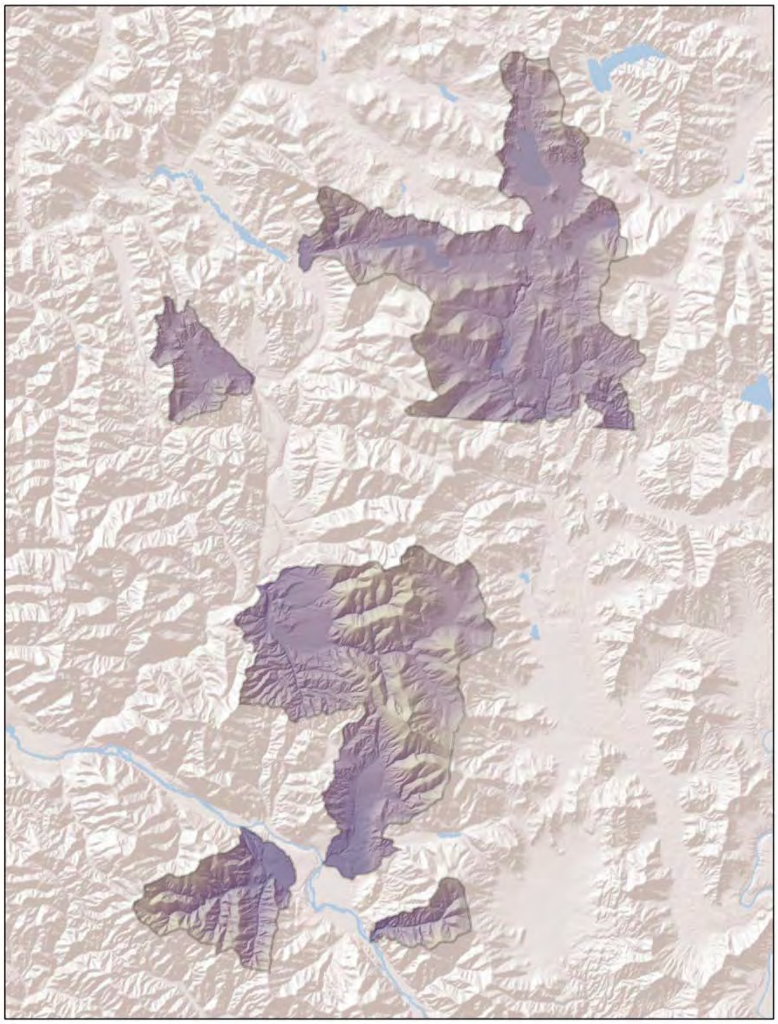
ATTACHMENT B – UPLAND EROSION ASSESSMENT

Thompson TMDL Project Area: Assessment of Upland Sediment Sources for TMDL Development



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1.0 INTRODUCTION

An assessment of the sediment loading from hillslope erosion within the Thompson 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 Thompson Project Area. The USLE based model was implemented as a watershed-scale, raster-based, GIS model using ArcGIS software.

1.1 SEDIMENT IMPAIRMENTS

The Thompson Project Area includes three TMDL Planning Areas (TPAs): Thompson TPA, a portion of the Lower Flathead TPA, and a portion of the Middle Clark Fork Tributaries TPA. Within the Thompson Project Area, there are nine water body segments listed on the 2012 303(d) List for sediment-related impairments (**Table 1-1**). McGinnis Creek, Lazier Creek, Little Thompson River, and McGregor Creek are listed as impaired due to sediment in the Thompson TPA, while Henry Creek, Lynch Creek and Swamp Creek are listed as impaired due to sediment in the Middle Clark Fork Tributaries TPA. The Little Bitterroot River and Sullivan Creek are listed as impaired due to sediment in the Lower Flathead TPA.

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

TPA	List ID	Waterbody Description
Thompson	MT76N005_070	MCGINNIS CREEK, headwaters to mouth (Little Thompson River)
Thompson	MT76N005_060	LAZIER CREEK, headwaters to mouth (Thompson River)
Thompson	MT76N005_040	LITTLE THOMPSON RIVER, headwaters to mouth (Thompson River), T22N R25W S8
Thompson	MT76N005_030	McGREGOR CREEK, McGregor Lake to mouth (Thompson River)
Middle Clark Fork Tributaries	MT76N003_170	HENRY CREEK, headwaters to mouth (Clark Fork River), T19N R26W S1
Middle Clark Fork Tributaries	MT76N003_010	LYNCH CREEK, headwaters to mouth (Clark Fork River)
Middle Clark Fork Tributaries	MT76N003_160	SWAMP CREEK, West Fork Swamp Creek to mouth (Clark Fork River), T20N R27W S3
Lower Flathead	MT76L002_060	LITTLE BITTERROOT RIVER, Hubbart Reservoir to Flathead Reservation Boundary
Lower Flathead	MT76L002_070	SULLIVAN CREEK, headwaters to Flathead Indian Reservation

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 Thompson 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 Thompson Project Area upland sediment assessment would be conducted. Subwatersheds were delineated on the basis of the USGS 6^{th} 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 McGregor Creek HUC12, which was split into areas draining upstream (above) and downstream (below) the McGregor Lake outlet, along with the Little Bitterroot River-Hubbart Reservoir HUC12, which was split into areas draining upstream (above) and downstream (below) the Hubbart Reservoir outlet. While a portion of the sediment derived from areas upstream of reservoirs on McGregor Creek and the Little Bitterroot River are likely retained in the reservoirs, no adjustment was made to sediment loading estimates since this assessment is focused on identifying areas where human sources of sediment loading can be reduced. In addition, the Upper Sullivan Creek, Little-Bitterroot River-Hubbart Reservoir, and Little Bitterroot River-Sickler Creek HUC12s were clipped to the TPA boundary. The Little Bitterroot River and Sullivan Creek flow in a southerly direction and the TPA boundary coincides with the northern boundary of the Flathead Indian Reservation.

Table 2-1. Subwatersheds in the Thompson Project Area

HUC10 Name	HUC12 Name	Subwatershed ID
Clark Fork River-Lynch Creek	Henry Creek	Henry Creek
	Lynch Creek	Lynch Creek
	Swamp Creek	Swamp Creek
Little Thompson River	Lower Little Thompson River	Lower Little Thompson River
	McGinnis Creek	McGinnis Creek
	Middle Little Thompson River	Middle Little Thompson River
	Mudd Creek	Mudd Creek
	Upper Little Thompson River	Upper Little Thompson River
Upper Thompson River	Lazier Creek	Lazier Creek
	McGregor Creek	McGregor Creek_above McGregor Lake
		McGregor Creek_below McGregor Lake
Sullivan Creek	Upper Sullivan Creek	Upper Sullivan Creek_clipped to TPA
Upper Little Bitterroot River	Little Bitterroot Lake	Little Bitterroot Lake
	Little Bitterroot River-Hubbart Reservoir	Little Bitterroot River-Hubbart Reservoir_above Hubbart Reservoir
		Little Bitterroot River-Hubbart Reservoir_below Hubbart Reservoir_clipped to TPA
	Little Bitterroot River-Sickler Creek	Little Bitterroot River-Sickler Creek_clipped to TPA
	Little Meadow Creek	Little Meadow Creek

