer zone determines its effectiveness as a sediment filter. Thus, a riparian health-based loading reduction was performed along with the distance based sediment delivery analysis.

2.3.1 Riparian Health Assessment

A riparian health assessment was conducted during the aerial assessment reach stratification process in which reaches were delineated based on a combination of physical attributes (ecoregion, valley slope, valley confinement, and stream order) and the presence and degree of adjacent human activity. For each reach, a riparian health assessment was performed using aerial photos, field notes, and best professional judgment. Riparian health for each reach was designated as ‘poor’, ‘poor/fair’, ‘fair’, ‘fair/good’, or ‘good’ based on adjacent land use practices, stream-side vegetation, and the presence or absence of human activities (**Figure 2-5**). The health classifications were then ground-truthed and modified based on field observations during August 2012. The cumulative length of the reaches within each riparian health category was tallied for each stream segment and the percent of stream length in each riparian health category was calculated. This information was then used to refine estimates of sediment delivery to streams from upland sources by incorporating the results of the riparian health assessment into the distance based sediment delivery ratio calculation.

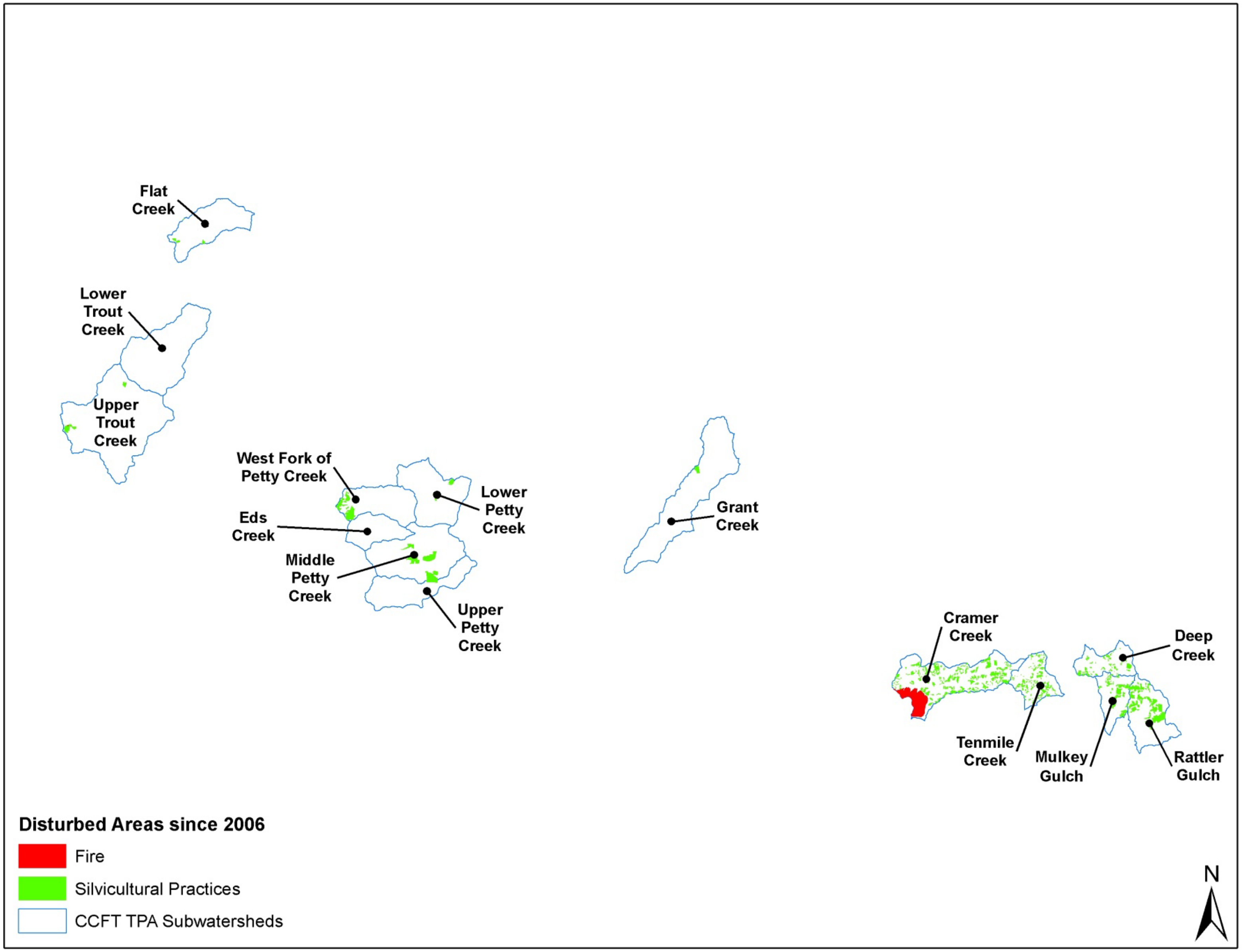

Figure 2-4. Fire and Timber Harvest Areas in the Central Clark Fork Tributaries Project Area since 2006