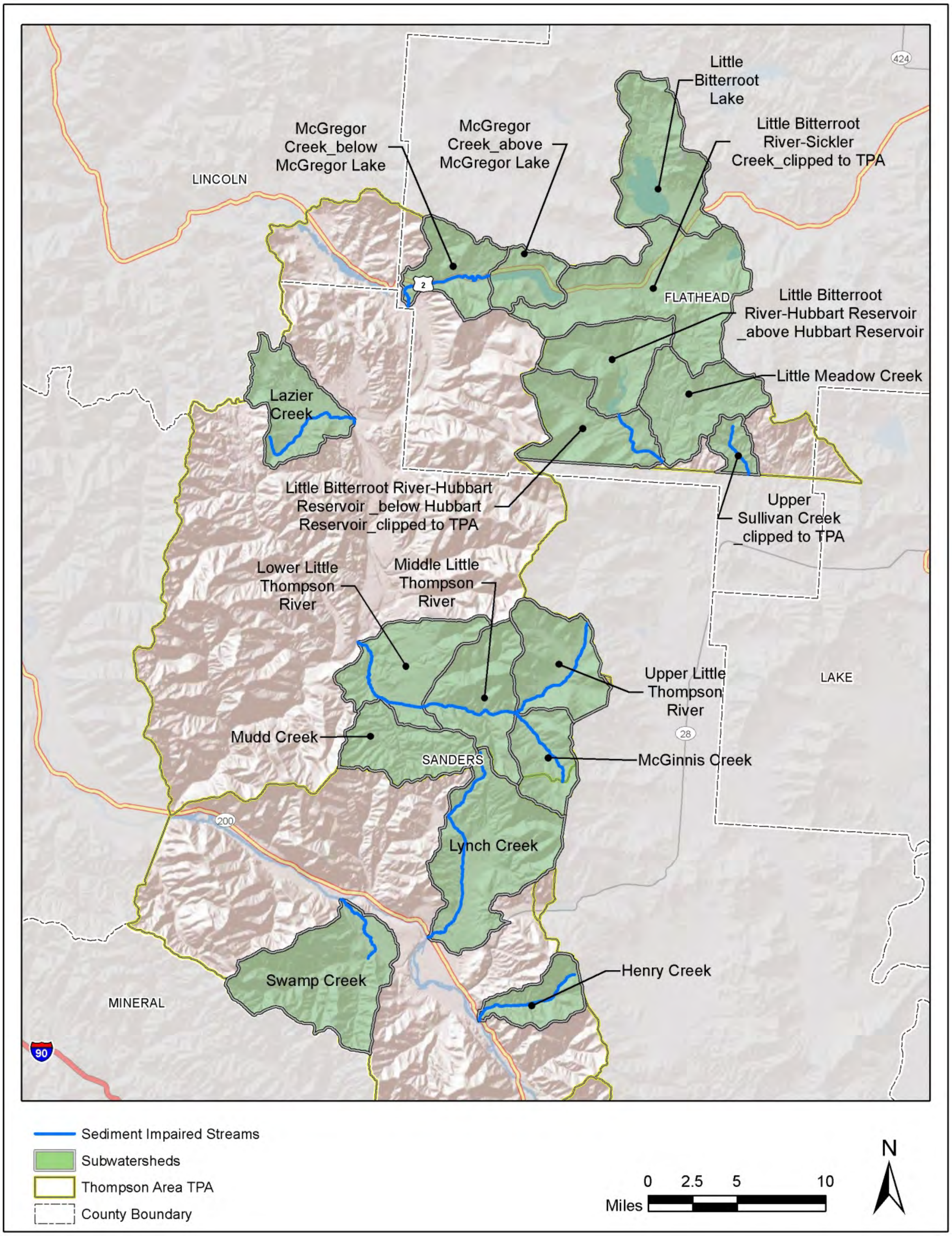

Figure 2-1. Subwatersheds in the Thompson Project Area

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 Thompson Project Area was obtained from the NRCS General Soil Map (STATSGO) database and the NRCS Soil Survey Geographic (SSURGO) database. The SSURGO database was used where available, which included portions of all of the subwatersheds in the Thompson Area TPA except McGinnis Creek, Upper Little Thompson River, and McGregor Creek above McGregor Lake. While the SSURGO database is more detailed and is more current than the STATSGO database, the SSURGO database for the Thompson Area TPA did not contain the required K-factor for the entire study area. 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 $= 10.8 \sin \theta + 0.03$ for $\theta < 9\%$
$= 16.8 \sin \theta - 0.50$ 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 Thompson 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 Thompson Area TPA 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.

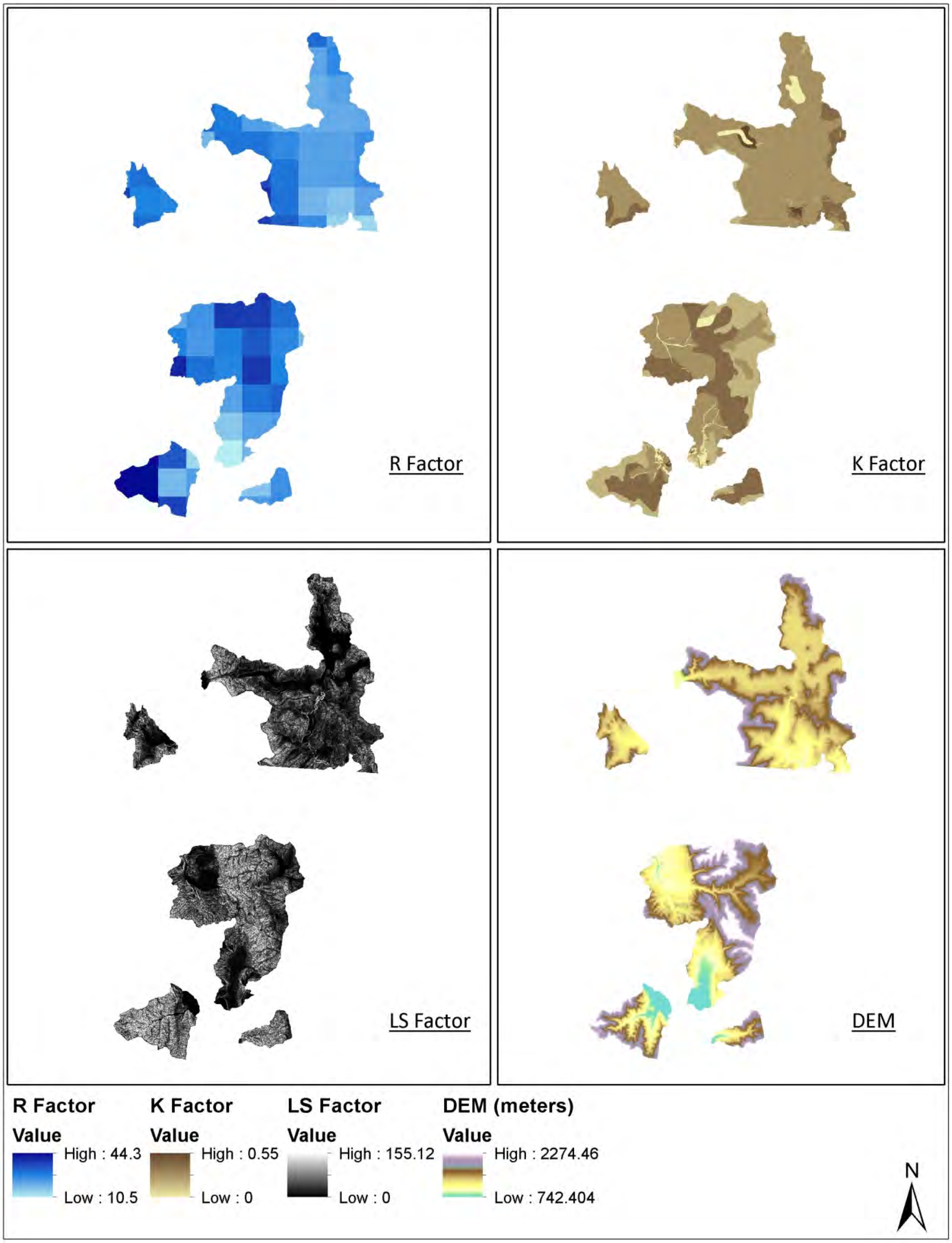

Figure 2-2. R-Factor, K-Factor, LS-Factor, and DEM for the Thompson Project Area

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 Thompson 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 Thompson 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 Thompson Project Area based on input from the local Natural Resources Conservation Service representative. NLCD land cover types for the Thompson 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 Thompson 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** and **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. 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 2-3** (Don Feist, personal communication).