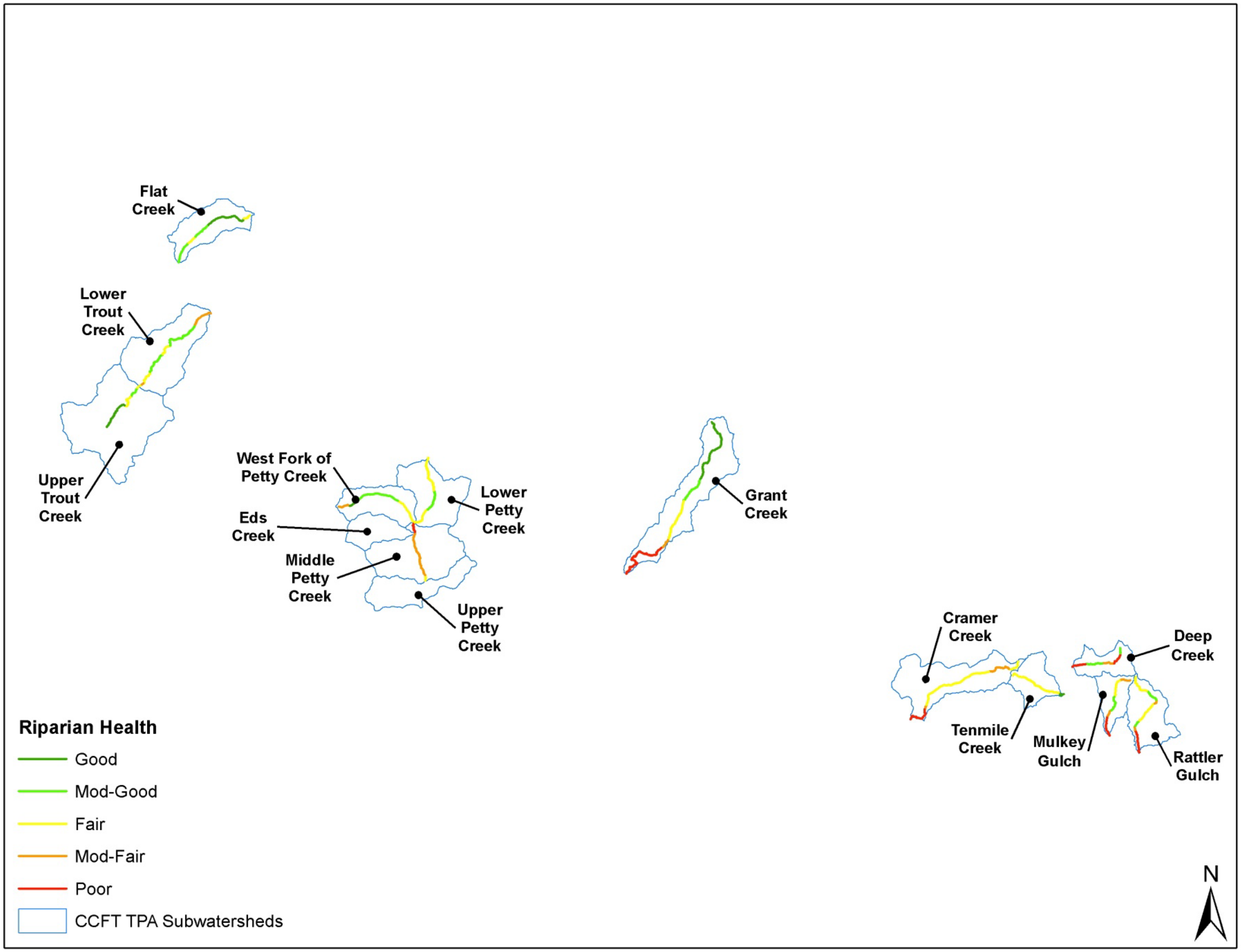

Figure 2-5. Aerial Assessment Reach Stratification Riparian Health Assessment

2.3.2 Distance based Sediment Delivery Ratio

The distance based sediment delivery ratio was calculated in the model for each grid cell based on the observed relationship between the distance from the delivery point to the stream and the percent of eroded sediment delivered to the stream using an equation developed by Megahan and Ketcheson (1996). Megahan and Ketcheson (1996) found that the relationship between the percentage (by volume) of sediment that travels a given percentage of the maximum distance is as shown in **Figure 2-6**. Megahan and Ketcheson's logarithmic regression of the data permits this relationship to be expressed by the equation presented in **Figure 2-6**, which may be restated as a function of three variables:

Volume % = or 103.62*EXP(-((D/Dtotal)*100)/32.88))-5.55

where:

Volume% = the percentage of sediment mobilized from a source that travels at least distance D from that source

D = distance from the sediment source, and

Dtotal = the maximum distance that sediment travels from the source.

As the Megahan and Ketcheson equation is dimensionless, to serve as an SDR it was scaled to the field conditions of the Central Clark Fork Tributaries Project Area by evaluating the equation with site specific values for D and Volume% at a single point and then solving for Dtotal. Having established a site specific Dtotal, the Megahan and Ketcheson equation reduces to the two variables that define a distance based SDR: distance and percent sediment delivered beyond that distance. This SDR was then used to estimate sediment delivery at all points on the sediment delivery path extending from the streambank to a distance Dtotal. A sediment delivery ratio example calculation is provided in **Attachment C**.

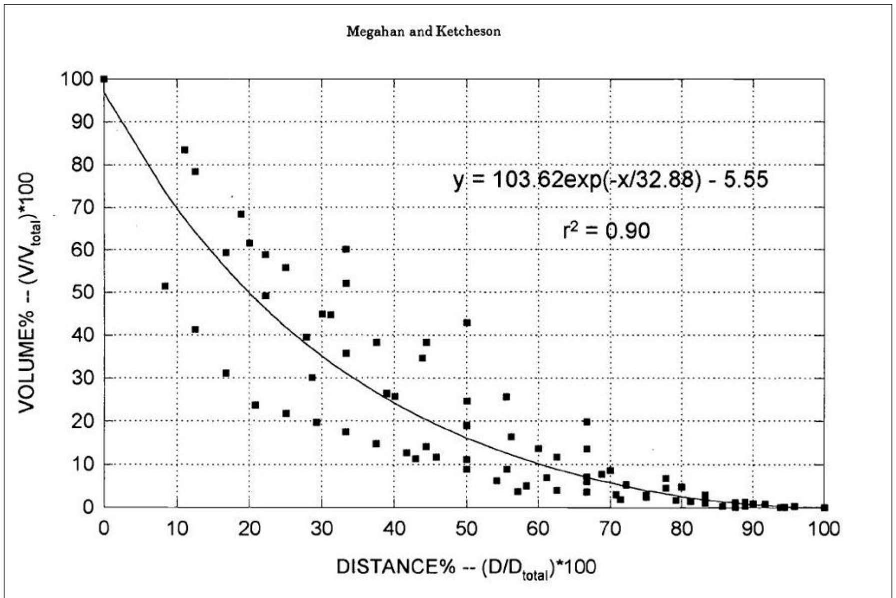

Figure 2. Dimensionless Plot of Sediment Volume Versus Travel Distance.

Figure 2-6 Sediment Volume vs. Travel Distance (Megahan and Ketcheson 1996)

2.3.3 Subwatershed Specific Sediment Delivery Ratio Scale Factors

Riparian zone sediment filtering capacity is typically expressed as a given percent reduction in delivery of sediment entering a riparian zone of a given buffer width. This rating of a known percent delivery (Volume%) from a known distance from the stream (D) permits scaling of the Megahan and Ketcheson's dimensionless equation (Section 2.3.2) for use in predicting percent delivery from other distances. Thirty feet is the minimum buffer width recommended by NRCS (Natural Resource Conservation Service, 2011b; 2011a) and 50 feet is the minimum width of the streamside management zone in Montana (DNRC 2006). Although buffer widths of 30 to 50 feet help reduce upland sediment loading to surface waters, the ability of riparian buffers to effectively filter sediment increases with increasing buffer width. For instance, a 100 foot wide, well-vegetated riparian buffer is a common recommended buffer width (Mayer et al., 2005; Cappiella et al., 2006) and has been found to filter 75-90% of incoming sediment from reaching the stream channel (Wegner, 1999; Knutson and Naef, 1997).

Although sediment removal efficiency is affected by factors such as ground slope, buffer health, and buffer composition, the literature values for a 100 foot buffer were used as the basis for applying a 75% sediment reduction efficiency (SRE) to buffers classified as 'good' and then scaling down the SRE based on the health classification (i.e., the SRE declines as buffer health/width declines) (**Figure 2-7**). The actual sediment removal efficiency is likely greater than shown in **Figure 2-7**, but conservative values from the literature were used as part of an implicit margin of safety. Note: Even though the health classifications assigned to streams in the Central Clark Fork Tributaries Project Area roughly correspond to different widths, and vegetative condition, density, and potential were considered during field verification of the classifications, the loading reductions based on riparian health are predominantly intended to highlight the importance of maintaining healthy riparian zones in reducing loading from upland sediment erosion. The values were not calibrated and do not necessarily reflect actual loading reductions associated with the riparian zone.

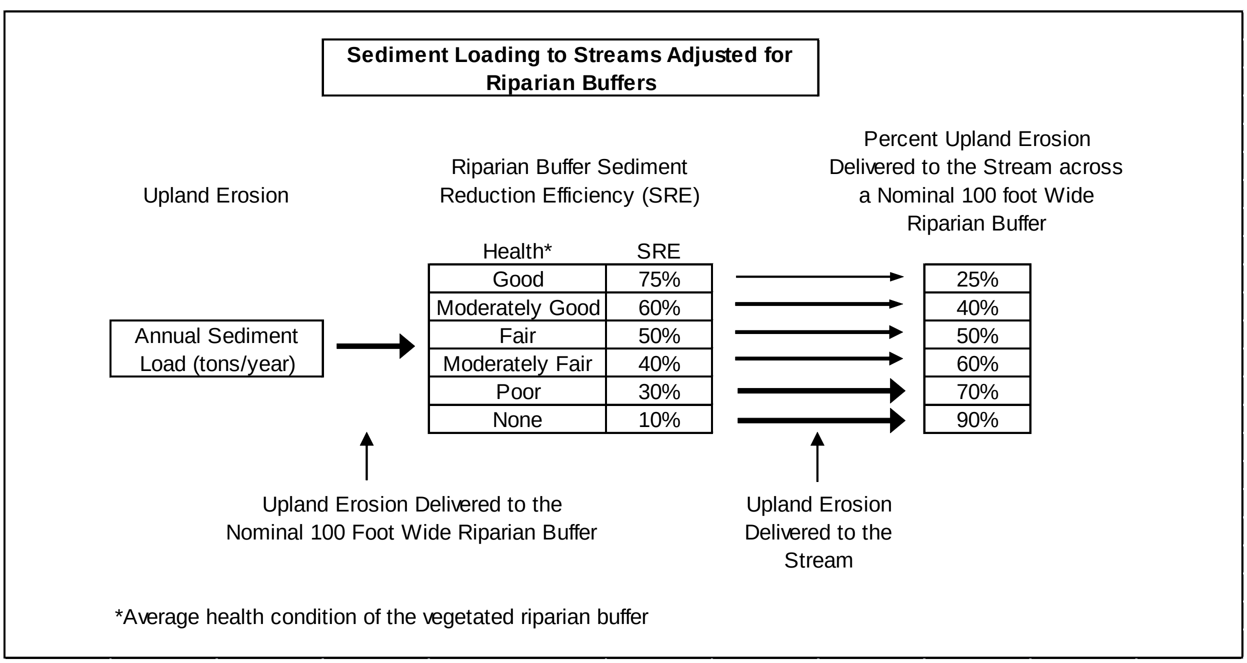

Figure 2-7. USLE Upland Sediment Load Delivery Adjusted for Riparian Buffer Capacity

The Central Clark Fork Tributaries Project Area riparian health assessment was used to develop a riparian health score based on the sediment reduction percentage for each individual stream segment subwatershed. This value represents the percent reduction in sediment delivery under existing conditions. For the BMP scenario, it was assumed that the implementation of BMPs on those activities that affect the overall health of the vegetated riparian buffer will increase riparian health. The potential to improve riparian health was evaluated for each reach based on best professional judgment through a review of color aerial imagery from 2011 and on-the-ground verification during August 2012.

2.4 Model Scenarios

Management scenarios include: (1) an existing conditions scenario that considers the current land cover, management practices, and riparian health in the watershed; (2) an upland BMP conditions scenario that considers improved grazing and cover management; (3) a riparian health BMP conditions scenario that considers improved riparian buffer zones; and (4) a riparian health BMP and upland BMP conditions scenario that considers improved riparian buffer zones and grazing and cover management. For each scenario, erosion was differentiated into two source categories: (1) natural erosion that occurs on the time scale of geologic processes and (2) anthropogenic erosion that is accelerated by human-caused activity. For scenarios 2 and 4, land cover types were conservatively adjusted to reflect a 10% improvement in ground cover over existing conditions as discussed in Section 2.2.4.2 and depicted in **Tables 2-4** and **2-5**. For scenarios 3 and 4, the riparian health score was adjusted to reflect improvements in riparian health as discussed in Section 2.3.3.