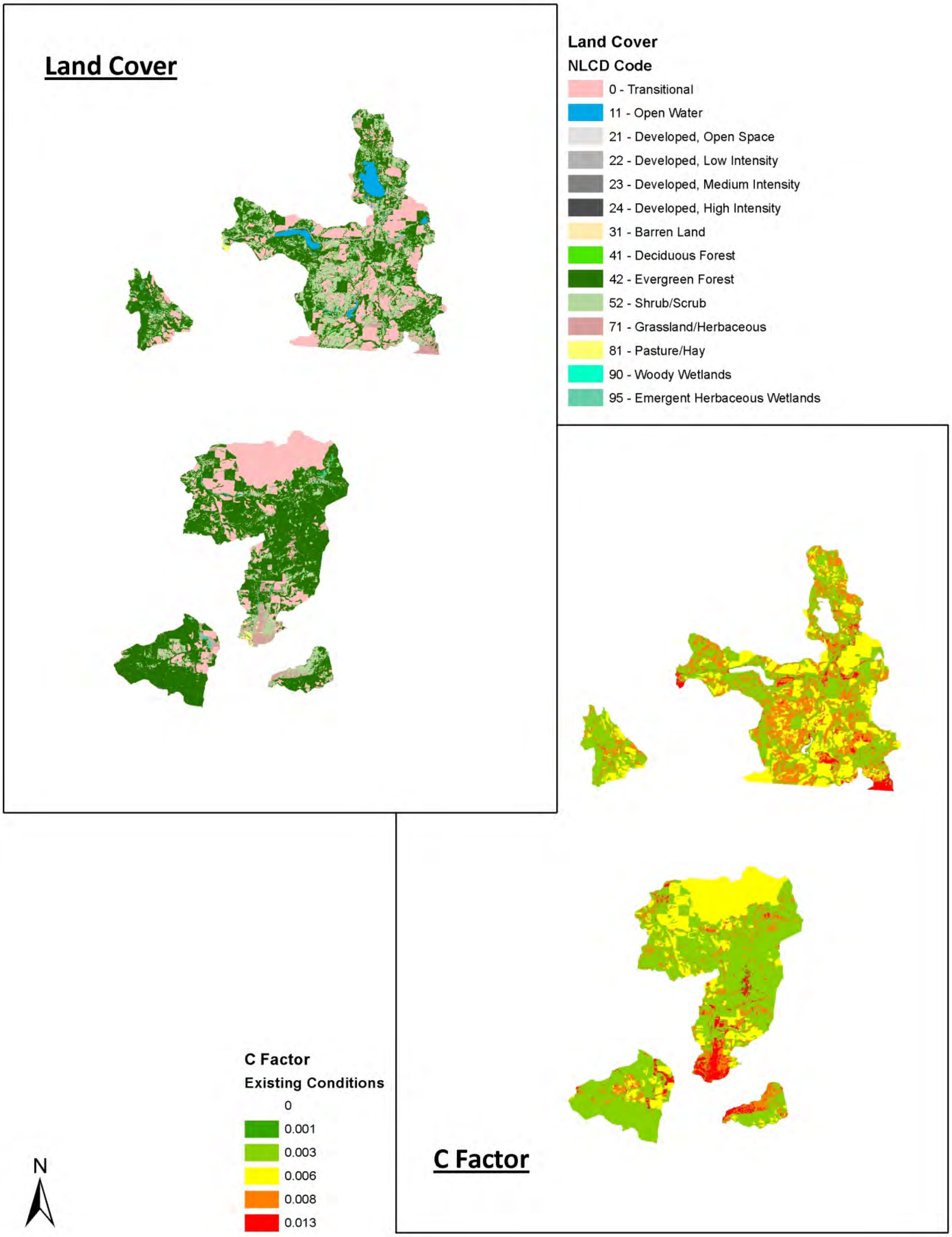

Figure 2-3. Land Cover and C-Factors for the Thompson Project Area

Table 2-2. C-factors for Existing and Desired Conditions

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
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

**Water and ice/snow classes will not be counted as surfaces contributing erosion

Table 2-3. Percent Ground Cover for Existing and Desired Land Cover Types

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 was used for logged areas (i.e. 'transitional') to represent a slightly lower percentage of ground cover than for 'deciduous/evergreen forest' (i.e., ~91% vs 95%, respectively) but still a very high percentage of ground cover because logging 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 since strip-cropping, terracing, and contouring practices were not present within the Thompson 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 Thompson 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 Thompson 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 2011. 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.