3.0 Results

Several hillslope erosion modeling scenarios were assessed in the Central Clark Fork Tributaries Project Area, including an assessment of existing conditions (Scenario 1) and several Best Management Practices (BMP) scenarios examining upland and riparian BMPs (Scenarios 2 through 4) as follows:

> **Scenario 1** - Existing conditions scenario that considers the current land cover, management practices, and riparian health in the watershed;
>
> **Scenario 2** - Upland BMP conditions scenario that considers improved grazing and cover management;
>
> **Scenario 3** - Riparian health BMP conditions scenario that considers improved riparian buffer zones;
>
> **Scenario 4** - Riparian health BMP and upland BMP conditions scenario that considers improved riparian buffer zones and grazing and cover management.

The results of this assessment are summarized by subwatershed in **Table 3-1**, with the complete modeling results presented by land cover category for each subwatershed in **Table 3-2**.

Table 3-1. Summary of Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
		Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
Clark-Fork Drummond								
Cramer Creek	**17,114**	**947.5**	**719.5**	**24%**	**392.0**	**59%**	**299.7**	**68%**
Deep Creek	**5,904**	**353.9**	**282.6**	**20%**	**238.3**	**33%**	**190.1**	**46%**
Tenmile Creek	**6,693**	**398.1**	**302.0**	**24%**	**173.2**	**56%**	**133.2**	**67%**
Mulkey Gulch	**5,743**	**560.51**	**415.14**	**26%**	**293.87**	**48%**	**217.12**	**61%**
Rattler Gulch	**9,671**	**624.6**	**477.2**	**24%**	**356.3**	**43%**	**271.7**	**56%**
Middle Clark Fork Tributaries								
Grant Creek	**19,719**	**296.0**	**273.5**	**8%**	**221.6**	**25%**	**205.1**	**31%**
Upper Petty Creek	9,749	709.8	707.6	<1%	460.4	35%	458.8	35%
Middle Petty Creek	16,368	810.9	807.4	<1%	525.0	35%	522.7	36%
Lower Petty Creek	12,349	366.1	362.9	1%	237.0	35%	235.3	36%
West Fork of Petty Creek	**9,453**	**258.4**	**258.4**	**<1%**	**201.7**	**22%**	**201.7**	**22%**
Eds Creek	6,278	297.1	297.1	<1%	188.8	36%	188.7	36%
Petty Creek Total	**54,197**	**2,442.3**	**2,433.4**	**<1%**	**1,612.9**	**34%**	**1,607.2**	**34%**
Upper Trout Creek	27,900	1,037.9	1,019.3	2%	886.3	15%	870.6	16%
Lower Trout Creek	17,635	525.0	521.7	1%	441.2	16%	438.6	16%
Trout Creek Total	**45,534**	**1,562.9**	**1,541.0**	**1%**	**1,327.5**	**15%**	**1,309.1**	**16%**
Flat Creek	**10,159**	**118.2**	**117.7**	**<1%**	**108.1**	**9%**	**107.6**	**9%**

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Land Cover Classification	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
Clark-Fork Drummond									
Cramer Creek	Transitional	4,795	91.79	91.79	0%	36.50	60%	36.50	60%
	Developed, Open Space	5	0.00	0.00	0%	0.00	57%	0.00	57%
	Developed, Low Intensity	19	0.00	0.00	0%	0.00	61%	0.00	61%
	Developed, Medium Intensity	11	0.00	0.00	0%	0.00	79%	0.00	79%
	Evergreen Forest	8,146	136.94	136.94	0%	62.37	54%	62.37	54%
	Mixed Forest	2	0.00	0.00	0%	0.00	0%	0.00	0%
	Shrub/Scrub	3,646	678.11	456.98	33%	271.95	60%	183.27	73%
	Grassland/Herbaceous	435	39.95	33.29	17%	20.81	48%	17.34	57%
	Hay/Pasture	45	0.69	0.45	35%	0.37	46%	0.24	65%
	Woody Wetlands	11	0.04	0.04	0%	0.03	28%	0.03	28%
	Total:	**17,114**	**947.5**	**719.5**	**24%**	**392.0**	**59%**	**299.7**	**68%**
Deep Creek sub6code	Transitional	641	11.84	11.84	0%	6.80	43%	6.80	43%
	Barren Land	0	0.00	0.00	0%	0.00	0%	0.00	0%
	Evergreen Forest	4,253	102.38	102.38	0%	68.11	33%	68.11	33%
	Mixed Forest	1	0.07	0.07	0%	0.06	16%	0.06	16%
	Shrub/Scrub	830	197.10	132.82	33%	131.53	33%	88.64	55%
	Grassland/Herbaceous	179	42.52	35.44	17%	31.78	25%	26.48	38%
	Total:	**5,904**	**353.9**	**282.6**	**20%**	**238.3**	**33%**	**190.1**	**46%**
Tenmile Creek	Transitional	1,111	22.43	22.43	0%	8.83	61%	8.83	61%
	Evergreen Forest	3,399	73.24	73.24	0%	37.92	48%	37.92	48%
	Shrub/Scrub	1,927	286.68	193.19	33%	118.92	59%	80.14	72%
	Grassland/Herbaceous	257	15.74	13.12	17%	7.54	52%	6.28	60%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Land Cover Classification	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
	Total:	**6,693**	**398.1**	**302.0**	**24%**	**173.2**	**56%**	**133.2**	**67%**
Mulkey Gulch	Transitional	869	24.84	24.84	0%	12.06	51%	12.06	51%
	Barren Land	8	0.00	0.00	0%	0.00	0%	0.00	0%
	Evergreen Forest	2,677	60.01	60.01	0%	32.24	46%	32.24	46%
	Mixed Forest	5	0.06	0.06	0%	0.02	68%	0.02	68%
	Shrub/Scrub	1,688	414.67	279.45	33%	220.52	47%	148.61	64%
	Grassland/Herbaceous	493	60.94	50.78	17%	29.03	52%	24.19	60%
	Hay/Pasture	3	0.00	0.00	0%	0.00	0%	0.00	0%
	Total:	**5,743**	**560.51**	**415.14**	**26%**	**293.87**	**48%**	**217.12**	**61%**
Rattler Gulch	Transitional	1,793	24.19	24.19	0%	12.50	48%	12.50	48%
	Developed, Open Space	1	0.00	0.00	0%	0.00	93%	0.00	93%
	Developed, Low Intensity	1	0.00	0.00	0%	0.00	99%	0.00	99%
	Evergreen Forest	4,703	88.45	88.45	0%	51.19	42%	51.19	42%
	Mixed Forest	40	1.53	1.53	0%	0.96	38%	0.96	38%
	Shrub/Scrub	2,030	390.98	263.49	33%	225.43	42%	151.92	61%
	Grassland/Herbaceous	1,102	119.46	99.55	17%	66.20	45%	55.16	54%
	Hay/Pasture	1	0.00	0.00	36%	0.00	16%	0.00	46%
	Total:	**9,671**	**624.6**	**477.2**	**24%**	**356.3**	**43%**	**271.7**	**56%**
Middle Clark Fork Tributaries									
Grant Creek	Transitional	113	1.75	1.75	0%	1.19	32%	1.19	32%
	Open Water	5	0.00	0.00	0%	0.00	0%	0.00	0%
	Developed, Open Space	560	0.85	0.85	0%	0.67	21%	0.67	21%
	Developed, Low Intensity	973	0.21	0.21	0%	0.16	24%	0.16	24%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Land Cover Classification	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
	Developed, Medium Intensity	577	0.06	0.06	0%	0.05	22%	0.05	22%
	Developed, High Intensity	64	0.00	0.00	0%	0.00	26%	0.00	26%
	Barren Land	159	0.01	0.01	0%	0.00	89%	0.00	89%
	Deciduous Forest	5	0.03	0.03	0%	0.03	18%	0.03	18%
	Evergreen Forest	10,808	209.92	209.92	0%	160.14	24%	160.14	24%
	Mixed Forest	16	0.32	0.32	0%	0.21	34%	0.21	34%
	Shrub/Scrub	1,400	23.76	23.76	0%	15.83	33%	15.83	33%
	Grassland/Herbaceous	3,096	55.51	34.16	38%	40.56	27%	24.96	55%
	Hay/Pasture	1,804	3.04	1.87	39%	2.38	22%	1.46	52%
	Woody Wetlands	133	0.48	0.48	0%	0.40	16%	0.40	16%
	Emergent Herbaceous Wetlands	5	0.03	0.03	0%	0.03	10%	0.03	10%
	Total:	**19,719**	**296.0**	**273.5**	**8%**	**221.6**	**25%**	**205.1**	**31%**
Upper Petty Creek	Transitional	141	1.12	1.12	0%	0.64	42%	0.64	42%
	Developed, Open Space	35	1.17	1.17	0%	0.88	25%	0.88	25%
	Developed, Low Intensity	2	0.00	0.00	0%	0.00	86%	0.00	86%
	Evergreen Forest	7,090	452.38	452.38	0%	307.19	32%	307.19	32%
	Shrub/Scrub	2,466	249.23	249.23	0%	147.46	41%	147.46	41%
	Grassland/Herbaceous	9	5.67	3.49	38%	4.10	28%	2.52	55%
	Woody Wetlands	3	0.11	0.11	0%	0.08	30%	0.08	30%
	Emergent Herbaceous Wetlands	2	0.07	0.07	0%	0.05	35%	0.05	35%
	Total:	**9,749**	**709.8**	**707.6**	**<1%**	**460.4**	**35%**	**458.8**	**35%**
Middle Petty	Transitional	1,007	61.55	61.55	0%	38.47	38%	38.47	38%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Land Cover Classification	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
Creek	Developed, Open Space	95	0.41	0.41	0%	0.23	43%	0.23	43%
	Developed, Low Intensity	11	0.01	0.01	0%	0.00	33%	0.00	33%
	Evergreen Forest	11,980	499.59	499.59	0%	337.14	33%	337.14	33%
	Shrub/Scrub	3,007	239.68	239.68	0%	142.64	40%	142.64	40%
	Grassland/Herbaceous	188	9.01	5.54	38%	6.06	33%	3.73	59%
	Hay/Pasture	6	0.04	0.02	38%	0.02	45%	0.01	66%
	Woody Wetlands	40	0.27	0.27	0%	0.20	24%	0.20	24%
	Emergent Herbaceous Wetlands	33	0.34	0.34	0%	0.26	24%	0.26	24%
	Total:	**16,368**	**810.9**	**807.4**	**<1%**	**525.0**	**35%**	**522.7**	**36%**
Lower Petty Creek	Transitional	130	2.64	2.64	0%	1.79	32%	1.79	32%
	Developed, Open Space	103	2.77	2.77	0%	1.51	46%	1.51	46%
	Developed, Low Intensity	35	0.22	0.22	0%	0.14	38%	0.14	38%
	Evergreen Forest	8,643	209.72	209.72	0%	146.24	30%	146.24	30%
	Shrub/Scrub	3,164	141.69	141.69	0%	82.24	42%	82.24	42%
	Grassland/Herbaceous	199	8.24	5.07	38%	4.45	46%	2.74	67%
	Hay/Pasture	5	0.08	0.05	39%	0.06	29%	0.04	56%
	Woody Wetlands	28	0.37	0.37	0%	0.31	19%	0.31	19%
	Emergent Herbaceous Wetlands	42	0.39	0.39	0%	0.31	20%	0.31	20%
	Total:	**12,349**	**366.1**	**362.9**	**1%**	**237.0**	**35%**	**235.3**	**36%**
West Fork of Petty Creek	Transitional	708	24.17	24.17	0%	19.26	20%	19.26	20%
	Developed, Open Space	3	0.02	0.02	0%	0.02	22%	0.02	22%
	Developed, Low Intensity	0	0.00	0.00	0%	0.00	33%	0.00	33%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	**Land Cover Classification**	**Area (Acres)**	**Scenario 1**	**Scenario 2 (BMP 1)**		**Scenario 3 (BMP 2)**		**Scenario 4 (BMP 3)**	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
	Evergreen Forest	5,916	124.00	124.00	0%	98.25	21%	98.25	21%
	Shrub/Scrub	2,703	109.74	109.74	0%	83.75	24%	83.75	24%
	Grassland/Herbaceous	29	0.07	0.04	38%	0.03	53%	0.02	71%
	Woody Wetlands	40	0.16	0.16	0%	0.14	15%	0.14	15%
	Emergent Herbaceous Wetlands	53	0.27	0.27	0%	0.23	14%	0.23	14%
	Total:	**9,453**	**258.4**	**258.4**	**<1%**	**201.7**	**22%**	**201.7**	**22%**
Eds Creek	Transitional	2	0.00	0.00	0%	0.00	0%	0.00	0%
	Developed, Open Space	5	0.01	0.01	0%	0.00	16%	0.00	16%
	Developed, Low Intensity	1	0.00	0.00	0%	0.00	0%	0.00	0%
	Evergreen Forest	4,266	192.08	192.08	0%	129.12	33%	129.12	33%
	Shrub/Scrub	1,976	104.81	104.81	0%	59.48	43%	59.48	43%
	Grassland/Herbaceous	12	0.06	0.04	39%	0.04	25%	0.03	54%
	Hay/Pasture	2	0.01	0.00	38%	0.00	77%	0.00	86%
	Woody Wetlands	8	0.06	0.06	0%	0.05	25%	0.05	25%
	Emergent Herbaceous Wetlands	8	0.08	0.08	0%	0.06	22%	0.06	22%
	Total:	**6,278**	**297.1**	**297.1**	**<1%**	**188.8**	**36%**	**188.7**	**36%**
Petty Creek Total	Transitional	1,989	89.48	89.48	0%	60.15	33%	60.15	33%
	Developed, Open Space	242	4.39	4.39	0%	2.64	40%	2.64	40%
	Developed, Low Intensity	50	0.24	0.24	0%	0.14	39%	0.14	39%
	Evergreen Forest	37,894	1477.78	1477.78	0%	1017.93	31%	1017.93	31%
	Shrub/Scrub	13,315	845.16	845.16	0%	515.57	39%	515.57	39%
	Grassland/Herbaceous	437	23.05	14.18	38%	14.68	36%	9.03	61%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	Land Cover Classification	Area (Acres)	Scenario 1	Scenario 2 (BMP 1)		Scenario 3 (BMP 2)		Scenario 4 (BMP 3)	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
	Hay/Pasture	14	0.12	0.08	39%	0.08	36%	0.05	61%
	Woody Wetlands	119	0.98	0.98	0%	0.77	21%	0.77	21%
	Emergent Herbaceous Wetlands	137	1.15	1.15	0%	0.91	21%	0.91	21%
	Total:	**54,197**	**2,442.3**	**2,433.4**	**<1%**	**1,612.9**	**34%**	**1,607.2**	**34%**
Upper Trout Creek	Transitional	257	4.30	4.30	0%	3.13	27%	3.13	27%
	Open Water	94	0.00	0.00	0%	0.00	0%	0.00	0%
	Barren Land	12	0.00	0.00	0%	0.00	41%	0.00	41%
	Evergreen Forest	19,094	598.31	598.31	0%	515.22	14%	515.22	14%
	Shrub/Scrub	7,830	386.37	386.37	0%	326.80	15%	326.80	15%
	Grassland/Herbaceous	594	48.38	29.77	38%	40.63	16%	25.00	48%
	Hay/Pasture	4	0.19	0.12	38%	0.16	18%	0.10	49%
	Woody Wetlands	9	0.23	0.23	0%	0.21	11%	0.21	11%
	Emergent Herbaceous Wetlands	6	0.15	0.15	0%	0.13	13%	0.13	13%
	Total:	**27,900**	**1,037.9**	**1,019.3**	**2%**	**886.3**	**15%**	**870.6**	**16%**
Lower Trout Creek	Evergreen Forest	12,917	331.99	331.99	0%	282.65	15%	282.65	15%
	Shrub/Scrub	4,446	184.39	184.39	0%	151.50	18%	151.50	18%
	Grassland/Herbaceous	247	8.38	5.16	38%	6.84	18%	4.21	50%
	Woody Wetlands	9	0.09	0.09	0%	0.08	11%	0.08	11%
	Emergent Herbaceous Wetlands	15	0.12	0.12	0%	0.11	10%	0.11	10%
	Total:	**17,635**	**525.0**	**521.7**	**1%**	**441.2**	**16%**	**438.6**	**16%**
Trout Creek	Transitional	257	4.30	4.30	0%	3.13	27%	3.13	27%