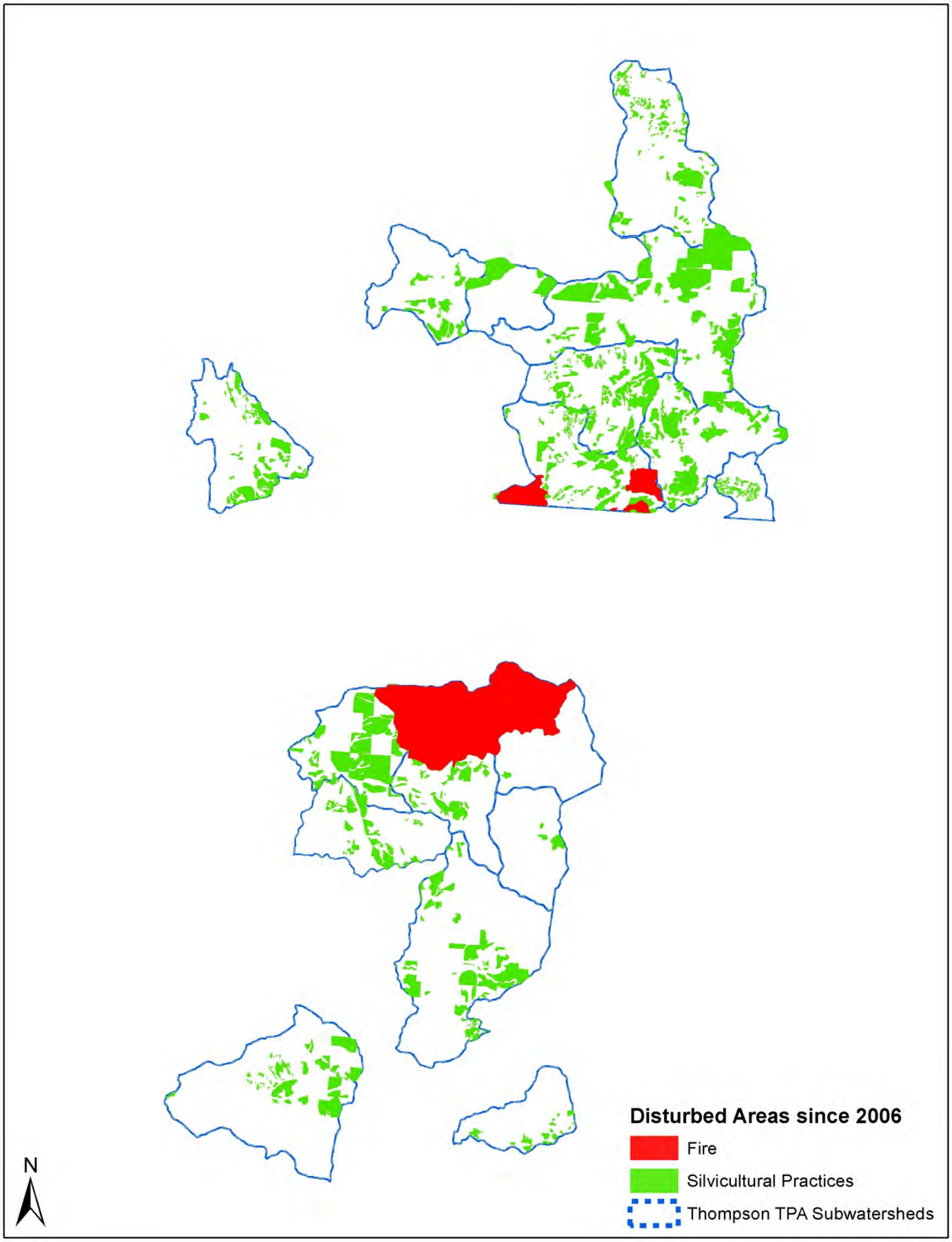

Figure 2-4. Fire and Timber Harvest Areas in the Thompson Project Area since 2006

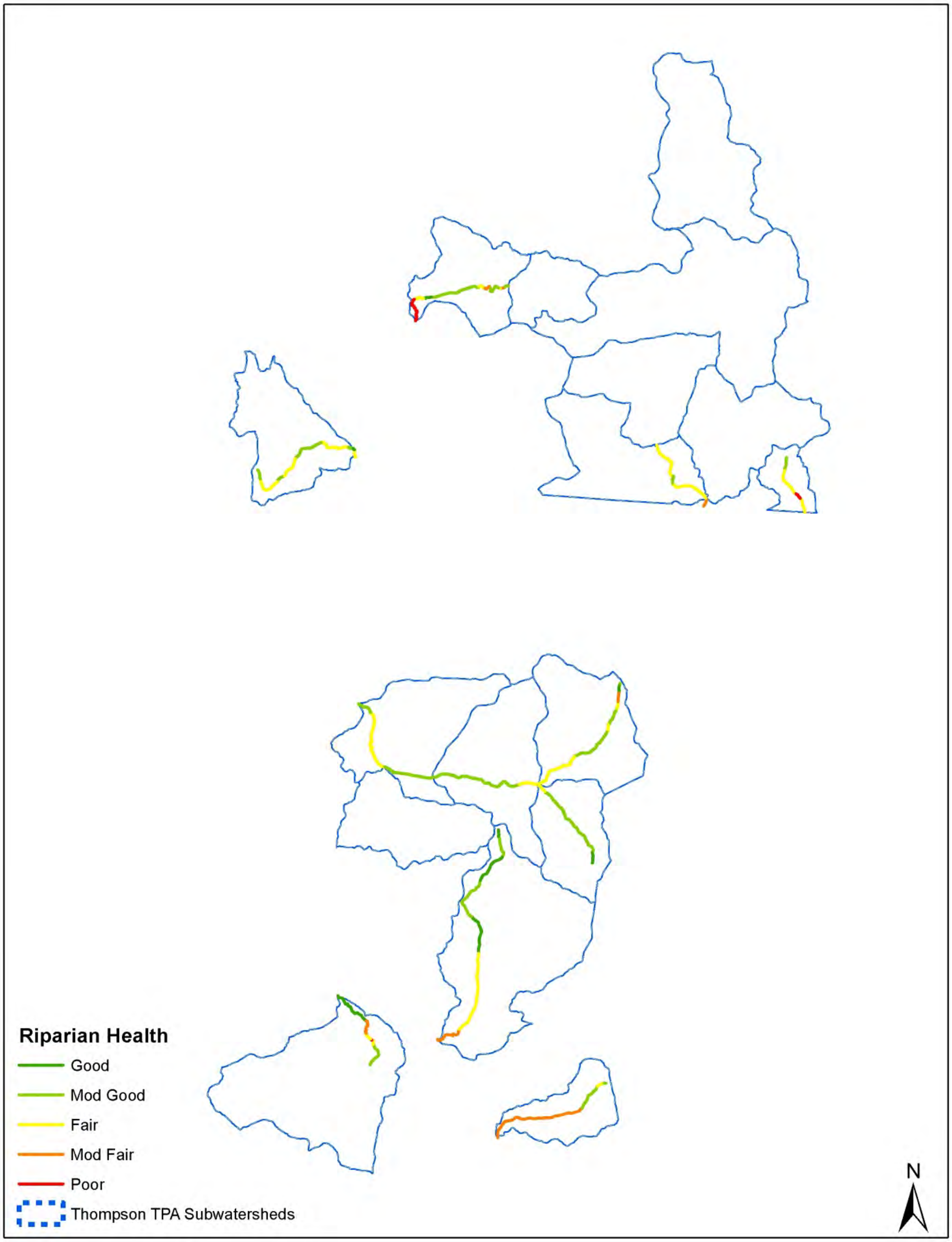

Figure 2-5. Aerial Assessment Reach Stratification Riparian Health Assessment

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 Kootenai-Fisher TPA 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**.

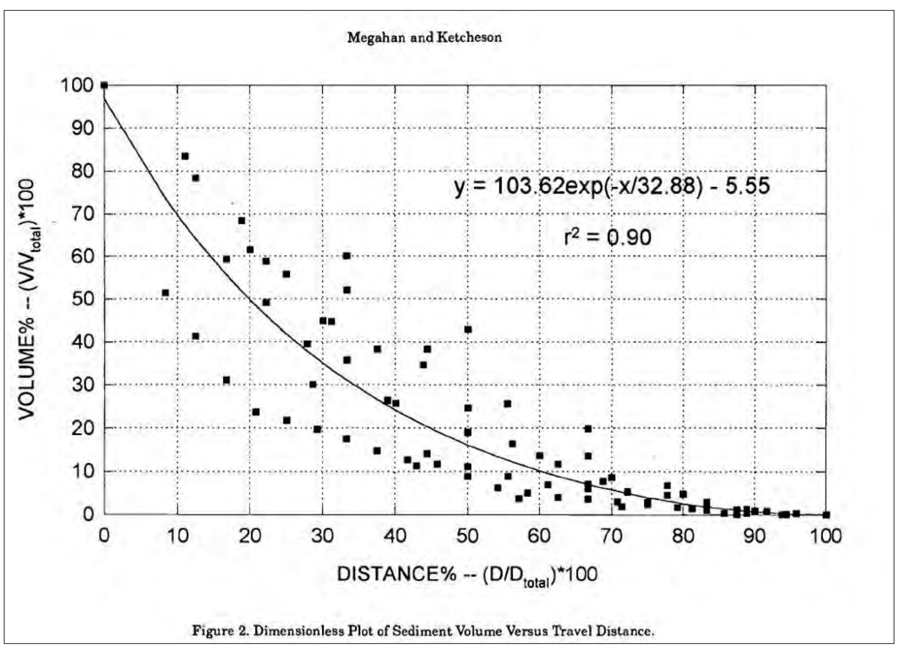

Figure 2-6 Sediment Volume vs. Travel Distance (Megahan and Ketcheson 1996)

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, 2011a; 2011b) 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 Thompson 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.

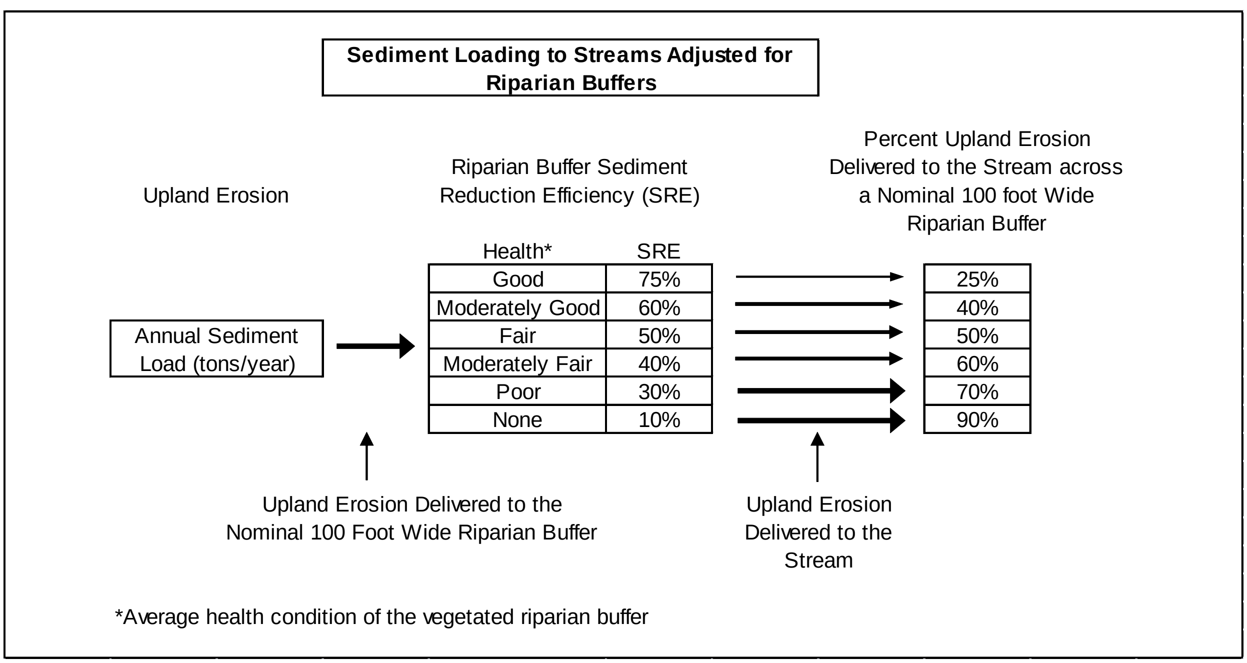

Figure 2-7. USLE Upland Sediment Load Delivery Adjusted for Riparian Buffer Capacity

The Thompson 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 2009 and on-the-ground verification during August 2011.

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 identified as 'grasslands/ herbaceous' and 'hay/pasture' 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 **Table 2-3**. 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 Thompson 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 Thompson 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		Upland Erosion Sediment Load for **BMP Conditions** and **Existing Riparian** Health		**Percent Reduction**	Upland Erosion Sediment Load for **Existing Conditions** and **BMP Riparian** Health		**Percent Reduction**	Upland Erosion Sediment Load for **BMP Conditions** and **BMP Riparian** Health		**Percent Reduction**
		(Tons/ Year)	(Tons/Acre/ Year)	(Tons/ Year)	(Tons/Acre/ Year)		(Tons/ Year)	(Tons/Acre/ Year)		(Tons/ Year)	(Tons/Acre/ Year)	
Little Bitterroot Lake	21,608	144.6	0.007	142.7	0.007	1%	99.1	0.005	31%	97.7	0.005	32%
Little Bitterroot River Sickler Creek	35,001	166.6	0.005	165.2	0.005	1%	116.8	0.003	30%	115.8	0.003	30%
Little Bitterroot River-Hubbart Reservoir above Hubbart Reservoir	15,992	124.3	0.008	123.5	0.008	1%	86.6	0.005	30%	86.1	0.005	31%
Little Bitterroot River-Hubbart Reservoir below Hubbart Reservoir	16,930	159.8	0.009	158.9	0.009	1%	112.7	0.007	29%	112.1	0.007	30%
Little Meadow Creek	17,006	134.8	0.008	132.8	0.008	1%	90.3	0.005	33%	89.1	0.005	34%
Little Bitterroot Total	**106,538**	**730**	**0.007**	**723**	**0.007**	**1%**	**506**	**0.005**	**31%**	**501**	**0.005**	**31%**
McGregor Creek above McGregor Lake	7,553	21.9	0.003	21.7	0.003	1%	13.7	0.002	37%	13.6	0.002	38%
McGregor Creek below McGregor Lake	12,132	174.3	0.014	172.8	0.014	1%	101.2	0.008	42%	100.1	0.008	43%
McGregor Creek Total	**19,686**	**196**	**0.010**	**194**	**0.010**	**1%**	**115**	**0.006**	**41%**	**114**	**0.006**	**42%**
Upper Little Thompson	16,916	116.5	0.007	116.1	0.007	<1%	72.7	0.004	38%	72.5	0.004	38%
McGinnis Creek	**11,208**	**78**	**0.007**	**78**	**0.007**	**<1%**	**51**	**0.005**	**35%**	**51**	**0.005**	**35%**
Middle Little Thompson	18,086	467.6	0.026	462.7	0.026	1%	286.1	0.016	39%	283.0	0.016	39%
Mudd Creek	14,017	251.1	0.018	250.9	0.018	<1%	145.7	0.010	42%	145.5	0.010	42%
Lower Little Thompson	18,065	235.9	0.013	234.7	0.013	<1%	146.8	0.008	38%	146.3	0.008	38%
Little Thompson Total	**78,291**	**1149**	**0.015**	**1142**	**0.015**	**1%**	**702**	**0.009**	**39%**	**698**	**0.009**	**39%**
Henry Creek	**8,476**	**192**	**0.023**	**181**	**0.021**	**6%**	**73**	**0.009**	**62%**	**69**	**0.008**	**64%**
Lazier Creek	**14,987**	**113**	**0.008**	**113**	**0.008**	<1%	**73**	**0.005**	**35%**	**73**	**0.005**	**36%**
Lynch Creek	**30,919**	**306**	**0.010**	**289**	**0.009**	**6%**	**221**	**0.007**	**28%**	**208**	**0.007**	**32%**
Swamp Creek	**28,592**	**423**	**0.015**	**418**	**0.015**	**1%**	**288**	**0.010**	**32%**	**284**	**0.010**	**33%**
Upper Sullivan Creek	**3,915**	**75**	**0.019**	**64**	**0.016**	**15%**	**44**	**0.011**	**42%**	**37**	**0.009**	**51%**

Table 3-2. Delivered Sediment Load by Land Cover Type in the Thompson 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**
Little Bitterroot Lake	Transitional	3,488	26.023	26.023	0%	16.574	36%	16.574	36%
	Open Water	2,960	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	31	0.002	0.002	0%	0.002	35%	0.002	35%
	Developed, Low Intensity	32	0.001	0.001	0%	0.001	24%	0.001	24%
	Developed, Medium Intensity	6	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, High Intensity	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	1	0.001	0.001	0%	0.000	95%	0.000	95%
	Evergreen Forest	9,375	52.473	52.473	0%	36.831	30%	36.831	30%
	Shrub/Scrub	5,251	60.861	60.861	0%	41.900	31%	41.900	31%
	Grassland/Herbaceous	300	5.077	3.125	38%	3.661	28%	2.250	56%
	Pasture/Hay	9	0.009	0.006	38%	0.006	34%	0.003	66%
	Woody Wetlands	28	0.118	0.118	0%	0.090	24%	0.090	24%
	Emergent Herbaceous Wetlands	125	0.069	0.069	0%	0.056	19%	0.056	19%
	Total:	**21,608**	**144.6**	**142.7**	**1%**	**99.1**	**31%**	**97.7**	**32%**
Little Bitterroot River Sickler Creek	Transitional	9,666	64.963	64.963	0%	45.706	30%	45.706	30%
	Open Water	243	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	227	0.377	0.377	0%	0.256	32%	0.256	32%
	Developed, Low Intensity	181	0.091	0.091	0%	0.060	34%	0.060	34%
	Developed, Medium Intensity	9	0.004	0.004	0%	0.002	43%	0.002	43%
	Barren Land	7	0.001	0.001	0%	0.001	57%	0.001	57%
	Deciduous Forest	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Evergreen Forest	14,948	50.832	50.832	0%	35.668	30%	35.668	30%
	Shrub/Scrub	8,116	46.258	46.258	0%	32.179	30%	32.179	30%
	Grassland/Herbaceous	911	3.194	1.965	38%	2.302	28%	1.409	56%