Table 3-2. Delivered Sediment Load by Land Cover Type in the Central Clark Fork Tributaries Project Area

Subwatershed	**Land Cover Classification**	**Area (Acres)**	**Scenario 1**	**Scenario 2 (BMP 1)**		**Scenario 3 (BMP 2)**		**Scenario 4 (BMP 3)**	
			Upland Erosion Sediment Load for **Existing Conditions** and **Existing Riparian** Health (Tons/Year)	Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health (Tons/Year)	**Percent Reduction**
Total	Open Water	94	0.00	0.00	0%	0.00	0%	0.00	0%
	Barren Land	12	0.00	0.00	0%	0.00	41%	0.00	41%
	Evergreen Forest	32,011	930.30	930.30	0%	797.87	14%	797.87	14%
	Shrub/Scrub	12,276	570.76	570.76	0%	478.30	16%	478.30	16%
	Grassland/Herbaceous	841	56.76	34.93	38%	47.47	16%	29.21	49%
	Hay/Pasture	4	0.19	0.12	38%	0.16	18%	0.10	49%
	Woody Wetlands	18	0.32	0.32	0%	0.29	11%	0.29	11%
	Emergent Herbaceous Wetlands	21	0.27	0.27	0%	0.24	11%	0.24	11%
	Total:	**45,534**	**1,562.9**	**1,541.0**	**1%**	**1,327.5**	**15%**	**1,309.1**	**16%**
Flat Creek sub6code	Transitional	101	1.29	1.29	0%	1.17	9%	1.17	9%
	Evergreen Forest	8,661	89.31	89.31	0%	82.00	8%	82.00	8%
	Shrub/Scrub	1,305	26.22	26.22	0%	23.62	10%	23.62	10%
	Grassland/Herbaceous	93	1.43	0.88	38%	1.28	10%	0.79	45%
	Total:	**10,159**	**118.2**	**117.7**	**<1%**	**108.1**	**9%**	**107.6**	**9%**