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**
	Pasture/Hay	156	0.420	0.259	38%	0.339	19%	0.205	51%
	Woody Wetlands	130	0.104	0.104	0%	0.074	29%	0.074	29%
	Emergent Herbaceous Wetlands	405	0.308	0.308	0%	0.231	25%	0.231	25%
	Total:	**35,001**	**166.6**	**165.2**	**1%**	**116.8**	**30%**	**115.8**	**30%**
Little Bitterroot River-Hubbart Reservoir above Hubbart Reservoir	Transitional	4,483	23.821	23.821	0%	16.151	32%	16.151	32%
	Open Water	308	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	11	0.002	0.002	0%	0.001	38%	0.001	38%
	Evergreen Forest	4,918	31.734	31.734	0%	22.596	29%	22.596	29%
	Shrub/Scrub	5,842	66.490	66.490	0%	46.397	30%	46.397	30%
	Grassland/Herbaceous	312	2.112	1.300	38%	1.308	38%	0.799	62%
	Pasture/Hay	8	0.000	0.000	0%	0.000	0%	0.000	0%
	Woody Wetlands	29	0.035	0.035	0%	0.024	31%	0.024	31%
	Emergent Herbaceous Wetlands	82	0.108	0.108	0%	0.083	24%	0.083	24%
	Total:	**15,992**	**124.3**	**123.5**	**1%**	**86.6**	**30%**	**86.1**	**31%**
Little Bitterroot River-Hubbart Reservoir below Hubbart Reservoir	Transitional	5,730	47.769	47.769	0%	32.376	32%	32.376	32%
	Evergreen Forest	5,362	48.762	48.762	0%	35.509	27%	35.509	27%
	Shrub/Scrub	5,432	60.506	60.506	0%	42.969	29%	42.969	29%
	Grassland/Herbaceous	233	2.379	1.464	38%	1.592	33%	0.980	59%
	Woody Wetlands	79	0.172	0.172	0%	0.137	20%	0.137	20%
	Emergent Herbaceous Wetlands	94	0.211	0.211	0%	0.165	22%	0.165	22%
	Total:	**16,930**	**159.8**	**158.9**	**1%**	**112.7**	**29%**	**112.1**	**30%**
Little Meadow Creek	Transitional	4,998	34.239	34.239	0%	22.298	35%	22.298	35%
	Evergreen Forest	6,432	39.456	39.456	0%	27.102	31%	27.102	31%
	Shrub/Scrub	4,756	55.939	55.939	0%	37.669	33%	37.669	33%
	Grassland/Herbaceous	776	5.022	3.090	38%	3.161	37%	1.944	61%

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**
	Woody Wetlands	8	0.038	0.038	0%	0.032	17%	0.032	17%
	Emergent Herbaceous Wetlands	38	0.064	0.064	0%	0.048	25%	0.048	25%
	Total:	**17,006**	**134.8**	**132.8**	**1%**	**90.3**	**33%**	**89.1**	**34%**
Little Bitterroot Total	Transitional	28,365	196.815	196.815	0%	133.105	32%	133.105	32%
	Open Water	3,511	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	258	0.379	0.379	0%	0.258	32%	0.258	32%
	Developed, Low Intensity	214	0.091	0.091	0%	0.060	34%	0.060	34%
	Developed, Medium Intensity	14	0.004	0.004	0%	0.002	43%	0.002	43%
	Developed, High Intensity	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	18	0.005	0.005	0%	0.002	58%	0.002	58%
	Deciduous Forest	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Evergreen Forest	41,035	223.257	223.257	0%	157.706	29%	157.706	29%
	Shrub/Scrub	29,397	290.054	290.054	0%	201.113	31%	201.113	31%
	Grassland/Herbaceous	2,531	17.784	10.944	38%	12.024	32%	7.384	58%
	Pasture/Hay	173	0.429	0.264	38%	0.345	20%	0.208	52%
	Woody Wetlands	275	0.467	0.467	0%	0.357	24%	0.357	24%
	Emergent Herbaceous Wetlands	744	0.760	0.760	0%	0.583	23%	0.583	23%
	Total:	**106,538**	**730.0**	**723.0**	**1%**	**505.6**	**31%**	**500.8**	**31%**
McGregor Creek above McGregor Lake	Transitional	1,283	6.697	6.697	0%	3.953	41%	3.953	41%
	Open Water	1,555	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	134	0.354	0.354	0%	0.234	34%	0.234	34%
	Developed, Low Intensity	41	0.033	0.033	0%	0.019	41%	0.019	41%
	Developed, Medium Intensity	60	0.048	0.048	0%	0.034	30%	0.034	30%
	Evergreen Forest	3,360	7.872	7.872	0%	5.009	36%	5.009	36%
	Shrub/Scrub	1,065	6.113	6.113	0%	3.980	35%	3.980	35%

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**
	Grassland/Herbaceous	23	0.459	0.282	38%	0.289	37%	0.178	61%
	Woody Wetlands	10	0.003	0.003	0%	0.001	58%	0.001	58%
	Emergent Herbaceous Wetlands	23	0.293	0.293	0%	0.193	34%	0.193	34%
	Total:	**7,553**	**21.9**	**21.7**	**1%**	**13.7**	**37%**	**13.6**	**38%**
McGregor Creek below McGregor Lake	Transitional	1,634	33.448	33.448	0%	18.947	43%	18.947	43%
	Open Water	0	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	107	0.703	0.703	0%	0.292	58%	0.292	58%
	Developed, Low Intensity	116	0.661	0.661	0%	0.407	38%	0.407	38%
	Developed, Medium Intensity	37	0.225	0.225	0%	0.148	34%	0.148	34%
	Evergreen Forest	6,479	76.557	76.557	0%	46.526	39%	46.526	39%
	Shrub/Scrub	3,427	58.508	58.508	0%	31.947	45%	31.947	45%
	Grassland/Herbaceous	93	3.887	2.392	38%	2.675	31%	1.646	58%
	Pasture/Hay	203	0.241	0.148	38%	0.139	42%	0.084	65%
	Woody Wetlands	6	0.002	0.002	0%	0.001	30%	0.001	30%
	Emergent Herbaceous Wetlands	30	0.111	0.111	0%	0.075	33%	0.075	33%
	Total:	**12,132**	**174.3**	**172.8**	**1%**	**101.2**	**42%**	**100.1**	**43%**
McGregor Creek Total	Transitional	2,917	40.145	40.145	0%	22.900	43%	22.900	43%
	Open Water	1,556	0.000	0.000	0%	0.000	0%	0.000	0%
	Developed, Open Space	241	1.057	1.057	0%	0.526	50%	0.526	50%
	Developed, Low Intensity	157	0.694	0.694	0%	0.427	39%	0.427	39%
	Developed, Medium Intensity	97	0.273	0.273	0%	0.182	33%	0.182	33%
	Evergreen Forest	9,839	84.429	84.429	0%	51.535	39%	51.535	39%
	Shrub/Scrub	4,492	64.620	64.620	0%	35.927	44%	35.927	44%
	Grassland/Herbaceous	116	4.346	2.674	38%	2.964	32%	1.824	58%
	Pasture/Hay	203	0.241	0.148	38%	0.139	42%	0.084	65%

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**
	Woody Wetlands	16	0.005	0.005	0%	0.002	48%	0.002	48%
	Emergent Herbaceous Wetlands	53	0.405	0.405	0%	0.268	34%	0.268	34%
	Total:	**19,686**	**196.215**	**194.451**	**1%**	**114.871**	**41%**	**113.676**	**42%**
Upper Little Thompson	Transitional	6,174	61.082	61.082	0%	38.478	37%	38.478	37%
	Evergreen Forest	8,634	39.678	39.678	0%	24.819	37%	24.819	37%
	Shrub/Scrub	1,681	14.087	14.087	0%	8.518	40%	8.518	40%
	Grassland/Herbaceous	132	1.160	0.714	38%	0.569	51%	0.350	70%
	Woody Wetlands	133	0.180	0.180	0%	0.127	29%	0.127	29%
	Emergent Herbaceous Wetlands	162	0.314	0.314	0%	0.223	29%	0.223	29%
	Total:	**16,916**	**116.5**	**116.1**	**<1%**	**72.7**	**38%**	**72.5**	**38%**
McGinnis Creek	Transitional	306	1.400	1.400	0%	0.929	34%	0.929	34%
	Open Water	9	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	26	0.000	0.000	0%	0.000	100%	0.000	100%
	Evergreen Forest	10,226	66.156	66.156	0%	43.568	34%	43.568	34%
	Shrub/Scrub	500	9.575	9.575	0%	5.782	40%	5.782	40%
	Grassland/Herbaceous	133	0.892	0.549	38%	0.395	56%	0.243	73%
	Woody Wetlands	6	0.018	0.018	0%	0.010	43%	0.010	43%
	Emergent Herbaceous Wetlands	1	0.001	0.001	0%	0.000	70%	0.000	70%
	Total:	**11,208**	**78.0**	**77.7**	**<1%**	**50.7**	**35%**	**50.5**	**35%**
Middle Little Thompson	Transitional	9,059	243.371	243.371	0%	148.317	39%	148.317	39%
	Open Water	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	13	0.000	0.000	0%	0.000	0%	0.000	0%
	Evergreen Forest	7,664	132.673	132.673	0%	82.158	38%	82.158	38%
	Shrub/Scrub	1,105	78.533	78.533	0%	47.452	40%	47.452	40%
	Grassland/Herbaceous	184	12.751	7.846	38%	7.984	37%	4.913	61%

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**
	Pasture/Hay	3	0.000	**0.000**	0%	0.000	0%	0.000	0%
	Woody Wetlands	53	0.199	0.199	0%	0.147	26%	0.147	26%
	Emergent Herbaceous Wetlands	2	0.028	0.028	0%	0.017	39%	0.017	39%
	Total:	**18,086**	**467.6**	**462.7**	**1%**	**286.1**	**39%**	**283.0**	**39%**
Mudd Creek	Transitional	1,850	27.573	27.573	0%	13.433	51%	13.433	51%
	Barren Land	1	0.000	0.000	0%	0.000	100%	0.000	100%
	Evergreen Forest	10,642	145.995	145.995	0%	87.724	40%	87.724	40%
	Shrub/Scrub	1,502	76.673	76.673	0%	43.900	43%	43.900	43%
	Grassland/Herbaceous	14	0.766	0.472	38%	0.503	34%	0.310	60%
	Woody Wetlands	7	0.111	0.111	0%	0.077	31%	0.077	31%
	Emergent Herbaceous Wetlands	1	0.031	0.031	0%	0.024	24%	0.024	24%
	Total:	**14,017**	**251.1**	**250.9**	**<1%**	**145.7**	**42%**	**145.5**	**42%**
Lower Little Thompson	Transitional	10,122	181.344	181.344	0%	115.407	36%	115.407	36%
	Barren Land	1	0.004	0.004	0%	0.003	30%	0.003	30%
	Evergreen Forest	6,483	33.581	33.581	0%	20.366	39%	20.366	39%
	Shrub/Scrub	1,091	17.598	17.598	0%	9.317	47%	9.317	47%
	Grassland/Herbaceous	215	2.903	1.786	38%	1.431	51%	0.881	70%
	Pasture/Hay	3	0.045	0.028	38%	0.028	38%	0.017	62%
	Woody Wetlands	85	0.274	0.274	0%	0.196	28%	0.196	28%
	Emergent Herbaceous Wetlands	64	0.111	0.111	0%	0.075	32%	0.075	32%
	Total:	**18,065**	**235.9**	**234.7**	**<1%**	**146.8**	**38%**	**146.3**	**38%**
Little Thompson Total	Transitional	27,511	514.770	514.770	0%	316.565	39%	316.565	39%
	Open Water	11	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	41	0.004	0.004	0%	0.003	31%	0.003	31%
	Evergreen Forest	43,649	418.084	418.084	0%	258.635	38%	258.635	38%

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**
	Shrub/Scrub	5,879	196.465	196.465	0%	114.968	41%	114.968	41%
	Grassland/Herbaceous	678	18.472	11.367	38%	10.882	41%	6.697	64%
	Pasture/Hay	6	0.045	0.028	38%	0.028	38%	0.017	62%
	Woody Wetlands	285	0.783	0.783	0%	0.558	29%	0.558	29%
	Emergent Herbaceous Wetlands	231	0.485	0.485	0%	0.339	30%	0.339	30%
	Total:	**78,291**	**1149.1**	**1142.0**	**1%**	**702.0**	**39%**	**697.8**	**39%**
Henry Creek	Transitional	528	5.637	5.637	0%	1.739	69%	1.739	69%
	Developed, Open Space	4	0.018	0.018	0%	0.009	52%	0.009	52%
	Developed, Low Intensity	2	0.002	0.002	0%	0.001	72%	0.001	72%
	Deciduous Forest	2	0.000	0.000	0%	0.000	0%	0.000	0%
	Evergreen Forest	4,529	83.490	83.490	0%	34.298	59%	34.298	59%
	Shrub/Scrub	2,538	74.499	74.499	0%	27.608	63%	27.608	63%
	Grassland/Herbaceous	865	28.129	17.310	38%	8.979	68%	5.526	80%
	Woody Wetlands	4	0.035	0.035	0%	0.013	61%	0.013	61%
	Emergent Herbaceous Wetlands	5	0.035	0.035	0%	0.022	37%	0.022	37%
	Total:	**8,476**	**191.8**	**181.0**	**6%**	**72.7**	**62%**	**69.2**	**64%**
Lazier Creek	Transitional	2,618	21.943	21.943	0%	12.834	42%	12.834	42%
	Evergreen Forest	9,725	68.002	68.002	0%	45.852	33%	45.852	33%
	Shrub/Scrub	2,321	21.086	21.086	0%	13.135	38%	13.135	38%
	Grassland/Herbaceous	80	1.309	0.806	38%	0.771	41%	0.475	64%
	Woody Wetlands	91	0.438	0.438	0%	0.341	22%	0.341	22%
	Emergent Herbaceous Wetlands	152	0.664	0.664	0%	0.521	22%	0.521	22%
	Total:	**14,987**	**113.4**	**112.9**	**<1%**	**73.5**	**35%**	**73.2**	**36%**
Lynch Creek	Transitional	4,450	43.597	43.597	0%	30.719	30%	30.719	30%