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Attachment A

National Land Cover Database Land Cover Type Descriptions

11. Open Water - areas of open water, generally with less than 25 percent cover of vegetation or soil.

21. Developed, Open Space - Includes areas with a mixture of constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.

22. Developed, Low Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49 percent of total cover. These areas most commonly include single-family housing units.

23. Developed, Medium Intensity - Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79 percent of the total cover. These areas most commonly include single-family housing units.

24. Developed, High Intensity – Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.

31. Barren Land (Rock/Sand/Clay) – Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.

41. Deciduous Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

43. Mixed Forest - Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.

52. Shrub/Scrub - Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

71. Grasslands/Herbaceous - Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

90. Woody Wetlands - Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

95. Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Attachment B

Assignment of USLE C-Factors to NLCD Land Cover Types

TABLE 10.—*Factor* **C** *for permanent pasture, range, and idle land*[1]

Vegetative canopy: Type and height[2]	Percent cover[3]	Type[4]	Percent ground cover: 0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6½ ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

[1] The listed **C** values assume that the vegetation and mulch are randomly distributed over the entire area.

[2] Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

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

[4] G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in deep.

W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

C-Factors for land cover types in the Clark Fork-Drummond TPA for Existing Conditions						
NLCD Code	Description	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-Factor
0*	Transitional*	no appreciable canopy	-	-		0.006
11	Open Water**			-		-
21	Developed, Open Space	no appreciable canopy	-	G	95-100	0.003
22	Developed, Low Intensity	-	-	-	-	0.001
23	Developed, Medium Intensity	-	-	-	-	0.001
24	Developed, High Intensity	-	-	-	-	0.001
31	Barren Land	-	-	-	-	0.001
41	Deciduous Forest	trees	75	G	95-100	0.003
42	Evergreen Forest	trees	75	G	95-100	0.003
43	Mixed Forest	trees	75	G	95-100	0.003
52	Shrub/Scrub	appreciable brush	25	G	55	0.046
71	Grassland/Herbaceous	no appreciable canopy	-	G	55	0.042
81	Hay/Pasture	no appreciable canopy	-	G	75	0.020
90	Woody Wetlands	trees	25	G	95-100	0.003
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest

**Open water will not be counted as contributing erosion

C-Factors for land cover types in the Clark Fork-Drummond TPA for Desired Conditions						
NLCD Code	Description	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-Factor
0*	Transitional*	no appreciable canopy	-	-		0.006
11	Open Water**			-		-
21	Developed, Open Space	no appreciable canopy	-	G	95-100	0.003
22	Developed, Low Intensity	-	-	-	-	0.001
23	Developed, Medium Intensity	-	-	-	-	0.001
24	Developed, High Intensity	-	-	-	-	0.001
31	Barren Land	-	-	-	-	0.001
41	Deciduous Forest	trees	75	G	95-100	0.003
42	Evergreen Forest	trees	75	G	95-100	0.003
43	Mixed Forest	trees	75	G	95-100	0.003
52	Shrub/Scrub	appreciable brush	25	G	65	0.031
71	Grassland/Herbaceous	no appreciable canopy	-	G	65	0.035
81	Hay/Pasture	no appreciable canopy	-	G	85	0.013
90	Woody Wetlands	trees	25	G	95-100	0.003
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest

**Open water will not be counted as contributing erosion

C-Factors for land cover types in the Middle Clark Fork Tributaries TPA for Existing Conditions						
NLCD Code	Description	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-Factor
0*	Transitional*	no appreciable canopy	-	-		0.006
11	Open Water**			-		-
21	Developed, Open Space	no appreciable canopy	-	G	95-100	0.003
22	Developed, Low Intensity	-	-	-	-	0.001
23	Developed, Medium Intensity	-	-	-	-	0.001
24	Developed, High Intensity	-	-	-	-	0.001
31	Barren Land	-	-	-	-	0.001
41	Deciduous Forest	trees	75	G	95-100	0.003
42	Evergreen Forest	trees	75	G	95-100	0.003
43	Mixed Forest	trees	75	G	95-100	0.003
52	Shrub/Scrub	appreciable brush	25	G	85	0.008
71	Grassland/Herbaceous	no appreciable canopy	-	G	80	0.013
81	Hay/Pasture	no appreciable canopy	-	G	80	0.013
90	Woody Wetlands	trees	25	G	95-100	0.003
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest

**Open water will not be counted as contributing erosion

C-Factors for land cover types in the Middle Clark Fork Tributaries TPA for Desired Conditions						
NLCD Code	Description	Type and Height of Raised Canopy	Percent Canopy Cover	Type	Percent Ground Cover	C-Factor
0*	Transitional*	no appreciable canopy	-	-		0.006
11	Open Water**			-		-
21	Developed, Open Space	no appreciable canopy	-	G	95-100	0.003
22	Developed, Low Intensity	-	-	-	-	0.001
23	Developed, Medium Intensity	-	-	-	-	0.001
24	Developed, High Intensity	-	-	-	-	0.001
31	Barren Land	-	-	-	-	0.001
41	Deciduous Forest	trees	75	G	95-100	0.003
42	Evergreen Forest	trees	75	G	95-100	0.003
43	Mixed Forest	trees	75	G	95-100	0.003
52	Shrub/Scrub	appreciable brush	25	G	85	0.008
71	Grassland/Herbaceous	no appreciable canopy	-	G	90	0.008
81	Hay/Pasture	no appreciable canopy	-	G	90	0.008
90	Woody Wetlands	trees	25	G	95-100	0.003
95	Emergent Herbaceous Wetlands	tall grass	75	G	95-100	0.003

* A code of "0" and a description of "Transitional" was developed to describe areas of Fire or Timber Harvest

**Open water will not be counted as contributing erosion

Sediment Delivery Ratio Example Calculation – West Fork Petty Creek

Existing Conditions

To create a final, subwatershed specific SDR, Megahan and Ketcheson's (1996) dimensionless equation relating percent sediment volume to percent travel distance was scaled to each subwatershed by using its riparian health assessment based 100-Foot Sediment Reduction Efficiency Percentage to derive a site specific maximum sediment travel distance. For each subwatershed, the following method was applied as described below using Raven Creek as an example.

From the subwatershed's Riparian Health Assessment, determine the expected % sediment delivery across a nominal 100 foot wide riparian zone. The riparian health assessment based Sediment Reduction Efficiency Percentage (SRE) computed for the West Fork Petty Creek subwatershed is presented in **Table 1**.

Table 1. West Fork Petty Creek Sediment Reduction Efficiency Percentage for Existing Conditions.

Riparian Health	Stream Length (Feet)	Percent of Total	Riparian Buffer Sediment Reduction Efficiency Percentage	Weighted Sediment Reduction Efficiency Percentage (Existing Conditions)
Good	4,339	11	75	8
Fair/Good	18,540	46	60	28
Fair	12,222	30	50	15
Poor/Fair	5,259	13	40	5
Poor			30	0
No data			10	
Total	40,361	100		**56**

Example:
Per **Table 1**, the West Fork Petty Creek subwatershed's expected sediment delivery across a **100**-foot wide riparian zone is (100%-**56**% reduction) = **44%** delivered.

Substitute the expected % sediment delivery across a **100**-foot wide riparian zone into Megahan and Ketcheson's dimensionless sediment volume vs travel distance equation.

Example:
Volume% = 103.62exp(-((D/Dtotal)*100)/32.88) -5.55 =

44% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Solve the equation for **Dtotal** to arrive at a representative maximum sediment travel distance for that subwatershed.

Example:
44% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Dtotal = **100**/(-0.3288*ln((**44**+5.55)/103.62))

Dtotal = **412** feet

Restate the equation using the subwatershed's calculated maximum sediment travel distance (Dtotal) to arrive at an integrated Distance and Riparian Health based Sediment Deliver Ratio (SDR) for that subwatershed.

Example:
Within the Raven Creek subwatershed, the SDR for an analytical pixel with a drainage path to the nearest stream of length **D** would be given by:

Volume% = 103.62exp(-((D/**412**)*100)/32.88) -5.55

So if the downslope distance (D) were 200 feet in this subwatershed, then

Volume % = 103.62exp(-((200/**412**)*100)/32.88) -5.55

Volume % = 18.1

By this method, the Sediment Delivery Ratio (SDR) for each analytical pixel in a West Fork Petty Creek subwatershed is obtained by evaluating this equation:

*SDR = (103.62*EXP(-((D/Dtotal)*100)/32.88)-5.55)/100*

Where:

SDR = the ratio of sediment generated from the pixel that is delivered to a stream,
D = the downslope distance from the pixel to the nearest stream channel, and
Dtotal = the subwatershed specific Riparian Health derived maximum sediment travel distance.

Therefore in the example above, that specific pixel would have an SDR value of 0.181 that will then be multiplied against the existing USLE soil loss to produce the final reduced soil loss rate for that cell.

BMP Conditions

Table 2. West Fork Petty Creek Sediment Reduction Efficiency Percentage for BMP Conditions.

BMP Riparian Health	Stream Length (Feet)	Percent of Total	Riparian Buffer Sediment Reduction Efficiency Percentage	Weighted Sediment Reduction Efficiency Percentage (BMP Conditions)
Good	9,599	24	75	18
Fair/Good	30,762	76	60	46
Fair		3	50	0
Poor/Fair		0	40	0
Poor		0	30	0
No data		0	10	0
Total	40,361	100		**64**

Example:
Per **Table 2**, the West Fork Petty Creek subwatershed's expected sediment delivery across a **100**-foot wide riparian zone is (100%-67% reduction) = **36%** delivered.

Substitute the expected % sediment delivery across a **100**-foot wide riparian zone into Megahan and Ketcheson's dimensionless sediment volume vs travel distance equation.

Example:
Volume% = 103.62exp(-((D/Dtotal)*100)/32.88) -5.55 =

36% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Solve the equation for **Dtotal** to arrive at a representative maximum sediment travel distance for that subwatershed.

Example:
36% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Dtotal = **100**/(-0.3288*ln((**36**+5.55)/103.62))

Dtotal = **333** feet

Restate the equation using the subwatershed's calculated maximum sediment travel distance (Dtotal) to arrive at an integrated Distance and Riparian Health based Sediment Deliver Ratio (SDR) for that subwatershed.

Example:
Within the West Fork Petty Creek subwatershed, the SDR for an analytical pixel with a drainage path to the nearest stream of length **D** would be given by:

Volume% = 103.62exp(-((D/**333**)*100)/32.88) -5.55

So if the downslope distance (D) were 200 feet in this subwatershed, then

Volume % = 103.62exp(-((200/**333**)*100)/32.88) -5.55

Volume % = 11.1

By this method, the Sediment Delivery Ratio (SDR) for each analytical pixel in a West Fork Petty Creek subwatershed is obtained by evaluating this equation:

*SDR = (103.62*EXP(-((D/Dtotal)*100)/32.88)-5.55)/100*

Where:

SDR = the ratio of sediment generated from the pixel that is delivered to a stream,
D = the downslope distance from the pixel to the nearest stream channel, and
Dtotal = the subwatershed specific Riparian Health derived maximum sediment travel distance.

Therefore in the example above, that specific pixel would have an SDR value of 0.111 that will then be multiplied against the existing USLE soil loss to produce the final reduced soil loss rate for that cell.