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, Open Space	38	0.027	0.027	0%	0.022	21%	0.022	21%
	Developed, Low Intensity	57	0.020	0.020	0%	0.015	28%	0.015	28%
	Developed, Medium Intensity	5	0.004	0.004	0%	0.003	20%	0.003	20%
	Barren Land	116	0.097	0.097	0%	0.072	26%	0.072	26%
	Evergreen Forest	16,633	147.278	147.278	0%	107.931	27%	107.931	27%
	Shrub/Scrub	5,418	69.841	69.841	0%	48.356	31%	48.356	31%
	Grassland/Herbaceous	3,640	44.806	27.573	38%	33.636	25%	20.698	54%
	Pasture/Hay	377	0.212	0.131	38%	0.167	21%	0.102	52%
	Woody Wetlands	68	0.235	0.235	0%	0.188	20%	0.188	20%
	Emergent Herbaceous Wetlands	116	0.201	0.201	0%	0.159	21%	0.159	21%
	Total:	**30,919**	**306.3**	**289.0**	**6%**	**221.3**	**28%**	**208.3**	**32%**
Swamp Creek	Transitional	3,014	27.535	27.535	0%	17.713	36%	17.713	36%
	Open Water	0	0.000	0.000	0%	0.000	0%	0.000	0%
	Barren Land	13	0.000	0.000	0%	0.000	0%	0.000	0%
	Evergreen Forest	22,008	330.935	330.935	0%	229.175	31%	229.175	31%
	Shrub/Scrub	2,360	51.143	51.143	0%	31.499	38%	31.499	38%
	Grassland/Herbaceous	899	13.141	8.086	38%	9.346	29%	5.750	56%
	Pasture/Hay	8	0.020	0.012	38%	0.013	34%	0.009	58%
	Woody Wetlands	99	0.054	0.054	0%	0.040	26%	0.040	26%
	Emergent Herbaceous Wetlands	191	0.110	0.110	0%	0.082	26%	0.082	26%
	Total:	**28,592**	**422.9**	**417.9**	**1%**	**287.9**	**32%**	**284.3**	**33%**
Upper Sullivan Creek	Transitional	575	8.734	8.734	0%	4.552	48%	4.552	48%
	Barren Land	4	0.009	0.009	0%	0.003	66%	0.003	66%
	Evergreen Forest	1,244	14.112	14.112	0%	8.355	41%	8.355	41%
	Shrub/Scrub	1,004	22.718	22.718	0%	13.292	41%	13.292	41%

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**
	Grassland/Herbaceous	1,086	29.350	18.062	38%	17.438	41%	10.731	63%
	Pasture/Hay	3	0.036	0.022	38%	0.029	20%	0.018	51%
	Total:	**3,915**	**75.0**	**63.7**	**15%**	**43.7**	**42%**	**36.9**	**51%**

4.0 ASSUMPTIONS AND UNCERTAINTY

Section 4.0 added by EPA, 2014

USLE models have been widely used for TMDL development and it is assumed that it adequately estimates sediment from upland sources in the Thompson Project Area. As stated in Section 2.0, the USLE 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. It is assumed that the climate and landscape data sources used to build the model were appropriate. The C-factor is the input with the most uncertainty because it was the variable specified by the modeler and changed between the existing condition and BMP scenario. Efforts were made to minimize uncertainty by using a USDA research-based table (**Attachment B**) and consulting with Montana NRCS personnel, project stakeholders, and DEQ modeling staff to select reasonable C-factors for each land cover type. Input parameters such as existing vegetative cover and the potential for vegetative cover improvement via BMP implementation for a particular land use are applied at the project area scale on an annual basis and are intended to reflect the long-term average condition. Therefore, there is no differentiation by season or ownership.

The upland erosion model integrates sediment delivery based on riparian health; riparian health evaluations linked to the stream stratification work are discussed in **Attachment A**. The riparian health classifications were performed using aerial imagery and a coarse classification system (i.e., poor, poor/fair, fair, fair/good, and good). There is uncertainty associated with classifying riparian health into such broad categories because vegetation type and health can vary greatly over small distances. Additionally, wetland vegetation, which has a high sediment removal capacity, can be difficult to distinguish from other grasses and is likely to be given a lower health rating than woody shrubs or trees. However, field verification of the original classifications as well as the potential improvement was conducted to help reduce the uncertainty. The riparian health classification is intended to be a general indicator of riparian condition within each watershed but is not detailed enough to identify where additional BMPs are necessary.

Each riparian health class was assigned a sediment reduction efficiency value based on literature values. There is high uncertainty that the reduction efficiencies applied are the actual reduction efficiencies because no field data were collected and they were based on ranges provided in literature. This uncertainty is acceptable for this project. The riparian health analysis was not performed with the expectation that it would identify specific locations for implementation of additional BMPs. Instead it was performed to simulate the buffering capacity of riparian vegetation and emphasize the importance of a healthy riparian buffer. Even with these uncertainties, the ability to reduce upland sediment erosion and delivery to nearby waterbodies is well documented in literature, and the estimated reductions are consistent with literature values for riparian buffers.

The riparian health classification was also used to scale the maximum travel distance for sediment within each watershed (i.e., beyond that distance, eroding sediment will not reach the channel). Watershed-specific scaling of the sediment delivery ratio is assumed to help reduce the uncertainty associated with a set maximum delivery distance. Nonetheless, values were intentionally chosen to be conservative (and potentially err on high side, allowing more sediment to be delivered) as part of the implicit margin of safety.

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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.

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		Cover that contacts the soil surface						
			Percent ground cover					
Type and height[2]	Percent cover[3]	Type[4]	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 Thompson Area 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
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

**Water and ice/snow classes will not be counted as surfaces contributing erosion

C-Factors for land cover types in the Thompson Area 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
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

**Water and ice/snow classes will not be counted as surfaces contributing erosion

Attachment C

Sediment Delivery Ratio Example Calculation

Sediment Delivery Ratio Example Calculation – Lazier 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 Lazier Creek subwatershed is presented in **Table 1**.

Table 1. Lazier 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	550	1	75	1
Fair/Good	15,399	39	60	23
Fair	23,703	60	50	30
Poor/Fair			40	0
Poor			30	0
No data			10	
Total	39,651	100		**54**

Example:
Per **Table 1**, the Lazier Creek subwatershed's expected sediment delivery across a **100**-foot wide riparian zone is (100%-**54**% reduction) = **46%** 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 =

46% = 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:
46% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Dtotal = **100**/(-0.3288*ln((**46**+5.55)/103.62))

Dtotal = **436** 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 Lazier 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/**436**)*100)/32.88) -5.55

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

Volume % = 103.62exp(-((200/**436**)*100)/32.88) -5.55

Volume % = 20.1

By this method, the Sediment Delivery Ratio (SDR) for each analytical pixel in a Lazier 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 0.201 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. Lazier 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	19,197	48	75	36
Fair/Good	19,193	48	60	29
Fair	1,260	3	50	2
Poor/Fair		0	40	0
Poor		0	30	0
No data		0	10	0
Total	39,651	100		**67**

Example:
Per **Table 2**, the Lazier Creek subwatershed's expected sediment delivery across a **100**-foot wide riparian zone is (100%-67% reduction) = **33%** 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 =

33% = 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:
33% = 103.62exp(-((**100**/Dtotal)*100)/32.88) -5.55

Dtotal = **100**/(-0.3288*ln((**33**+5.55)/103.62))

Dtotal = **308** 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 Lazier 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/**308**)*100)/32.88) -5.55

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

Volume % = 103.62exp(-((200/**308**)*100)/32.88) -5.55

Volume % = 8.8

By this method, the Sediment Delivery Ratio (SDR) for each analytical pixel in a Lazier 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 0.088 that will then be multiplied against the existing USLE soil loss to produce the final reduced soil loss rate for that cell.